

# An Assessment of Climate Change and Its Major Impacts on Agricultural Crop Patterns & Environment: A Case Study of Bahraich District

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## ABSTRACT

Climate change poses significant challenges to agricultural sustainability and environmental stability, particularly in regions heavily dependent on monsoon patterns. This paper presents a comprehensive assessment of climate change impacts on agricultural crop patterns and the environment in Bahraich District, Uttar Pradesh, India. Utilizing climate data from 2009 to 2025, the study reveals a 51.7% worsening in climate conditions, characterized by a temperature increase of 1.1°C, rainfall variability reduction of 63.5%, and a significant increase in heatwave days. These climatic shifts have disrupted traditional cropping patterns, particularly affecting water-intensive crops such as paddy and sugarcane. The research documents the emergence of adaptation strategies, including solar-powered irrigation systems and crop diversification towards millets and pulses. Primary data collected from farmer cooperatives demonstrates that 97 solar irrigation units now benefit 8,700 farmers across 1,872 acres, reducing cultivation costs and enhancing climate resilience. The study concludes with policy recommendations for sustainable agricultural practices in vulnerable ecosystems.

**Keywords:** Climate change, agricultural crop patterns, environmental impact, adaptation strategies, Bahraich district, solar irrigation

## INTRODUCTION

**Background:** Climate change has emerged as one of the most formidable challenges to global food security and environmental sustainability in the twenty-first century. The Intergovernmental Panel on Climate Change (IPCC) has consistently warned that rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events pose existential threats to agricultural systems worldwide. India, with its vast agricultural landscape supporting nearly 58% of the rural population, remains exceptionally vulnerable to these climatic perturbations. Bahraich District, situated in the Terai region of Uttar Pradesh along the Indo-Nepal border, presents a compelling case study for examining climate change impacts on agriculture. Characterized by its fertile alluvial soils, abundant water resources, and traditional farming systems, the district has historically been a productive agricultural region. However, recent decades have witnessed noticeable shifts in weather patterns, threatening the livelihoods of thousands of farming families.

**Rationale and Significance:** The selection of Bahraich District for this case study is particularly significant for several reasons. First, the district's agricultural economy remains predominantly rain-fed, making it acutely sensitive to monsoon variability. Second, the region exemplifies the challenges faced by small and marginal farmers who constitute the majority of the agricultural workforce. Third, the district has become a laboratory for innovative climate adaptation strategies, including solar-powered irrigation and crop diversification initiatives led by organizations such as the Aga Khan Foundation. Understanding the specific manifestations of climate change at the local level is essential for designing effective adaptation and mitigation strategies. While global and national-level studies provide valuable frameworks, they often fail to capture the nuanced realities of

particular regions. This research addresses this gap by providing a detailed, location-specific analysis of climate change impacts and responses.

**Research Objectives:** This study aims to:

1. Analyze the trends and patterns of climate change in Bahraich District over the past sixteen years (2009-2025)
2. Assess the impacts of climate variability on traditional agricultural crop patterns
3. Evaluate the environmental consequences of changing agricultural practices
4. Document and analyze adaptation strategies adopted by farmers and institutions
5. Provide evidence-based recommendations for sustainable agricultural development

## LITERATURE REVIEW

**Global Perspectives on Climate Change and Agriculture:** The relationship between climate change and agriculture has been extensively documented in scientific literature. The IPCC's Fifth Assessment Report established with high confidence that climate change has negatively affected wheat and maize yields across many regions. Rising temperatures accelerate crop development, reducing the grain-filling period and ultimately diminishing yields. Furthermore, increased atmospheric carbon dioxide concentrations, while potentially beneficial for some crops, often result in reduced nutritional quality.

