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The Impact of Climate Change on the Yield of Major Agricultural Crops in India: An Econometric Study

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Abstract

This study seeks to examine the impact of climate change on the yield of major crops in India. We compiled annual time series data of seven major crops namely, rice, wheat, pulses, groundnut, rapeseed and mustard, sugarcane, and cotton for 57 years (1964-65 to 2020-21) to study the impact of climatic variables namely, rainfall, maximum, and minimum temperatures on major crop yields in India. Ordinary least square as well as quantile regression technique were used to estimate the impact of climate change on the yield of seven major crops. The estimated results indicate that rainfall has a significant favourable effect on the yields of most crops except rapeseed and mustard (R&M). The average maximum temperature has a significantly adverse effect on rice, pulses and rapeseed and mustard (R&M) yields except on sugarcane and cotton yields. However, average minimum temperature has a positive relationship with crop yield in general. Thus, proper agricultural policy is needed to mitigate the adverse effects of climatic factors on crop yields.

Key words: Climate change, Crop yield, Regression models

The agriculture sector is very crucial in India for the sustainable and inclusive economic growth of the country. Although the share of agriculture in gross domestic product (GDP) has declined significantly to 17.4% in 2023-24 due to an increase in the share of other sectors of the economy, it remains the predominant sector in terms of employment and livelihood. The agriculture sector creates its own value as a product for the economy and it absorbs almost 61.5 percent of the working population [1]. Since, it is the sole sector for providing food to the nation, it has a significant role in food security. Furthermore, agriculture provides the raw materials to the other sectors of the economy. Thus, any disruption in agriculture affects adversely to the economy as a whole. It is a well-known fact that Indian agriculture depends critically on climatic factors, particularly monsoon rainfall. Unlike developed countries, any changes in climatic patterns through changes in rainfall and temperature would have adverse impact on agricultural productivity. Furthermore, people adjust their cropping pattern in response to the change in climatic patterns. Thus, climate change would have direct as well as indirect impacts on agricultural production. The study of the impacts of climate change on Indian agriculture is extremely important, particularly in the context of life and livelihood. This study seeks to empirically estimate the impacts of climate change on crop yield for the agriculture sector in India. The objective of the study is to estimate the impact of climate change (through changes in rainfall and temperature) on the yield of major crops in India.

The residual part of the paper is structured as follows. Section 2 provides a brief literature review. The data sources and empirical methodology are described in Section 3. Section 4 covers the empirical results and discussion. The last section presents the conclusion of the study.

In India, a large number of studies have evaluated the impact of climate change on crop yields using different methodologies. Using Ricardian approach, Kumar and Parikh [2] shown that climate change badly affected the yield of wheat and paddy crops in India. In the empirical evidence on the impacts of climate change on agricultural crop yield, most of the studies reported that climate variations adversely affect agriculture production in India. In literature, majority of the studies used either the crop modelling approach or Ricardian approach. There are fewer studies that use econometric methods with time series data. Moreover, most studies examined empirically the effect of climatic change on agricultural production based on single crop or multiple crops considering state level or region level [3-11]. However, there are limited studies that examined the impact of climate change on agriculture production considering more than two crops using time series data at the national level. Hence, the present study seeks to evaluate the effects of climate factors on seven major crops namely, rice, wheat, pulses, rapeseed and mustard, cotton, sugarcane, and groundnut in India.

MATERIALS AND METHODS

Data Sources

The main objective of this study is to empirically estimate the impact of climate change on the yields of major crops in India for the time period 1964-65 to 2020-21. The study is carried out using the time series data of seven major crops such as rice, wheat, pulses, groundnut, rapeseed and mustard

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(R&M), sugarcane, and cotton. All these crops accounted for more than 70% of the total agricultural cropped area. Annual time series secondary data are drawn from various sources. The data on the yields of agricultural crops and crop-wise cultivated area were obtained from Agricultural Statistics, Ministry of Agriculture and Farmers Welfare, Government of India. The data on climatic variables, namely actual rainfall, maximum temperature, and minimum temperature, was drawn from Environment Statistics, Ministry of Statistics and Programme Implementation, Government of India. The yields of selected crops are measured in kilogram per hectare (kg/ha) and cropped area measured in hectares. Furthermore, the rainfall is measured in millimetre (mm) and the average maximum and minimum temperatures are measured in Celsius (°C). The summary statistics of different variables used in this study were presented in (Table 1).

