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Adaptation mechanisms to address the vulnerability of heat and drought in the bundelkhand region of Uttar Pradesh

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Abstract

The Bundelkhand region of Uttar Pradesh is characterized by a semi-arid climate, erratic rainfall, and a recurrent vulnerability to heat waves and droughts that has intensified pressure on agriculture, water availability, livelihoods, and human health. Over the past decades the region has recorded a mean temperature rise of 0.5-0.9 °C, and more than 60% of the years between 2001 and 2020 received below-average rainfall, resulting in progressive groundwater depletion and the drying of traditional water bodies. Under the National Innovations in Climate Resilient Agriculture (NICRA) programme, adaptive management interventions were implemented in two villages each of four risk-indexed districts - Jhansi, Hamirpur, Chitrakoot, and Sonbhadra: Spanning natural resource management (NRM), crop production, livestock, fisheries and institutional strengthening. Under the NRM component, a check dam constructed at Chitrakoot created a water-holding capacity of 20,63,799 litres, assured at least two irrigations for 10ha wheat command area, raised the local groundwater table by 2 m, and increased cropping intensity by 200%. Micro-irrigation demonstrations conducted over 25 ha under sprinkler systems recorded a 46.96% yield increase over flood irrigation, a benefit-cost ratio of 3.54, and water savings of up to 65% in field pea. Introduction of drought-tolerant varieties raised yields by an average of 38%, while in-situ moisture conservation practices such as broad-bed-and-furrow layouts and mulching saved 15-25% of irrigation water. Livelihood diversification through livestock, poultry, and small-scale enterprises, together with institutional mechanisms such as Village Climate Risk Management Committees, seed banks, fodder banks, and Custom Hiring Centres, strengthened community-level resilience. The results indicate that an integrated, multi-dimensional strategy combining water conservation infrastructure, climate-resilient crop and livestock technologies, livelihood diversification, and community institutions offer a scalable model for reducing heat and drought vulnerability in semi-arid, rainfed regions such as Bundelkhand.

Keywords: Bundelkhand, climate resilience, drought adaptation, heat stress, NICRA, rainwater harvesting, sprinkler irrigation, water-use efficiency

Introduction

Rainfed agriculture in the semi-arid tropics is increasingly exposed to the compounding effects of rising temperatures and erratic precipitation, and the Bundelkhand region spanning southern Uttar Pradesh and northern Madhya Pradesh is widely regarded as one of India's most climate-vulnerable agro-ecological zones. The region's climate is marked by extreme temperature fluctuations and a recurrent susceptibility to heat waves and droughts, with summer temperatures frequently exceeding 45 °C and severe water scarcity during the lean months. These localised stresses mirror a broader pattern of climate change impacts on Indian agriculture, in which rising mean temperatures and an increasing frequency and intensity of heat-wave events are projected to depress crop productivity and threaten farm livelihoods across the country unless adaptation and mitigation measures are scaled up (Aggarwal, 2008; Bal *et al.*, 2022) ^[1, 2].

Long-term climatic records indicate that the Bundelkhand region has experienced a mean temperature increase of 0.5-0.9 °C over recent decades, a trend that has been associated with reduced crop yields and heightened heat stress on both human and livestock populations (Gupta

et al., 2021) ^[4]. Rainfall variability compounds this vulnerability: over 60% of the years between 2001 and 2020 recorded below-average precipitation (Singh *et al.*, 2020) ^[13, 14], and the resulting recurrent droughts, together with the progressive depletion of groundwater reserves and the drying of traditional water bodies, have aggravated water scarcity across the region (Rathore *et al.*, 2021) ^[11]. Trend and multi-scalar assessments of meteorological and hydrological drought corroborate an increasing frequency and severity of drought events across Bundelkhand (Kumar & Gautam, 2022; Patidar *et al.*, 2024) ^[9, 10], while integrated watershed development and groundwater-recharge interventions have been shown to rebuild climate resilience in this degraded agricultural landscape (Garg *et al.*, 2020; Joshi *et al.*, 2021) ^[3, 6].

