SRI VENKATESWARA INTERNSHIP PROGRAM
FOR RESEARCH IN ACADEMICS
(SRI-VIPRA)

SRI-VIPRA

Project Report of 2024: SVP-2415

"Impact of Climate Change on Cropping Patterns and Crop Production in India: A District level Analysis"

"Agriculture is our wisest pursuit, because it will in the end contribute most to real wealth, good morals, and happiness." – Thomas Jefferson

IQAC
Sri Venkateswara College
University of Delhi
Benito Juarez Road, Dhaula Kuan, New Delhi
New Delhi -110021

SRIVIPRA PROJECT 2024

Title: "Impact of Climate Change on Cropping Patterns and Crop Production in India: A District level Analysis"

Name of Mentor: Dr. Veena Budhraja

Name of Department: Statistics

Designation: Professor

List of students under the SRIVIPRA Project

S. No	Photo	Name of the student	Roll number	Course	Signature
1		Aadishri Batra	0123014	BA Programme Economics+Statistics	
2		Aman Kumar	1722012	B.Sc (H) Mathematics	
3		Dharmendra Thakur	1923019	B.Sc (H) Statistics	
4		Divye Kalra	1922001	B.Sc (H) Statistics	
5		Hitesh Singh	1922011	B.Sc (H) Statistics	

6		Mayank More	1722035	B.Sc (H) Mathematics	[illegible]
7		Navya Agarwal	0523007	B.A(H) Economics	Navya
8		Siddhant Singh	1922003	B.Sc (H) Statistics	Siddhant Singh
9		Shivam Puri	1922021	B.Sc (H) Statistics	Shivam
10		Utkarsh Prakash	0522038	B.A(H) Economics	Utkarsh Prakash

Signature of Mentor

Certificate of Originality

This is to certify that the aforementioned students from Sri Venkateswara College have participated in the summer project SVP-2415 titled "Impact of Climate Change on Cropping Patterns and Crop Production in India: A District level Analysis". The participants have carried out the research project work under my guidance and supervision from 1st July, 2024 to 30th September 2024. The work carried out is original and carried out in an online/offline/hybrid mode.

Signature of Mentor

Acknowledgements

We are very grateful to our mentor Prof. Veena Budhraja, Department of Statistics, Sri Venkateswara College, University of Delhi, for guiding us and giving us valuable suggestions and ideas throughout the project.

We would also like to extend our deepest gratitude to our college Principal, Professor Vajala Ravi for providing this platform to learn and gain skills under the guidance of our mentor.

We would also like to thank the Indian Meteorological Department (IMD Pune) for providing us with high quality datasets without which this research wouldn't have been possible.

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Impact of Climate Change on Cropping Patterns and Crop Production in India: A District level Analysis

Introduction:

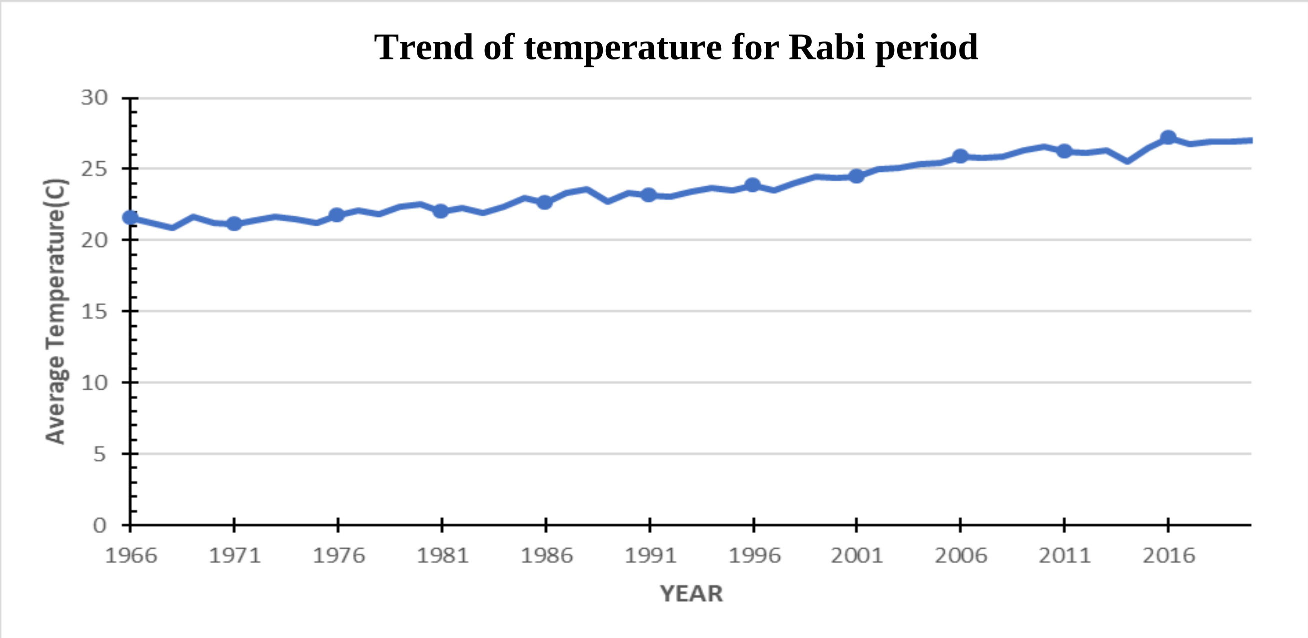
As per Census 2011, the total number of agricultural cultivators **Significance of Agriculture Sector:** The Agriculture Sector occupies centre stage in the Indian economy embodying three thrust areas as (1) to promote inclusive growth, (2) to enhance rural income, and (3) to sustain food security. It accounts for nearly **14% of GDP** and exports and supports half of the country's population as its principal source of income.