Table 1 Summary statistics

Variables	Mean	Standard deviation	Minimum	Maximum	Observations
Rice yield	1731.62	529.49	861.69	2720.14	57
Rice area	413.98	27.80	353	455	57
Wheat yield	2217.80	755.65	825.40	3535.84	57
Wheat area	242.04	49.03	126.00	316.00	57
Pulses yield	585.90	112.21	377.83	893.06	57
Pulses area	234.58	20.76	204.00	298.00	57
Groundnut yield	1027.44	332.19	553.25	2060.04	57
Groundnut area	67.77	10.61	45.90	87.10	57
Rapeseed and mustard yield	847.75	307.90	396.12	1513.07	57
Rapeseed and mustard area	50.19	14.16	28.70	73.20	57
Sugarcane yield	61993.01	10072.53	40360.87	82150.21	57
Sugarcane area	36.91	9.02	20.50	51.50	57
Cotton yield	1516.67	769.73	609.30	3071.00	57
Cotton area	88.65	18.48	64.60	134.80	57
Rainfall	1153.74	102.34	938.40	1400.60	57
Maximum temperature	30.78	0.26	30.22	31.54	57
Minimum temperature	20.52	0.24	19.93	21.08	57

The present study used the linear regression model to estimate the impact of climate change on the yield of seven major crops. Since these seven crops are mainly cultivated during monsoon season, any change in climate, particularly rainfall and temperature would affect the yields of these crops. Here, we have considered three climatic variables: rainfall, maximum and minimum temperatures as explanatory variables and crop yield as a dependent variable. The following linear regression equation is:

$$\ln Y_t = \beta_0 + \beta_1 \ln(Rainf_t) + \beta_2 \ln(MaxTemp_t) + \beta_3 \ln(Mintemp_t) + \beta_4 \ln(Area_t) + \beta_5 T + \varepsilon_t \ldots.. (1)$$

Where, Y_t denotes crop yields (kg\ha), $Rainf_t$ means actual rainfall (mm), $MaxTemp_t$ and $MinTemp_t$ denote average maximum temperature (0^C), and average minimum temperature (0^C) respectively. $Area_t$ represents crop wise cultivated area, T means time trend and ε_t is the error term. Furthermore, β_0 is the intercept, and $\beta_1, \beta_2, \beta_3, \beta_4$and β_5 are the regression coefficients. In regression equation (1), all the variables are measured in natural log scale except time trend. Hence, the regression coefficients denote elasticity, i.e., proportionate change in crop yield to proportionate change in explanatory variables. The regression equation (1) has been estimated using STATA 12.

Since all the variables used in this study, are time series variable, we need to check the stationarity properties of the variables. Prior to estimate the econometric model, if we do not check the stationarity property of the variables, the estimated results may give us the spurious or incorrect results. Thus, first we need to confirm that the data series are free of unit root problem, i.e. the data series are stationary. If the data series of the variables are not stationary then we have to make them stationary by taking difference. We have used two popular tests; Augmented Dickey–Fuller (ADF) test [12] and Phillips-Perron (PP) test [13] to check the unit root problem of the data series of variables.

RESULTS AND DISCUSSION

The unit root test results for Augmented Dickey–Fuller (ADF) and Phillips-Perron (PP) tests are reported in (Table 2-3) respectively. The results of the unit root test with trend and without trend show that the data series of yield of selected seven crops as well as their cropped area are not stationary at the level but stationary at the first difference.

Thus, the data series of yield and cropped area for all seven corps are integrated of order one, i.e., I (1). In case of climate variables viz, rainfall, maximum temperature and minimum temperature the data series are stationary at the level at 1 % level of significance. Thus, the data series of all three climate variables are integrated of order zero, i.e., I (0). As the dependent and explanatory variables are integrated of different order, we cannot run Johansen co-integration test to estimate the long run relationship between climate variables and the yield of crops. Rather, we can perform multiple regression analysis using either an ordinary least square (OLS) method with differenced variables or quantile regression (quantile at 50%). Moreover, we cannot perform casualty test because it is assumed that yield changes are caused by climate variation rather than the vice versa proposed by Lobell and Field [14]. The dependent variable (crop yield) and explanatory variables (climate variables) have different integration orders, the Johansen co-integration test is not appropriate for estimating their long-run relationship. Instead, you can proceed with multiple regression analysis using either ordinary least squares (OLS) with differenced variables or quantile regression at the 50% quantile.