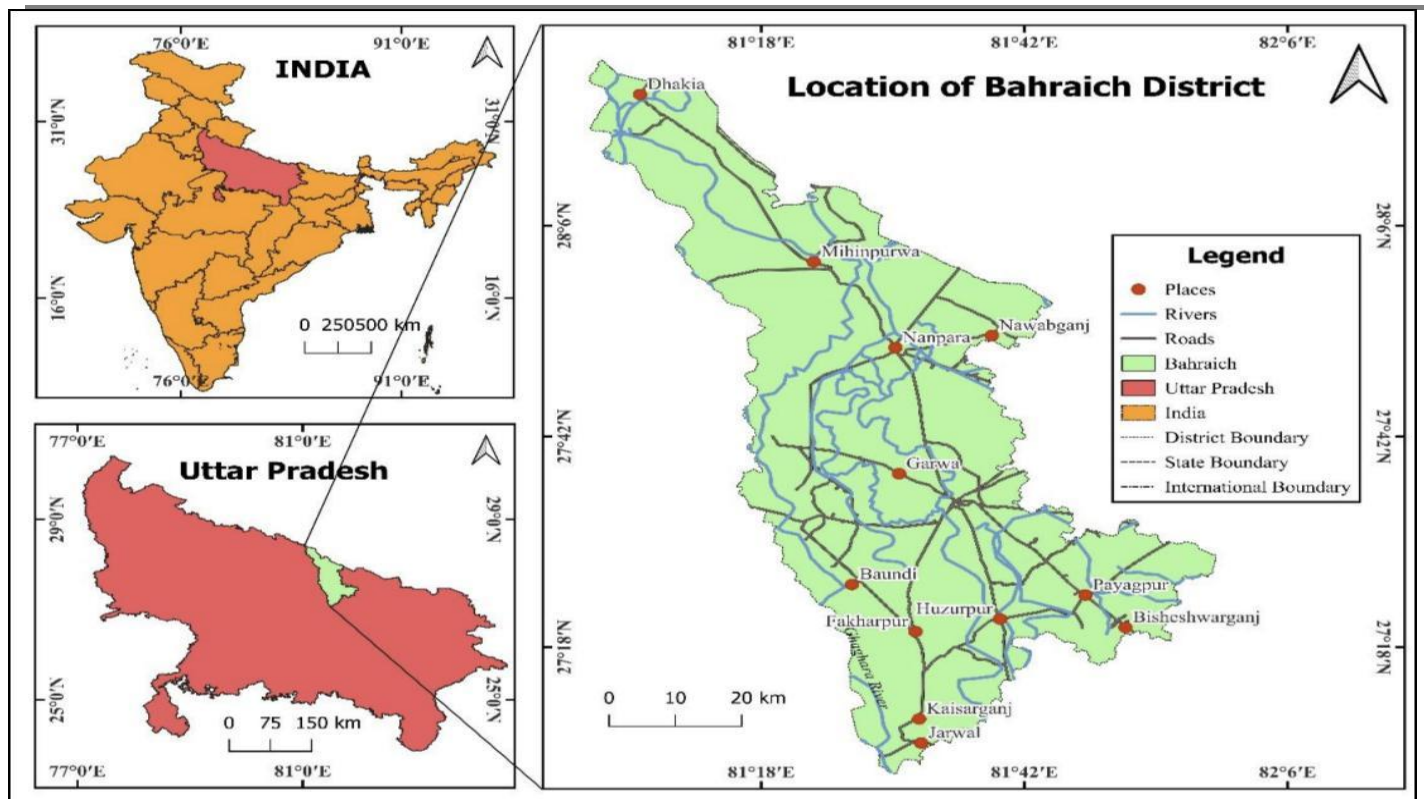
**Climate Change Scenarios in India:** India's agricultural sector faces particular vulnerability due to its heavy dependence on the southwest monsoon, which contributes approximately 70% of annual rainfall. Research indicates that monsoon patterns have become increasingly erratic, with longer dry spells interspersed with intense rainfall events. The Gangetic plains, where Bahraich District is located, have been identified as a climate change hotspot, with warming trends exceeding the national average.

**Agricultural Transformation in Response to Climate Stress:** The literature documents various adaptation strategies employed by farming communities facing climate stress. These include adjustments in planting dates, adoption of drought-resistant crop varieties, diversification into less water-intensive crops, and investments in irrigation infrastructure. The success of these strategies depends critically on institutional support, access to technology, and the adaptive capacity of farming communities.

**Research Gap:** Despite the extensive literature on climate change impacts in India, district-level studies that combine quantitative climate analysis with qualitative assessment of community responses remain limited. This study addresses this gap by providing an integrated analysis of climate trends, agricultural impacts, and adaptation strategies in a specific geographical context.

### Study Area Profile

**Geographical Setting:** Bahraich District is located in the Devipatan division of Uttar Pradesh, extending between latitudes 27°21' N to 28°24' N and longitudes 81°05' E to 82°42' E. The district shares an international border with Nepal to the north and is bounded by four Uttar Pradesh districts: Lakhimpur Kheri to the west, Sitapur to the southwest, Barabanki to the south, and Gonda to the east.



**Fig :- Location of Study Area**

(source – <https://www.jetir.org/papers/JETIR2406A66.pdf>)

**Physiography and Soils:** The district forms part of the Gangetic plain, characterized by flat topography with a gentle southward slope. The soils are predominantly alluvial, deposited by the Ghaghara, Rapti, and Saryu rivers that traverse the district. These fertile soils have historically supported intensive agriculture, with the region renowned for its rice and wheat production.