and agricultural labourers increased from **234 million** in 2001 to **263 million** in 2011. The share of agri-exports in total exports increased from **13.08%** in 2012-13 to **14.17%** (Rs 268,000 Cr) in 2013-14, a record level.

In addition to the existing Missions/Schemes, following four new schemes had been introduced in the year 2014-15 such as (a) **Soil Health Card Scheme** (b) **Pradhan Mantri Krishi Sinchai Yojana** (c) **Price Stabilisation fund for Cereals and Vegetables** (d) **National Agri-tech Infrastructure**

Such high government intervention in the Agricultural industry highlights its significance and reflects that it still stands as the backbone of our economy.

Rationale behind this research: Policy makers rely on research to make informed decisions about agricultural technologies and to craft policies that boost food production and sustainability. Considering that majority of Indian agriculture is dependent on climate directly, productivity has to increase against the background of increasing climate volatility. Shortages of water and land, weakening soil quality, and of course climate change-induced temperature increases and rainfall variability, are all going to impact agriculture in India. It is therefore imperative to analyze the effect of climate change on Indian agriculture. In India, considerable research over the last decade has focused on understanding how climate change affects crop yields. Agriculture is highly sensitive to both short-term weather variations and long-term climate shifts, with Indian agriculture particularly dependent on factors like temperature, rainfall, and indirect effects on soil and seed germination. This has led us to explore how these climate dependencies have caused significant changes in Indian agriculture over time.


Trend of temperature for Rabi period
Average Temperature(C)
30
25
20
15
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1966
1971
1976
1981
1986
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2006
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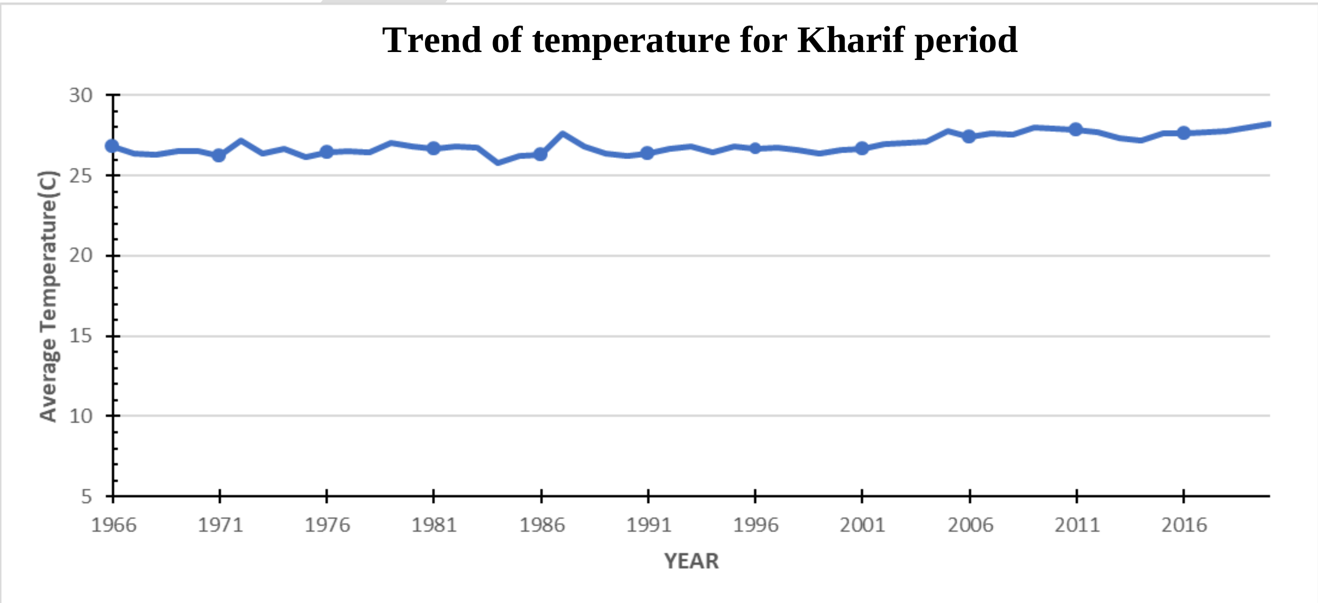
YEAR