Table 2 Unit root test results (Variables at level)

Variables	Augmented Dicky-fuller test (ADF test)		Phillips Peron test	
	Intercepts only	Intercepts and trends	Intercepts only	Intercepts and trends
Rice yield	-2.28	-2.53	-0.36	-2.59
Rice area	-2.25	-2.58	-1.65	-2.41
Wheat yield	-2.10	-2.24	-2.09	-2.23
Wheat area	-2.41	-2.09	-2.18	-2.50
Pulses yield	-0.05	-2.50	-1.01	-2.53
Pulses area	-1.36	-2.26	-2.25	-2.39
Groundnut yield	-0.41	-1.48	-2.03	-2.05
Groundnut area	-1.10	-1.19	-1.60	-2.52
R&M yield	-0.73	-2.11	-0.63	-2.31
R&M area	-1.57	-2.52	-1.58	-2.43
Sugarcane yield	-0.84	-1.84	-0.65	-2.17
Sugarcane area	-1.21	-2.40	-0.94	-2.83
Cotton yield	-0.81	-2.52	-0.71	-2.56
Cotton area	-0.03	-2.01	-0.13	-2.56
Temperature max	-5.24***	-8.35***	-8.39***	-8.31***
Temperature ain	-3.45**	-4.76***	-4.18***	-5.29***
Rainfall	-8.45***	-5.65***	-4.13***	-5.69***

Note: MacKinnon (1996) one-sided p-values of z(t) (at 1%, 5% and 10% level is -3.605, -2.936 and -2.606 respectively) is used
***Significance at the 1% level (p<.01); **Significance at the 5% level (p<.05); *Significance at the 10% level (p<0.1)

Table 3 Unit root test results (Variables at first difference)

Variables	Augmented Dicky-fuller test (ADF test)		Phillips Peron test	
	Intercepts only	Intercepts and trends	Intercepts only	Intercepts and trends
Rice yield	-5.87***	-5.82***	-8.07***	-8.12***
Rice area	-5.04***	-5.18***	-13.24***	-13.57***
Wheat yield	-4.62***	-4.85***	-9.02***	-9.72***
Wheat area	-4.42***	-6.42***	-7.33***	-7.90***
Pulses yield	-5.69***	-5.74***	-13.65***	-13.68***
Pulses area	-7.75***	-7.78***	-11.79***	-12.19***
Groundnut yield	-4.92***	-5.05***	-25.77***	-25.80***
Groundnut area	-3.42***	-7.57***	-9.57***	-9.42***
R&M yield	-5.88**	-5.82**	-15.79***	-15.68***
R&M area	-5.69***	-5.67***	-8.80***	-8.76***
Sugarcane yield	-3.20**	-3.56**	-9.30**	-9.21***
Sugarcane area	-5.70***	-5.68***	-7.12***	-6.99***
Cotton yield	-3.42**	-3.38**	-9.83***	-9.73***
Cotton area	-3.92**	-7.39***	-8.38***	-8.65***

Note: MacKinnon (1996) one-sided p-values of z(t) (at 1%, 5% and 10% level is -3.605, -2.936 and -2.606 respectively) is used.
***Significance at the 1% level (p<.01); **Significance at the 5% level (p<.05); *Significance at the 10% level (p<0.1)

Data depicted in (Table 4-5) present the empirical results of OLS regression analysis and quantile regression analysis respectively of seven major crops. Both regression models give almost similar results. Quantile regression is more robust to outliers than OLS regression. Since quantile regression does need the classical assumptions regarding the distribution of the regression error term and is suitable for heteroscedastic data, it is better to discuss the estimated results obtained from quantile (median) regression.

The regression analysis of rice shows that the R-squared value is 0.61 indicating the 61% of the variation in the rice yield is explained by explanatory variables used in this study in India. The estimated coefficients of rainfall, minimum temperature, area and time trend for rice yield are positive and statistically significant except for maximum temperature which is negative and statistically significant at 10% level. Thus, rainfall, minimum temperature, area and time have a positive effect on rice yield whereas maximum temperature has an adverse effect on rice yield. Thus, the results indicate that an increase in rainfall and minimum temperature would mean higher rice yield rates and growing in maximum temperature would mean reducing rice yields. The positive and significant time trend coefficient means that time has a positive effect on rice yield indicating technological progress has occurred over time in rice production in India.

