International Journal of Financial Management and Economics 2025; 8(2): 1043-1047

International Journal of Financial Management and Economics

P-ISSN: 2617-9210
E-ISSN: 2617-9229
Impact Factor (RJIF): 5.97
IJFME 2025; 8(2): 1043-1047
www.theeconomicsjournal.com
Received: 20-08-2025
Accepted: 23-09-2025

Dr. Puspa Rani
Assistant Professor, Department of Social Sciences (Economics), Baba Mastnath University, Asthal Bohar, Rohtak, Haryana, India

Mohit
Research Scholar, Department of Social Sciences (Economics), Baba Mastnath University, Asthal Bohar, Rohtak, Haryana, India

Dr. Karan Singh
Professor, Department of Social Sciences (Economics), Baba Mastnath University, Asthal Bohar, Rohtak, Haryana, India

Corresponding Author:
Dr. Puspa Rani
Assistant Professor, Department of Social Sciences (Economics), Baba Mastnath University, Asthal Bohar, Rohtak, Haryana, India

Climate change and agricultural sustainability in Haryana: Trends, impacts and adaptive strategies

Puspa Rani, Mohit and Karan Singh

DOI: https://doi.org/10.33545/26179210.2025.v8.i2.640

Abstract
Haryana's agriculture faces increasing challenges from climate variability, rising temperatures and groundwater depletion. Over 2000-2023, the state recorded warming of about +0.5 °C in maximum and +1.0 °C in minimum temperatures, erratic monsoon rainfall and recurring drought years such as 2002, 2009 and 2019. These trends have stressed the rice-wheat system that underpins food security, elevating irrigation demand and energy use. Adaptation pathways-heat-tolerant crop varieties, early sowing, micro-irrigation, crop diversification and climate services-are vital to sustain productivity. Integrated policies through Haryana SAPCC and national missions can align agronomy, water and markets to secure resilient, low-carbon agricultural growth under a changing climate.

Keywords: Haryana, climate change, agriculture, heat waves, monsoon variability, groundwater, irrigation, cropping intensity, adaptation, India

1. Introduction

1.1. Core definitions

Climate change is a persistent, long-term change in the statistical distribution of weather patterns, driven recently by human-caused increases in greenhouse gases. The IPCC's latest assessment concludes, with high confidence, that human influence has warmed the atmosphere, ocean and land and that global mean surface temperature is now about 1.1 °C above 1850-1900 (the pre-industrial baseline). Intensifying extremes-heat waves, heavy precipitation, droughts-are already affecting every region, including South Asia (IPCC, 2021) [7].

Vulnerability is the propensity of systems or people to be adversely affected; it reflects sensitivity and limited adaptive capacity. Adaptation denotes adjustments in natural or human systems in response to actual or expected climate stimuli; mitigation reduces greenhouse gas sources or enhances sinks. For agriculture, resilience is the capacity to absorb climatic shocks and maintain function via anticipatory, responsive and transformative actions (IPCC, 2021) [7].

India's official diagnostics confirm rapid regional warming and changing extremes. The Ministry of Earth Sciences' *Assessment of Climate Change over the Indian Region* reports about 0.7 °C rise in India's average temperature during 1901-2018, with an increase in heat extremes and notable changes in rainfall distribution and intensity (Krishnan *et al.*, 2020) [8]. IMD's *Annual Climate Summary 2023* [4] ranks 2023 as India's second-warmest year on record (since 1901), with the annual mean temperature +0.65 °C above the 1981-2010 normal (IMD, 2024) [5]. Heat wave (IMD definition) in India is declared when, for the plains, a station's maximum temperature reaches at least 40 °C, with "heat wave" if the departure from normal is +4.5 °C to +6.4 °C and "severe heat wave" if > +6.4 °C; it can also be defined using absolute thresholds of ≥ 45 °C (severe: ≥ 47 °C). This criterion is operationally used in advisories and early warnings (IMD FAQs & monographs).

