Assessing the Economic Impact of Climate Change on the Production of Wheat in Haryana: 1967-2020

Nehal Chahal[1], BA (H) Economics, SGTB Khalsa College, University of Delhi

Abstract

Climate change is a multidimensional concept which has an impact on practically every area of life either directly or indirectly. Agriculture is one such area that bears the direct brunt of any such change and is responsible for the sustenance of all those who are dependent on it. This paper aims to study the 'economic' impact of climate change on the production of wheat in Haryana. An attempt to explain the variability in the yield of wheat due to changes in certain climate variables (maximum and minimum temperatures, total rainfall in the region and area under its production) over the time period 1967-2020 is made using the techniques of multivariable regression analysis. The results showed that, considered together, these variables do explain a large percentage of variability in the total yield of wheat in Haryana over the chosen time horizon. But it fails to explain any statistically significant changes in yield due to these individual variables. These findings are extremely important as they guide us in knowing the extent and type of implications that the phenomena of climate change lay in front of us. It can help the policymakers and researchers to design better and more effective policies as well as efficient institutions to deal with inevitable changes like that of climate change and global warming.

Keywords: Wheat, Haryana, Climate Change, Rainfall, Crop Yield

[1] E-Mail ID – nehalchahal1868@gmail.com

1. Introduction

Over the years, as per the FAO (Food and Agriculture Organisation), India has become the second largest producer of wheat in the world. Of all its states, Haryana is the fourth largest producer of wheat (as per the year 2021-22; 10447.21 thousand tonnes of production) according to the Ministry of Agriculture and Farmers Welfare, which makes it an extremely significant region. Intuitively it is expected that any major gradual impact of climate change on the production of wheat in this state is bound to have huge impacts on the availability of this crop in the country and hence impact the major chunk of population that is dependent on it for consumption purposes. Though, at present, India produces far more wheat that is required domestically due to initiatives such as Green Revolution which boosted its production in the latter half of the 20th century, but it was not always the case, especially at the time of India's independence in 1947 and even for a few decades thereafter.

Nevertheless, climate change is bound to impact every sector and hence to be able to be prepared for what comes in the future, a wise step would be to analyse its trends and impacts at the earliest. A lot of researchers have worked in this domain in the last couple of decades understanding the gravity of the situation. This paper attempts to contribute to the research in this area as it tries to delve deeper into this question by focussing on a specific state and a specific crop over a span of 50 years.

The choice of wheat as a subject of study was based on the fact that it is the 2nd most important cereal crop in India. The Ministry of Agriculture and Farmers Welfare stated that the total wheat production in the country was about 111.32 million tonnes for the year 2021-22. A large part of northern and north-western parts of the country are primarily dependent on it for consumption purposes. Therefore, it is crucial to assess the variations in agricultural output over time, particularly as the issue of climate change continues to intensify.

Another important point to note is that this phenomenon of global warming that is primarily responsible for climate change has human origins. There is growing evidence indicating that the consequences of global warming are largely attributable to human activities. The WMO (World Meteorological Organisation) Statement on the State of the

Global Climate (2020) highlights, that the global average temperature in 2020 was about 1.2°C above the pre-industrial (1850-1900) level. It is mainly due to human-induced climate change. This assertion is supported by the findings presented in the first part of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), 2013. Hence, it is of extreme importance that people and institutions understand the negative implications of these things and take immediate measures to stop them.

Recent empirical analyses (Aragón et al. 2021) suggest that small-scale farmers are highly susceptible to various environmental and economic shocks. This vulnerability is closely linked to the prevailing socio-economic disparities within rural communities. Hence, it is extremely important to carefully monitor such changes which have an impact on everybody, particularly the poor and the distressed. This paper concludes by presenting key policy recommendations and identifying potential areas for future research in this domain.

2. Literature Review

Recent studies, such as those by Deschênes and Greenstone (2007) and Guntukula (2020), highlight the negative impact of rising temperatures on agricultural yields. Their research demonstrates a correlation between increasing temperatures and declining crop productivity, with projections indicating potential yield reductions for key crops like wheat. Guntukula (2020) specifically notes that climate variability disrupts yield stability, raising significant concerns about food security.

This research seeks to fill the gaps in previous study by exploring the economic impact of climate change on wheat production in Haryana from 1967 to 2020, utilizing multivariable regression analysis. The results indicate that while climate variables collectively explain a significant portion of yield variability, the individual contributions of these variables lack statistical significance. This underscores the need for more sophisticated models that can isolate the effects of each climatic factor.

