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Research Paper

An assessment of the impact of climate on wheat yield in Indo-Gangetic plain region of India: A panel data analysis

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ABSTRACT

This paper is an attempt to assess the impact of climate on wheat yield in the Indo-Gangetic Plain (IGP) region of India by using panel data analysis. Five IGP states namely Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal have been considered to frame a panel. The study used the data of climatic and non-climatic variables from 1990 to 2022 to achieve the objective of the study. The Im-Pesaran-Shin unit-root test was applied to check the stationarity of data. The results of the panel least square dummy variable model indicated that all the climatic variables had non significant influence. Among non-climatic variables that help increase wheat yield, fertilizer consumption and mechanization in agriculture were found to have a significant positive impact on wheat yield in the IGP region of India.

Keywords: Climatic variables, Wheat yield, IGP region, Panel data analysis, non-climatic variables, Mechanization

In the present era when industrialization is the prime way to economic development, agriculture plays a decent part in the economic progress of developing countries. In India, agriculture and allied activities contributed about 18.3 percent of total gross value added (GVA) in 2022-23 (Press Information Bureau, 2023). The climate change and global warming has impacted the different crops differently (Baylie and Fogarassy, 2021).

Wheat is one of the most consumed food crops in India as well as globally. Wheat ensures food security in India specifically the northern part of the country. India is the second largest producer of wheat. Indo-Gangetic Plains (IGP)**,** also called North Indian Plains, is one of the oldest plains situated in the extensive north-central section of the Indian subcontinent. The IGP region of India constitutes the most important agricultural region in south asia (Abrol *et.al*., 1999), so, considered as the 'food bowl of South Asia'. It covers 15 percent of the total geographical area of the country and produces about 50 percent of the total foodgrains to feed 40 percent of the population of India. Although five states of the IGP region, viz., Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal have different cropping patterns, the principal crop of this region is wheat which covers 67.18 percent of cultivated area in the region.

It has been observed in recent years that the productivity of wheat is declining in the IGP region of India (Sekar and Pal, 2012). The changes in climatic conditions, i.e., shifts in the timing of rainfall and changes in average temperature in the region are a matter of great concern for wheat yield in the region (Zacharias *et al*., 2014). The importance of the wheat crop, the prevailing climatic conditions in the IGP region, and the economic importance of the IGP region motivated the researchers to examine the impact of climate on wheat yield in selected five states of the IGP region of India.

MATERIAL AND METHODS

The area under study includes five states of the IGP region of India viz Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal. The study is based on secondary state-wise data of climatic variables and wheat yield of five state for a period of 32 years (1990 to 2022). The data on climatic variables including maximum temperature, minimum temperature, average temperature, and rainfall and non-climatic variables includes fertilizer consumption, irrigation intensity, and mechanization in agriculture etc considered for the study were collected from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and Central Institute of Agricultural Engineering (CIAE), Bhopal (Table 1).

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Table 1: Description of selected variables

Variable Name	Notation	Measure	Source
Dependent variables			
Wheat yield	WY	kg ha^{-1}	ICRISAT
Independent variables: (A) climatic variables			
Average temperature	AVT	Celsius (^{O}C)	ICRISAT
Maximum temperature	MXT	Celsius (^{O}C)	ICRISAT
Minimum temperature	MNT	Celsius (^{O}C)	ICRISAT
Rainfall	RF	mm	ICRISAT
(B) Non-climatic Variables			
Fertilizer consumption	FRCN	Ton/ Hectare	ICRISAT
Irrigation intensity	IRR	Percent of Irrigated Area	ICRISAT
Tech. mechanism	TECM	Annual sale of tractors	CIAE

Table 2: Results of Hausman specification test

Variables	Wheat yield (WY)			
	FEM	REM	(b-B)	SE
AVT	-47.72	137.25	-184.98	43.18
MXT	28.05	-85.72	113.78	27.45
MNT	18.65	-53.13	71.78	15.97
RF	-0.060	-0.322	0.261	0.047
FRCN	0.227	0.324	-0.097	0.034
TECH	0.044	-0.006	0.051	0.019
IRR	-0.002	0.219	-0.222	0.041
Chi^2	70.92			
Prob.	0.000			

Panel data analysis

Since data of dependent and independent variables for selected states frame a panel, the researchers besides descriptive statistics, Im-Pesaran-shin unit-root test (Im *et al*., 2003) used panel data analysis (Sanghi and Mendelsohn, 2008). Panel data analysis can be performed by using three techniques, namely pooled ordinary least square (PLS) model, fixed effect model (FEM), and random effects model (REM). A panel unit root test is a statistical method used to assess whether a set of time series data has a unit root, which implies that the series is non-stationary. Panel data refers to data that involves multiple individuals, entities, or observations measured over time. Unit roots are a feature of non-stationary time series data, indicating that the series has a stochastic trend and does not tend to revert to a constant mean over time. To identify an appropriate method for the study, the Hausman specification test (Hausman, 1978) was used. It states that if the probability value associated with an asymptotic chi-square is less than 0.05, FEM is appropriate, else REM should be used (Table 2).

