



Climate-Resilient Agriculture: Evaluating Smallholder Farmer Adaptation Strategies to Heat-waves in the Awadh Region

Jigyasa Rajput

Research Scholar, M.Sc.

Dr. Bhimrao Ambedkar University, Agra

jigyasarajut94@gmail.com

Abstract

Heatwaves have become one of the most severe climate risks for agriculture in South Asia, with projections indicating sharp increases in their frequency, intensity, and duration. The Awadh region of Uttar Pradesh characterized by rice-wheat systems and dense smallholder cultivation is especially vulnerable. This paper evaluates how smallholder farmers in Awadh are adapting to escalating heat stress through the lens of climate-resilient agriculture (CRA). Using a conceptual framework that integrates climate resilience, sustainable livelihoods, and vulnerability analysis, the study synthesizes evidence from peer-reviewed research, government reports, and grey literature from Uttar Pradesh and the broader Indo-Gangetic Plains.

The paper examines regional heatwave trends, their impacts on crops and livelihoods, and the range of adaptation strategies employed or promoted. These include agronomic measures such as heat-tolerant varieties and modified sowing dates, improved soil and water management, agroforestry, crop and livelihood diversification, livestock practices, and climate information services. Although farmers are actively adapting, structural constraints small landholdings, limited irrigation and credit, weak extension systems, and gendered inequalities restrict transformative resilience. Existing policy efforts, including state climate plans, weather-information networks, and technology demonstrations, offer partial support but lack alignment with smallholder needs. The paper recommends scaling co-designed CRA interventions, strengthening local climate services, and integrating social protection with adaptation.

Keywords: Climate-resilient agriculture; Heatwaves; Smallholder farmers; Awadh region; Indo-Gangetic Plains; Climate adaptation; Agronomic strategies

1. Introduction

Across South Asia, climate change has intensified the occurrence of extreme heat events, including multi-day heatwaves that now routinely exceed thresholds for human and crop health (IPCC, 2021, 2022). The Indo-Gangetic Plains (IGP), stretching across northern India, Pakistan, and Bangladesh, have emerged as a global hotspot for humid heat extremes, where high temperatures coincide with significant humidity to create hazardous wet-bulb conditions (Speizer et al., 2022). These climatic changes intersect with dense rural populations, widespread poverty, and agriculture-dependent livelihoods, rendering smallholder farmers particularly vulnerable.

India has experienced several high-impact heatwaves in the past decade, many concentrated in northern states such as Uttar Pradesh (UP). Analyses of recent events show that anthropogenic climate change has at least doubled the likelihood of deadly heatwaves in UP, with temperatures exceeding 42-45°C in districts where agriculture is the primary occupation. At the same time, research indicates that climate change is already affecting rice and wheat yields across the IGP, with projections of declining productivity under future warming scenarios if no adaptation takes place (Datta et al., 2022; Impact of climate change on agriculture in Indo-Gangetic Plains, 2024).

The state of Uttar Pradesh is central to India's food security, contributing roughly one-third of national wheat production and significant shares of rice, pulses, sugarcane, and potatoes (Government of Uttar Pradesh, 2014; State Agriculture Profile-Uttar Pradesh, 2024). Within UP, the Awadh region encompassing districts such as Lucknow, Barabanki, Ayodhya, Sitapur, Sultanpur, Rae Bareilly and neighbouring areas is a historically important

agrarian landscape with fertile alluvial soils, monsoon-dependent agriculture, and high rural population density. Traditionally, Awadh has been defined as a cultural-historical region, but it also corresponds to a climatic and agro-ecological zone in the central-eastern part of UP, characterized by a subtropical monsoon climate with hot summers, cool winters, and annual rainfall of roughly 900-1,100 mm.

Smallholder farmers dominate agriculture in Awadh. The average landholding size in UP is below 1 ha for the majority of cultivators, with high fragmentation and tenancy. Rice-wheat cropping systems remain predominant, supplemented by pulses (e.g., lentil, chickpea), oilseeds, sugarcane, and increasingly horticulture. While canal irrigation and tubewell irrigation are present, access is uneven, and many farmers depend on monsoon rainfall. These characteristics underpin both the region's agricultural productivity and its vulnerability to climate extremes.

Heatwaves constitute a compound stressor in this context. At the biophysical level, elevated temperatures during sensitive crop growth stages such as wheat grain filling or rice flowering can cause accelerated phenological development, spikelet sterility, shrivelled grains, and yield losses of 15-25% or more in severe events (ICAR-CRIDA, 2023; Heat Wave 2022 bulletin). In addition, heat increases evapotranspiration demand, depletes soil moisture, and raises irrigation requirements, thereby intensifying pressure on already stressed groundwater resources. At the socio-economic level, heatwaves reduce labour productivity, raise input costs (particularly for irrigation and pest control), and increase health risks for farmers and farm workers, with disproportionate impacts on women, landless labourers, and other marginal groups (Imdad et al., 2024; CEEW, 2025; Singh et al., 2020).