In the case of regression analysis of wheat, the R-squared value shows that 54% of the variation in the wheat yield is explained by climate and time trend variables in India. The estimated coefficients of minimum temperature, area and time are positive and statistically significant. However, the estimated coefficients of rainfall and maximum temperature both are negative but not statistically significant. Therefore, the estimated results suggest that an increase in minimum temperature and cropped area leads to an increase in the yield rate of wheat. Moreover, an increase in rainfall and a decrease in maximum temperature do not refer to the increase in wheat yield rates. The positive and statistically significant time trend coefficient indicates that technological progress occurred over time in India. The favourable technological effect occurred from the green revolution to date due to the application of high yielding seeds and modern technology, etc.

The regression analysis of pulses shows that although the estimated coefficients of rainfall, minimum temperature and cropped area are positive, only the coefficients of rainfall and cropped area are statistically significant, whereas the coefficient of maximum temperature is negative and statistically significant. This implies that an increase in rainfall, and cultivated area would increase the yield rates of pulses, whereas the increase in maximum temperature has an adverse effect on the yield rate of pulses. Furthermore, the estimated coefficient of time-trend is positive but not statistically significant. Thus, positive time trend coefficient does not refer to the occurrence of technological progress in pulses production in India during the period under study. Moreover, The R-squared value for regression analysis of pulses indicates that 52% of the variation in the pulses yield is explained by climate variables in India. Thus, there are some factors other than variables used in this study that may explain the variation of yields of pulses.

Table 4 OLS regression results (Sample period: 1965-66 to 2020-21)

Explanatory variables	Crop yield						
	Rice	Wheat	Pulses	Groundnut	R&M	Sugarcane	Cotton
Rainfall	0.48*** (0.17)	0.32** (0.12)	0.64*** (0.23)	-1.83** (0.92)	0.87 (0.53)	0.12 (0.11)	-0.66** (0.31)
Max temperature	-2.39* (1.28)	-1.04 (1.08)	-3.40* (1.83)	-3.13 (4.16)	-3.14** (1.35)	0.76* (0.37)	3.69** (1.81)
Min temperature	4.97** (2.12)	4.20* (2.28)	4.95 (3.10)	10.64* (6.13)	9.89 (5.01)	2.40 (1.78)	6.00 (4.66)
Area	1.22*** (0.40)	0.45** (0.20)	0.34* (0.18)	0.37 (0.41)	0.15* (0.07)	0.09** (0.04)	0.07* (0.04)
Time	0.018* (0.01)	0.02** (0.01)	0.01 (0.01)	0.008 (0.01)	0.01 (0.01)	0.009 (0.01)	0.019* (0.01)
Constant	-13.27** (5.95)	-13.47*** (4.98)	-11.15 (9.66)	39.84* (20.15)	-31.01*(14.40)	-6.74 (4.97)	-14.05 (13.09)
R-squared	0.61	0.59	0.53	0.51	0.51	0.50	0.58
No. of observation	56	56	56	56	56	56	56

Note: the standard errors are in parentheses
***Significance at the 1% level (p<.01); **Significance at the 5% level (p<.05); *Significance at the 10% level (p<0.1)

Table 5 Quantile regression results (Sample period: 1965-66 to 2020-21)

Explanatory variables	Crop yield						
	Rice	Wheat	Pulses	Groundnut	R&M	Sugarcane	Cotton
Rainfall	0.31** (0.14)	0.40** (0.16)	0.63*** (0.22)	2.01** (0.93)	0.61 (0.33)	0.13 (0.07)	-0.80* (0.42)
Max temperature	-2.18** (1.05)	-0.93 (1.42)	-2.96* (1.61)	-1.68 (4.73)	-2.35** (0.96)	0.61** (0.28)	2.15** (0.98)
Min temperature	3.17* (1.68)	4.07* (2.31)	7.10 (4.61)	11.9** (5.63)	8.27 (8.31)	0.71 (1.26)	5.95 (6.77)
Area	0.97*** (0.35)	0.37* (0.21)	0.25** (0.12)	0.39 (0.46)	0.05* (0.023)	0.12** (0.06)	0.14** (0.66)
Time	0.017*(0.01)	0.029*** (0.01)	0.005 (0.01)	0.002 (0.01)	0.003 (0.001)	0.001 (0.01)	0.001** (0.0005)
Constant	-6.48** (3.21)	-13.92** (6.44)	-19.92 (12.20)	49.83** (22.64)	-24.74 (12.68)	-1.54 (3.42)	-19.45 (19.24)
R-squared	0.59	0.57	0.58	0.51	0.53	0.52	0.62
No. of observation	56	56	56	56	56	56	56

