Wheat Under Stress: Climate Change, Rising Heat, and Adaptation Pathways in India's Major Wheat-Growing States

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Executive Summary

This report assesses the impacts of climate change on wheat cultivation across India's major producing states, combining scientific analysis with field insights from Gujarat and Punjab. It finds that rising temperatures, particularly warmer winters, increasing night-time temperatures, and more frequent terminal heat events are already disrupting wheat growth cycles, reducing yields, and affecting grain quality. Critical growth stages such as flowering and grain filling are especially vulnerable, with heat stress shortening crop duration and leading to shrivelled grains and lower productivity.

Climate variability is also intensifying risks through unseasonal rainfall, especially during harvest, contributing to crop damage, storage losses, and declining grain quality. Evidence shows that minimum temperatures are rising faster than maximum temperatures across major wheat-growing regions, increasing night-time heat stress and accelerating crop respiration losses. These trends are most pronounced in the Indo-Gangetic Plain, India's primary wheat belt.

Farm-level findings reveal consistent impacts across diverse geographies: poor germination, reduced tillering, early maturity, and increased pest pressures. While both smallholder farmers in Gujarat and larger producers in Punjab experience similar climatic stresses, their adaptive capacity differs significantly due to variations in access to irrigation, finance, and institutional support.

Farmers are responding through a range of adaptation strategies, including adjusting sowing dates, adopting short-duration and heat-tolerant varieties, improving water and nutrient management, and enhancing storage practices. However, these responses remain incremental and constrained by resource and knowledge gaps.

The report concludes that without coordinated and scaled adaptation such as climate-informed advisories, improved irrigation systems, and development of heat-resilient crop varieties, climate change poses a significant threat to India's wheat production and national food security. Strengthening resilience will require integrating scientific innovation with local knowledge and targeted institutional support.

1. Background

Wheat occupies a central place in our agricultural economy and food systems. India, the second-largest wheat producer in the world, contributes approximately 14% of global production of the grain, amounting to around 107.59 million metric tons annually. Wheat along with rice contribute three-quarters of the country's cereal products, which comprise 60-70% of our per capita calorie consumption (Davis et al., 2019).

The Indo-Gangetic Plains, spanning Uttar Pradesh, Punjab, Haryana, and Madhya Pradesh, are the primary breadbasket for this crop, which is sown during the rabi season (October–December) and harvested between February and April. Beyond its nutritional value as a rich source of carbohydrates, protein, fibre, and micronutrients, wheat anchors rural livelihoods, sustains allied industries such as flour milling and food processing, and contributes significantly to India's agricultural GDP and export earnings.

However, wheat production is affected by climate change. Rising temperatures, erratic monsoon patterns, and increasing frequency of extreme weather events are disrupting wheat cultivation cycles, reducing yields, and exacerbating ecological stress on already fragile agro-ecosystems.[1] The 2022 heatwave, made 30 times more likely by climate change, resulted in a 10%–35% yield decline in Haryana, Punjab, and Uttar Pradesh. Across India, the heat wave caused wheat production to plummet by 3 million metric tons, and the states of Punjab and Haryana reported stunted grain yields as well. This led the government to halt wheat exports to manage domestic food security.

Studies project wheat production losses of 10–40% in India by the end of the century under current practices. On the other hand, India's population is projected to reach 1.7 billion by 2050 which will necessitate raising wheat yields from the current average of 2.6 tonnes/hectares to 3.5 tonnes/hectares within the next 25 years. These projections raise a number of concerns especially in terms of food and livelihood security particularly for the vast majority of small and marginal farmers who are disproportionately affected by climate change impacts.

This study addresses these intersecting challenges by investigating how climate change impacts different stages of wheat cultivation from sowing till harvest in the major producing states of India, focusing on farm-level vulnerabilities and adaptation pathways. It adopts a qualitative approach to generate a comprehensive understanding of risks and resilience pathways. By situating wheat within the broader nexus of climate impacts, food security, farmer incomes, and ecological sustainability, this work seeks to contribute actionable insights for practice, and future research.