Against this backdrop, climate-resilient agriculture (CRA) has emerged as a central policy and research paradigm. Building on climate-smart agriculture (CSA) and resilience thinking, CRA aims to enhance the capacity of agricultural systems to absorb and adapt to climate shocks while sustaining or improving productivity, equity, and ecosystem services (Sahoo et al., 2024; Acevedo et al., 2020). For smallholders in Awadh, CRA is not a purely technical challenge; it is intertwined with questions of land tenure, access to climate information, social protection, local institutions, and broader rural development trajectories.

This paper examines smallholder adaptation strategies to heatwaves in the Awadh region through the conceptual lens of CRA. Specifically, it seeks to:

1. Characterize the nature of heatwave risk for smallholder agriculture in Awadh.
2. Document and classify the main on-farm and off-farm adaptation strategies adopted or promoted.
3. Critically evaluate the effectiveness, limitations, and distributional implications of these strategies.
4. Identify policy and research priorities for strengthening climate-resilient agriculture in Awadh.

Rather than presenting new primary field data, the paper synthesizes existing empirical research, official reports, and practice-oriented literature relevant to Awadh and comparable contexts in the IGP, situating these within wider debates on adaptation, vulnerability, and resilience in smallholder agriculture.

2. Conceptual and Analytical Framework

2.1 Climate-resilient agriculture and heatwave adaptation

Climate-resilient agriculture refers to agricultural practices, technologies, and institutional arrangements that enhance the capacity of agro-ecosystems and farming communities to anticipate, absorb, recover from, and adapt to climate shocks and stresses, while maintaining or improving productivity, equity, and ecological integrity (Sahoo et al., 2024). CRA overlaps with, but is not identical to, climate-smart agriculture (CSA); it places greater emphasis on resilience to extremes and on social justice dimensions.

Heatwaves pose a specific type of stress: rapid-onset, high-temperature episodes lasting several days or weeks, sometimes combined with high humidity, drought, or hot dry winds. Climate models project continued increases in both mean temperature and extreme heat indices under all but the most stringent mitigation pathways (IPCC, 2021; Yu et al., 2025). For agricultural systems, heatwave resilience involves three partially overlapping strategies:

- **Reducing exposure** (e.g., adjusting cropping calendars to avoid the hottest days);
- **Reducing sensitivity** (e.g., heat-tolerant cultivars, shading, soil moisture conservation); and
- **Enhancing adaptive capacity** (e.g., access to climate information, credit, irrigation, social networks).

These dimensions align with classic vulnerability frameworks, in which vulnerability is conceptualized as a function of exposure, sensitivity, and adaptive capacity (Smit & Wandel, 2006; Adger, 2006).

2.2 Livelihoods, vulnerability and social differentiation

The Sustainable Livelihoods Framework (SLF) emphasizes that rural households draw on combinations of human, social, natural, physical, and financial capital to pursue diverse livelihood strategies within institutional and policy contexts (Chambers & Conway, 1992; Ellis, 2000). Applying this to climate adaptation highlights that farmers' ability to adopt CRA practices is shaped by access to land and water, gendered control over assets, caste relations, extension services, market linkages, and state support (Morton, 2007; Singh et al., 2020).

Recent work on smallholder vulnerability in the IGP underscores that livelihood vulnerability is highly differentiated even within seemingly similar agro-ecological settings. Venus et al. (2022) use a Livelihood Vulnerability Index in Bihar and Haryana to show that poorer households, those lacking irrigation, and those with limited education and off-farm income are significantly more vulnerable to climate risks, including heat and rainfall variability. Studies on perceived climate variability and compounding stressors among Indian smallholders similarly reveal how climate shocks interact with debt, health costs, and social exclusion to shape adaptation options (Singh et al., 2020; Patel et al., 2023).

In the context of Awadh, this implies that adaptation to heatwaves cannot be evaluated solely on technical or yield criteria; it must also be assessed in terms of who can adopt which strategies, at what cost, and with what implications for equity and long-term resilience.

3. Study Area: The Awadh Region

Awadh (often spelled Oudh) is a historical-cultural region in central-eastern Uttar Pradesh, roughly

centered on Lucknow and extending across neighbouring districts such as Barabanki, Ayodhya (formerly Faizabad), Sultanpur, Rae Bareilly, Sitapur, and others. Historically, Awadh has been an important granary and site of agrarian politics, with colonial-era debates on model farming and agro-forestry already documented in 19th-century records (Singh, 2006-2007; Singh, 2022).

Climatically, Awadh lies in the middle Gangetic plain. The region experiences a subtropical monsoon climate with three main seasons: a hot dry summer (March-June), a warm and humid monsoon (June-September), and a cool dry winter (November-February). Mean summer maximum temperatures traditionally range around 38-40°C, but recent decades have seen more frequent exceedances of 43-45°C during heatwave episodes (UPSDMA & University of Manchester, 2024; Lucknow City Heat Action Plan, 2025). Annual rainfall is concentrated in the monsoon months; delayed onset, long dry spells, and erratic distribution have become more common, echoing broader IGP trends (Mongabay India, 2024).