The paper stresses the importance of continuous monitoring of crop varieties and the implementation of educational initiatives to promote sustainable agricultural practices. In conclusion, despite extensive research on the impacts of climate change on agriculture, particularly in recent years, there is an urgent need for more localized studies. Such research not only enhances the existing body of knowledge but also provides critical insights for policymakers. By addressing the identified gaps and focusing on the effects of climate change on wheat production in Haryana, this study serves as a valuable resource for future research and policy development.

Despite the increasing volume of research, significant gaps remain in understanding the localized effects of climate change on agricultural productivity. While aggregate analyses offer valuable insights, they often obscure the specific impacts on particular crops and regions. For instance, Costinot et al. (2016) projected a modest average effect on global GDP due to yield declines, potentially underestimating the severe consequences for countries like India, where agriculture is a cornerstone of the economy.

Focusing on the wheat-producing states of Punjab and Haryana, the analysis by Mukherjee et al (2019) reveals a connection between yield reductions and climate variability and change. During the 2002–2010 period, decreased monsoon and winter rainfall, coupled with an increase in average winter temperatures, were observed. These climatic shifts collectively had an adverse impact on wheat yields, both directly and indirectly.

Gupta et al. (2023) evaluated the economic risks posed by climate change to wheat farmers in Haryana, using econometric models to project future yield scenarios under different climate change pathways. Their findings indicated that, without effective adaptation measures, wheat yields could potentially decrease by up to 20% by 2050, underscoring the urgent need for strong institutions and policies to support farmers in adapting to a changing climate.

As per Daloz et al (2021), climate change impacts wheat yields in the Indo-Gangetic Plain by altering temperature, precipitation patterns, and water availability for irrigation. These changes lead to direct yield losses ranging from 1% to 8%.

Collectively, these studies highlight the significant challenges climate change poses to wheat production in Haryana and stress the necessity for focused research and policy measures to mitigate these impacts. The research underscores the importance of continuous monitoring, adaptive management, and the development of resilient agricultural systems to ensure food security amid a changing climate. Patel et al (2023) emphasized the importance of government policies in enhancing farmers' resilience to climate change.

Sheetal and Falendra (2021) highlighted the socio-economic impacts of climate change, particularly on smallholder farmers. While marginal and small farmers employ various coping and climate-smart adaptation strategies, they face significant social, economic, and institutional barriers, highlighting the need for planned or policy-driven adaptation efforts. These studies collectively emphasize the need for an integrated approach that combines scientific research, policy initiatives, and farmer support to sustain agricultural productivity in the face of climate challenges.

The primary distinction of this study, compared to previous research in this field, is its focus on a broader and more detailed set of factors that could be directly or indirectly related to wheat yield or production in Haryana, a key wheat-producing region in a developing country like India. This study examines the influence of these variables over time and connects them to changes in wheat yield within the same period. It involves a case study based on time series data, analyzing critical variables such as maximum and minimum temperatures, rainfall, and the area dedicated to wheat production in Haryana.

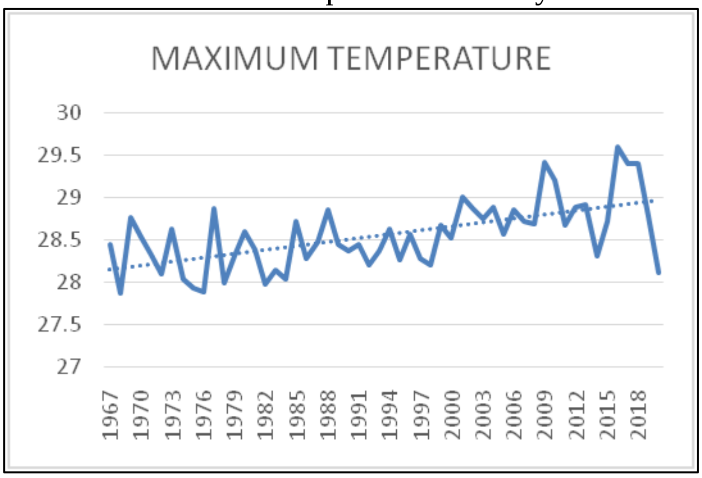
3. Methodology

To assess the impact of climate change on wheat production in Haryana, this paper uses a 'Multi-variable Linear Regression' methodology. It utilizes time series data for several climate variables, including average maximum and minimum temperatures, total rainfall, and the area under wheat cultivation, covering the period from 1967 to 2020. The logarithmic values of average wheat yield are regressed against the respective logarithmic values of each climate variable to determine the effect of changes in these variables on yield variability. The log-log form is employed to directly obtain elasticities. Initially, each independent variable is analysed separately, followed by a combined analysis that incorporates all variables.