Trend of temperature for Kharif period
Average Temperature(C)
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1966
1971
1976
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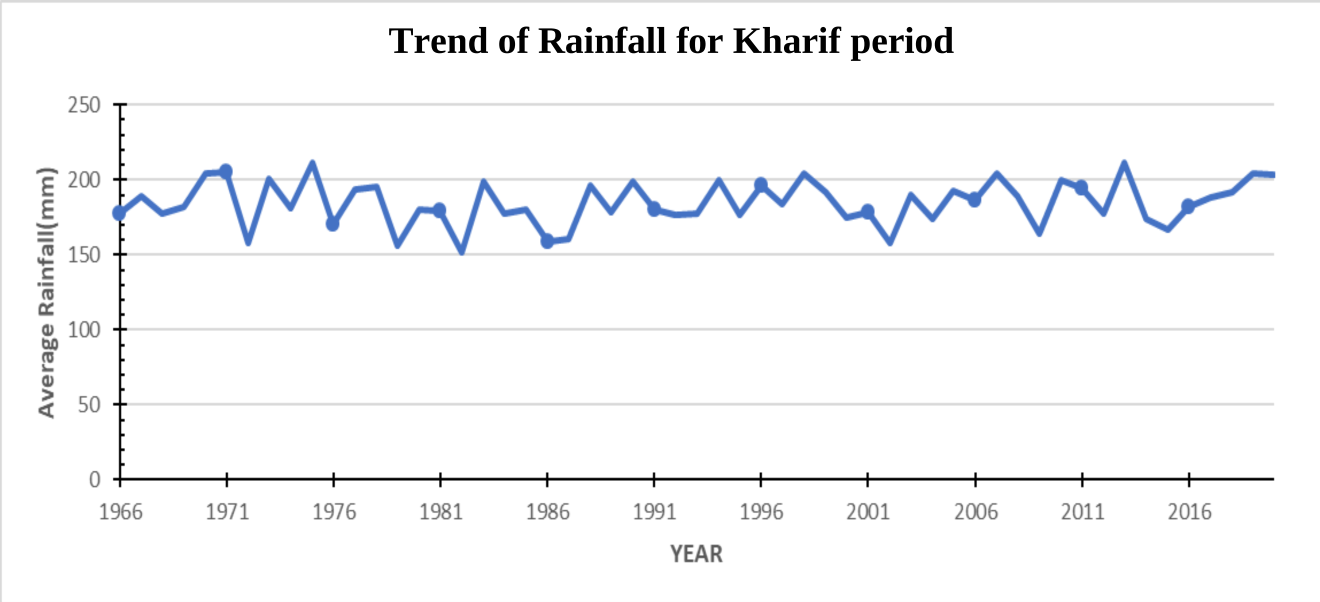
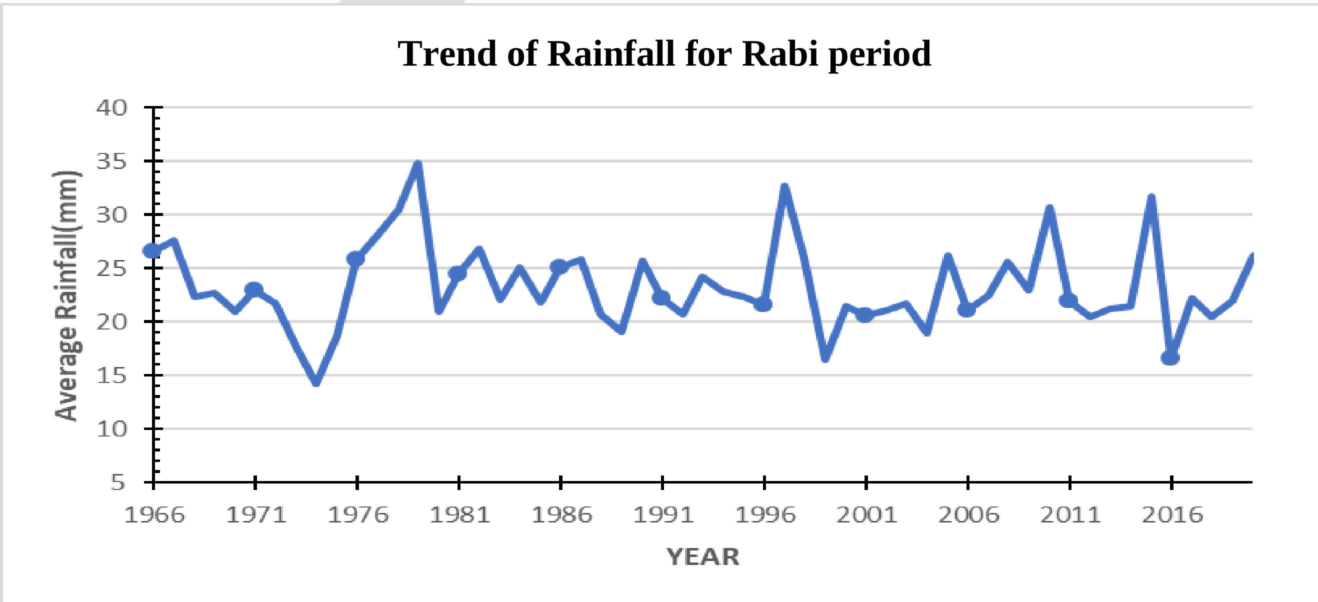

