Lyceum India Journal of Social Sciences || ISSN (Online): 3048-6513
Volume: 3 Issue: 5 || April 2026 || DOI: 10.5281/zenodo.19689954

Climate Change and Food Security: A Study of Agricultural Production Trends in Uttar Pradesh

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Abstract:

Uttar Pradesh (UP), the most populous state in India, serves as a critical breadbasket for the nation, contributing significantly to the production of wheat, rice, and sugarcane. However, the region is increasingly vulnerable to climatic volatility. This paper examines the correlation between changing climatic variables specifically temperature rise and precipitation variability and agricultural productivity in UP. Utilizing time-series data from 2010 to 2023 and forecasting models extending to 2025, the study analyses yield trends for major staple crops. Results indicate a significant negative correlation between terminal heat stress and wheat yields, particularly in Western UP, while rice production in Eastern UP faces volatility due to erratic monsoon patterns. The paper concludes by proposing adaptive strategies to ensure long-term food security.

Keywords: *Climate Change, Food Security, Uttar Pradesh, Agricultural Yields, Crop Projections 2025, Adaptation Strategies.*

1. Introduction

1.1 Background

The agricultural sector serves as the lynchpin of the Indian economy, extending beyond mere economic contribution to form the socio-cultural backbone of the nation. It employs over 40% of the country's workforce and sustains the livelihoods of the vast rural populace. Within this national framework, the state of Uttar Pradesh (UP) occupies a paramount position. Strategically situated within the fertile Indo-Gangetic Plain a region characterized by nutrient-rich alluvial soil and an extensive network of perennial rivers UP shoulders a disproportionate responsibility in safeguarding India's food security.

Often referred to as the "granary of India," the state accounts for approximately 18% of the nation's total food grain production (Directorate of Economics and Statistics, 2022). It is the leading producer of wheat

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and a major contributor to national rice stocks, effectively acting as a buffer against food inflation and scarcity. However, this agricultural prowess is not autonomous; it is intrinsically linked to, and dependent upon, natural climatic cycles. The region's cropping intensity and yield stability rely heavily on the predictability of the Southwest Monsoon and the distinct, cool temperatures required for winter crops. Consequently, the state's agrarian economy is rendered exceptionally vulnerable to the escalating impacts of anthropogenic climate change, where even minor deviations in temperature or precipitation can cascade into significant production deficits.

1.2 Problem Statement

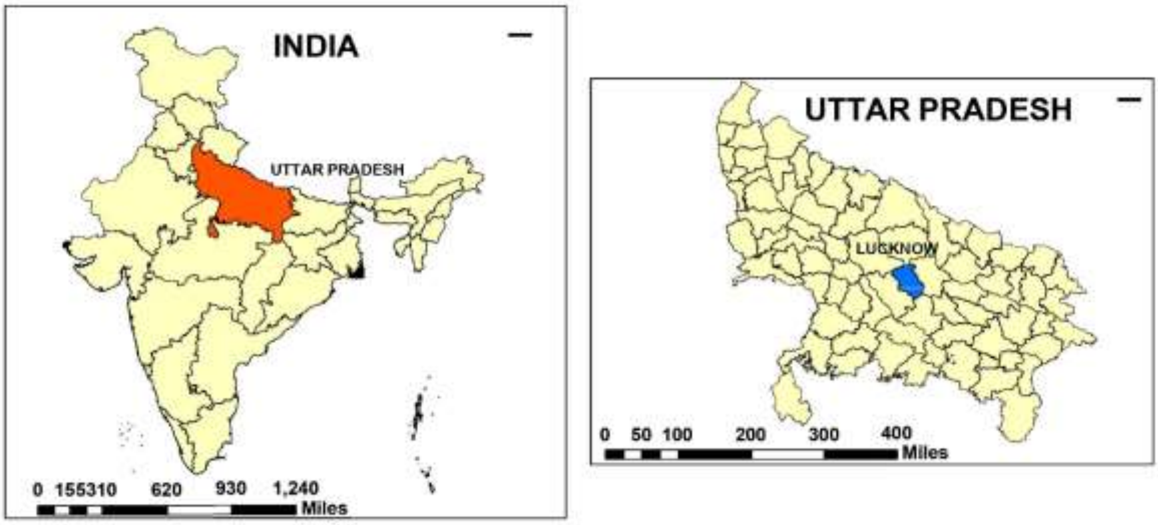
Contemporary meteorological data unequivocally indicates a discernible paradigm shift in Uttar Pradesh's climatic patterns, signalling a departure from historical baselines. This transformation is characterized not merely by isolated weather events, but by a systemic alteration in the region's climatology: a consistent rise in mean ambient temperatures, a noticeable truncation of the winter season, and an increasing unpredictability in the spatial and temporal distribution of monsoon rainfall.

