An Econometric Analysis of the Impact of Climate Change on Wheat Yield in the Gangetic Indo-Plains of India : A Study of Meerut District

Swami Prasad Saxena [1]
Anuj Kumar [2]

Abstract

Purpose : The study aimed to examine how climate change is affecting wheat crop yields in Meerut, a significant wheat-producing district in India's Indo-Gangetic Plain (IGP) region.

Methodology : The OLS technique was applied to annual data covering 40 years, from 1980 to 2020, in order to investigate the effects of variations in meteorological variables, specifically mean temperature, maximum temperature, minimum temperature, and rainfall, on wheat yield.

Findings : The results of OLS estimation indicated that around 61% of changes in wheat yield are governed by climatic factors. The results revealed that the average mean temperature was good for wheat crops in the second (growth) stage. In the final stage, which is before harvesting, the highest temperature reduces wheat output. In the past 10 years, it has also been noted that lower minimum temperatures and higher maximum temperatures during the initial stages of the crop had a negative impact on wheat output. Rainfall timing, which is crucial for the wheat crop, is changing in the area; it was occurring after the wheat was torn, which had a detrimental effect on wheat output.

Practical Implications : The output of wheat harvested in the Meerut district is being adversely affected by climate change. To maintain the crop, the government and farmers need to work together to implement various adaptation strategies.

Originality : There was a paucity of research work at the district level in the current domain of research. This paper tried to bridge the gap in the literature, focusing primarily on the study of the impact of climate change on wheat yield in Meerut, a district of the IGPs region of India.

Keywords : econometric analysis, climate change, wheat yield, rainfall

JEL Classification Codes : C5, Q54, Q1, Q540

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A major concern of the modern era is climate change, which has an impact on practically all economic and non-economic activities. Policymakers and other stakeholders are worried about how anthropogenic and natural activities are altering climate variables. Numerous previous studies have provided scientific evidence that the earth's climate is changing and that people are experiencing these changes in weather patterns (Nath & Mandal, 2018). Agriculture is one of the main economic activities that is directly impacted by the climatic conditions of a given geographical area, among various other areas affected by changes in temperature

[1] *Professor (Macroeconomics and Finance),* Department of Applied Business Economics, Dayalbagh Educational Institute Dayalbagh, Agra - 282 005, Uttar Pradesh. (Email : spsaxena@dei.ac.in)
[2] *Assistant Professor (Corresponding Author),* Department of Commerce, Institute of Oriental Philosophy, Vrindavan, Mathura - 281 121, Uttar Pradesh. (Email : achaudhary278@gmail.com) ;
ORCID iD : https://orcid.org/0000-0002-2619-980X

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and weather patterns. The two primary climate variables, temperature and rainfall, are the most important inputs for any agricultural crop; even a small change in the weather has an impact on crop yield. As the developing world lacks resources and knowledge to cope with climate change, the adverse impacts of climate change are more severe in developing countries like India (Kumar & Parikh, 2001).

One of India's main economic sectors is agriculture. The majority of the county's inhabitants, over half, either directly or indirectly make their living from agriculture. The agricultural industry contributes around 18.3% of the overall GDP (Press Information Bureau, 2023). Additionally, this industry guarantees the availability of raw resources for other manufacturing sectors. India's large population's over-reliance on the agriculture sector makes the negative effects of climate change more severe. The severity of the problem is increased by the absence of general awareness, scientific knowledge, and awareness of adaptation and mitigation solutions (Birthal et al., 2014).

Although climate change is not a recent occurrence, its effects on wheat yield have not received as much attention. Kumar et al. (2014) studied the sensitivity of wheat crops toward climate change and assessed that climate change may reduce the wheat yield by 6% to 23% by 2050. Ahmad et al. (2014) examined the impact of climate change on wheat productivity in Pakistan over a period from 1981 to 2010. They mentioned that rainfall is good for wheat productivity, but the temperature rise is dangerous for wheat crops in the initial days of sowing. Kumar and Singh (2014) analyzed the relationship between climatic variables and wheat crops and used the historical data from 1969 to 1990 of Indian Agriculture. The results revealed that the increase in temperature does not impact crops too much, and adaptation techniques like agroforestry are expected to mitigate the impact of climate change on wheat yield.