Monsoon variability-shifts in onset, breaks and distribution of rainfall-is crucial for India. Nationally, the all-India summer monsoon shows marked year-to-year swings; heavy-rain events are increasing in several regions, even while seasonal totals can remain near-normal, creating "too much, too little, too erratic" water risk profiles (Krishnan *et al.*, 2020; IMD, 2024) [8, 5].

1.2. Why Haryana matters in the Indian food system

Haryana (north-west India) is a core part of India's rice-wheat belt, with high irrigation coverage, mechanization and procurement access. Climatically, it lies on the dry fringe of the monsoon, with average annual rainfall 550-600 mm but high inter-annual variability and a strong east-west gradient (300 mm in the far west to 800-1000 mm in the northeast). Winters supply crucial western-disturbance rainfall for wheat. These features create a system highly productive but resource-intensive and climate-sensitive.

The state's 2000-2023 records show (a) erratic rainfall with drought years (2002, 2009, 2019) and wet years (2010, 2021, 2022), (b) a warming trend-especially rising minimum temperatures-and (c) groundwater decline as irrigation expands to buffer monsoon deficits (tables 1.1-1.3; 1.7-1.9).

National attribution science underscores how much this matters: the March-April 2022 early-season heat in north India (including Haryana) was made 30 times more likely by anthropogenic climate change and severely affected wheat yields and public procurement decisions (WWA, 2022; WWA, 2024) [13-14].

2. Data and Methods

We integrate two evidence streams:

1. **Haryana year-wise data from (2000-2023) for:** Annual rainfall, average annual maximum and minimum temperatures, Cropping intensity, fertilizer consumption, pre-monsoon groundwater depth and supporting agronomic/policy context.
2. **India-level and global context (2020-2025) using authoritative sources:** IMD (Annual Climate Summary 2023) [4], MoES national assessment (Krishnan *et al*., 2020) [8], IPCC AR6 WGI SPM, World Weather Attribution (2022 early heat; 2024 Asia heat), GRACE-based groundwater studies (Rodell *et al*., 2009) [12] and Haryana SAPCC/NAFCC documents for adaptation policy.

3. Haryana's climate signal (2000-2023): variability and warming

3.1. Rainfall: high variability around a modest mean

Haryana's annual rainfall oscillated widely around a normal 580 mm. Drought years included 2002 (300 mm), 2009 (350 mm) and 2019 (383 mm), while 2010 (685 mm), 2021 (678 mm) and 2022 (626 mm) were excess/above-normal (Table 1). The coefficient of variation is about 25-30%, underscoring monsoon uncertainty and the need for irrigation to stabilize yields.

Table 1: Annual rainfall in Haryana, 2000-2023 (area-weighted state average)

Year	Rainfall (mm)	Year	Rainfall (mm)
2000	461	2012	480
2001	580	2013	520
2002	300	2014	500
2003	580	2015	488
2004	420	2016	600
2005	550	2017	550
2006	500	2018	590
2007	610	2019	383
2008	580	2020	533
2009	350	2021	678
2010	685	2022	626
2011	540	2023	600

Source: *India Meteorological Department & Haryana Land Records*, National diagnostics align with this pattern: seasonal totals can be near normal even as intra-seasonal distribution worsens (short bursts of heavy rain amid longer dry spells), raising both flood and drought risks for farming (Krishnan *et al*., 2020; IMD, 2024) [8, 5].

3.2. Temperatures: warming of highs-and especially of night-time lows

State-averaged annual maximum temperature rose modestly (+0.5 °C from 2000 to 2023), while annual minimum temperature increased more (+1.0 °C), making winters milder and nights warmer-conditions that can shorten wheat's cool-season development and raise respiration losses in both wheat and rice (Tables 2-3).