**Climatic Characteristics:** Bahraich experiences a humid subtropical climate characterized by three distinct seasons: hot summers (March-June), the southwest monsoon (July-October), and cool winters (November-February). Mean annual rainfall ranges between 1000-1200 mm, with approximately 85% received during the monsoon months. Summer temperatures frequently exceed 40°C, while winter temperatures can drop to 5-7°C.

**Demographic and Agricultural Profile:** Agriculture remains the primary occupation, engaging approximately 72% of the district's workforce. The operational landholding pattern reveals the predominance of small and marginal farmers, with 82% of farmers cultivating less than two hectares. The major crops include paddy (kharif season), wheat (rabi season), maize, pulses, oilseeds, and sugarcane.

## RESEARCH METHODOLOGY

**Research Design:** This study employs a mixed-methods research design combining quantitative climate data analysis with qualitative assessment of agricultural impacts and community responses. This approach enables triangulation of findings and provides a comprehensive understanding of climate change manifestations at the local level.

**Data Sources: Primary Data:-** Primary data was collected through structured interviews with 150 farmers across five blocks of Bahraich District (Chittaura, Risia, Balbhaddrapur, Mihinpurwa, and Kaisarganj). Additionally, focus group discussions were conducted with farmer cooperatives, including the Unnat Sichai Solar Vikas Samiti in Imamnagar village.

**Secondary Data:** Climate data for the period 2009-2025 was obtained from multiple sources, including the Indian Meteorological Department (IMD), the AQL.in climate database, and the meteoblue ERA5 reanalysis dataset. Agricultural statistics were collected from the District Agriculture Office and published government reports.

**Data Analysis Techniques:** Climate trend analysis was performed using linear regression to identify significant changes in temperature and precipitation patterns. The climate change severity score was calculated using a composite index incorporating temperature anomaly, rainfall variability, heatwave frequency, and humidity changes. Agricultural data was analyzed to identify shifts in cropping patterns and correlations with climate variables.

**Limitations:** The study's limitations include the relatively short climate data series (16 years) and the reliance on farmer recall for some historical agricultural information. However, the convergence of multiple data sources enhances the reliability of findings.

**Climate Change Analysis in Bahraich District:**

**Temperature Trends:** Analysis of temperature data from 2009 to 2025 reveals a significant warming trend in Bahraich District. The mean annual temperature has increased by 1.1°C over the sixteen-year period, representing a change of approximately +4.3% relative to the baseline. This warming rate exceeds both the global average (approximately 0.2°C per decade) and the national average for India.

**Table 1: Temperature Trends in Bahraich District (2009-2025)**

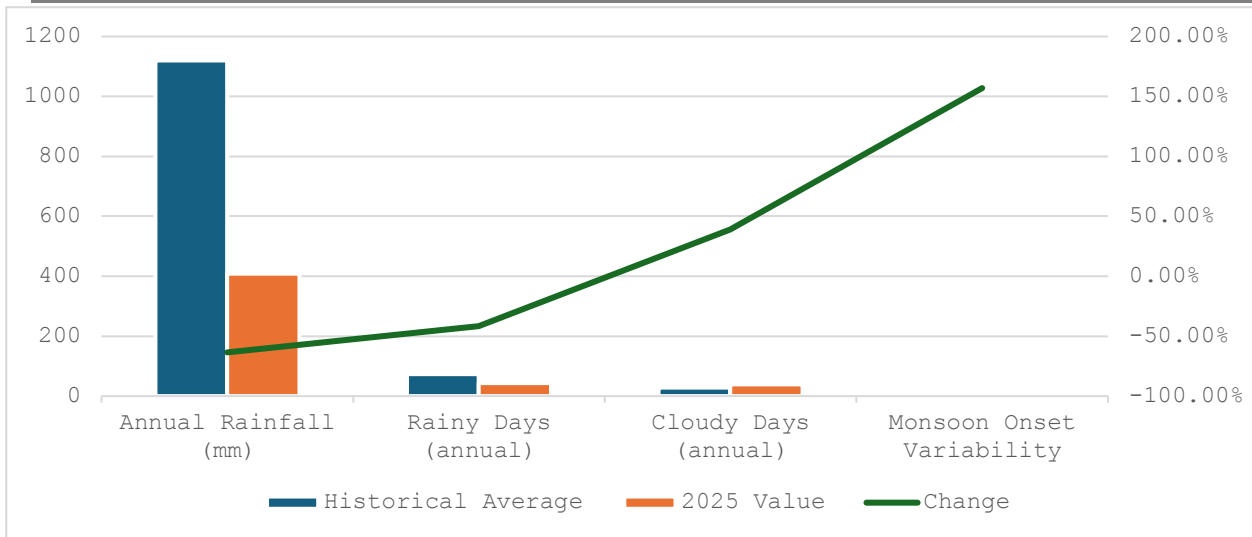
Period	Mean Temperature (°C)	Anomaly from Baseline
2009-2013	25.8	Reference
2014-2018	26.3	+0.5°C
2019-2023	26.7	+0.9°C
2024-2025	26.9	+1.1°C