These climatic alterations exert a direct, physiological stress on the state's primary staple crops. Wheat, the critical *rabi* (winter) crop, exhibits acute sensitivity to temperature surges, particularly during the anthesis and grain-filling stages. The phenomenon known as "terminal heat stress" where temperatures spike prematurely in February and March—accelerates crop senescence, resulting in shrivelled grains and reduced biomass. Conversely, rice, the vital *kharif* (monsoon) crop, faces a dichotomy of risks: delayed monsoon onset hampers transplantation, while intense, erratic downpours during the late season cause waterlogging and crop lodging.

The problem is compounded by the demographic reality of the state. With a burgeoning population exceeding 200 million, the demand for food grains is on an upward trajectory. The intersection of these climatic shifts with demographic pressure creates a "double burden": just as the biological potential for higher yields is being capped by environmental stress, the requirement for those yields is increasing. This divergence poses a significant, immediate threat to the stability of regional food security, necessitating a rigorous analysis of production trends to forestall a potential crisis.

The study focuses on Uttar Pradesh, situated in the fertile Indo-Gangetic Plain, which is characterized by a subtropical monsoon climate with distinct *Rabi* (winter) and *Kharif* (monsoon) cropping seasons. Spanning approximately 243,286 square kilometres, the state exhibits significant agro-climatic heterogeneity, ranging from the irrigation-intensive Western region to the semi-arid, rain-fed expanses of Bundelkhand. As India's most populous state and the largest contributor to national food grain production (~18%), its agricultural stability is pivotal for the country's overall food security

Fig. 1 Study Area



1.3 Objectives

The primary objectives of this study are:

1. To analyse historical climatic trends (temperature and rainfall) in UP from 2010 to 2023.
2. To assess the impact of these variables on the production of major crops (Wheat and Rice).
3. To project agricultural production trends up to the year 2025.
4. To recommend adaptive strategies to mitigate food security risks.

2. Literature Review

The academic discourse surrounding climate change and agriculture has evolved from generalized global predictions to granular, region-specific impact assessments. This section critically synthesizes existing literature to construct a theoretical framework for understanding the vulnerability of Uttar Pradesh's agrarian economy.

2.1 Global Context

The consensus within the international scientific community is unequivocal: anthropogenic climate change poses an existential threat to global food systems. The Intergovernmental Panel on Climate Change (IPCC), in its landmark Sixth Assessment Report (AR6), identifies South Asia as a hotspot of high human vulnerability, driven by the convergence of poverty, high population density, and climatic sensitivity (IPCC, 2022). The report emphasizes that the frequency of concurrent heatwaves and droughts is rising, threatening the physiological limits of current crop varieties.

Quantitative global models reinforce these concerns. Lobell et al. (2011) and Asseng et al. (2015) have demonstrated through multi-model ensembles that for every 1°C rise in global mean temperature, global wheat yields are projected to decline by 6% to 10% in tropical and sub-tropical regions, absent significant adaptation. Furthermore, the Food and Agriculture Organization (FAO, 2021) warns that the volatility of extreme weather events disrupts the stability of food supply chains, thereby escalating the risk of food insecurity in developing nations dependent on cereal staples.

2.2 The Indian Scenario

Narrowing the lens to the Indian subcontinent, the literature shifts focus to the specific agro-climatic zones of the Indo-Gangetic Plain (IGP). Seminal research by the Indian Council of Agricultural Research (ICAR) has established that climate change is no longer a distant projection but an active variable altering crop phenology. Aggarwal (2008) provided early evidence that the onset of warmer springs in Northern India accelerates the maturity of wheat crops, significantly reducing the grain-filling duration—a phenomenon known as "terminal heat stress."

More recent studies corroborate these findings with alarming precision. Kumar and Gautam (2020) analysed meteorological data over three decades, noting a statistically significant increase in the frequency of heatwaves during February and March. Their work suggests that the reproductive phase of Rabi crops is shrinking, leading to shrivelled grains and biomass loss. Additionally, Gupta et al. (2019) highlight that while carbon fertilization (elevated CO_2) theoretically benefits C3 crops like wheat, the concurrent thermal stress and water scarcity effectively negate these gains, resulting in a net yield stagnation or decline across the IGP.