Howard et al. (2016) studied the impact of climate change on wheat crops and used the annual data from 1949 to 2014. The research's conclusion shows that while temperature and rainfall have a short-term favorable relationship with wheat productivity, over time, both meteorological factors have a negative impact on wheat production. Geng et al. (2019) assessed the impact of climate change on wheat yield in China and used the data on climatic factors from 1981 to 2016. They found that the growing seasonal temperature negatively affects the wheat crop while the rainfall during wheat growing time has a positive impact on wheat yield.

According to recent research, Guntukula and Goyari (2020) studied the relationship between meteorological conditions and maize yield in the Indian state of Telangana from 1956 to 2015. They stated that although minimum and maximum temperatures reduce risk, rainfall and other factors shield farmers from it. Daloz et al. (2021) tried to examine the direct and indirect impact of climate change on wheat yield in the Indo-Gangetic Plain (IGP) of India. Their findings revealed that the changes in temperature and precipitation may reduce the wheat yield by 1% to 8% in different regions of IGP. They mentioned that due to high temperatures and less precipitation in the region, the availability of water for irrigation may be reduced, which may hurt wheat yield.

In the current era, when climate change is a vital issue of the world and agriculture is an economic activity majorly governed by the climatic conditions of a geographical area; therefore, the current era demands quantifying the impact of climate change on agriculture. Although a few studies have been conducted in India to examine the impact of climate change on agriculture at the country level or state level. The previous studies mainly used simple economic and statistical tools. As a result, there is a shortage of research at the district, regional, and methodology levels. This work aims to fill a vacuum in the literature by conducting an econometric analysis of the effects of climate change on wheat output in the Indian district of Meerut, which is located in the IGP. The study also applied different suitable econometric techniques to bridge the research gap.

Climatic Conditions and Wheat Production in the Meerut District of the IGP Region of India

The North India River Plain is the common term for the IGP region, which is named after the Ganga and Indus river systems. The land's fertility in this particular region is primarily due to the plain's river system. Food security in South Asia is guaranteed by the IGP region, which is situated in the Indian subcontinent. Due to the good productivity of food crops, it is also known as the “Food Bowl of South Asia.” The plain covers the northern states of India, the western region of Pakistan, and some parts of Bangladesh, and Nepal also (Aggarwal et al., 2004). The southwest monsoon provides rainwater to agriculture, and the normal temperature of the plain is supportive of food crops like wheat, rice, sugarcane, and cotton. In the last few decades, the timing of rainfall has shifted, and the normal temperature has also risen in the IGP (New et al., 2012).

The national capital of India lies 70 kilometers from Meerut, an IGP district in western Uttar Pradesh that is well-known for its food crop yield. The Ganga River runs through the district. In Meerut, sugarcane, wheat, and rice are the main crops. The average rainfall of the district is 800–1000 mm/ year. The average maximum temperature falls between 4–45 ºC in summer and 20–23 ºC in winter.

Furthermore, the average minimum temperature falls between 19–21 ºC in summer and 03–05 ºC in winter (KVK, Meerut). The climatic conditions of the district are favorable for the cropping system. The canal system of western Uttar Pradesh ensures an adequate supply of water for the crops. However, in the last few decades, it has been observed that the weather conditions in the region are changing frequently. A brief description of the weather variables is presented in Figures 1 and 2.

The major weather input for the wheat crop is temperature; it requires moderately low temperature at the growing stage and moderate-high temperature at the time of ripping (Ramdas et al., 2012). The district's average annual temperature has risen from 23.340 ℃ to 25.780 ℃ during the past 40 years, according to Figure 1 trend of average annual temperature. This increase could have an impact on the number and quality of crops.