Trend of Rainfall for Kharif period
250
200
150
100
50
0
Average Rainfall(mm)
1966
1971
1976
1981
1986
1991
1996
2001
2006
2011
2016
YEAR


Trend of Rainfall for Rabi period
40
35
30
25
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Average Rainfall(mm)
1966
1971
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2016
YEAR

As climate remains the least controllable resource, identifying key areas to address food security is crucial. To contribute to ongoing studies, our review aims to:

- Assess the impact of climate change on cropping patterns in India
- Examine the effect of climate change on total crop production of different crops.

The study includes a review of literature based on Agriculture, Climate and its impact on productivity and production. It further relates to the methodology adopted in order to measure the impact of climate changes on agriculture production and area, with other covariates.

Review of literature:

Economic Survey of India 2017-18 "Climate, Climate Change, and Agriculture": Provides a broad understanding of climate change's effects on Indian agriculture, offering context for our district-level analysis.

Melissa Dell, Benjamin F. Jones, and Benjamin A. Olken "Climate Change and Economic Growth: Evidence from the Last Half Century": Offers insights into the broader economic consequences of climate change, helping us link agricultural impacts to economic growth.

R. K. Mall et al. "Impact of Climate Change on Indian Agriculture: A Review": Reviews key studies on the relationship between climate change and Indian agriculture, helping frame our findings within the existing literature.

S. Naresh Kumar et al. "Vulnerability of Wheat Production to Climate Change in India": Provides specific insights into crop-specific vulnerabilities, helping to inform our analysis on climate impacts across different crops.

Chand, Ramesh, and Shinoj Parappurathu "Temporal and Spatial Variations in Agricultural Growth and Its Determinants": Helps understand regional disparities and growth patterns in agriculture, which aligns with our district-level approach.

Marshall Burke and Kyle Emerick "Adaptation to Climate Change: Evidence from US Agriculture": Offers evidence on adaptation strategies, which can guide policy recommendations for climate resilience in Indian agriculture.

Olivier Deschenes and Michael Greenstone "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather": Highlights the economic effects of weather fluctuations on agriculture, reinforcing the importance of our focus on climate variability.