Note: the standard errors are in parentheses
***Significance at the 1% level (p<.01); **Significance at the 5% level (p<.05); *Significance at the 10% level (p<0.1)

The estimated R-squared value of groundnut regression is 0.51 indicating the overall significance of the regression analysis. The estimated coefficients of explanatory variables; rainfall, minimum temperature, cropped area and time trend are positive but not statistically significant except for rainfall and minimum temperature. Thus, it indicates rainfall has a positive impact on groundnut yields and an increase in minimum temperature has a favourable effect on the yield rate of groundnut. Although the regression coefficient of maximum temperature is negative but not statistically significant. Thus, we cannot strongly say that an increase in maximum temperature has an adverse effect on groundnut yield rate.

In the case of rapeseed and mustard (R&M), the regression analysis shows that the estimated coefficients of rainfall, minimum temperature, cropped area and time trend are positive but not statistically significant except for cropped area. Thus, the results indicate that neither rainfall nor minimum temperature have a significant positive effect on the R&M yield rate whereas, the cropped area of R&M is positively related with the R&M yield rate. However, the coefficient of maximum temperature is negative and statistically significant indicating that an increase in maximum temperature has an adverse effect on the R&M yield rate. The R-squared value R&M regression analysis indicates that 50% of the variation in the rapeseed and mustard yield is explained by explanatory variables used in this study.

The R-squared value of sugarcane regression specifies that explanatory variables used in this study explain 47% of the variation in the sugarcane yield in India. All the estimated coefficients namely rainfall, maximum temperature and minimum temperature, area and time trend are positive but not statistically significant except area and maximum temperature. Thus, the result implies that cropped area and maximum temperature have a significant positive effect on sugarcane yields.

The regression analysis of cotton shows that the R-squared value is 0.62 specifying climate variables in India explain 62% of the variation in the cotton yield. The estimated coefficients of maximum temperature, minimum temperature, cropped area and time trend are positive and statistically significant except for minimum temperature Thus, the result implies that the maximum temperature, has a favourable effect on cotton yield rate and the cropped area is positively associated with cotton yield rates. Furthermore, the positive time-trend of cotton over time during the study period indicates that time has a favourable effect on cotton yield rate due to could have technological progress. Moreover, the negative and statistically significant estimated coefficient of rainfall indicates that rainfall has an adverse effect on cotton yield rates.

CONCLUSION

The study examined the impact of climatic variables on the yield of major crops in India using time series variables during the period 1964-65 to 2020-21. We have taken seven major crops, namely rice, wheat, pulses, groundnut, rapeseed and mustard (R&M), sugarcane, and cotton, comprising approximately 71% of the overall gross cropped area in India. In this study, variables such as rainfall, average maximum temperature and average minimum temperature are considered as climatic variables. Both OLS and quantile regression models were used to estimate the impact of climate variables on the yields of major crops. The estimated results have shown that the significance and sign of the estimated regression coefficients are found to be different for different crops. Thus, the estimated results indicate that the three climate variables have substantial impacts on crop yield, but the impacts vary across the seven major crops. An increase in rainfall has a significant favourable effect on rice, wheat, pulses and groundnut yields, whereas it has an adverse effect on cotton yields. However, although rainfall has a positive relationship with rapeseed and mustard (R&M) and sugarcane yields, it was not significant during the study period. Further, the average maximum temperature has a significantly adverse effect on rice, pulses and rapeseed and mustard (R&M) yields, whereas it has a significantly positive effect on sugarcane and cotton yields. Although average maximum temperature has a negative relationship with wheat and groundnut yield, it was not significant during the study period. Moreover, the average minimum temperature has a positive relationship with the yield of all seven major crops, but the relationship is significant only for rice, wheat and groundnut yields. Conclusively, this study revealed that climatic factors such as rainfall has a positive effect whereas average maximum temperature has an adverse effect on crop yield in general. Since climate variables are beyond the control of farm households and any changes in climate variables affect crop yields, there must be some proper policies to mitigate the adverse effects of climate change on crop yield. Hence, sustainable agriculture growth needs modern technology, temperature-tolerant variety seeds, plentiful irrigation facilities, a proper credit facility and crop insurance policy to deal with the possible losses to farmers due to climate change.

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