These compounding climatic stresses have translated into significant socio-economic distress, undermining agricultural productivity, water availability, rural livelihoods, and public health. Building adaptive capacity in such water-scarce, drought-prone tracts therefore requires interventions that address water conservation, drought-frequency management, and groundwater depletion simultaneously, rather than in isolation. Against this backdrop, the National Innovations in Climate Resilient Agriculture (NICRA) programme, implemented through the Krishi Vigyan Kendra (KVK) network under ICAR-ATARI, Zone-III, Kanpur, sought to demonstrate and institutionalise a portfolio of adaptation measures spanning natural resource management, climate-resilient crop production, livestock management, and community-based institutional strengthening. The present study reports the outcomes of these interventions across four risk-indexed districts of the Bundelkhand region Jhansi, Hamirpur, Chitrakoot, and Sonbhadra - with the objective of evaluating their contribution to reducing the vulnerability of farming communities to heat and drought.

2. Materials and Methods

2.1 Study area and site selection

Four districts of the Bundelkhand region of Uttar Pradesh - Jhansi, Hamirpur, Chitrakoot, and Sonbhadra- were selected on the basis of the climate-risk index assigned by ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA), Hyderabad. Within each district, two villages were adopted under the NICRA programme for the demonstration of adaptive management practices targeted at heat and drought vulnerability.

2.2 Intervention framework

Interventions in the adopted villages were organized under four complementary components:

- **Natural Resource Management (NRM):** construction of rainwater harvesting structures (check dams, ponds, and tanks) and implementation of micro-irrigation facilities (drip and sprinkler systems) to conserve monsoon runoff and improve on-farm water-use efficiency.

- **Crop Production:** introduction of heat- and drought-tolerant crop varieties, promotion of crop diversification away from water-intensive monocultures, and demonstration of in-situ soil-moisture-conservation techniques such as broad-bed-and-furrow (BBF) layouts and mulching.
- **Livestock and Fisheries:** introduction of drought-resistant fodder crops and new fodder varieties, together with improved veterinary care and livestock management practices, to secure fodder availability and reduce livestock vulnerability during periods of heat and water stress.
- **Institutional Intervention:** establishment of Custom Hiring Centres (CHCs) for farm machinery, constitution of Village Climate Risk Management Committees (VCRMCs), and institutionalization of seed banks and fodder banks in the NICRA villages.

2.3 Data collection and evaluation

Performance of the check-dam intervention was assessed by comparing catchment area, structural dimensions, water-holding capacity, irrigated command area, cropping pattern, and groundwater level before and after construction (Table 1). Front-line demonstrations of sprinkler irrigation were conducted to compare crop water requirement, water saved, yield, and the benefit-cost (B-C) ratio against the prevailing flood-irrigation practice (Table 2). Yield advantage from drought-tolerant varieties and water savings from in-situ moisture-conservation practices were recorded across the demonstration sites at KVK Jhansi, Hamirpur, Chitrakoot, and Sonbhadra.

3. Results and Discussion

3.1 Water conservation and management

The check dam constructed at KVK Chitrakoot exemplified this intervention: it commanded a catchment of about 400 ha drained by four rivulets, and with a depth of 2 m, length of 45 m, and width of 30 m, achieved a water-holding capacity of 20,63,799 litres (72,900 cubic feet) at a construction cost of Rs. 2.95 lakh (Table 1, Figure 1). The structure assured at least two irrigations for 10 ha wheat command area, enabled the introduction of additional crops (moong, mustard, chickpea, and field pea alongside the existing wheat-chickpea system), increased overall cropping intensity by 200%, and raised the local groundwater table from 157 m to 155 m - a rise of 2 m. This outcome is consistent with evidence that rainwater-harvesting structures raise crop productivity in rainfed tracts by capturing otherwise-lost monsoon runoff for supplemental irrigation (Singh *et al.*, 2020) ^[13, 14], and with multiproxy groundwater-recharge assessments confirming that such structures are an effective means of augmenting depleted aquifers in the Bundelkhand region (Joshi *et al.*, 2021) ^[6].