Agriculturally, the region is dominated by alluvial soils and intensive cultivation. Rice-wheat is the predominant cropping system, supplemented by pulses, oilseeds, sugarcane and, in some districts, potato and vegetables (Government of Uttar Pradesh, 2014; CRIDA, 2018). Fragmented smallholdings, extensive use of groundwater for irrigation, residual dependence on monsoon rainfall, and high population density define the structural context within which heatwaves impact smallholder farmers.

4. Methods and Sources

Given the constraints of time and data availability, this paper adopts a **narrative, structured review**

approach rather than primary empirical analysis. The methodology involved three main steps:

1. **Targeted literature search:** Peer-reviewed journal articles, books, and reports were identified via academic databases (e.g., ScienceDirect, Web of Science, Google Scholar) and institutional repositories, using combinations of keywords such as “heatwaves,” “Uttar Pradesh,” “Awadh,” “Indo-Gangetic Plains,” “climate-resilient agriculture,” and “smallholder adaptation.” Recent review articles on climate change and Indian agriculture (e.g., Datta et al., 2022; Sahoo et al., 2024; CRIDA, 2023) provided starting points.
2. **Grey literature and policy documents:** State-level documents, including the Uttar Pradesh State Action Plan on Climate Change, climate-resilient technology compilations, heat action plans, and climate risk assessments, were reviewed to capture current policy framings and recommended practices (Government of Uttar Pradesh, 2014; CRIDA, 2018; UPSDMA, 2024; Lucknow Municipal Corporation, 2025; CEEW, 2025).
3. **Analytical synthesis:** The adaptation strategies identified in the literature were classified into thematic categories (e.g., agronomic adjustments, water management, diversification, institutional strategies). Their reported benefits, costs, and constraints were examined through the conceptual lens outlined in Section 2, with attention to social differentiation where evidence allowed.

The review is necessarily selective and constrained by limited Awadh-specific quantitative studies on heatwave adaptation. To address this, it draws on

evidence from comparable parts of eastern and central UP, as well as the broader IGP, while carefully indicating where extrapolation rather than direct observation is involved.

5. Heat-waves and Smallholder Agriculture in Awadh

5.1 Trends in heat extremes

The India Meteorological Department defines a heatwave in the plains as a situation where the maximum temperature reaches at least 40°C and is 4–6°C above normal; severe heatwave conditions involve anomalies of 6°C or more. District-level analyses for Uttar Pradesh indicate that average temperatures have risen over the past few decades and that both the frequency and duration of heatwaves have increased, especially in central and eastern districts encompassing much of Awadh (Imdad et al., 2024).

In 2022 and 2023, northern India experienced prolonged heatwaves in pre-monsoon months, with several UP districts recording temperatures above 44–46°C. These events coincided with sensitive crop stages for wheat and pulses, contributing to visible grain shrivelling and yield reductions. Technical bulletins from ICAR-CRIDA attribute yield losses of 15–25% in wheat in parts of northern India to heatwaves that occurred during grain filling (ICAR-CRIDA, 2023).

Model-based projections reinforce these observations. High-resolution downscaled simulations for Asia suggest further intensification of extreme heat events in northern India even under moderate emissions scenarios (Yu et al., 2025), while IPCC assessments project that significant parts of South Asia will experience heat stress conditions approaching or exceeding critical thresholds for outdoor labour (IPCC, 2021, 2022).

5.2 Biophysical impacts on crops

Heat stress affects crops through multiple pathways. At the physiological level, high temperatures reduce photosynthetic efficiency, increase respiration, and accelerate phenological development, shortening grain filling duration. For wheat, temperatures above $\sim 30\text{--}32^{\circ}\text{C}$ during grain filling are associated with reduced kernel weight and shrivelling; for rice, temperatures above $\sim 35\text{--}36^{\circ}\text{C}$ during flowering can induce spikelet sterility, drastically reducing yield. Review studies on heatwave impacts in Indian agriculture highlight these mechanisms and document yield losses for wheat, rice, maize and pulses under recent events (CRIDA, 2023; Datta et al., 2022).

In Awadh, where wheat is often sown in November–December and harvested in April, early onset of heatwaves in March can compress grain filling into a shorter, hotter period. Farmers report premature yellowing, incomplete grain filling, and reductions in both yield and quality of wheat grains. For pulses such as lentil and chickpea, which are usually grown as rabi crops on residual soil moisture, high late-season temperatures exacerbate terminal drought stress, leading to flower drop and low pod filling.

Heatwaves also intensify pest and disease dynamics. Warmer temperatures can favour certain insect pests and pathogens, or alter their phenology in ways that decouple traditional pest management calendars. For example, increased incidence of whitefly in pulses and altered pest pressures in cereals have been reported during recent heatwave years in northern India (TERI, 2024).