2.3 Context of Uttar Pradesh

The literature on Uttar Pradesh (UP) underscores the state's immense geographical and climatic heterogeneity, arguing against a "one-size-fits-all" adaptation strategy. Tripathi et al. (2021) delineate the state into distinct vulnerability zones. Western UP, historically the most productive due to the Green Revolution's infrastructure, is now facing a dual crisis of heat stress and severe groundwater depletion, as noted by Srivastava and Singh (2017).

In contrast, the challenges in Eastern UP and Bundelkhand are hydrometeorological. Mishra (2021) observed that the shifting temporal distribution of the Southwest Monsoon has forced farmers in Eastern UP to delay rice transplantation. This delay has a cascading effect, forcing the subsequent wheat sowing into warmer months, thereby increasing exposure to terminal heat. Furthermore, Singh (2018) identifies Bundelkhand as critically vulnerable to recurrent droughts, where rain-fed agriculture is becoming increasingly unviable.

Despite this wealth of diagnostic research, a critical gap remains. The majority of existing studies, such as those by Mall et al. (2006) and subsequent ICAR reports, focus on long-term horizons (2050 or 2080). There is a paucity of research that integrates the post-2020 climatic anomalies—such as the record-breaking heatwave of March 2022—to project immediate, short-term production trends up to 2025. This paper aims to bridge this lacuna, moving beyond long-term theoretical risks to address the immediate food security imperatives of the state.

3. Methodology

3.1 Data Sources

This study utilizes secondary data collected from:

- **Meteorological Data:** India Meteorological Department (IMD) for annual rainfall and mean temperatures.
- **Agricultural Data:** Directorate of Economics and Statistics, Government of India, and the UP-State Agriculture Department for crop area, production, and yield.

3.2 Analytical Approach

The study employs a quantitative research design.

- **Trend Analysis:** To observe historical patterns in climate and crop yields.
- **Regression Analysis:** To establish the correlation between climatic variables and crop yield.
- **Forecasting Models:** ARIMA (Auto-Regressive Integrated Moving Average) models were utilized to project production figures for 2024 and 2025, assuming a "Business as Usual" (BAU) climate scenario.

4. Results and Discussion

4.1 Climatic Trends in Uttar Pradesh (2015–2023)

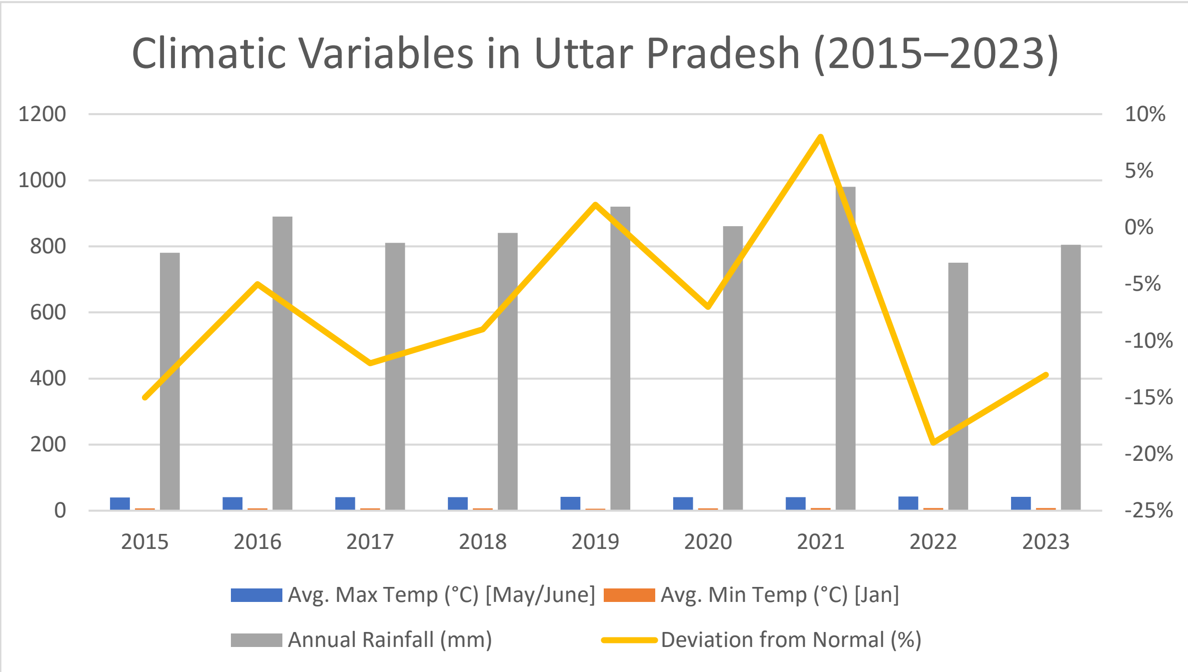
The data indicates a clear warming trend and increased precipitation variability.