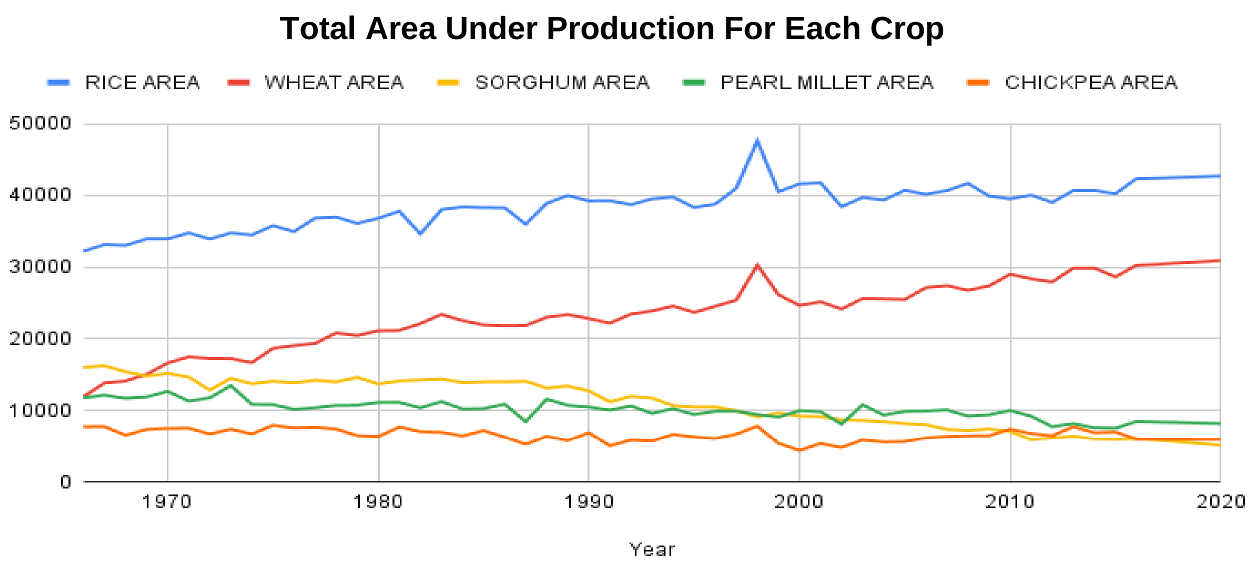
Dawson "Moderation in Management Research: What, Why, When, and How (2014)": Provides methods for analysing moderator variables, useful for identifying factors that influence the relationship between climate change and crop production.

Methodology:

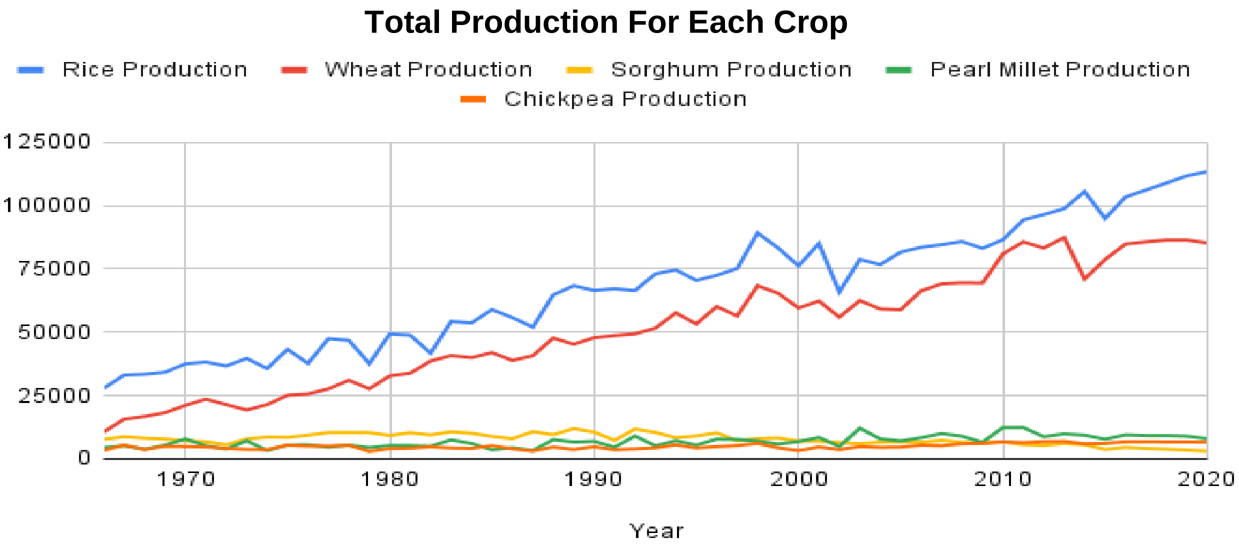
To assess the impact of climate change on cropping patterns and crop production, we employ three key regression models under which we employ moderating variables to explore the influence of specific climate factors on agricultural outcomes. The scope of the research is limited to the following states: Assam, Andhra Pradesh, Madhya Pradesh, Karnataka, Kerala, West Bengal, Chhattisgarh, Maharashtra, Odisha, Bihar, Uttarakhand, Punjab, Gujarat, Uttar Pradesh, Haryana, Tamil Nadu, Jharkhand, Himachal Pradesh and Rajasthan. Further we considered five crops : Rice and Pearl Millet (Kharif crop), Wheat, Sorghum and Chickpea (Rabi crop). The District wise data for different variables and for different states for the period from 1966 to 2020 was collected for the study.