5.3 Socio-economic impacts

The socio-economic impacts of heatwaves extend beyond yield losses. Imdad et al. (2024) emphasize

that additional irrigation, pest control, and labour costs during heatwaves increase financial burdens on farmers, often leading to higher indebtedness, especially among those without reliable irrigation or access to affordable credit. Heatwaves also reduce labour productivity and increase health risks for agricultural workers, particularly during peak daytime hours, potentially constraining the timing and quality of field operations.

Veterinary and livestock studies for eastern UP document farmer-led strategies such as constructing shade structures, changing feeding times, and altering watering regimes to protect livestock from heat stress, yet these often impose additional costs and labour demands (Yadav et al., 2022; Maiti et al., 2025). For landless and marginal farmers who rely on wage labour, heatwaves may mean reduced work hours or income loss when work is suspended or shifted to early morning and evening hours.

Overall, heatwaves act as a risk multiplier: they intensify existing challenges of groundwater depletion, input price volatility, and market uncertainty, thereby shaping adaptation space in Awadh.

6. Smallholder Adaptation Strategies to Heat-waves in Awadh

While Awadh-specific empirical studies are limited, the available evidence from UP and the IGP, combined with field reports and extension literature, reveals a diverse portfolio of adaptation strategies pursued by smallholders in response to rising heatwaves. These can be grouped into agronomic, technological, ecological, institutional, and livelihood strategies.

6.1 Agronomic adjustments: calendars, varieties and cropping systems

Shifting sowing dates. One of the most commonly reported farmer responses is adjustment of sowing dates, especially for wheat. Early sowing of wheat (e.g., in late October to early November) allows the crop to complete grain filling before the onset of extreme heat in March-April. Research from the IGP shows that advancing sowing can significantly reduce yield losses under terminal heat stress (Datta et al., 2022; CRIDA, 2018). In Awadh, early sowing is constrained by the timing of rice harvest and the availability of irrigation, but where possible farmers have adopted this adjustment.

Adoption of short-duration and heat-tolerant varieties. A second key strategy is the use of shorter-duration wheat, rice and pulse varieties, and increasingly, explicitly heat-tolerant cultivars. Plant breeding programmes and institutions such as ICAR, ICRISAT and IRRI have released varieties with improved tolerance to high temperature and drought conditions. For example, recent development of heat-tolerant pigeon pea cultivars capable of withstanding up to $\sim 45^{\circ}\text{C}$ demonstrates the potential of such traits to support resilience to heat (ICRISAT, 2025). In UP, climate-resilient technology compilations highlight heat-tolerant wheat and rice varieties suitable for state conditions (CRIDA, 2018). Adoption, however, depends on seed access, trust in new varieties, and market preferences.

Cropping system changes. Some farmers diversify away from the rice-wheat double-crop sequence towards combinations that are less water- and heat-sensitive. This includes replacing water-intensive, long-duration rice varieties with shorter-duration or drought-tolerant ones, increasing the share of pulses and oilseeds, or introducing

millet varieties that are more tolerant to heat and water stress. National policies promoting millets as “nutri-cereals” and climate-resilient crops provide additional incentives (Acevedo et al., 2020).

6.2 Soil and water management

Heatwaves magnify the importance of efficient soil moisture and water management. In Awadh, common adaptation practices include:

- **Conservation tillage and residue management:** Minimum tillage and retention of crop residues improve soil moisture conservation, reduce soil temperature, and protect soil biota. However, residue burning remains prevalent in parts of UP due to labour constraints and rapid turnaround between crops, despite policy efforts to curb the practice and promote alternatives such as bio-decomposers and residue management machinery (Times of India, 2025).
- **Mulching:** Application of crop residues or other organic mulches around crops helps reduce soil surface temperature and evaporation, thereby buffering crops against short heat spikes. This practice is promoted in CRIDA’s climate-resilient technologies for UP and adopted where farmers have sufficient residues and labour (CRIDA, 2018).
- **Improved irrigation scheduling and micro-irrigation:** To cope with higher evapotranspiration during heatwaves, farmers adjust irrigation schedules, often irrigating at night or early morning to reduce losses. Drip and sprinkler systems are being promoted under schemes such as the Pradhan Mantri Krishi Sinchai Yojana (PMKSY), though adoption among smallholders remains limited due to upfront costs. Emerging

research in eastern UP on sensor-based irrigation for direct-seeded rice illustrates the potential for data-driven irrigation scheduling to enhance water efficiency and resilience under heat stress (IRRI-ISARC, 2025).

- **Farm ponds and in situ water harvesting:** In some parts of UP, farm ponds and small water harvesting structures are promoted as a buffer against rainfall variability and heat-exacerbated drought. Their uptake in Awadh depends on land availability, local hydrology, and access to public support.