Table 1: Effect of check-dam intervention on water availability and cropping intensity (KVK Chitrakoot).

Particulars	Before	After	Remarks
Water catchment area (surrounding area)		400 ha (4 rivulets)	
Depth of check dam (m)		2	
Length of check dam (m)		45	
Width of check dam (m)		30	
Construction cost (Rs. lakh)		2.95	
Area irrigated by check dam (ha)		25	
Water holding capacity (litres)		20,63,799 (72,900 cubic ft)	
Duration of water holding	Run-off	Last week of February to last week of March	
Irrigation method	Rainfed	Flood irrigation of wheat crop	Water lifted through pumping set
Irrigated crops	Wheat and chickpea	Wheat, moong, mustard, chickpea, field pea, etc.	Cropping intensity increased by 200%
Groundwater level (m below ground)	157	155	Rise of 2 m

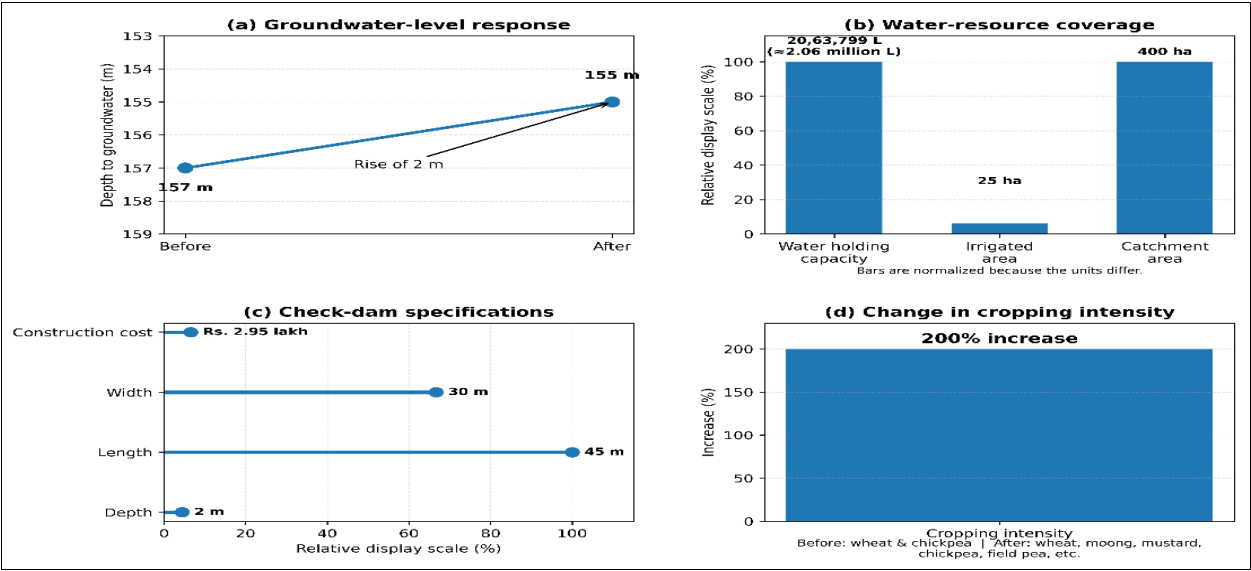


Fig 1: Effect of check-dam intervention on water availability and cropping intensity