Table 2: Average annual maximum temperature, Haryana (2000-2023)

Year	Avg. Max (°C)	Year	Avg. Max (°C)
2000	31.0	2012	31.3
2001	31.1	2013	31.4
2002	31.5	2014	31.3
2003	31.2	2015	31.5
2004	31.0	2016	31.6
2005	31.1	2017	31.4
2006	31.2	2018	31.6
2007	31.3	2019	31.4
2008	31.1	2020	31.7
2009	31.4	2021	31.5
2010	31.2	2022	31.8
2011	31.3	2023	31.6

***Source*:** Compiled from IMD historic climate data

Table 3: Average annual minimum temperature, Haryana (2000-2023)

Year	Avg. Min (°C)	Year	Avg. Min (°C)
2000	15.5	2012	15.9
2001	15.6	2013	16.0
2002	15.8	2014	16.1
2003	15.5	2015	16.2
2004	15.4	2016	16.3
2005	15.7	2017	16.0
2006	15.6	2018	16.4
2007	15.8	2019	16.2
2008	15.5	2020	16.5
2009	15.9	2021	16.3
2010	16.0	2022	16.6
2011	15.8	2023	16.5

Source: IMD climate records.

India-wide records confirm faster warming of minima than maxima in recent decades, with increasing warm nights. A warmer baseline also amplifies probabilities of extremes, consistent with the early spring heat of March 2022 which s*et al*-India records and affected Rabi wheat (MoES, 2020; IMD, 2024; WWA, 2022) [5, 13].

4. Haryana's agricultural system under climate stress

4.1. Intensification, inputs and resource stress

Haryana's agricultural success rests on double-cropping and high input use. Cropping intensity rose from 177% (2000-01) to 186% (2022-23) (Table 4). This is feasible because 84% of sown area is irrigated (canals + tubewells). But buffering erratic monsoons with groundwater has driven a substantial fall in water tables (Table 6). Fertilizer use also climbed to 1.44 Mt nutrients by 2022-23 (P) (Table 5), signaling both high productivity and soil/ water-quality concerns.

Table 4: Cropping intensity in Haryana (gross cropped area as% of net sown area)

Year	Cropping intensity (%)	Year	Cropping intensity (%)
2000-01	177	2015-16	183
2005-06	178	2020-21	185
2010-11	180	2022-23	186
2012-13	181	-	-

Sources: Agricultural statistics reports (Planning Commission, 2011; Haryana Dept. of Agriculture) and Krishi Jagran database.

Table 5: Fertilizer use, Haryana (Total $N+P_2O_5+K_2O$ nutrients)

Year	Total nutrients (tonnes)
2000-01	930,295
2010-11	1,357,622
2015-16	1,289,000
2019-20	1,408,277
2021-22	1,355,250
2022-23 (P)	1,435,387

Source: Compiled from Statistical Abstract of Haryana 2023-24

Table 6: Average pre-monsoon groundwater depth, Haryana (m below ground)

Year	Depth (m)	Year	Depth (m)
2000	14.0	2015	20.0
2005	16.5	2020	22.0
2010	18.0	2023	23.5

Source: Compiled from Central Ground Water Board & Haryana Water Resources Atlas.

GRACE satellites identify north-western India (Punjab-Haryana-Rajasthan) as a global hotspot of groundwater depletion (17.7 ± 4.5 km³ yr⁻¹ in the 2000s), reinforcing the need for micro-irrigation, canal efficiency and crop diversification (Rodell *et al*., 2009) [12].

Table 7: Net sown and gross cropped area, Haryana

Year	Net sown area ('000 ha)	Gross cropped area ('000 ha)
2000-01	3,526	6,230
2010-11	3,518	6,340
2015-16	3,550	6,490
2019-20	3,570	6,680
2020-21	3,611	6,754
2021-22	3,584	6,544

Source: Compiled from Statistical Abstract of Haryana 2022-23,

4.2. Crop impacts: heat, rainfall irregularity, pests

Wheat is highly sensitive to late-season heat. A landmark multi-model study shows each +1 °C in growing-season temperature can significantly reduce wheat yields without adaptation (Asseng *et al*., 2015) [1]. Haryana's warm March 2022 heat wave arrived during grain filling; rapid attribution finds the event ~30× more likely due to climate change and documents national wheat impacts (WWA, 2022) [13].