This section outlines the methodology used to estimate the impact of climate change on agriculture, focusing on two key variables:

- **Cropping Pattern**: Measured by the area under production for different crops, this variable tracks the proportion of land allocated to Rice, Wheat, Sorghum, Chickpea, and Pearl Millet from 1966 to 2020.



- **Crop Production**: Based on FAO's definition, this refers to both marketed production and auto-consumption. We measure total crop quantity produced in India for the same crops over the same period.



We consider the following models

Model 1: $Y_{cdt} = \gamma_0 + \alpha_1\, Rainfall_{\,dt} + \alpha_2\, Rainfall_{\,dt}^{2} + \alpha_3\, Temperature_{\,dt} + \alpha_4\, Temperature_{dt}^{2} + \beta_1\, Rainfall_{\,dt} * Irrigation_{cdt} + \beta_2\, Rainfall_{dt}^{2} * Irrigation_{\,cdt} + \beta_3\, Temperature_{\,dt} * Irrigation_{\,cdt} + \beta_4\, Temperature_{dt}^{2} * Irrigation_{\,cdt} + \delta_1\, NPK\ Consumption_{\,dt} + \varepsilon_t$

- This model will provide insights into whether higher rainfall or temperature (including their quadratic effects) increases or decreases crop productivity. The role of irrigation as a mitigating factor in these effects will also be highlighted, and the impact of NPK consumption on productivity will be quantified.

Model 2: $Y_{cdt} = \gamma_0 + \alpha_1\, Rainfall_{\,dt} + \alpha_2\, Rainfall_{\,dt}^{2} + \alpha_3\, Temperature_{\,dt} + \alpha_4\, Temperature_{dt}^{2} + \beta_1\, Rainfall_{\,dt} * Irrigation_{cdt} + \beta_2\, Rainfall_{dt}^{2} * Irrigation_{\,cdt} + \beta_3\, Temperature_{\,dt} * Irrigation_{\,cdt} + \beta_4\, Temperature_{dt}^{2} * Irrigation_{\,cdt} + \delta_1\, NPK\ Consumption_{\,dt} + \delta_2\, Land\ under\ Non\text{-}Agricultural\ use_{\,cdt} + \varepsilon_t$

- In addition to the effects captured in Model 1, this model includes land under non-agricultural use. It will help determine whether the conversion of agricultural land affects crop area and productivity. It will provide a broader understanding of how not only climate factors but also land use changes impact agricultural outputs.

Model 3: $Y_{cdt} = \alpha_0 + \alpha_1$ *Rainfall Variation* $_{dt} + \alpha_2$ *Temperature Variation* $_{dt} + \beta_1$ *Rainfall Variation* $_{dt}$ * *Irrigation* $_{cdt} + \beta_2$ *Temperature Variation* $_{dt}$ * *Irrigation* $_{cdt} + \varepsilon_t$

- This model focuses on the variation (rather than absolute levels) in rainfall and temperature, along with their interaction with irrigation. It will help you understand how fluctuations or anomalies in climate (e.g., unexpected droughts or heat waves) influence crop production. The findings will highlight how well irrigation can buffer against these variations.