Since the probability value of asymptotic chi-square is less than 0.05, and panel data considered in the study also matches the properties of FEM; the fixed effect least squares dummy variable (LSDV) method for further estimation. The basic equation of the fixed effect LSDV model is:

$$Y_{it} = \alpha_{it} + X'_{it}\beta + \mu_{it} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For i = 1, 2, 3…. n, and t = 1, 2, 3…. n. In equation - 1, Y_{it} is the response for unit i at time t, α_i is the individual-specific intercept, vector X'_{it} contains k regressors for unit i at time t, vector β contains k regression coefficients to be estimated, and μ_{it} is the error component for unit i at time t.

The empirical model for wheat crop yield (WY) in IGP region of India is as follows.

$$WY_{i,t} = \alpha_{it} + AVT_{it}\beta_{1i,t} + MXT_{it}\beta_{2i,t} + MNT_{it}\beta_{3i,t} + RF_{it}\beta_{4,t} + FRCN_{it}\beta_{5i,t} + TECM_{it}\beta_{6i,t} + IRR_{it}\beta_{7i,t} + D_{1.t,}\beta_{12i,t} + D_{2,t}\beta_{13i,t} + D_{4,t}\beta_{14i,t} + D_{5,t}\beta_{14i,t} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The functional relationship in the fixed effect LSDV model suggests that changes in the dependent variable (WY) are explained by independent variables β_1 to ε_{it}. Where ε_{it} is the stochastic error term added to the equation. Dummy variables belonging to the cross-section of Haryana, Bihar, Uttar Pradesh, Punjab, and West Bengal (D_1, D_2, D_3, D_4 and D_5) are equal to 1. the dummy variable for cross-section D_3 is not used due to the problem of collinearity.

RESULTS AND DISCUSSION

Table 3 presents basic descriptives statistics viz. mean, median, standard deviation, skewness, kurtosis, Jarque-Bera value, and its associated probability of variables under consideration. The probability associated with JB statistics (a test of normality) of all the variables, except maximum temperature (MXT) is less than 0.05, which means all the variables (except MXT) are normally distributed. For convenience in analysis, all the data sets are converted to their natural logarithm form.

Test of stationarity – Panel unit root test

To check the unit root problem, i.e., stationarity of data series, the Im-Pesaran-Shin unit-root test is used. The dependent variable, i.e., wheat yield (WY) is stationary at first difference. Among dependent variables, all the climatic variables (AVT, MXT, MNT, and RF) are stationarity at level, while all the non-climatic variables (FRCN, TECH, and IRR) are stationarity at first difference (Table 4). Statistics of the relationship between the dependent variable (WY) and identified independent variables examined by using panel fixed effect LSDV are presented in Table 5.

Table 3: Descriptive statistics

Variable	Mean	Med.	Max.	Min.	SD	Skew.	Kurto.	JB	Prob.
WY	3171.0	2825.0	5188.0	1609.0	990.90	0.33	1.75	12.49	0.00
AVT	25.4	25.5	26.80	23.3	0.63	-0.48	3.23	6.13	0.04
MXT	31.5	31.5	33.2	29.6	0.65	0.13	2.93	0.46	0.79
MNT	19.4	19.4	21.5	17.1	0.91	0.07	2.55	1.36	0.00
RF	1011.6	897.6	1992.8	385.8	411.08	0.59	2.21	12.45	0.00
FRCN	153.7	155.3	256.6	56.8	48.56	0.10	2.27	9.18	0.01
TECM	26091.1	21365.5	120664.0	700.0	22023.44	1.73	6.28	142.20	0.00
IRR	71.2	62.3	100.0	29.3	25.82	0.02	1.29	18.24	0.00

Note**:** Significant at 10%, 5%, and 1 % level of significance.

Table 4: Results of Im-Pesaran-Shin unit-root test

Variables	Z(t)	Prob. (0.05)	Order of Integration	Remark
WY	-11.03	0.00	I(1)	Stationary
AVT	-4.39	0.00	I(0)	Stationary
MXT	-4.74	0.00	I(0)	Stationary
MNT	-4.43	0.00	I(0)	Stationary
RF	-8.38	0.00	I(0)	Stationary
FRCN	-13.72	0.00	I(1)	Stationary
TECM	-6.99	0.00	I(1)	Stationary
IRR	-14.59	0.00	I(1)	Stationary