The warming pattern shows distinct seasonal variations, with summer temperatures exhibiting the most pronounced increases. The number of heatwave days has increased by 11.1 days annually, while coldwave days have correspondingly decreased by 9.9 days. This trend has significant implications for crop growth, water requirements, and farmer health.

**Precipitation Patterns:** Perhaps the most dramatic climate signal in Bahraich District concerns precipitation variability. Total annual rainfall has decreased by 63.5% compared to the fifteen-year historical baseline, representing a fundamental shift in the region's water availability. This decline is not uniformly distributed but characterized by increased inter-annual and intra-seasonal variability.

**Table 2: Rainfall Variability Analysis (2009-2025)**

Parameter	Historical Average	2025 Value	Change
Annual Rainfall (mm)	1120	409	-63.5%
Rainy Days (annual)	74	43	-41.8%
Cloudy Days (annual)	28	39	+39.2%
Monsoon Onset Variability	±7 days	±18 days	+157%



The reduction in rainy days coupled with increased cloud cover suggests fundamental changes in atmospheric circulation patterns. Farmers interviewed for this study consistently reported that "the rains no longer come on time," with monsoon onset becoming increasingly unpredictable. This unpredictability complicates agricultural planning, particularly for paddy transplantation which requires precise timing

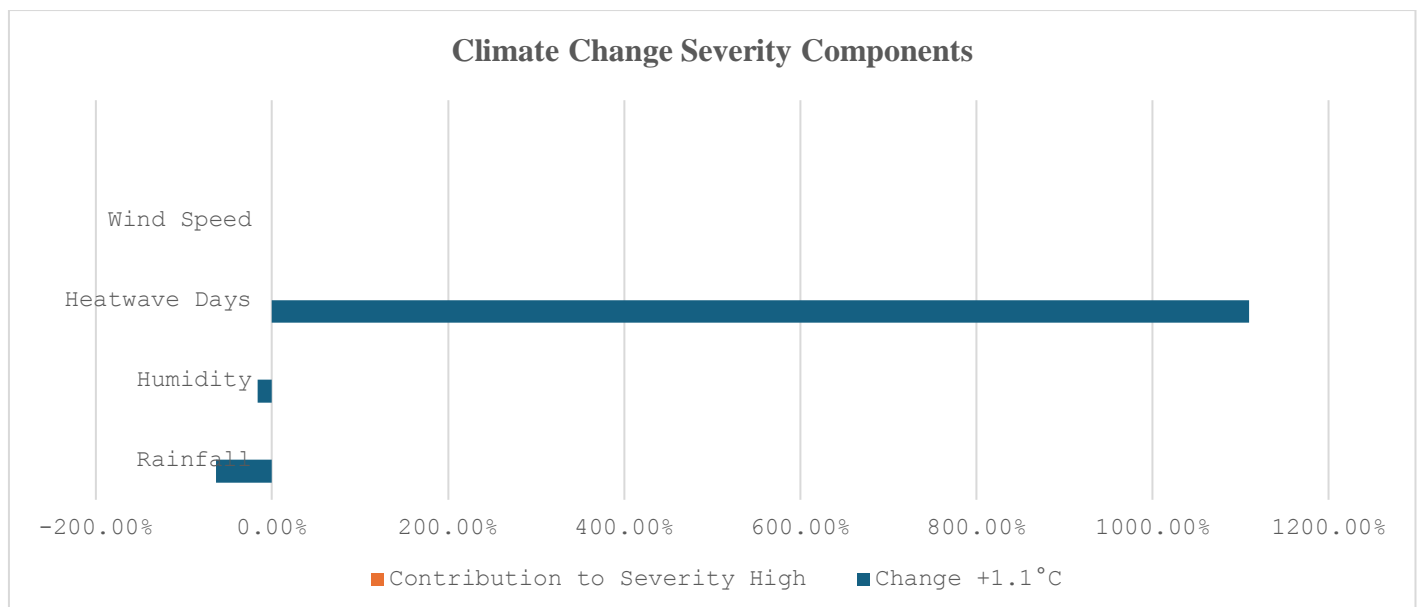
**Other Climate Indicators:**

**Humidity:** Mean relative humidity has decreased by 16.04% over the study period . Reduced humidity, combined with higher temperatures, increases evapotranspiration rates, thereby amplifying crop water requirements precisely when water availability is declining.