Rainfall plays a crucial role in maintaining soil moisture levels and determining soil fertility. It is a crucial input for wheat crops since at least four irrigations are necessary for improved crop quality and yield. Figure 2 shows the rainfall pattern, which shows significant annual fluctuations in the district's total rainfall. Monsoon, the major season of rainfall is also delayed in the district every alternative year. It is also observed that rainfall happens at the time of harvesting of wheat crop causing loss of productivity.

Figure 1. ***Average Annual Temperature (°celsius) in Meerut District (1980–2020)***

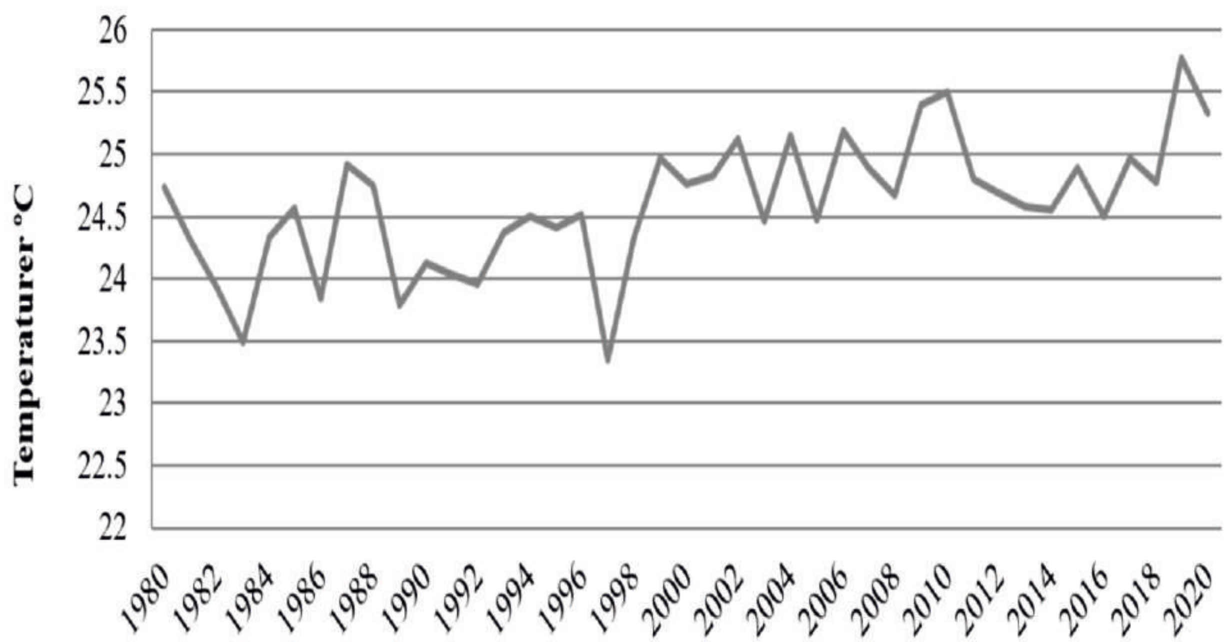


Figure 2. *Annual Total Rainfall (MM) in Meerut District (1980–2020)*

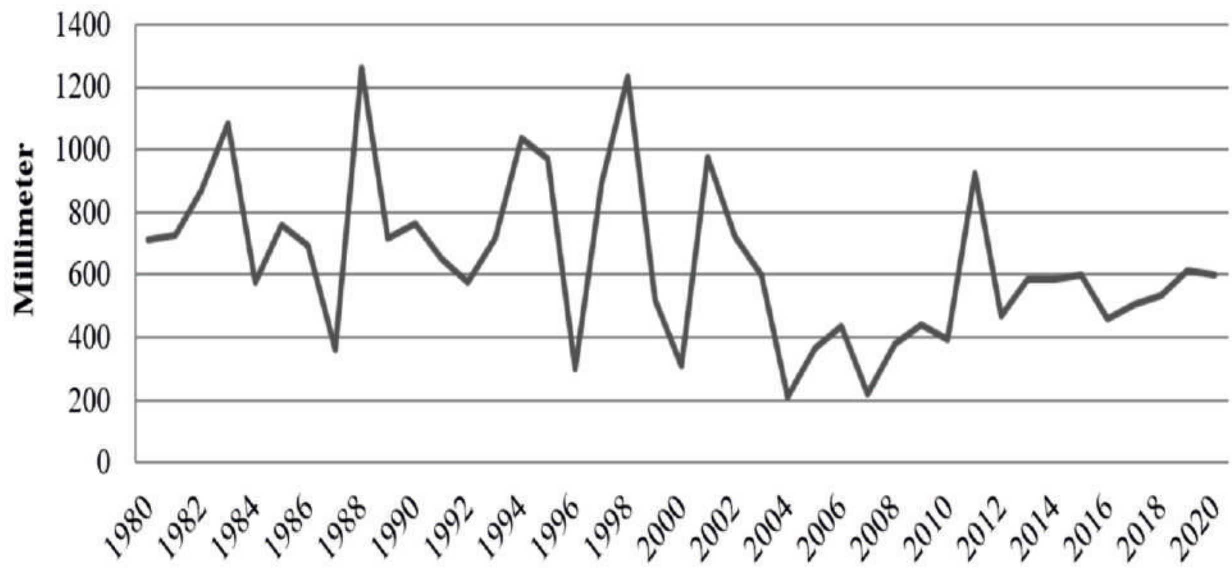
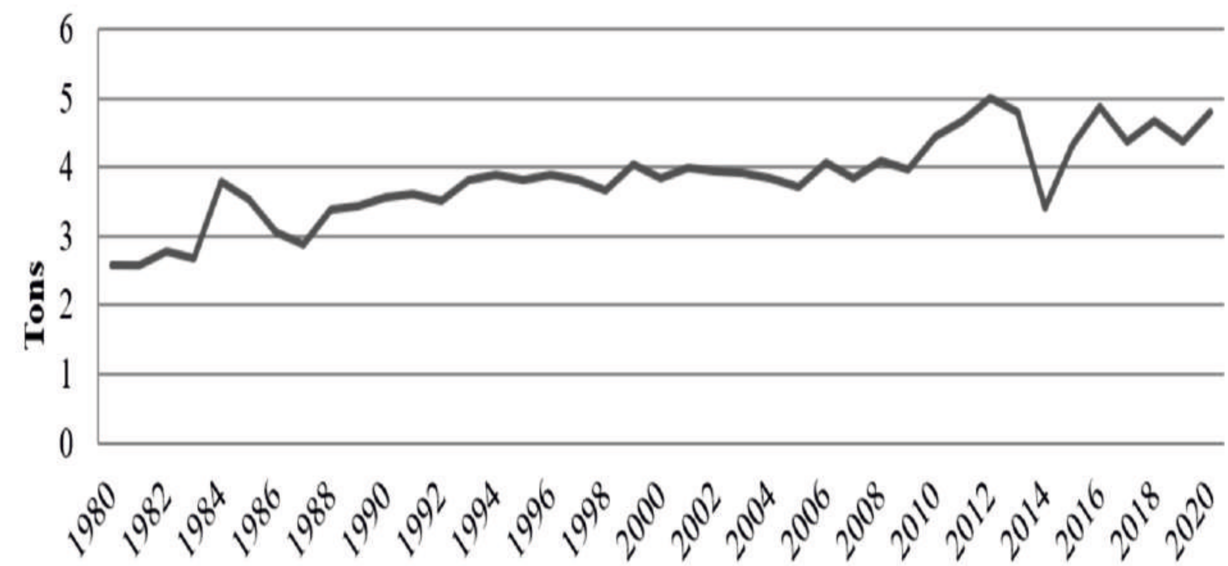


Figure 3. *Wheat Yield (Ton/Hectare) in Meerut District (1980–2020)*



Wheat is one of the most important crops in the world, and India is one of the largest producers and exporters of wheat. This crop ensures food security in many states of India, especially in the northern states of the country. Punjab, Haryana, Uttar Pradesh, and Madhya Pradesh are known for the good quality of wheat in the country. Uttar Pradesh is one of the major producers of wheat in the country, where wheat is cropped in the winter season (Ravi). Meerut district is known for the highest yield (4.23 tons/ hectare) of wheat in the state. The district's trend of increasing wheat production (Figure 3) over the past 40 years is most likely attributable to the application of contemporary agro-technology, high-yield variety seeds, improved irrigation systems, timely fertilizer availability, etc.