6.3 Agroforestry and on-farm microclimate management

Trees integrated into farms whether as boundary plantations, scattered shade trees, or more systematic agro-forestry provide multiple benefits for heatwave resilience: shading that reduces crop and soil temperatures, diversification of production (timber, fruit, fodder), and enhanced soil organic matter. Recent survey-based research in the Awadh region indicates increasing interest in agroforestry, but also identifies constraints, including limited landholding size, concerns about competition for water, and lack of clear tenure over trees (Singh & colleagues, 2025).

Programs encouraging tree planting (e.g., afforestation campaigns) may indirectly support on-farm microclimate regulation, but their alignment with smallholder CRA depends on tree species, spacing, and the extent to which farmers retain control over tree products.

6.4 Livestock and shade management

Livestock particularly cattle and buffalo are integral to mixed farming systems in Awadh. Heat stress reduces milk yields, fertility, and animal health,

which in turn affects household income and nutrient security. Farmer-led adaptation strategies documented in eastern UP include provision of shade structures using local materials, increased watering frequency, changes in feeding times (e.g., cooler hours), and, where possible, integration of trees to provide natural shade (Yadav et al., 2022). These measures are largely incremental, relying on local knowledge and low-cost materials, but may be insufficient during extreme heatwaves, especially when accompanied by water scarcity.

6.5 Climate information services and institutional adaptation

Access to timely, localized weather and climate information can significantly enhance farmers' ability to adjust sowing dates, irrigation schedules, and crop protection practices in anticipation of heatwaves. Uttar Pradesh has launched the Weather Information Network and Data System (WINDS), deploying automatic weather stations and rain gauges across the state to provide hyper-local weather information and advisories (Government of UP, 2025).

In principle, such systems can enable early warning of heatwaves and support decisions such as advancing irrigation prior to heat spikes, rescheduling labour-intensive operations, or deploying protective measures (e.g., mulching, temporary shading). In practice, benefits depend on the quality, lead time, and communication of forecasts, as well as farmers' trust and capacity to act on them. Studies across India emphasize that while awareness of "climate change" is relatively high, understanding of probabilistic forecasts and formal adaptation options remains limited among many smallholders (Datta et al., 2022; Patel et al., 2023).

Lucknow and other cities in Awadh have also developed Heat Action Plans that include early

warning systems, public awareness campaigns, and guidelines for working hours during heatwaves (Lucknow Municipal Corporation, 2025). To date, these are primarily urban-focused, but they provide a template for integrating agricultural considerations and rural outreach in future iterations.

6.6 Livelihood diversification and social protection

Finally, many households adapt to climatic risks, including heatwaves, through livelihood diversification and engagement with social protection programmes. Seasonal migration to urban areas, off-farm employment in construction or services, and participation in wage employment schemes such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) can provide income buffers during climate-induced crop losses. However, extreme heat in urban workplaces can also create new vulnerabilities for migrants.

Social protection instruments like crop insurance (e.g., Pradhan Mantri Fasal Bima Yojana) and targeted transfers can play a role in buffering against heat-induced losses, yet evidence suggests low enrolment, delays in claim settlement, and limited tailoring to heatwave risks in many regions (Datta et al., 2022). In Awadh, the extent to which social protection effectively supports heatwave adaptation remains under-documented and is a priority area for research.

7. Evaluating the Effectiveness of Adaptation Strategies

7.1 Biophysical effectiveness

Agronomic adaptations such as early sowing, short-duration varieties, and improved soil moisture management have demonstrated potential to reduce yield losses under heat stress in experimental trials and on-farm demonstrations (CRIDA, 2018; Datta et

al., 2022). Early wheat sowing, for instance, consistently reduces exposure of grain filling to late-season heatwaves. Similarly, mulching and conservation tillage lower soil temperatures and maintain higher soil moisture, which can help crops withstand brief heat spikes.

However, the effectiveness of these practices under real-world smallholder conditions is variable. Constraints include limited control over planting dates due to delayed monsoon or late rice harvest, scarcity of residues for mulching, and inadequate irrigation to take advantage of improved scheduling. The benefits of heat-tolerant varieties can also be masked by poor soil fertility, water stress, or pest pressures.

7.2 Economic feasibility and scalability

From an economic perspective, many current adaptations are low-cost, incremental strategies such as adjusting sowing dates or using locally available materials for shading that fit within existing livelihood systems. These have the advantage of being accessible to poorer households but may offer limited protection under increasingly severe heatwaves.

More transformative strategies, including micro-irrigation, farm ponds, sensor-based irrigation, and systematic agroforestry, require substantial upfront investment, technical support, and secure land tenure. While government subsidies exist for some technologies, smallholders in Awadh often face credit constraints, lack of collateral, and transaction costs in accessing schemes. Venus et al. (2022) show that in the IGP, households with more diversified income sources and better access to finance are more likely to adopt capital-intensive adaptation measures. This pattern likely holds in Awadh, raising concerns about adaptation that benefits relatively better-off farmers while leaving poorer ones at risk.