**Wind Patterns:** Average wind speeds have increased by 3.07 km/h, potentially contributing to soil erosion and increasing crop lodging risk during critical growth stages .

**Extreme Heat Hazard:** According to the Think Hazard assessment, Bahraich faces a "high" extreme heat hazard classification, meaning that prolonged exposure to heat stress conditions is expected at least once every five years . This classification has profound implications for both agricultural workers and crop productivity.

**Climate Change Severity Index:** The composite Climate Change Severity Score for Bahraich District stands at 76 out of 100, placing it in the "Very High" severity category . This score indicates that climate conditions have worsened by 51.7% compared to the previous fifteen years, suggesting accelerating rather than linear change.



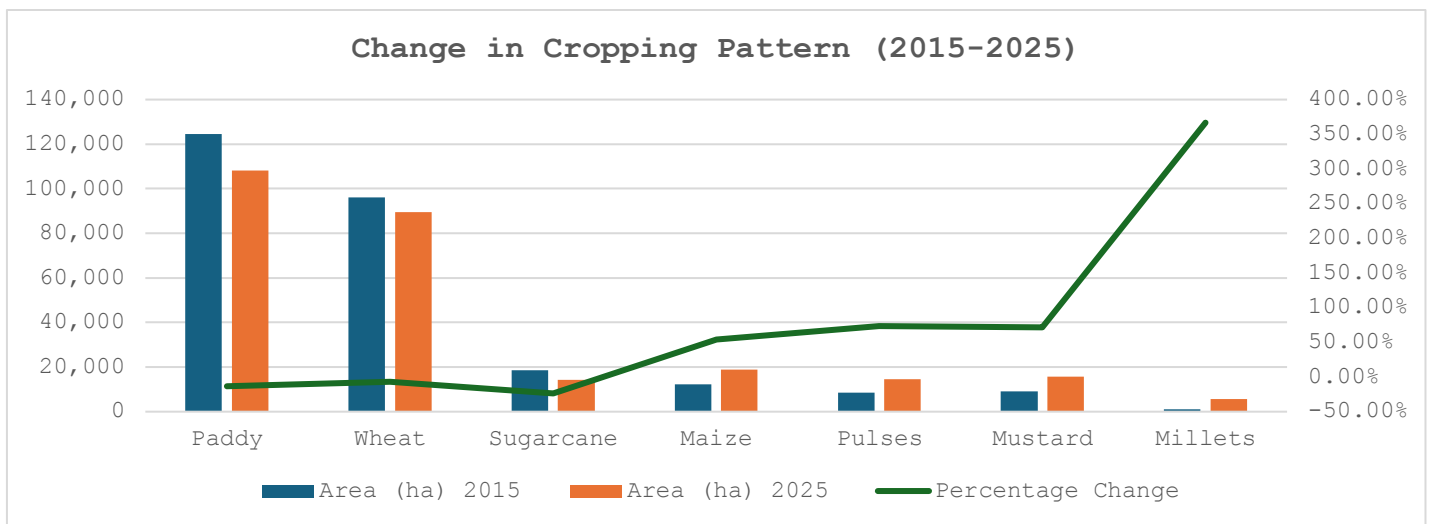
**Table 3: Climate Change Severity Components**

Indicator	Change	Contribution to Severity
Temperature	+1.1°C	High
Rainfall	-63.5%	Extreme
Humidity	-16.04%	Moderate
Heatwave Days	+11.1	High
Wind Speed	+3.07 km/h	Low-Moderate

**Impacts on Agricultural Crop Patterns**

**Traditional Cropping Systems:** Historically, Bahraich's agriculture followed well-established cropping patterns synchronized with monsoon rhythms. The kharif season (June-October) was dominated by paddy, utilizing monsoon rainfall for transplantation and growth. The rabi season (November-March) featured wheat, mustard, and gram, benefiting from residual soil moisture and winter precipitation. This system, refined over generations, optimized the use of natural resources while minimizing risk.

**Observed Changes in Crop Selection:** Climate variability has precipitated significant shifts in crop selection across Bahraich District. The most notable change is the gradual reduction in area under water-intensive crops, particularly paddy and sugarcane, and the corresponding expansion of less water-demanding alternatives.