$_{cdt}$ represents the crop 'c' for district 'd' in time 't'

Independent/Dependent Variable (Key Metric)	Significance (Why we are studying this variable)	Unit of Measurement
Area under production*	Measures the amount of land allocated to crop production	Hectares (ha)
Total Production*	Evaluates the total output of crops produced in a region	Per 1000 Tonnes
Rainfall**	Examines the direct impact of rainfall on crop production and patterns	Millimetres (mm)
Rainfall²**	Captures non-linear effects of rainfall on agricultural outcomes	Millimetres squared (mm²)
Temperature**	Analyses the effect of temperature on crop growth and yields	Degrees Celsius (°C)
Temperature²**	Accounts for non-linear temperature effects on crop production	Degrees Celsius squared (°C²)
Rainfall * Irrigation ***	Assesses the interaction between rainfall and irrigation in influencing crop outcomes	Millimetres * Irrigated Area in hA
Rainfall² * Irrigation ***	Explores nonlinear interactions between rainfall and irrigation	Millimetres squared * Irrigated Area in hA
Temperature * Irrigation ***	Evaluates how temperature and irrigation together affect crops	Degrees Celsius (°C) * Irrigated Area in hA

Temperature² * Irrigation * **	Considers non-linear interactions between temperature and irrigation	Degrees Celsius Squared (°C²) * Irrigated Area in hA
NPK Consumption**	Measures the impact of chemical fertiliser use on crop yield(Nitrogen,	Kilograms per hectare (kg/ha)
Land under Non-Agricultural Use**	Investigates how land diversion affects overall crop production/Area under production	Hectares (ha)
Rainfall Variation**	Captures short-term fluctuations in rainfall that may impact crops	Millimetres (mm)
Temperature Variation**	Analyses short-term temperature variations and their effects on crop production	Degrees Celsius (°C)
Rainfall Variation * Irrigation	Evaluates how variations in rainfall, combined with irrigation, affect crop outcomes	Millimetres * Irrigated Area in hA
Temperature Variation * Irrigation	Examines the impact of temperature fluctuations and irrigation on crops	Degrees Celsius (°C) * Irrigated Area in hA

*Dependent Variable **Independent Variable ***Moderator Variable (Independent)

Estimation of Results:

The regression equations for the model were run, the results are interpreted using the p-values and on the basis of sign of coefficients of different variables. The conclusion is done at 5% level of significance.

Model 1a: Area Under Production (Response Variable)

For **Rice**, temperature has a positive effect on the area under production, while extreme temperature (represented by the squared temperature variable) shows a significant negative impact, indicating the adverse effects of heat extremes. Rainfall has a negative effect, while extreme rainfall (represented by the squared rainfall variable) has a significant positive impact on rice cultivation.

For **Wheat, Sorghum, Pearl Millet**, and **Chickpea**, temperature positively affects the area under production. However, extreme temperature negatively impacts wheat and sorghum, while for pearl millet and chickpea, it shows a positive effect. Rainfall has an insignificant yet positive effect for pearl millet and chickpea, while it negatively impacts wheat and sorghum. Extreme rainfall exhibits a negative influence across all four crops.

The interaction of **Rainfall with Irrigation** has an insignificant yet positive effect for rice, wheat, sorghum, and chickpea, but it is positive and significant for pearl millet and sorghum, indicating that these crops benefit from irrigation during rainy periods. On the other hand, the interaction of **Rainfall Squared with Irrigation** shows a negative impact for all crops, with significant effects observed for wheat, pearl millet, and chickpea.

The interaction of **Temperature with Irrigation** shows a significant negative impact on Area under production for the crop Sorghum and Chickpea and a significant and positive effect for Wheat and Pearl Millet, Moving on to **Temperature Squared with Irrigation** displays a positive effect across all crops, with significant impacts for wheat and chickpea, suggesting that irrigation can help mitigate the extreme temperature effects for these crops.

As the Non-Agricultural Area increases, it can be seen that area under production significantly increases for Chickpea in Rabi season and decreases for Wheat and Pearl Millet in Kharif.

Model 2a: Area under production (Response Variable)

The analysis indicates that **fertiliser consumption** has a positive effect on the area under production for all crops studied. However, this effect is **statistically significant** only for **wheat** and **pearl millet**.

For **Wheat**, the statistical significance of fertiliser consumption suggests that variations in fertiliser application have a consistent and measurable impact on its area under production, likely due to wheat's reliance on adequate nutrient supply, particularly nitrogen, which is crucial for its growth and yield. Similarly, for **Pearl Millet**, the significance may be attributed to its cultivation in nutrient-poor or arid regions, where fertiliser inputs substantially enhance the crop's productivity and the area under cultivation, highlighting the importance of nutrient supplementation in supporting its growth.