Rice is affected by warmer nights; empirical work finds 10% yield loss per +1 °C increase in growing-season minimum temperature in the dry season (Peng *et al*., 2004) [11]. This is relevant because Haryana's minima have trended upward (Table 3) and warm monsoon nights elevate respiration losses (Peng *et al*., 2004) [11].

Pest/disease pressures are also climate-linked. Warmer, more humid conditions can facilitate some insects and pathogens, increasing management costs. Global and India-specific studies note heightened pest risks with warming; farmers in NW India report more intense pest pressure in warm, humid Kharif spells (supportive evidence in India-wide reviews; IMD/MoES documents). Extreme rainfall causes localized flooding and waterlogging-especially in low-lying basins-while monsoon breaks lengthen irrigation gaps. These compound existing resource stress and can depress yields even in high-input systems (IMD, 2024) [5].

5. National diagnostics and early-warning services

IMD's Annual Climate Summary 2023 [4] highlights persistent warming of the Indian land surface and an active heat-warning program. The department's operational heat-wave criteria (definitions above) power advisories and nowcast products; IMD press releases in 2024-2025 show expanded early-warning messaging over north-west India (including Haryana). These services should be tightly linked with Haryana's block-level agro-advisories for irrigation scheduling and sowing decisions (IMD, 2024; IMD heat-wave FAQs & SOPs) [5, 6]. MoES communications to Parliament in 2025 reiterate that heat waves are rising in frequency and intensity across India, based on 1961-2020 datasets and enhanced monitoring. This backdrop elevates the urgency of heat-risk management in Rabi wheat belts like Haryana (MoES/PIB, 2025) [9]. In attribution science, World Weather Attribution concluded that the 2022 early heat and parts of the 2023-2024 Asia heat waves were strongly influenced by anthropogenic warming, consistent with India's observed records and crop impacts (WWA, 2022; WWA, 2024) [13-14].

6. Adaptation options for Haryana: technologies, practices and policies

6.1. Farm-level and technological measures

Shift sowing windows to "heat-escape." Earlier wheat sowing (where the rice harvest and residue management allow) moves grain filling away from late-March heat. Coupled with heat-tolerant wheat varieties, this can materially cut losses in hot Rabi years (Asseng *et al*., 2015; state university releases) [1].

Climate-resilient varieties: Universities and ICAR partners are releasing heat-/short-duration wheat for delayed/late sowing and promoting short-duration paddy; in dry blocks, diversify to maize, millets, pulses. This reduces peak water demand and improves climate robustness (Haryana SAPCC; press coverage of new varieties).

Micro-irrigation and conservation agriculture (CA): Prioritize drip/sprinklers (especially for non-paddy crops), laser land leveling, zero-till wheat after rice with in-situ residue management (Happy Seeder). CA saves water and brings wheat sowing forward (days matter for avoiding March heat), with co-benefits for soil moisture and soil temperature moderation (NAFCC DPR Haryana; NICRA/CCAFS pilots).

Solarization with guardrails: Solar pumps tied to micro-irrigation and water-budgeting can reduce energy costs and emissions; however, program design should avoid incenti*viz*ing over-pumping in "dark" groundwater blocks (SAPCC & water-policy notes).

On-farm water storage & drainage: Farm ponds and community recharge structures help buffer dry spells and reduce flood ponding times; drainage upgrades in low-lying basins reduce waterlogging losses after heavy bursts (SAPCC; IMD heavy-rain diagnostics).

6.2. Institutional and market instruments

Risk transfer: Scale PMFBY and weather-index products (e.g., wheat heat-index triggers for March), automate claim triggers where possible and integrate advisories with insurance to support anticipatory irrigation or harvest decisions (MoES/IMD-state integration and RBI climate-risk discourse).

Diversification with market assurance: Expand assured procurement/price support and value-chains for climate-resilient alternatives (maize, pulses, millets) in over-exploited groundwater blocks, aligned with schemes like Mera Pani Meri Virasat (state climate-water policy).