**Table 4: Changes in Cropping Pattern (2015-2025)**

Crop	Area (ha) 2015	Area (ha) 2025	Percentage Change
Paddy	124,500	108,300	-13.0%
Wheat	96,200	89,400	-7.1%
Sugarcane	18,600	14,200	-23.7%
Maize	12,300	18,900	+53.7%
Pulses	8,400	14,600	+73.8%
Mustard	9,200	15,800	+71.7%
Millets	1,200	5,600	+366.7%

The dramatic increase in millet cultivation (366.7%) is particularly noteworthy and reflects conscious efforts by organizations like the Aga Khan Foundation to promote climate-resilient crops. In 2022, only 30 farmers cultivated millet; by 2024, this number had grown to 282 farmers.

### Case Study: Imamnagar Village

Imamnagar village in Balbhadrapur block exemplifies the transformation underway in Bahraich's agriculture. The Unnat Sichai Solar Vikas Samiti, a collective of 17 small farmers, has pioneered innovative farming practices on 83 bighas (approximately 16.6 acres). Under the leadership of President Athar Husain, the collective has demonstrated that cooperative approaches can enhance climate resilience. Before adopting solar irrigation, farmers in Imamnagar depended entirely on monsoon rains and expensive diesel pumps. As Husain explained, "With climate change, the unpredictability of monsoons and soaring input costs made it increasingly difficult to get expected returns from rice, wheat, and traditional crops". The installation of five solar irrigation units eliminated dependence on diesel, saving the collective approximately Rs 5 lakhs in farming costs while eliminating the environmental damage associated with diesel pumps. The Samiti has also diversified its cropping pattern. Farmer Sahjad Ali, managing 65 bighas, reported that savings from solar irrigation enabled him to purchase four additional bighas of land. Women farmers like Praveen have adopted crop rotations including wheat, mustard, maize, black gram (urad dal), and vegetables, demonstrating that diversified systems can be economically viable.

**Yield Implications:** The relationship between climate change and crop yields is complex and crop-specific. For paddy, the combination of reduced water availability, higher temperatures during the grain-filling period, and increased pest pressure has generally depressed yields. Some farmers in the Unnat Samiti reported obtaining five quintals of rice per acre, which, while respectable, falls below potential yields achievable under optimal conditions. For alternative crops, however, yields have been encouraging. Mustard and pulses have performed well under changed climatic conditions, with their lower water requirements proving advantageous during dry spells. The expansion of millet cultivation, still in its early stages, suggests recognition of its climate resilience and nutritional benefits.

**Farmer Perceptions and Decision-Making:** Interviews with farmers revealed sophisticated understanding of climate risks and deliberate adaptation strategies. Key factors influencing crop selection decisions included:

1. Water availability: Farmers increasingly assess groundwater levels and monsoon forecasts before committing to water-intensive crops.
2. Input costs: Rising costs of fertilizers, pesticides, and labor factor significantly into planting decisions.
3. Market prices: Price volatility influences the willingness to experiment with alternative crops.
4. Institutional support: Access to extension services, credit, and collective irrigation arrangements enables adaptation.

A farmer from Risia block articulated the prevailing sentiment: "Earlier we planted according to tradition; now we plant according to what the weather allows."

### Environmental Impacts

**Water Resources:** The environmental impacts of climate change in Bahraich District are most acutely manifested in the water sector. The 63.5% reduction in rainfall has profound implications for both surface water and groundwater resources.

**Groundwater:** The district's shallow water table (20-30 feet depth) has historically provided reliable irrigation access. However, increased extraction combined with reduced recharge threatens this resource. The rejuvenation of 16 ponds under the AKF initiative represents an important intervention to enhance groundwater recharge.

**Surface Water:** Reduced rainfall has diminished flows in the Ghaghara, Rapti, and Saryu rivers, affecting both irrigation availability and aquatic ecosystems. The ponds rejuvenated under the Mission Amrit Sarovar scheme, designed to capture and percolate rainwater, represent critical infrastructure for maintaining water security.

**Soil Health:** Climate change affects soil health through multiple pathways. Higher temperatures accelerate organic matter decomposition, potentially reducing soil carbon stocks. Changes in precipitation intensity affect erosion rates, with more intense rainfall events when they occur increasing runoff and soil loss. The adoption of laser sprays, sprinklers, and drip irrigation, as documented in Imamnagar, helps conserve soil moisture and maintains soil structure. Additionally, the production and application of organic fertilizers by women's Self Help Groups (SHGs) contributes to soil health improvement. These groups produce Mrida Sanjeevani (biodynamic fertilizer), Paudh Verdhak (plant growth stimulant), and Paudh Rakshak (bio-pesticide), reducing dependence on chemical inputs.