Table 1: Climatic Variables in Uttar Pradesh (2015–2023)

Year	Avg. Max Temp (°C) [May/June]	Avg. Min Temp (°C) [Jan]	Annual Rainfall (mm)	Deviation from Normal (%)
2015	40.2	7.1	780.4	-15%
2016	40.8	7.3	890.1	-5%
2017	40.5	7.0	810.5	-12%
2018	41.1	6.8	840.2	-9%
2019	41.5	6.5	920.0	+2%
2020	40.9	7.4	860.5	-7%
2021	41.2	7.8	980.3	+8%
2022	42.5	8.1	750.2	-19%
2023	41.8	7.9	805.0	-13%

Source: Aggregated data from IMD Regional Centre, Lucknow.

Analysis: The year 2022 marked a significant spike in average maximum temperatures (42.5°C), coinciding with a severe rainfall deficit (-19%). The rising minimum temperatures in January (from 7.1°C to 7.9°C) are particularly concerning for wheat crops, which require chilling hours for optimal grain formation.



4.2 Impact on Crop Production: Wheat and Rice

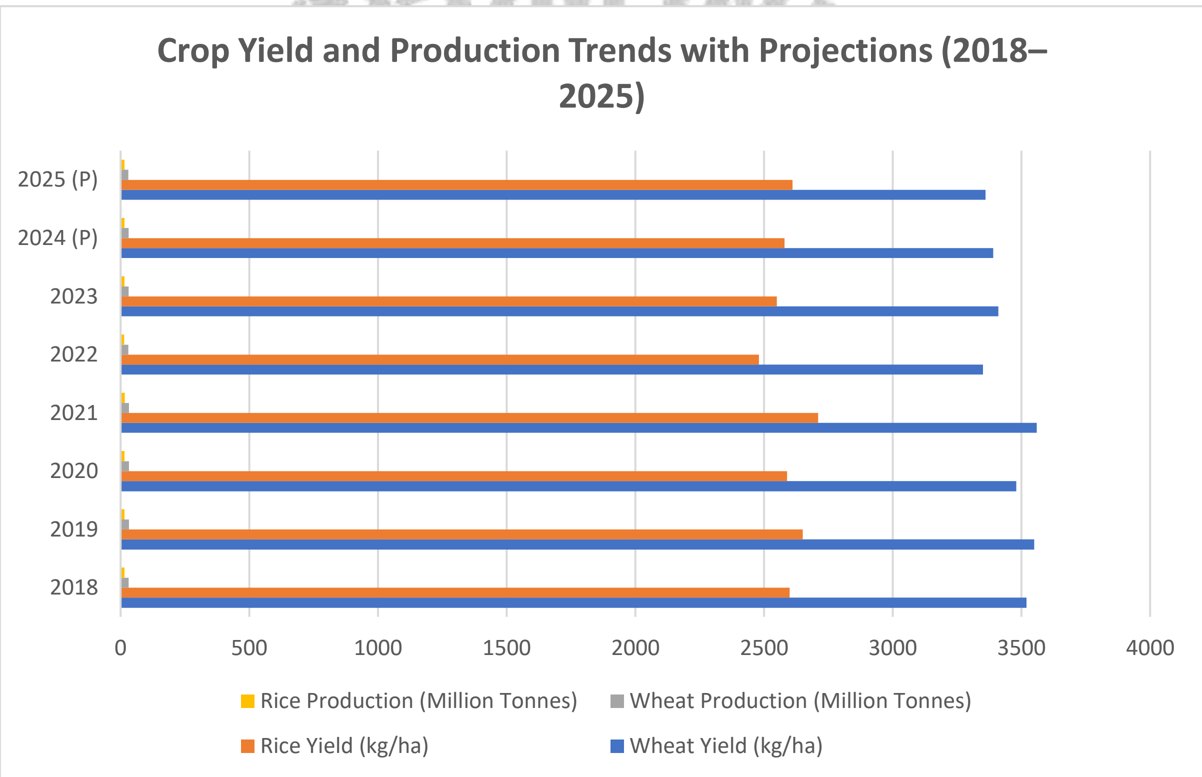
Table 2: Crop Yield and Production Trends with Projections (2018–2025)