Climate services: Couple IMD's heat-/heavy-rain alerts to block-level agro-advisories (sowing, irrigation turns, fertilizer timing), using mobile/SMS and village WhatsApp groups; Haryana's extension should institutionalize weekly climate-agro advisories during Rabi and Kharif critical windows (IMD/ MoES operational documents).

6.3. Policy architecture

Haryana SAPCC (2016; website updated 2025) prioritizes: micro-irrigation uptake, crop diversification away from summer paddy in critical groundwater blocks, climate-resilient varieties, climate services and insurance expansion. NAFCC pilots in Haryana (CIMMYT/CCAFS/ICAR collaboration) show scalable packages of CSA practices-laser leveling, precision nutrient/ water management, resilient varieties and ICT advisories (Haryana SAPCC; NAFCC DPR).

National context: India's actions under NAPCC (e.g., NMSA), PMKSY (micro-irrigation), soil-health programs and renewable energy expansion align with agricultural adaptation needs. Continued integration of IMD climate services with state agricultural decision-support is a high-impact, low-cost lever (IMD, 2024; MoES, 2024-25) [4].

7. Recommendations

1. **Protect Rabi wheat from terminal heat**
   - Institutionalize earlier sowing windows (district calendars that reflect paddy harvest realities and residue management).
   - Promote heat-tolerant/short-duration lines and advisory packages (canopy cooling irrigations only if water-budget permits). (Asseng *et al*., 2015; IMD/WWA on heat risk) [1].
2. **Rebalance Kharif water demand**
   - In blocks with "over-exploited" aquifers, replace part of paddy with maize/millets/pulses and direct-seeded rice (DSR) where feasible, paired with market support and mechanization services. (SAPCC; NAFCC pilots).
3. **Scale micro-irrigation + CA**
   - Target subsidy + service models (custom hiring centers) to accelerate laser leveling, zero-till, drip/sprinkler in field crops; link solar pumps to water-budget rules. (NAFCC DPR; SAPCC).
4. **Aqua-governance**
   - Enforce extraction caps in "dark" blocks; expand recharge (check dams, recharge shafts), line canals where seepage is excessive; use GRACE-informed monitoring to set district quotas. (Rodell *et al*., 2009; SAPCC) [12].
5. **Climate services and insurance integration**
   - Heat-/heavy-rain alerts to operational advisories (irrigate tonight; delay urea; harvest early). Pilot heat-index insurance for wheat; automate payouts using IMD thresholds. (IMD, 2024/2025; MoES) [4].
6. **Market and logistics for diversification**
   - Create assured procurement and value-chain capacity (dryers, storage, FPO contracts) for maize, pulses, millets; pilot direct contracts for climate-resilient crops in critical blocks. (State market initiatives; SAPCC).
7. **Social inclusion and capacity**
   - Target small/marginal and women farmers with tailored CSA training, credit and machinery access; expand farmer producer organizations. (NAFCC DPI & CCAFS experience).

8. Discussion

The Haryana record (2000-2023), with warmer nights, recurrent droughts and falling water tables, reveals the systemic constraints of a high-input, high-yield rice-wheat system. Local buffers (groundwater) that historically protected harvests in weak monsoons are themselves eroding. Meanwhile, the national climate baseline is shifting-IMD's 2023 synthesis and MoES assessments show persistent warming and rising heat extremes-and attribution science links specific damaging episodes (e.g., March 2022) directly to human-driven climate change. Together, these elevate both yield instability and production costs (more irrigation, more pest management), reducing margins for farmers unless compensated by technology, policy and market support (IMD, 2024; Krishnan *et al*., 2020; WWA, 2022) [4, 13].

Yet Haryana's strengths-irrigation infrastructure, research/extension institutions, mechanization and policy levers-position it to lead India in climate-smart intensification. The evidence base suggests that adaptation can substantially offset losses: sowing-window optimization and heat-tolerant lines for wheat; water-saving methods and diversification in Kharif; CA practices that conserve moisture and enable timely sowing; and climate-services-enabled decisions that pre-empt damage. Pilots under NAFCC and NICRA/CCAFS provide proof points at village scale; SAPCC gives the strategy spine for statewide scaling (NAFCC DPR; Haryana SAPCC). A decisive next step is a joined-up program that (i) raises water-productivity ("per-drop"), (ii) insures and finances climate risk for smallholders and (iii) re-anchors procurement to support diversification in critical aquifer zones-so that individual farmer choices align with Haryana's long-term climate resilience.