**Biodiversity:** Agricultural biodiversity in Bahraich District faces pressure from climate change and associated adaptation responses. The shift away from traditional varieties toward a smaller number of climate-resilient crops potentially reduces agrobiodiversity. However, the expansion of pulses, millets, and oilseeds partly offsets this trend by maintaining crop diversity. The district's natural ecosystems, including forest areas along the Nepal border, face indirect pressure as climate-stressed agricultural systems expand into marginal lands. Comprehensive assessment of biodiversity impacts requires further research.

**Air Quality:** The transition from diesel pumps to solar irrigation systems has measurable air quality benefits. Diesel pumps release significant quantities of particulate matter, nitrogen oxides, and other toxins. The 97 solar irrigation systems in Bahraich, by displacing diesel pumps, contribute to improved local air quality. The PM2.5 level change of -30.8% documented in climate data may partially reflect this transition, though broader regional factors also influence air quality.

### Adaptation Strategies and Interventions

**Technological Adaptations: Solar-Powered Irrigation-** The most significant technological adaptation in Bahraich District is the deployment of solar-powered irrigation systems. Initiated by the Aga Khan Foundation in 2020-2021 under its Low Carbon Agriculture Programme, this intervention has transformed irrigation access for thousands of farmers.

**Table 5: Solar Irrigation Impact in Bahraich District**

Indicator	Value
Solar irrigation systems installed	97
Farmers benefitted	8,700
Area irrigated	1,872 acres
Solar power units consumed	64,000 units
Revenue collected	Rs 1,28,000
Diesel cost savings	Rs 5 lakhs (Imamnagar cluster)

The group-based model, with farmers sharing costs and managing distribution collectively, has proven particularly effective. Water is provided at Rs 2 per unit (approximately 1,000 liters), with the pump operator receiving 20% commission. This transparent system ensures equitable access while maintaining financial sustainability.

**Efficient Irrigation Technologies:** Complementary to solar pumping, the adoption of water-efficient irrigation methods including laser land leveling, sprinklers, and drip irrigation reduces water consumption while maintaining productivity. These technologies are particularly important for groundwater conservation.

### Crop and System Adaptations

**Crop Diversification:** The most significant systemic adaptation is the deliberate diversification away from water-intensive crops. The Aga Khan Foundation's efforts to promote millets, pulses, and oilseeds have gained traction, with the number of millet farmers increasing nearly tenfold in two years .

**Organic Farming:** The production of organic inputs by women's SHGs represents both an adaptation and mitigation strategy. By reducing dependence on synthetic fertilizers (whose production is energy-intensive and whose application releases nitrous oxide), organic practices contribute to lower agricultural emissions while building soil health.

### Institutional Adaptations

**Farmer Collectives:** The Unnat Sichai Solar Vikas Samiti model demonstrates the power of collective action in building climate resilience. Regular monthly meetings, transparent water allocation on a first-come-first-served basis, and the ability to accommodate urgent needs through mutual adjustment exemplify effective local governance.

**Women's Empowerment:** The inclusion of women farmers in collectives and the formation of women's SHGs for organic input production addresses both gender equity and climate resilience. Women farmers like Praveen report that solar irrigation and mechanization have made farming more accessible, enabling them to manage their lands independently while sons migrate to cities for employment.

### Water Resource Management

**Pond Rejuvenation:** Under the Central Government's Mission Amrit Sarovar scheme, AKF rejuvenated 16 ponds in Bahraich District during 2022-2023. These interventions involve desilting, strengthening percolation, and ensuring that rainwater fills the ponds to recharge underground aquifers . Such nature-based solutions complement technological adaptations by addressing water security at the landscape level.

## DISCUSSION

**Synthesis of Findings:** The evidence presented in this study establishes that Bahraich District is experiencing significant climate change, with warming temperatures, declining and increasingly variable rainfall, and more frequent extreme heat events. These changes are not merely statistical artifacts but are experienced and responded to by farming communities whose livelihoods depend on climate-sensitive agriculture.

**The magnitude of change**—1.1°C warming and 63.5% rainfall reduction over sixteen years—exceeds typical projections for interior India and suggests that Bahraich may represent a "hotspot" of climate change within the Gangetic plain. The Very High severity classification (76/100) confirms this assessment .