Methodology

Type of Research. The present study is empirical and analytical.

Research Design

Data and Methods of Data Collection

The study depends on district-level secondary data on climatic variables (temperature and rainfall) and wheat yield collected from different sources (Table 1). Data on climatic variables is collected from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and the data on wheat yield is extracted from various issues of the *Statistical Abstract of Uttar Pradesh.* The OLS estimation technique is used to analyze the data on E-Views 7.0 software.

Table 1. ***Description of Variables***

Variables	Description
Wheat Yield	Average Annual Yield (Ton/ Hectare)
Rainfall	Total Annual Rainfall (Millimeter)
Maximum Temperature	Average Maximum Temperature (°C)
Minimum Temperature	Average Minimum Temperature (°C)
Mean Temperature	Average Mean Temperature (°C)

Period of the Study

The analysis takes into account the meteorological and wheat crop data for the Meerut district from 1980 to 2020.

Analysis and Results

The descriptive statistics presented in Table 2 indicate that the average yield of wheat is 3.83 (Ton/Ha), which is high compared to most of the districts of the state. There is little deviation in wheat yield. The mean rainfall of the district is 642.33 mm during the years of study. The standard deviation of rainfall is very high, which clearly indicates the inconsistency of rainfall over the years in the study area. The maximum and minimum temperatures also have a standard deviation of more than 1. This is the indication of fluctuation from normal values of temperature, which may be an upward rise in temperature in the district. The p-value of the Jarque–Bera test reflects that wheat yield, rainfall, and average temperature follow the normal distribution, while the other two variables have a departure from normality.

Table 2. ***Descriptive Statistics***

Variables	Unit	Mean	Std. Dev.	Maximum	Minimum	Jarque–Bera	Prob.	Observations
Wheat	Ton/ Ha	3.83	0.616	5.011	2.569	0.407	0.81580	41
Rainfall	MM	642.33	257.110	1259.700	210.000	2.102	0.34945	41
Ave. Temp.	°C	24.59	0.521	25.775	23.346	0.335	0.84557	41
Max. Temp.	°C	31.14	1.620	35.680	29.090	34.540	0.00000	41
Min. Temp.	°C	18.05	1.319	19.585	14.250	30.289	0.00000	41

Table 3. ***Augmented Dickey-Fuller (ADF) Unit Root Test***

Variables	**At Level**		**At 1 Difference**		**Decision**
	***t*-Statistic**	***P*-Value**	***T*-Statistic**	***P*-Value**	
Wheat Yield	–4.821375	0.0020***	–6.478066	0.0000	I(0)
Rainfall	–5.120871	0.0001***	–6.942731	0.0000	I(0)
Mean Temperature	–5.690692	0.0002***	–9.483926	0.0000	I(0)
Maximum Temperature	–1.967987	0.6005	–6.209234	0.0000***	I(1)
Minimum Temperature	–1.823036	0.3643	–6.859844	0.0000***	I(1)

Note. *** 5% level of significance.

Table 4. ***Lag Length Selection Criteria***

Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
0	333.4192	NA	1.34e–14	–17.75239	–17.53470	–17.67564
1	379.2517	76.80036	4.42e–15	–18.87847	17.57232*	–18.41799
2	411.7482	45.67076*	3.18e–15*	–19.28368	–16.88908	–18.43947*
3	433.9945	25.25255	4.57e–15	–19.13484	–15.65177	–17.90689
4	474.0468	34.63988	3.20e–15	–19.94848*	–15.37695	–18.33680

Note. LogL = Log-Likelihood, LR = Likelihood Ratio, FPE = Final Prediction Error, AIC = Akaike's Information Criterion, SC = Schwarz's Criterion, HQ = Hannan and Quinn Criterion.