2. Climate Change Impacts on Wheat Production Across Major Wheat-Growing Regions of India: A Review of Literature

Wheat is a central component of India's food security system and one of the most climate-sensitive cereal crops grown in the country. Recent evidence suggests that productivity growth of both wheat and rice has slowed significantly in recent decades, raising serious concerns for national and global food security.[1] Climatic factors, especially temperature, play a dominant role in determining wheat growth, phenology and yield. Even moderate increases in temperature can cause physiological injury, leaf senescence, and abortion of reproductive structures, thereby reducing grain number, grain filling duration and crop maturity.[2]

Current observations confirm that winters in northern India are shortening and February–March warming is becoming common, increasing the risk of terminal heat stress on wheat. These temperature changes coincide with the reproductive and grain filling stages of wheat and are already affecting production in major wheat-growing regions.[2]

2.1. Regional Impacts of Climate Change on Wheat Cultivation

The Indo-Gangetic Plain, including Punjab, Haryana, Uttar Pradesh and Bihar, produces the majority of India's wheat. Regional climate and crop modelling studies project that direct climate impacts (temperature and precipitation changes) will reduce wheat yields by 1–8% in this region.[3] However, indirect impacts, especially reduced irrigation water availability, are expected to be far more severe, potentially causing yield losses of 4–36% by mid-century under high-emission scenarios.[3] Crop simulation modelling using Info Crop-WHEAT further projects yield reductions of 6–23% by 2050 and 15–25% by 2080.[4] Spatial variation is significant: wheat yields in Punjab and Haryana are projected to decline by 8–22%, while Uttar Pradesh could experience reductions of about 24% by mid-century.[4] Lobell et al. (2012) reported wheat yield reductions of up to 20% in certain pockets of the IGP, due to a 2°C increase in seasonal temperature.[5]

Central, Eastern and Western India: Long-term climate analysis across 29 states shows that rising seasonal temperatures during the Rabi season have negatively affected nearly 99.85% of India's wheat area, while precipitation variability has affected 56.26%.[6] February temperatures and March rainfall exert the strongest negative influence on yields, explaining up to 78% of yield variability.[6]

District-level evidence shows strong negative relationships between wheat yield and both minimum and maximum temperatures in Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh and Maharashtra.[6] In Gujarat, diurnal fluctuations in temperatures particularly in November and December since 2000 have been associated with declining wheat productivity even in timely sown crops.[7] A substantial area in Central and Eastern India is under late and very late-sown conditions (until the third week of December), exposing the crop to heat stress in the grain filling period results in considerable yield reduction.[4]

2.3. Temperature Sensitivity at Different Stages of Wheat Production

Temperature is the single most important environmental variable controlling wheat phenology, growth, and yield. Scientists often describe wheat cultivation in India as "a gamble in temperature".[8] Observed warming patterns show rising minimum temperature occurring faster than maximum temperature across India's wheat belt.

Across major wheat-growing areas, minimum temperature is rising faster than maximum temperature, increasing at about 0.32 °C per decade compared to 0.28 °C per decade. Even small temperature increases have large effects: mean wheat yields for the period 1980–2011 declined by 7% (204 kg ha−1) for a 1 ◦C rise in Tn. During the post-anthesis period in February, nearly 79.4% of wheat-growing regions show significant warming.[9]

Wheat yield is projected to be reduced in areas with mean seasonal maximum and minimum temperatures in excess of 27 and 13°C, respectively.[4] Wheat crops exposed to temperatures >34°C have significantly low yields because of accelerated senescence. The optimum temperature range is 17 to 23°C during the entire growth period, with maximum temperatures not exceeding 37°C. Temperature optima are ~22°C for vegetative development and 21°C for reproductive development, while ~35.4°C is the maximum limit for grain filling. [4]

Wheat growth includes emergence, tillering, flowering, grain filling and maturity. Climate change affects each stage differently.