7.3 Social differentiation and equity

Evidence from participation-based studies in UP and elsewhere in India underscores that adaptation capacity is deeply shaped by social differentiation: gender, caste, age, and tenancy status (Singh et al., 2020; Patel et al., 2023; Yadav et al., 2022). Women farmers, for instance, often have limited independent land rights but shoulder major responsibilities for both crop and livestock management. They may have less access to climate information, credit, or extension services, which can constrain their ability to adopt new practices. Tenant farmers may hesitate to invest in agroforestry or soil improvements when tenure security is weak.

Equity concerns also arise in the design of climate-resilient programmes. If heat-resilient technologies are primarily disseminated through large farmer field schools or require substantial co-financing, they may be captured by medium and large farmers. Similarly, early warning messages disseminated through digital platforms may not reach illiterate or marginalized households. Without explicit attention to inclusion, adaptation efforts risk reproducing or exacerbating existing inequalities.

7.4 Risk of maladaptation

Some strategies, while beneficial in the short term, may generate new risks over time. For example, increased reliance on groundwater irrigation to combat heat stress can deepen groundwater depletion, undermining long-term water security and increasing energy costs (Eos, 2022; UNDP, 2019). Expansion of tube-well irrigation has already transformed parts of the IGP; in Awadh, unmanaged extraction could interact with heatwaves to exacerbate drought risk.

Similarly, promotion of certain tree species in agroforestry or boundary plantations without

adequate consideration of water use, biodiversity, or local preferences may lead to trade-offs between shade provision and water competition. Careful, context-specific design is thus essential to avoid maladaptation.

8. Policy and Programmatic Landscape in Uttar Pradesh and Awadh

8.1 State and national frameworks

The Uttar Pradesh State Action Plan on Climate Change (SAPCC), first developed in the early 2010s, recognizes agriculture as a highly climate-sensitive sector and highlights increased frequency of heatwaves and altered rainfall as key risks (Government of Uttar Pradesh, 2014). The SAPCC calls for the development and dissemination of stress-tolerant varieties, improved water management, enhanced agro-meteorological services, and strengthened extension for climate-smart practices.

At the national level, the National Mission for Sustainable Agriculture (NMSA), the National Innovations in Climate Resilient Agriculture (NICRA) program, and schemes such as PMKSY and PMFBY provide institutional frameworks and funding streams for CRA interventions. NICRA, in particular, has supported climate-resilient technology demonstrations including drought- and heat-tolerant cultivars, resource-conserving technologies, and weather-based agro-advisories in selected clusters across UP (CRIDA, 2018).

However, these frameworks rarely single out heatwaves as a distinct hazard with specific adaptation needs; heat is often treated alongside drought and general “temperature rise.” Given the rapid intensification of heat extremes, there is a growing argument for more explicit integration of

heatwave considerations into agricultural policy and planning.

8.2 Emerging initiatives: weather networks and heat action plans

Recent years have seen several initiatives in UP that could support heatwave resilience in Awadh. The WINDS project aims to deploy hundreds of automatic weather stations and tens of thousands of rain gauges to generate hyper-local weather data, enabling more precise advisories for farmers (Government of UP, 2025). If effectively integrated with extension systems and digital platforms, WINDS could significantly improve early warning for heatwaves and support adaptive scheduling of farm operations.

At the same time, Lucknow and other cities in Awadh have adopted heat action plans that outline thresholds for heat alerts, recommended actions for public health, and sometimes guidance for outdoor workers (Lucknow Municipal Corporation, 2025). These plans have yet to be systematically aligned with agricultural extension, but they offer institutional entry points for integrated rural-urban heat governance.

8.3 Gaps and challenges

Despite this evolving policy landscape, several gaps remain in tailoring climate-resilient agriculture to heatwave risks in Awadh:

- **Limited Awadh-specific evidence:** Most empirical studies focus on larger spatial units (e.g., entire UP, IGP) or other regions, making it difficult to derive precise, localized recommendations for Awadh.
- **Fragmented implementation:** CRA interventions (e.g., promotion of heat-tolerant varieties, micro-irrigation,

residue management) are often implemented in project mode, with limited upscaling and institutionalization.

- **Insufficient integration of social protection and adaptation:** Crop insurance and social safety nets are not fully aligned with heatwave risks and do not systematically target the most vulnerable smallholders.
- **Under-representation of smallholders in design:** Farmer participation in the design of adaptation programmes remains limited; top-down interventions may miss local constraints and opportunities.

Addressing these gaps will be crucial to making adaptation strategies in Awadh both effective and equitable.

9. Recommendations for Strengthening Climate-Resilient Agriculture in Awadh

Building on the evidence reviewed, several strategic directions emerge for enhancing smallholder adaptation to heatwaves in the Awadh region.

9.1 Co-design and scaling of CRA technology packages

Rather than promoting individual practices in isolation, agricultural research and extension agencies should co-design integrated CRA packages for dominant cropping systems such as rice-wheat. These packages could combine:

- optimal sowing windows based on updated climate data;
- heat-tolerant, short-duration varieties of rice, wheat, and pulses;
- conservation tillage and residue retention or alternative residue management solutions;

- context-appropriate irrigation strategies (including sensor-based scheduling where feasible); and
- pest and disease management tailored to warmer conditions.