Note. A '*' indicates the optimum lag.

While maximum and minimum temperatures are stationary at the first difference, wheat yield, rainfall, and mean temperature are stationary at the level, according to the results of the Augmented Dickey–Fuller (ADF) test (Table 3), which was used to determine whether or not selected variables are stationary at level.

In time series data, the series forms an order over some time. The econometrics methodology suggests deciding on lag order before applying the OLS modeling technique. The application of AIC is common among several criteria to determine the ideal lag length. The maximum lag length of 4, which is seen to be ideal for additional analysis, is suggested by the AIC lag length criterion values displayed in Table 4.

For OLS modeling, wheat yield is regressed with climatic variables, namely average mean temperature, average maximum temperature, average minimum temperature, and total annual rainfall in the selected district. The basic form of the OLS estimation model is presented below.

$$\text{Ln}WYield = \beta_0 + \beta_1 \text{Ln}MeanT + \beta_2 \text{Ln}MaxT + \beta_3 \text{Ln}MinT + \beta_4 \text{Ln}Rainfall + \upsilon i \quad \ldots\ldots\ldots\ldots (1)$$

where, Ln*WYield* = Log value of Wheat Yield (Ton/ Ha), Ln*MeanT* = Log value of average mean, Temperature (°C), Ln*MaxT* = Log value of average maximum temperature (°C), Ln*MinT* = Log value of average minimum temperature (°C), Ln*Rainfall* = Log value of total annual rainfall (Millimetre), and υi = Error term.

Based on the results of OLS estimation presented in Table 5, equation (1) can be written as:

$$\text{Ln}WYield = 7.45 + 88.85\ \text{Ln}MeanT - 58.70\ \text{Ln}MaxT - 30.51\ \text{Ln}MinT - 0.10\ \text{Ln}Rainfall + \upsilon i \ldots (2)$$

Discussion

The average mean temperature in the Meerut area has a positive effect (88.85%) on wheat output, according to the statistics (Table 5). This is most likely a result of the chosen district's constant average mean temperature during the study period. Other independent variables, viz., average maximum temperature, average minimum

Table 5. *Results of OLS*

Dependent Variable : Wheat Yield						
Period : 1980 – 2020						
	Coefficient	**Prob.**	R^2	**Adj.** r^2	F	F **(Prob.)**
Constant (β_0)	7.44539	0.0343	0.6132	0.5648	12.683	0.000
Mean Temperature (β_1)	88.8503	0.0000				
Maximum Temperature (β_2)	–58.7018	0.0000				
Minimum Temperature (β_3)	–30.5068	0.0000				
Rainfall (β_4)	–0.100127	0.0084				

temperature, and rainfall, had a negative impact (58.70% and 30.51%, respectively) on wheat yield. This is due to the district's average maximum temperature rising and the average minimum temperature falling year over year, both of which have a negative impact on wheat yield. The literature indicates that the maximum temperature over a certain limit leads the crop to ripen prematurely, which in turn impacts the quality of wheat grain. Similar to other winter crops, wheat benefits from an average minimum temperature that is advantageous to some extent before having a negative effect on wheat production beyond a certain point (the average minimum temperature in the chosen region is rapidly dropping). The maximum temperature has a stronger effect than the minimum temperature, which indicates that rising temperatures are more hazardous for wheat harvests than falling ones.

The total annual rainfall is an important climatic factor that governs the productivity of a crop. The wheat crop requires a limited amount of irrigation in the growth stage. It is observed that the total annual rainfall has decreased in the last one and a half decades, and the timing of rainfall is also shifting in the selected district. The findings show that, throughout the study period, rainfall in the Meerut area had a negative impact on wheat output, albeit one with very little intensity (0.10). This is due to the abundance of irrigation infrastructure in Meerut. Rainfall is also seen to be falling throughout the district's wheat crop ripening and harvesting season, which further reduces wheat crop production.