Germination and Emergence: Germination occurs optimally at 20–25 °C. Higher temperatures (30–35 °C) significantly reduce germination and seedling vigour. Heat-tolerant genotypes such as WH 730, WH 1123 and HD 2967 perform better under early heat stress conditions.[10]

Vegetative Phase (Tillering): High air temperature reduces tiller formation, grain number and biomass production.[11] Warmer conditions shorten the crop cycle, reducing radiation interception and total biomass.[12]

Flowering (Antithesis): Exposure to continual Tn exceeding 12 ◦C for 6 days and terminal heat stress with Tx exceeding 34 ◦C for 7 days during post-anthesis period are the other thermal constraints in achieving high productivity.[9] Similarly, Tashiro and Wardlaw (1990) found that temperatures of 36 ◦C during the day and 31 ◦C at night just before anthesis resulted in many sterile grains.[9] A few days later (after 50% anthesis), when half of the ears in a population have flowered, a temperature of 27 ◦C also results in a high proportion of sterile grains.[9] Temperatures >31°C just before anthesis induce pollen sterility and reduced grain number and yield.[4] Anthesis is one of the most temperature-sensitive stages. The optimal minimum temperature range is 18–24 °C. [4]

Grain Filling: Grain filling is particularly vulnerable to terminal heat stress occurring in late February and March. Terminal heat stress occurring in late February and March shortens the grain filling period and reduces grain weight.[13] High night temperatures increase respiration losses, reducing assimilate availability.[14]

Maturity: The maturity stage is the most heat-sensitive stage.[15] High temperature accelerates senescence and shortens crop duration, producing smaller and lower-quality.[5] Yield reductions of about 2.26% per unit rise in terminal stage temperature have been reported in the north Indian plains. [16]

Post-harvest Impacts: Rising temperatures further accelerate biochemical reactions in grains, causing faster spoilage. Excess humidity after harvest fosters fungal growth and pest infestations. Together, these factors contribute to major storage issues like mold, insect activity, weight loss, discoloration, and contamination, increasing post-harvest losses. [21]

Table 1: Climate Impacts on Different Stages of Wheat Cultivation

Growth Stage	Climate Stress	Observed Effect	Yield Impact
Germination	Early season warming	Reduced germination and seed vigour	Poor crop stand
Tillering	Warm winters	Reduced tiller number and biomass for fodder	Lower yield potential
Anthesis	Heat >31 degrees Celsius	Pollen sterility	Reduced grain number
Grain Filling	Sudden warming in Feb and March	Shortened grain filling period and grain weight	Shrivelled grains
Maturity	Terminal Heat	Accelerated senescence	Poor quality and lower yield

2.4. Sowing Time Adjustments: The Primary Adaptation Response

Sowing dates strongly influence exposure to heat stress. Delayed sowing in Punjab from 25 October to 10 December reduced yield by approximately 19%.[17] Late-sown crops experience flowering and grain filling in April heat, causing forced maturity and shrivelled grains. The high temperatures in April, combined with hot western winds, accelerate maturity and hinder the proper production and translocation of food to the developing grains. This leads to immature and shrivelled grains, resulting in a lower thousand-grain weight in late-sown crops.[18]

Optimal sowing windows across states:

- **Punjab:** 20th October to 9th December. Maximum yield is obtained from sowing on 24th November. [19]
- **Madhya Pradesh:** mid-November to late November highest grain yield (55.88 q/ha) was recorded for the November 25 sowing date. [18]
- **Uttar Pradesh:** Mid-October to early December with maximum yield obtained around 15 November. [20]
- **Gujarat:** November. The first fortnight of November (around 1–15 November) is considered the optimal period for high yields.