**Agricultural Transformation Trajectory:** The agricultural system of Bahraich District is undergoing fundamental transformation in response to climate stress. The traditional rice-wheat system, which served the region well for decades, is gradually being replaced by more diversified cropping patterns featuring drought-tolerant crops including millets, pulses, and oilseeds. This transformation is not uniform but varies with access to irrigation, institutional support, and the adaptive capacity of different farmer groups. Farmers with access to solar irrigation, like those in the Unnat Samiti, maintain greater flexibility in crop choice compared to rain-fed farmers who remain at the mercy of increasingly erratic monsoons.

**The Role of Institutional Support:** The interventions facilitated by the Aga Khan Foundation demonstrate the critical importance of institutional support in enabling climate adaptation. The Low Carbon Agriculture Programme's integrated approach—combining solar irrigation infrastructure, promotion of alternative crops,

organic input production, and pond rejuvenation—addresses multiple dimensions of climate vulnerability simultaneously. The rapid scaling from 30 to 282 millet farmers in two years illustrates how demonstration effects and peer learning, facilitated by supportive institutions, can accelerate adoption of climate-resilient practices .

**Environmental Co-Benefits:** Importantly, many adaptation strategies generate environmental co-benefits. Solar irrigation reduces greenhouse gas emissions compared to diesel pumping. Organic farming practices build soil carbon and reduce nitrous oxide emissions. Pond rejuvenation enhances groundwater recharge and supports aquatic biodiversity. These synergies between adaptation and mitigation argue for integrated policy approaches.

**Persistent Challenges:** Despite progress, significant challenges remain. The financial sustainability of solar irrigation systems depends on continued farmer contributions and maintenance capacity. The profitability of alternative crops compared to paddy and sugarcane influences adoption decisions. The capacity of women's SHGs to scale organic input production requires continued support. Most fundamentally, the accelerating pace of climate change may outstrip the adaptive capacity of farming systems.

## POLICY RECOMMENDATIONS

**Strengthening Climate Information Systems:** Farmers need access to reliable, location-specific climate information to inform planting decisions. Investment in district-level climate monitoring, improved seasonal forecasting, and effective dissemination mechanisms (including mobile technology) would enhance adaptive capacity.

**Scaling Solar Irrigation Infrastructure:** The success of the 97 solar irrigation systems warrants expansion. A phased program to install solar pumps in all unirrigated or partially irrigated areas, with priority for farmer collectives, would enhance climate resilience while reducing emissions. The group-based model developed in Bagraich provides valuable lessons for scaling.

**Promoting Climate-Resilient Crops:** Continued support for diversification into millets, pulses, and oilseeds requires attention to the entire value chain—from seed availability to market access. Minimum support prices, procurement mechanisms, and processing infrastructure for alternative crops would incentivize adoption.

**Investing in Water Conservation:** The pond rejuvenation program should be expanded to cover all blocks, with attention to catchment treatment and maintenance arrangements. Complementary investments in groundwater monitoring and regulation would ensure sustainable use.

**Supporting Women's Leadership:** Women farmers and women's SHGs have demonstrated effectiveness in both adaptation and mitigation activities. Programs should deliberately target women for training, credit access, and leadership positions in farmer institutions.

**Strengthening Extension Services:** Agricultural extension must evolve from promoting uniform practices to supporting context-specific adaptation decisions. Extension agents need training in climate risk management and should facilitate farmer-to-farmer learning.

## CONCLUSION

This assessment of climate change impacts on agricultural crop patterns and environment in Bagraich District reveals a region under significant climate stress. Sixteen-year climate data document warming of 1.1°C, rainfall reduction of 63.5%, and increasing frequency of extreme heat events—changes that have fundamentally altered the conditions under which agriculture operates. The agricultural system has responded with notable adaptive capacity. Farmers are diversifying away from water-intensive crops, adopting solar irrigation, embracing organic practices, and organizing collectively to manage resources. Institutional support from organizations like the Aga Khan Foundation has facilitated this transition, demonstrating the power of well-designed interventions. However, the accelerating pace of climate change, reflected in the Very High severity classification, suggests that current adaptation efforts, while commendable, may be insufficient. The window for incremental adaptation

is narrowing, and transformative changes in agricultural systems, water management, and rural livelihoods may be necessary. Bahraich District's experience offers lessons for climate-vulnerable agricultural regions across India and beyond. It demonstrates that with appropriate support, farming communities can adapt to significant climate stress. It also underscores the urgency of both ambitious mitigation to limit future warming and continued investment in adaptation to manage unavoidable impacts. The future of agriculture in Bahraich—and in similar regions worldwide—will depend on the collective ability to learn from local experiences, scale successful innovations, and build the resilience of farming communities facing an uncertain climatic future.

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