Table 5: Panel least square dummy variables (LSDV) fixed effect

Variables	Wheat yield (WY)			
	Coeff.	SE	‘t’	Prob.
C	9.08	2.93	3.10	0.002
AVT	-47.72	44.07	-1.08	0.281
MXT	28.05	27.56	1.02	0.311
MNT	18.65	16.61	1.12	0.263
RF	-0.063	0.055	-1.09	0.276
FRCN	0.227	0.044	5.17	0.000
TECH	0.044	0.018	2.40	0.018
IRR	-0.002	0.048	-0.05	0.957
D_1	0.354	0.062	5.62	0.000
D_2	-0.211	0.053	-3.95	0.000
D_4	0.378	0.066	5.67	0.000
D_5	-0.012	0.124	-0.10	0.922
R^2	0.928			
Adj. R^2	0.922			
RMSE	0.088			
F Stat.	160.92			
Prob. (F)	0.000			

Table 6: Results of model diagnostics and residual checking

Test	Test Stat.	Prob.
Pesaran CD test	-0.88	0.234
Modified Wald test	73.83	0.462
Wooldridge test	47.178	0.002

In the Table 5, the dummy variables D_1, D_2, D_4 and D_5 indicate cross sections of Haryana, Bihar, Punjab, and West Bengal, respectively. Panel regression equation describing the relationship between wheat yield and identified independent variables with dummy variables expressed through fixed effect least square dummy variable (LSDV) model is as follows.

$WY_{i,t} = 9.08 - 47.72AVT_{it} + 28.05MXT_{it} + 18.65MNT_{it} - 0.063RF_{it} + 0.227FRCN_{it} + 0.044TECM_{it} - 0.002\ IRR_{it} + 0.354D_{1,t,} - 0.211D_{2,t} + 0.\ 0.378D_{4,t} - 0.012D_{5,t} + \varepsilon_{it}$………… (3)

The results indicated that among climatic variables, average temperature (AVT) and rainfall (RF) have a negative impact, while maximum temperature (MXT) and minimum temperature (MNT) have a positive impact on wheat yield, probably due to the nature of the wheat crop. The wheat crop requires a normal average temperature but the average temperature is rising in the IGP region. The timing of rainfall is shifted to March and April month, before the harvesting of the wheat crop ultimately resulting in a negative impact on the wheat crop. The wheat crop requires minimum temperature in the initial days after ploughing, and high temperature just before harvesting. It has been observed that the minimum temperature is stable and the maximum temperature is rising and both are favourable for the wheat crop. However, the probability value (> 0.05) associated with these factors is statistically insignificant, which means climatic factors do not have a significant effect on wheat yield in the IGP region. These findings are similar to Kumar and Sidana (2017), and Senapati and Goyari (2020). Non-climatic variables although help to increase wheat yield, only fertilizer consumption (FRCN), and mechanization in agriculture (TECM) are found statistically significant ($P < 0.05$) at a 5 percent level of significance, meaning that these variables have a significant positive impact on wheat yield. Irrigation intensity (IRR) is a statistically insignificant factor, meaning that irrigation does not have a significant impact on wheat yield in the IGP region. Kumar and Sidana (2017) in a study conducted in Punjab state also reported similar results. The coefficient of determination (r^2) of the model is 0.928, which indicates that 92.8 percent of variations in wheat yield (WY) are caused by the variations in identified independent variables considered in the model. The remaining variations in wheat yield are attributed to changes in other unknown factors termed as stochastic error terms. Since the value of F statistics is significant at a 5 percent level of significance, and the value of root mean square error (RMSE) used to assess the reliability of the model is 0.088, it can be concluded that the model is best fit and capable of predicting the data accurately.

Model diagnostics

The econometric theory suggests that the residuals of FEM must be free from cross-sectional dependence, heteroscedasticity, and autocorrelation otherwise, the basic assumption associated with a model will not hold. Accordingly, the residuals in the model are tested on all the parameters. Cross-sectional dependence, heteroscedasticity in residuals, and the problem of autocorrelation in the panel data models are examined by using the Pesaran CD test, Modified Wald test, and Wooldridge test respectively. The results of these tests are presented in Table 6. The results of the Pesaran CD test (Chi-square P-value = 0.234), modified Wald test (P-value = 0.462), and Wooldridge test (P-value = 0.002) indicate no cross-sectional dependence, heteroscedasticity, and autocorrelation in the model; hence, above model holds true.

CONCLUSION

The present paper explores the impact of climate on the wheat crop in the IGP region of India by applying the panel data technique. The study takes secondary data from 1990 to 2022. The results of the study reveal that the climate plays a significant role in determining the wheat crop in the region. All the climatic factors are important for the wheat crop. The average temperature and rainfall adversely affect the wheat crop. The maximum temperature and minimum temperature positively impact the wheat crop. Non-climatic variables viz. fertilizer consumption and mechanization in agriculture were found to have a significant positive impact on wheat yield in the IGP region of India. The implications of the study are crucial for the different stakeholders and policymakers. Climate is negatively affecting the wheat crop in the region.

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***Authors contribution*: A. Kumar**: Methodology and Data collection, Data Analysis, Writing-original draft, Referencing; **S. P. Saxena**: Conceptualization, Visualization, Critical review.

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