Participatory on-farm trials in representative villages across Awadh can help refine these packages, ensuring they are compatible with local labour, resource, and market constraints.

9.2 Strengthening local climate services and heat early warning

Efforts like WINDS and municipal heat action plans should be extended and integrated to create **farmer-oriented local climate services**. This entails:

- converting raw weather and temperature forecasts into actionable agro-advisories (e.g., “advance irrigation by 2-3 days before predicted heatwave,” “avoid harvesting or transplanting between 12-4 pm on alert days”);
- disseminating advisories via multiple channels SMS, voice messages, community radio, local leaders to reach diverse farmer groups, including women and marginalised communities; and
- systematically evaluating the uptake and effectiveness of advisories in reducing heat-related crop and health impacts.

Linking district-level heat thresholds (Imdad et al., 2024) with agricultural advisories can help align meteorological and agricultural responses.

9.3 Integrating social protection and climate adaptation

Given the poverty and vulnerability profile of many Awadh smallholders, social protection must be

embedded within CRA strategies. Priority actions include:

- tailoring crop insurance products to explicitly cover heatwave-related yield losses and simplifying claim procedures;
- using MGNREGA and other public works programmes to support climate-resilient infrastructure (e.g., farm ponds, shade structures, community water harvesting) while providing income during climate shocks;
- targeting cash or in-kind support (e.g., subsidized seeds of heat-tolerant varieties, low-cost mulching materials) to the poorest households, renters, and women farmers.

Such measures can expand adaptive capacity and reduce reliance on maladaptive coping strategies (e.g., distress sales of livestock, high-interest loans).

9.4 Addressing water and energy sustainability

To avoid maladaptation through unsustainable groundwater extraction, CRA strategies in Awadh must be aligned with integrated water resource management. This involves:

- promoting water-saving irrigation practices (e.g., alternate wetting and drying in rice, deficit irrigation) linked to energy-efficient pumping;
- regulating and monitoring groundwater use where feasible, while offering alternatives such as community irrigation systems and support for low-energy technologies;
- encouraging diversification into less water-intensive crops, particularly in areas with declining groundwater levels.

Synergies between heat adaptation and water/energy conservation should be prioritized for instance, using solar-powered micro-irrigation systems combined with heat-resilient cropping.

9.5 Focusing on equity, gender and social inclusion

Finally, adaptation in Awadh must be designed with explicit attention to equity and inclusion. Practical steps include:

- ensuring that women farmers, tenant cultivators, and lower-caste groups are represented in farmer producer organizations (FPOs), water user associations, and local adaptation planning forums;
- tailoring extension content and delivery to the specific needs and schedules of women (e.g., women-only training sessions, female extension workers);
- collecting sex-disaggregated and caste-disaggregated data on adoption of CRA practices and heatwave impacts to guide targeted support.

Without such measures, adaptation may reinforce existing power imbalances and leave the most vulnerable farmers behind.

10. Conclusion

Heatwaves have rapidly emerged as a defining climate risk for smallholder agriculture in the Awadh region of Uttar Pradesh. Situated within the broader Indo-Gangetic Plains, Awadh combines high exposure to rising temperatures and humid heat extremes with structural vulnerabilities rooted in small and fragmented landholdings, dependence on monsoon rainfall, and socio-economic inequalities.

This paper has reviewed the evolving climate context, biophysical and socio-economic impacts of heatwaves, and the portfolio of adaptation strategies

pursued by smallholders and promoted by policy actors. Farmers in Awadh are not passive victims: they adjust sowing dates, experiment with varieties, manage soil and water to the extent possible, protect livestock from heat stress, and diversify livelihoods. Policy frameworks such as the UP SAPCC, NICRA, and emerging weather information networks provide important enabling conditions, and a growing body of agronomic research offers promising climate-resilient technologies.

Yet, the review also highlights substantial limitations. Many adaptations remain incremental, under-resourced, and unevenly distributed. The most vulnerable farmers those with least land, water, and social capital often have the fewest options to adopt effective CRA strategies. Heatwaves are still insufficiently mainstreamed into agricultural planning, and key systemic issues groundwater depletion, inequitable access to information and finance, fragmented governance remain unresolved.

Going forward, climate-resilient agriculture in Awadh will require integrated, multi-scalar efforts that combine co-designed technology packages, robust local climate services, aligned social protection, sustainable water and energy management, and deliberate attention to equity. Continued empirical research especially participatory, mixed-methods studies in representative Awadh villages is needed to better understand how farmers perceive and respond to heatwaves, which strategies work under which conditions, and how adaptation pathways can be steered towards both resilience and social justice.

In an era of intensifying heat, the resilience of Awadh's smallholder agriculture is not merely a technical challenge; it is a central question of livelihood security, regional food systems, and climate-just development in northern India.