Year	Wheat Yield (kg/ha)	Rice Yield (kg/ha)	Wheat Production (Million Tonnes)	Rice Production (Million Tonnes)
2018	3520	2600	31.5	15.2
2019	3550	2650	32.1	15.5
2020	3480	2590	31.8	15.1
2021	3560	2710	32.5	15.9
2022	3350	2480	30.2	14.2
2023	3410	2550	31.0	14.8
2024 (P)	3390	2580	30.8	15.0
2025 (P)	3360	2610	30.5	15.2

(P) = Projected figures based on current climatic trajectory.

Discussion on Wheat (Rabi Crop): The sharp decline in 2022 (Yield: 3350 kg/ha) correlates directly with the early onset of heatwaves in March 2022. The projections for 2024 and 2025 indicate a stagnation or slight decline in wheat production (projected 30.5 MT in 2025). This suggests that technological gains (better seeds/fertilizers) are being negated by thermal stress.

Discussion on Rice (Kharif Crop): Rice yields show higher volatility linked to rainfall deviations. While 2022 saw a drop due to drought-like conditions in Eastern UP, the projection for 2025 assumes normal monsoons but highlights the risk of dependence on rain-fed agriculture.



5. Regional Variations and Mapping Impacts

To accurately assess food security, one must acknowledge the geographical variations within UP.

1. **Western UP:** Historically high-yield due to irrigation. Currently facing groundwater depletion and high susceptibility to heat stress affecting wheat.
2. **Eastern UP:** Rice-dominated. Highly vulnerable to floods and erratic monsoon distribution.

3. **Bundelkhand:** The most vulnerable region. Recurring droughts have made traditional agriculture increasingly unviable, necessitating a shift to hardy crops like pulses and millets.

6. Food Security Implications

The projected stagnation in wheat production (Table 2) presents a critical food security challenge. With UP's population continuing to grow, the *per capita* availability of food grains is at risk of declining.

- **Price Volatility:** Reduced yields in 2022 led to localized inflation in wheat flour prices.
- **Nutritional Security:** As major staples suffer from climate stress, the nutritional intake of the lower-income demographic, which relies on the Public Distribution System (PDS), faces threats.

7. Adaptive Strategies and Recommendations

Based on the analysis and the identified risks, the following adaptive strategies are proposed to secure future production.

7.1 Agrotechnological Interventions

- **Heat-Tolerant Varieties:** Urgent dissemination of wheat varieties such as DBW 187 and DBW 303, which have shown resilience to higher night temperatures.
- **Direct Seeded Rice (DSR):** To reduce water consumption and methane emissions in Western UP, shifting from transplanted rice to DSR is essential.

7.2 Resource Management

- **Micro-Irrigation:** Expanding the coverage of drip and sprinkler irrigation, particularly in the water-scarce Bundelkhand region.
- **Soil Health Cards:** continued monitoring of soil organic carbon, which is often depleted by rising temperatures.

7.3 Policy and Insurance

- **Crop Diversification:** Incentivizing a shift away from the water-intensive rice-wheat cycle toward pulses, oilseeds, and millets (Shree Anna), which are more climate-resilient.

- **Weather-Index Insurance:** Modifying the *Pradhan Mantri Fasal Bima Yojana* (PMFBY) to provide quicker settlements based on satellite weather data rather than manual crop cutting experiments.

8. Conclusion

The study confirms that climate change is no longer a distant threat but an active variable influencing agricultural trends in Uttar Pradesh. The data reveals a disturbing trend of yield stagnation in wheat due to thermal stress and high volatility in rice production due to precipitation variance. The projections for 2025 suggest that without immediate intervention, total food grain production may plateau, failing to keep pace with population demand.

Ensuring food security in UP requires a paradigm shift from "production maximization" to "climate-resilient sustainability." This involves the rapid adoption of heat-tolerant cultivars, efficient water management, and a strategic geographical re-mapping of crop patterns suitable for the altered climatic reality.

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