All the variables considered in the model are significant at 5% and the value of the coefficient of determination (r^2) is 0.6132, which means 61.32% changes in wheat yield occur due to changes in selected climatic variables. Thus, it can be concluded that selected climatic variables play a vital role in assessing wheat yield in the selected district, and the above model is fit for further analysis.

The OLS estimation assumed that the residuals of the model must be free from autocorrelation and heteroskedasticity. To test whether the above assumptions hold, we applied the Breusch–Godfrey serial correlation LM test and the Breusch–Pegan–Godfrey test. In the Breusch–Godfrey serial correlation LM test, the null hypothesis is that there is no serial correlation in the series. The test results presented in Table 6 show the value of the test is more than 0.05, which means the null hypothesis is accepted and the model is free from the

Table 6. *Tests of Model Validity*

(A) Breusch–Godfrey Serial Correlation LM Test			
F-statistics	1.130864	Probability F (2,30)	0.3361
R-squared	2.593908	Probability χ^2 (2)	0.2734
(B) Breusch–Pegan–Godfrey Test			
F-statistics	0.174915	Probability F (4,32)	0.9497
R-squared	0.791672	Probability χ^2 (4)	0.9396
F-statistics	0.824949	Probability χ^2 (4)	0.9351

problem of autocorrelation. Heteroskedasticity, which refers to the non-constant standard errors of the variable, states that the residuals of the OLS model should be homoscedastic, i.e., there must be no heteroskedasticity in the residuals. Since the *p*-value of this test is also more than 0.05, it can be concluded that the model is free from the problem of heteroskedasticity.

Conclusion and Implications of the Study

The present paper explores the impact of climate change on the wheat yield in Meerut district by applying the OLS estimation technique by taking secondary from 1980 to 2020. The study's findings indicate that a major factor influencing the wheat output in the Meerut district is the climate. Every aspect of the climate influences wheat yield. While rainfall, average maximum and lowest temperatures, and other climatic factors have an adverse effect on wheat crops, the mean temperature has a favorable effect on wheat output. According to the study's findings, the district's crops suffered during the study period due to fluctuating weather conditions.

The implications of the study are crucial for the different stakeholders and policymakers. Almost, half of the population of India still depends on agriculture for their livelihood. Climate change is negatively affecting the yield of wheat crops in the Meerut district. The government and farmers should collectively take some adaptation measures to maintain the crop.

Limitations of the Study and Scope for Further Research

The current investigation centers on an econometric analysis of how climate change affects wheat yield in the Meerut district. The current study uses just two meteorological variables to examine how climate change is affecting a specific crop in the Meerut district. In the future, in addition to temperature and rainfall, researchers may attempt to determine how climate change affects other crops in the Meerut district by including more climatic parameters.

Authors' Contribution

Prof. Swami Prasad Saxena conceived the idea and developed qualitative and quantitative designs, verified the analytical methods, and supervised the study. Dr. Anuj Kumar extracted research papers with high reputations, filtered these based on keywords, and generated concepts and codes relevant to the study design. The numerical computations were done by Dr. Anuj Kumar using E-Views 7.0 and also wrote the manuscript under the supervision of Prof. Swami Prasad Saxena.

Conflict of Interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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About the Authors

Prof. Swami Prasad Saxena obtained his master's degree from the University of Delhi and his Ph.D. from Agra University. He is currently working as a Professor of macroeconomics and finance with the Department of Applied Business Economics, Faculty of Commerce, Dayalbagh Educational Institute (Deemed to be University), Agra.

Dr. Anuj Kumar obtained his M.Phil. and Ph.D. degrees from Dayalbagh Educational Institute (Deemed to be University), Agra in 2024. He is currently working as an Assistant Professor with the Department of Commerce, Institute of Oriental Philosophy, Vrindavan, Mathura, which is a government-aided post-graduate college affiliated with Agra University. His areas of research are environmental economics, macroeconomics and finance.

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