The average maximum and minimum temperatures of India for each time period are calculated by taking the mean of the six months (i.e., October, November, December of year *t*; and January, February, March of the year *t+1*) for a particular production season of wheat. Similarly, the total rainfall is calculated for the same months for the respective time periods. However, a proxy for the total rainfall in Haryana is used here which is the total rainfall over the entire region of Haryana, Punjab and Delhi. This is done due to some data availability constraints. Since this entire region is part of a similar geographical region, it is assumed that any change in the annual levels of total rainfall would be more or less symmetric. Also, caution was taken while choosing the mean temperatures (both maximum and minimum) as only the months which pertain to the growing and harvesting season of wheat in a particular production year are chosen. Then, the area under the production of wheat over the same time period for each year was taken considering it might have something to do with its yield and hence not omit any variable from the model. Visualizing changes in area, production, and yield variables is essential for identifying long-term trends before exploring trends in weather variables (Sendhil et al. 2015).

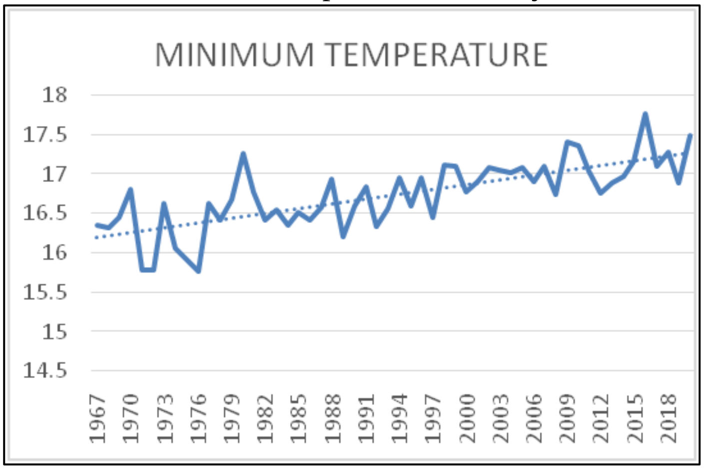
Employing changes in climate over time, as suggested by Burke and Emerick (2016), might offer a strong approach to link climate with outcomes like profits or behaviours such as crop selection, especially when considering long-term adaptation.

Figure 1: Trend in Maximum temperatures of Haryana over 1967-2020



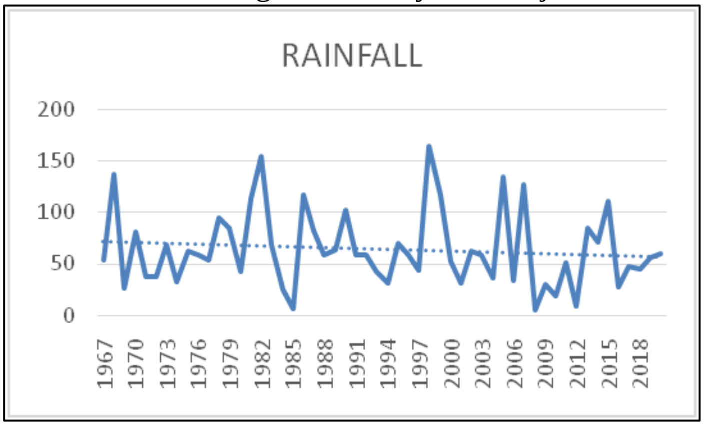
Source: Indian Meteorological Department's Data Library

Figure 2: Trend in Minimum temperatures of Haryana over 1967-2020



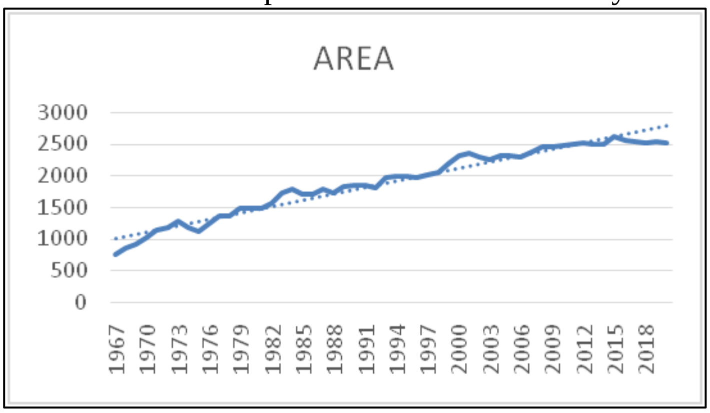
Source: Indian Meteorological Department's Data Library