Timely sowing allows vegetative growth under favourable winter temperatures and reproductive development during cooler January conditions. Adjusting sowing dates is therefore considered one of the most practical climate adaptation strategies.[4]

2.5. Optimum Temperature Requirements at Different stages

In the IGP region wheat is cultivated between October to April. It has a cycle length of 128-158 days depending on the variety.[2] A wheat plant requires medium (50-60%) humidity for growth, but requires less humidity at the time of maturity.[2] Rainfall has limited influence on wheat cultivation since >85% of wheat area is irrigated.[4] The Ideal sowing temperature is 18-22 degrees. The optimum temperature range for ideal germination of wheat seed is 20-25°C. However, the seed can germinate in the temperature range of 3.5°-35°C. Germination happens within 5-10 days of sowing.[2]

Table 2: Optimum Monthly Temperature Requirements for Wheat Cultivation

Month	Maximum	Minimum
December	20–23 ℃	5–9 ℃
January	17–20 ℃	3– 8 ℃
February	19–25 ℃	5–11 ℃
March	25–30 ℃	10–15 ℃

Source: Kaur.P. et al. (2015). Agrometeorology of wheat in Punjab state of India. *Punjab Agricultural University, Ludhiana*, 85.

Table 3: Temperature Requirements at Different stages of Wheat Cultivation

	Crop Stage	**Maximum Temperature**	**Minimum Temperature**	**Duration (days)**	**Month**
Vegetative Growth	**Crown Root Initiation (CRI)**	21-29 °C	6-13 °C	25-35	December
	Tillering stage	20-29 °C	7-16 °C	30-35	January
Reproductive Growth	**Booting Stage**	18-28 °C	6-9 °C	10-17	1st fortnight of February
	Anthesis Stage	19-22 °C	7-10 °C	7-15	2nd fortnight of Feb
	Milking Stage	20-24 °C	7-9 °C	15-30	First Fortnight of March
	Hard Dough Stage	20-25 °C	8-12 °C	7-15	3rd week of March
Maturity	**Physiological Maturity**	22-24 °C	8-10 °C	5-10	4th week of March

Source: Kaur.P. et al. (2015). Agrometeorology of wheat in Punjab state of India. *Punjab Agricultural University, Ludhiana*, 85.

Note: The above thresholds are based on research on four cultivars namely PBW-550, DBW-17, PBW-343 and PBW 621 during Rabi 2009-10 to Rabi 2012-13. The tentative months corresponding to each stage is based on the sowing in the 2nd fortnight of November. The exact thresholds may vary slightly across genotypes. However, wheat temperature thresholds do not fundamentally change by state as the crop biology is the same. States like Gujarat are hotter than Punjab and might reach the optimum temperature for sowing only in November. Crop calendars thus have to be adjusted based on local climatic conditions.

3. Research Objectives

Despite strong evidence, several gaps remain. Most studies focus on biophysical yield impacts, with limited integration of socioeconomic dimensions such as farmer adaptation capacity and vulnerabilities. The current research aims to bridge this gap by holistically examining the impacts of climate change on wheat cultivation and agricultural livelihoods and identify pathways of building climate resilience in this sector. It further examines the role of climatological variables in affecting wheat yield in the major producing states of Uttar Pradesh, Madhya Pradesh, Punjab, Haryana and Gujarat.

The study addresses the following questions:

1. What has been the trend in temperature and wheat yield in major producing states of India?
2. How does rising temperatures in the winter months affect different stages of wheat cultivation?
3. What socio-economic conditions make farmers particularly vulnerable to climate impacts?
4. What pathways of adaptation are farmers adopting to safeguard their yields from weather aberrations?

4. Methodology

In order to assess the impact of meteorological variables on crop yield, a trend analysis on maximum, minimum and average temperatures have been conducted. This analysis utilized temperature data from the ERA5 dataset and rainfall data from the Indian Meteorological Department. Correlation and regression analysis have been done to connect the climatic factors with crop yield across 5 states of India between 2010 and 2025.