Complementing the surface-storage intervention, farmers were encouraged to adopt water-efficient micro-irrigation systems, particularly drip and sprinkler irrigation, for drought-resistant crops such as pulses, oilseeds, and vegetables. Ten front-line demonstrations of sprinkler irrigation were conducted across 25 ha (subsequently reported as an expanded 35 ha command area in Table 2, Figure 2), covering gram, field pea, wheat, and lentil. Sprinkler irrigation reduced water use from 60,00,000 litre/ha under flood irrigation to 21,00,000 litre/ha, a saving of 39,00,000 litres, equivalent to about 65% water saving in field pea - while recording a 46.96% yield increase over the traditional flood-irrigation system and a benefit-cost ratio of 3.54, with an overall water saving of 60% across the demonstrated area. These efficiency gains are in line with farm-level evidence that sprinkler irrigation in wheat substantially reduces water application while improving output per unit of water used (Kishore, 2019) [8], and with a recent Bundelkhand-specific evaluation reporting comparable water-saving and yield benefits of sprinkler technology in pulse production (Yadav *et al.*, 2026) [16].

Table 2: Performance of sprinkler irrigation relative to flood irrigation across NICRA demonstration villages

Particulars	Before (flood irrigation)	After (sprinkler irrigation)	Remarks
Crop	Chickpea / Barley	Gram / Field pea / Wheat / Lentil	
Area (ha)	2	35	
Water use in crop irrigation (litre/ha)	60,00,000	21,00,000	65% water saving in field pea
Water saved (litres)			39,00,000 litres
Cropping system	Sesame/Barley/Chickpea/Field pea/Lentil	Sesame-Wheat/Chickpea/Field pea/Lentil	
Land holding size (ha)	2.5	2.5	

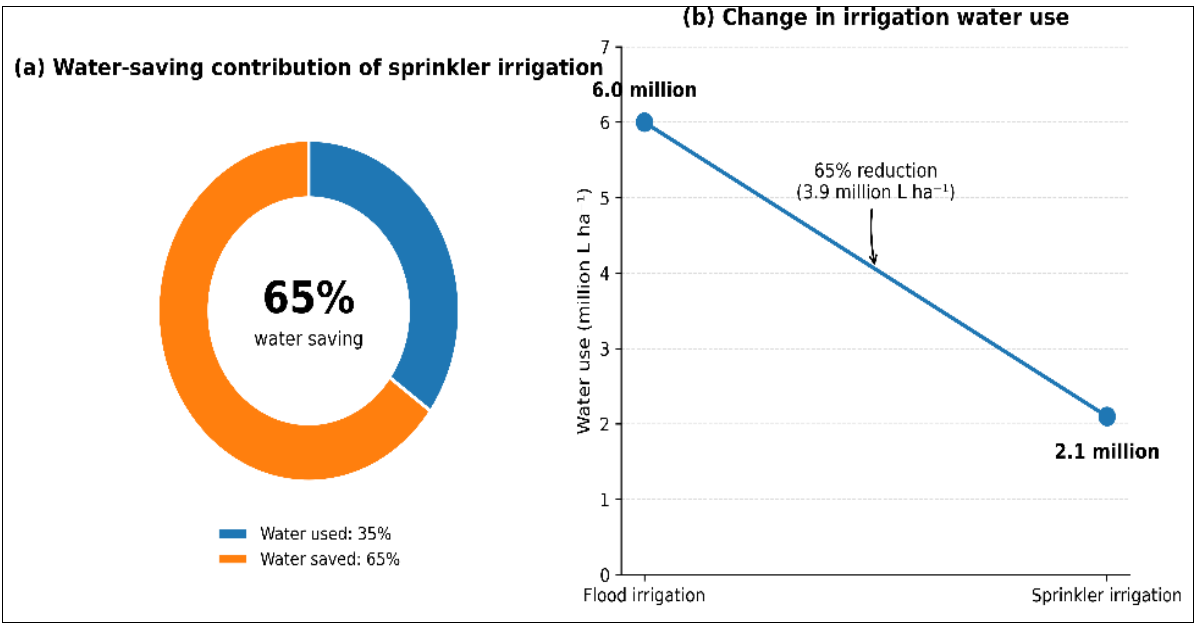


Fig 2: Water-use performance of sprinkler irrigation relative to flood irrigation

Taken together, these results indicate that conjunctive use of rainwater-harvesting infrastructure and micro-irrigation technology can substantially buffer the region's water deficit, both by capturing otherwise-lost monsoon runoff and by curbing the high conveyance and application losses inherent to flood irrigation.