Table 3: Trend in Rainfall over the regions of Haryana, Punjab and Delhi over 1967-2020



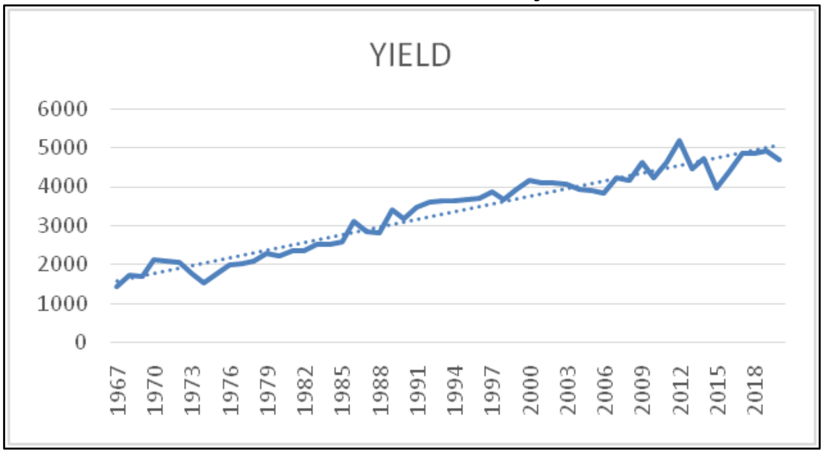
Source: Indian Meteorological Department's Data Library

Table 4: Trend in total area under production of wheat in Haryana over 1967-2020



Source: Ministry of Agriculture, Haryana

Table 5: Trend in Yield of Wheat in Haryana over 1967-2020



Source: Ministry of Agriculture, Haryana

The data used for this analysis is taken from multiple authentic and reliable sources. The data on mean maximum and minimum temperature and the total rainfall is taken from the Indian Meteorological Department's Data Library. The data on average crop yield and total area under production is taken from the Ministry of Agriculture, Haryana.

Regression Model for combined analysis:

$$\textbf{Log } Y_t = B_1 + B_2 \text{ Log}X_2 + B_3 \text{ Log}X_3 + B_4 \text{Log}X_4 + B_5 \text{ Log}X_5 + u_t \quad (1)$$

Regression Model for individual analysis:

$$\textbf{Log } Y_t = B_1 + B_2 \text{Log}X_i + u_t \quad (2)$$

Here, Y_t is the average crop yield, X_1, X_2, X_3 and X_4 are the independent variables i.e., Maximum temperature, Minimum temperature, Rainfall and the Area under production of wheat, respectively. The last term in both the equations is the error term.

A multivariable linear regression model is used to analyse the situation at hand. It is an extension of the model used by Raju Guntukula (2019), which was itself inspired by the works of Kaul and Ram (2008) and Sarker, Alam, and Gow (2012) in which the authors used a linear multivariable regression equation.

4. Results and Analysis

Tables below give the results of the model. As per the results of this model, it can be concluded that the climatic variables considered here along with the area under the production of wheat do explain the variations in the annual crop yield for wheat in the state of Haryana to a large extent.

Hence, when we take the above observations together, we may conclude that while overall the model is highly significant but we should be extremely cautious while interpreting the significance of individual variables.

Table 6: Effect of all variables on the Average Wheat Yield in Haryana

Independent Variable	**Slope**	**Standard Error**	**t-Ratio**	**Probablility**
Maximum Temperature	1.845	1.658	1.113	0.271
Minimum Temperature	-0.181	1.008	-0.18	0.858
Rainfall	0.017	0.024	0.691	0.493
Area	1.026	0.064	16.148	
Constant	-2.338	1.857	-1.259	0.214
R Square	0.919			
F-Ratio	139.349			
n	54			

Source: Author's calculations

Table 7: Effect of changes in Maximum Temperature on the Average Wheat Yield in Haryana

Independent Variable	**Slope**	**Standard Error**	**t-Ratio**	**Probablility**
Maximum Temperature	13.963	2.927	4.771	0
R square	0.304			
F Ratio	22.763			
n	54			

Source: Author's calculations

However, due to the statistical insignificance of the respective t and p values of each variable, comments on the individual impacts of the different variables on the dependent variable cannot be made.