Model 3a: Area under production (Response Variable)

The regression analysis reveals that rainfall and temperature variations, along with their interactions with irrigation, impact the area under production for various crops. Rainfall variation has a **significantly negative** impact on **Rice** and **Chickpea**, suggesting these crops are sensitive to changes in rainfall. Similarly, **Sorghum** and **Pearl Millet** show negative effects, both significant, indicating that reduced or erratic rainfall adversely affects their cultivation. For **Wheat**, while the impact is negative, it is not statistically significant.

Regarding temperature variation, wheat, sorghum, and chickpea demonstrate significantly negative coefficients, indicating that extreme temperatures can reduce the area under production for these crops. Pearl millet shows a **negative impact**, though it is not statistically significant, while rice is also negatively affected but not at a **significant level**.

When interacting with irrigation, rainfall variation positively impacts pearl millet significantly, suggesting that irrigation helps mitigate the negative effects of rainfall variability for this crop. Temperature variation with irrigation **positively influences** wheat, chickpea, and pearl millet significantly, highlighting that irrigation can buffer the adverse impacts of temperature fluctuations for these crops, making irrigation an essential adaptive measure for these climates.

Model 1b: Total Production (Response Variable)

We observe that there is no significant effect of temperature on any of the crops except wheat which is positively affected by temperature. Also, the effect of high temperature is non-significant for all the crops except wheat and sorghum. Total production of wheat is negatively affected by high temperature while sorghum production is affected positively with very small variation. We see that the effect of rainfall is non-significant on the production of every crop while the effect of extreme rainfall is extremely conducive to production of every crop except rice, rice shows positive growth when exposed to high rainfall. From the interaction variable we infer that the effect of temperature is significant on unirrigated areas and negatively impacts the production for the crops (rice, pearl millet). Also, the effect of extreme temperature on unirrigated areas is significant for the production i.e. the production declines when there is extreme temperature in unirrigated lands, while there is no significant effect when an irrigation facility is available. Also, the amount of Non-agricultural area available has a significant effect only in the case of wheat (negative effect) and pearl millet (positive effect).

Model 2b: Total Production (Response Variable)

There is no significant effect of fertiliser consumption on the production of crops, this might be because of a shift of farmers to organic farming.

Model 3b: Total Production (Response Variable)

There is a significant effect of rainfall variation on the crop production of sorghum, pearl millet and chickpea, i.e. their production decreases when there is any variation in rainfall. There is no significant effect of temperature on the production of any of the crops except sorghum which is affected negatively with the variation in temperature. We see that there is a significant effect of rainfall variation on irrigated lands on production of wheat and sorghum only (affected positively). The effect of temperature variation is highly significant on irrigated land in case of pearl millet and chickpea, while it is significant on unirrigated lands in case of wheat and sorghum.

Conclusion:

The regression analysis highlights the significant impact of rainfall and temperature variations on crop production, emphasising the vulnerability of crops like sorghum, pearl millet, rice, chickpea, and wheat to climate variability. Rainfall variation negatively affects most crops, with extreme rainfall proving conducive to production except in the case of rice, which thrives under such conditions. Temperature variation has a particularly negative impact on wheat and sorghum, with unirrigated lands suffering more under extreme temperatures. However, irrigation plays a crucial role in mitigating these adverse effects, especially for wheat, chickpea, and pearl millet, underscoring its importance in climate adaptation.

The analysis also reveals that the availability of non-agricultural land and the shift towards organic farming are additional factors influencing crop production. Wheat's negative response to non-agricultural land suggests competition for space, while pearl millet adapts more positively. Fertiliser consumption, being insignificant in this context, indicates a potential transition towards organic farming.

Overall, the study underscores the need for targeted adaptive measures like irrigation to buffer the negative effects of climate variability, while also recognizing the broader shifts in agricultural practices that may impact future production patterns. Effective water management and sustainable farming practices will be key to addressing the challenges posed by climate change on agriculture.

Policy Implications:

- Technologies such as drip irrigation, sprinklers, and water management may well hold the key to future Indian agriculture and should be accorded greater priority in resource allocation.
- Another Policy Implication is the need to embrace agricultural science and technology with renewed enthusiasm. Agricultural research will be vital in increasing production but also in increasing reliance to all the pathologies that climate change threatens to bring in its wake: extreme heat, rainfall, pests and crop disease.
- Government should build on the current crop insurance programs and use innovative technologies (like drones) to determine losses so as to compensate farmers within weeks of a catastrophe.

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