3.2 Climate-resilient agriculture

Crop diversification away from water-intensive monoculture, particularly paddy, toward drought-resistant and heat-tolerant crops such as millets, sorghum, and chickpea, was promoted as a core adaptation strategy, since these crops require less water and better withstand elevated temperatures. Mustard varieties DRMR-541 and Pitambari were demonstrated in Hamirpur and Chitrakoot and were well received by participating farmers.

The replacement of local cultivars with drought-tolerant varieties delivered an average yield advantage of 38% at KVK Jhansi, underscoring the contribution of improved germplasm to productivity under water-scarce conditions, in line with breeding evidence that resilient, drought-adapted genotypes deliver measurable productivity gains in rainfed ecosystems (Venuprasad *et al.*, 2010). In parallel, in-situ soil-moisture-conservation techniques including broad-bed-and-furrow layouts and mulching were demonstrated under the TDS-NICRA project across KVK Jhansi, Hamirpur, Chitrakoot, and Sonbhadra, achieving water savings of 15-25% and thereby extending the effective duration of available soil moisture during dry spells, consistent with reviews identifying mulching as an effective and low-cost water-saving technique for dryland agriculture (Kader *et al.*, 2019) [7].

3.3 Livelihood diversification

Recognizing the region's structural vulnerability to climate variability, the programme promoted diversification of rural livelihoods beyond crop agriculture. Support for livestock rearing, poultry farming, handicrafts, and small-scale enterprises was extended to provide households with a livelihood safety net during drought periods, addressing the heightened livelihood vulnerability that farm households in Bundelkhand report in their own perceptions of climate change relative to farmers elsewhere in Uttar Pradesh (Jatav, 2024; Singh, 2020) [5, 13, 14]. Climate-smart livestock management encompassing drought-resistant fodder crops, improved veterinary care, and better husbandry practices was promoted to reduce the exposure of the livestock sector to extreme heat and water scarcity, reinforcing coping strategies already reported among dairy farmers of the Bundelkhand region under recurrent drought (Sankhala *et al.*, 2016) [12].

3.4 Community-based adaptation and institutional strengthening

Institutional mechanisms were established to sustain the adopted practices beyond the demonstration phase. Village Climate Risk Management Committees (VCRMCs) were constituted to oversee implementation and monitoring of adaptation activities and were empowered to take decisions on the formation of Custom Hiring Services and the procurement of heavy machinery required for site-specific vulnerability reduction. Custom Hiring Centres providing access to bunding, levelling, furrow-making, and sprinkler and drip irrigation equipment were established in the adopted villages, assuring continued in-situ moisture conservation, while seed banks and fodder banks were institutionalised to secure planting material and livestock feed during periods of stress.

4. Conclusion

Adaptation to heat and drought vulnerability in the Bundelkhand region requires a multi-dimensional strategy that integrates water-conservation infrastructure, climate-resilient crop and livestock technologies, livelihood diversification, and community-level institutions. The check-dam and micro-irrigation interventions demonstrated substantial gains in water availability, cropping intensity, and water-use efficiency, while drought-tolerant varieties and in-situ moisture-conservation practices delivered measurable yield and water-saving benefits. Institutional mechanisms such as Village Climate Risk Management Committees, Custom Hiring Centres, and seed and fodder banks provided the governance structure needed to sustain these gains at the community level. The experience gained through the TDC-NICRA interventions in Bundelkhand offers a replicable model of climate-resilient agriculture and water management that could inform larger-scale programmes for combating heat and drought vulnerability in similarly semi-arid, rainfed regions of India.

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