References

- Acevedo, M., Pixley, K., Zinyengere, N., Meng, S., Tufan, H., Cichy, K., Bizikova, L., Isaacs, K., Ghezzi-King, D., & Mason-d'Croz, D. (2020). A scoping review of adoption of climate-resilient crops by smallholder farmers in South Asia. *Nature Plants*, 6(8), 989-997.
- Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, 16(3), 268-281.
- CEEW. (2025). *Mapping climate risks and impacts of extreme heatwave disasters in Indian districts*. Council on Energy, Environment and Water.
- Chambers, R., & Conway, G. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century* (IDS Discussion Paper 296). Institute of Development Studies.
- CRIDA. (2018). *Promising climate resilient technologies for Uttar Pradesh*. ICAR-Central Research Institute for Dryland Agriculture.
- CRIDA. (2023). *Heat wave 2022 - Causes, impacts and way forward for Indian agriculture* (Technical Bulletin). ICAR-Central Research Institute for Dryland Agriculture.
- Datta, P., Samanta, S., Mandal, M., & Banerjee, M. (2022). Climate change and Indian agriculture: A systematic review of farmer perceptions, adaptation responses and policy interventions. *Climate Risk Management*, 37, 100450.
- Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press.
- Government of Uttar Pradesh. (2014). *Uttar Pradesh State Action Plan on Climate Change*. Department of Environment, Government of Uttar Pradesh.
- Government of Uttar Pradesh. (2024). *State agriculture profile: Uttar Pradesh*. Department of Agriculture & Farmers Welfare.
- India Meteorological Department & UPSDMA; Imdad, K., et al. (2024). *District wise heat wave threshold determination for Uttar Pradesh*. Uttar Pradesh State Disaster Management Authority & University of Manchester.
- IPCC. (2021). *Climate change 2021: The physical science basis*. Contribution of Working Group I to the Sixth Assessment Report of the IPCC. Cambridge University Press.
- IPCC. (2022). *Climate change 2022: Impacts, adaptation, and vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the IPCC. Cambridge University Press. (See Chapter 10: Asia).
- IRRI-ISARC. (2025, July 3). IRRI scientists work on sensor-based irrigation to boost water efficiency. *The Times of India*.
- Maiti, S., Yadav, P., Meena, H. R., Bhakat, M., & Dixit, A. K. (2025). Climate adaptation in South Asian livestock production: Farmer-led strategies and policy implications. *VeriXiv*.
- Mongabay India. (2024, October 16). Changing rainfall patterns impact agriculture in the Indo-Gangetic Plain.
- Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences*, 104(50), 19680-19685.
- Patel, S., et al. (2023). Passive adaptation to climate change among Indian farmers. *Journal of Environmental Management*, 332, 117375.
- Singh, N. (2006-2007). Colonial discourse on agro-forest policy in Awadh during the 19th

- century: A study of 'model farming' and Voelcker report on Indian agriculture. *Proceedings of the Indian History Congress*, 67, 666-677.
- Singh, N. (2022). Grain trade, climate change and famines: A study of Awadh from c. 1858-1900. *Indian Historical Review*, 49(1), 37-62.
- Singh, R. K., Singh, A., Kumar, S., et al. (2020). Perceived climate variability and compounding stressors: Implications for risks to livelihoods of smallholder Indian farmers. *Climatic Change*, 162(3), 1243-1261.
- Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, 16(3), 282-292.
- Speizer, S., et al. (2022). Concentrated and intensifying humid heat extremes in the era of climate change. *Geophysical Research Letters*, 49(5), e2021GL097261.
- State Agriculture Profile - Uttar Pradesh. (2024). Ministry of Agriculture & Farmers Welfare, Government of India.
- TERI. (2024, September 18). Heat waves and action plans: How does India fare? The Energy and Resources Institute.
- Times of India. (2025, February-November). Series of reports on stubble burning, afforestation campaigns, and agricultural adaptation in Uttar Pradesh, including *UP sees sharp dip in stubble burning cases in 20 districts* and related articles.
- UNDP. (2019). *Understanding climate change adaptation for agricultural value chains: Adaptation to climate change - Uttar Pradesh*. United Nations Development Programme.
- Venus, T. E., et al. (2022). Livelihood vulnerability and climate change: A comparative analysis in the Indo-Gangetic Plains. *Environment, Development and Sustainability*, 24(10), 11835-11859.
- Yadav, P., Maiti, S., Meena, H. R., Bhakat, M., & Dixit, A. K. (2022). A study on the effectiveness of farmer-led adaptation strategies for livestock rearing to climate change in eastern Uttar Pradesh through a participatory approach. *International Journal of Livestock Research*, 12(2), 23-30. <https://doi.org/10.5455/ijlr.20220222020551>
- Yu, J., et al. (2025). High-resolution dynamically downscaled projections of extreme heat over South Asia. *Science of the Total Environment*, 920, 170000.