The correlation coefficients of average yield and each one the independent variables (average maximum and minimum temperatures, total rainfall in the region and area under its production) respectively are 0.579, 0.69, -0.131 and 0.963. It establishes somewhat strong positive relation with the maximum and minimum temperatures, weak negative relation with the total rainfall, but extremely strong positive relation with the area under its production.

Table 8: Effect of changes in Minimum Temperature on the Average Wheat Yield in Haryana

Independent Variable	Slope	Standard Error	t-Ratio	Probablility
Minimum Temperature	9.456	1.697	-4.757	0
R square	0.472			
F Ratio	46.483			
n	54			
Constant	-8.073			

Source: Author's calculations

Table 9: Effect of changes in Total Rainfall on the Average Wheat Yield in Haryana

Independent Variable	Slope	Standard Error	t-Ratio	Probablility
Rainfall	-0.063	0.069	-0.903	0
R square	0.015			
F Ratio	0.815			
n	54			
Constant	3.604			

Source: Author's calculations

Table 10: Impact of Total Area under Wheat Production on the Average Wheat Yield in Haryana

Independent Variable	Slope	Standard Error	t-Ratio	Probablility
Area	1.053	0.044	23.863	0
R square	0.916			
F Ratio	569.436			
n	54			
Constant	0.064			

Source: Author's calculations

Table 11: Descriptive Statistics for Yield of Wheat in Haryana, 1967-2020

Mean	3.49621	Standard Error	0.021251
Median	3.558709	Standard Deviation	0.156163
Sample Variance	0.024387	Range	0.560766
Kurtosis	-0.96758	Skewness	-0.56373
Minimum	3.153815	Maximum	3.714581
Sum	188.7953	Count	54

Source: Author's calculations

On comparing with some of the earlier studies, some differences and similarities to the results were observed. The R-squared value in the analysis of R. Guntukula (2019) indicates that climate variables in India account for 93% of the variability in wheat yield. Interestingly, none of the individual climatic variables i.e., minimum and maximum temperatures, as well as actual rainfall, emerge as statistically significant in the wheat model. However, the cropped area dedicated to wheat shows a statistically significant and positive association with wheat yield. Despite the lack of statistical significance, both minimum and maximum temperatures exhibit a negative relationship with wheat yield, while rainfall has an adverse impact on wheat yield. These findings diverge from some of the earlier analysis done in this domain. These differences might have arisen because of some major distinctions in terms of the geographical locations, time period considered or models used.

5. Conclusion

To sum up, it can be said that the impact of climate change on agriculture, specifically on the production of wheat in Haryana is present and it should not be ignored while making important long term policy decisions. Overall speaking, the changes in the maximum and minimum temperatures, total rainfall in the region and area under the production of wheat are able to explain the variability in the yield of the said crop to a great extent. Though this paper fails to explain the variability in response to each one of the individual variables respectively, it still gives us some important directions to proceed.

There are a few policy implications and directions for further research that can be inferred from the results. Firstly, the department of agriculture should carefully monitor how different varieties of wheat (or any other crop) are evolving with time. A few researchers have also focussed on the concept of adaptability of crops overtime with climate change (Kumar, 2014). This is also a scope of further research in the domain as important policy decisions should cater to the fact of how different crops and their varieties are adapting to the climate change that is happening.

Secondly, certain informative sessions could be conducted by the agricultural department to educate the people at different levels (students, farmers, environmentalists) via different mediums (online, in person sessions) catering to the needs of the people so that this phenomenon becomes widely known to people and they become even more attentive to sustainable means of living and production of various kinds of crops. This would help is in at least slowing down the negative impacts of adverse climate change, if not completely avoid it.

Thirdly, as pointed out by Dani Rodrik in his book *One Economics, Many Recipes: Globalisation, Institution and Economic Growth* (2007), the importance of institutions is equally significant even in this case as well. Better and efficient institutions would be able to handle these changes and generate responses at the earliest that are beneficial for everyone. So, an effort should be made to construct and create well-designed institutions. They can prove extremely beneficial in doing further research as well as implementation of various measures required for proper adaptability techniques that can be used for a better response to climate change.

A few more improvements could also be made to the study done here to get better results. Firstly, future research may look into the aspect of creating better models that avoid the problem of multicollinearity that is one of the possible causes behind not confirming to individual significance of each climate variable considered here to the dependent variable, i.e., the crop yield. Secondly, similar analysis should be done for other crops and states to get a better idea of the situation.

Lastly, focus should be given on how the quality of wheat is getting impacted with the change in climate. It is an extremely important point as even Kawasaki and Uchida (2016) point out that the impacts of climate change on crop quality may be more negative than on crop yields.

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