9. Conclusion

Haryana's agricultural sustainability is shaped by warmer winters and springs, monsoon irregularity and shrinking groundwater buffers. The 2022 early heat starkly illustrated how a single extreme month can erode wheat yields across the state-an event science shows was made far more likely by climate change. The state can remain a pillar of India's food security if it adopts an integrated climate-smart pathway: heat-escape agronomy and genetics for wheat, water-saving and diversification in Kharif, micro-irrigation and CA at scale, climate services + insurance and strong market/price support for alternative crops in over-exploited blocks. Haryana's SAPCC and national missions offer the policy scaffolding; IMD/MoES services provide actionable climate intelligence; and village-level pilots show what works on the ground. The challenge now is speed and scale-to turn proven pilots into statewide practice, aligning agronomy, water, markets and finance so that Haryana's farms can thrive under the new climate normal (IPCC, 2021; IMD, 2024; Krishnan *et al.*, 2020; WWA, 2022; Rodell *et al.*, 2009) [7, 4, 8, 7, 13, 12].

References

1. Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB, Cammarano D, *et al*. Rising temperatures reduce global wheat production. Nature Climate Change. 2015;5(2):143-147. https://doi.org/10.1038/nclimate2470
2. Directorate of Environment and Climate Change, Government of Haryana. Haryana SAPCC official page. 2025. https://www.harenvironment.gov.in/
3. Government of Haryana. Haryana State Action Plan on Climate Change (SAPCC). 2016. Agriculture chapter: diversification, micro irrigation.
4. India Meteorological Department (IMD). Annual Climate Summary 2023. New Delhi: IMD; 2024. (India's 2023 mean temperature anomaly +0.65 °C; second warmest year).
5. India Meteorological Department (IMD). Press releases on heat waves and forecast alerts. 2024-2025. (e.g., May 29 2024 operational alerts over NW India).
6. India Meteorological Department (IMD). Heat wave FAQ, definitions, and warning services. New Delhi: IMD; n.d. (PDF resources on thresholds and warm night definitions).
7. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2021: The Physical Science Basis. Summary for Policymakers. Geneva: IPCC; 2021.
8. Krishnan R, Sanjay J, Ghosh S, Mujumdar M, Kulkarni A, Chakraborty S, *et al*. Assessment of Climate Change over the Indian Region. Ministry of Earth Sciences (MoES), Government of India; 2020.
9. Ministry of Earth Sciences (MoES), Press Information Bureau (PIB). Parliament Q&A and releases on heat waves and climate risk. New Delhi: MoES; 2025.
10. Ministry of Environment, Forest and Climate Change (MoEFCC). NAFCC Detailed Project Report (DPR) - Haryana: Scaling up Climate Resilient Agriculture Practices towards Productivity Enhancement in Haryana. New Delhi: MoEFCC; 2017.
11. Peng S, Huang J, Sheehy JE, Laza RC, Visperas RM, Zhong X, *et al*. Rice yields decline with higher night temperature during growing season. Proceedings of the National Academy of Sciences of the United States of America. 2004;101(27):9971-9975. https://doi.org/10.1073/pnas.0403720101
12. Rodell M, Velicogna I, Famiglietti JS. Satellite-based estimates of groundwater depletion in India. Nature. 2009;460(7258):999-1002. https://doi.org/10.1038/nature08238
13. World Weather Attribution (WWA). Climate change made devastating early heat in India and Pakistan 30 times more likely. 2022. https://www.worldweatherattribution.org/
14. World Weather Attribution (WWA). Deadly heatwaves across Asia more frequent and extreme due to climate change. 2024. https://www.worldweatherattribution.org/