The top 10 wheat producing states of Uttar Pradesh, Madhya Pradesh, Punjab, Haryana and Gujarat have been selected for the analysis based on the volume of their production.

Table 4: Wheat Production in Major Producing States of India

State	Production in 000 tonnes
Uttar Pradesh	35,652.86
Madhya Pradesh	24,509.10
Punjab	17,993.21
Haryana	11,399.88
Gujarat	3,867.17

Source: Agriculture and Processed Food Products Export Development Authority

Two qualitative case studies on Punjab, Haryana and Gujarat have been conducted to explore the implications of climate change on different stages of wheat cultivation. The case studies will also capture localized adaptation strategies adopted by different stakeholders to cope with climate impacts. By creating a repository of local practices aimed at building climate resilience in wheat production, the report would facilitate knowledge sharing and learnings across states.

The case studies involved qualitative interviews and focused group discussions with multiple stakeholders including farmers, civil society organizations and agriculture scientists. Punjab and Gujarat were chosen to account for geographical and socio-economic diversity. While big landholders in Punjab produce and export wheat on an industrial scale, the small farmers of

Gujarat mostly cultivate for self-consumption. These starkly different case studies would highlight regional differences in impacts, vulnerabilities and adaptation measures.

State	Districts	Participants	Respondents in Each Category
Gujarat	Mehsana	• Small Farmers • SEWA • SEWA processing unit • Krishi Vigyan Kendra	30
Punjab	Fazilka	• Big Landholding Farmers • Krishi Vigyan Kendra • Wheat Processing Unit	20

Table 5: Details on Field Interviews

5. The Impact of Meteorology on Crop Yield

5.1. District-wise Spatial Variability of Seasonal Mean, Maximum and Minimum Temperatures During the Wheat Growing Season (October–April)

The district-wise climatological assessment for the wheat growing season (October–April) across the study states revealed substantial spatial variability in mean, maximum, and minimum temperatures. In general, the warmest districts were concentrated in Gujarat and parts of western Madhya Pradesh, while the coolest districts were primarily located in Punjab, Haryana, and adjoining northwestern plains. Across all districts, seasonal mean temperatures ranged approximately from 17.1°C to 26.4°C, maximum temperatures from 23.1°C to 32.6°C, and minimum temperatures from 12.1°C to 21.1°C, indicating a broad thermal gradient across the wheat belt.

Among all districts, Bhavnagar (Gujarat) recorded one of the highest seasonal mean temperatures (26.37°C), followed closely by Surat (26.29°C), Navsari (26.17°C), and Bharuch (26.11°C). Several other Gujarat districts such as Ahmadabad, Anand, Rajkot, Surendranagar, and Vadodara also exhibited mean temperatures above 25°C, highlighting Gujarat as the warmest state during the October–April period. In terms of daytime heating, the highest seasonal maximum temperature was observed in Surendranagar (32.61°C), followed by Vadodara (32.35°C), Surat (32.41°C), Rajkot (32.24°C), and Ahmadabad (32.61°C), indicating strong daytime thermal conditions in western India.

In contrast, the lowest seasonal mean temperatures were recorded in Panchkula (Haryana, 17.09°C), followed by Gurdaspur (Punjab, 18.25°C), Jalandhar (18.58°C), Rupnagar

(18.62°C), and Tarn Taran (18.65°C). These districts also exhibited relatively lower maximum temperatures, reflecting cooler winter conditions in the northwestern region. Minimum temperatures were lowest in Panchkula (12.13°C), followed by Gurdaspur (12.75°C), Rupnagar (12.89°C), Jalandhar (12.95°C), and Moga (13.27°C), suggesting stronger nocturnal cooling in Punjab and Haryana compared with warmer western and central districts.

Districts of Uttar Pradesh largely occupied an intermediate thermal zone, with mean temperatures mostly between 20°C and 22.5°C, maximum temperatures around 27°C to 29.5°C, and minimum temperatures between 14°C and 16.9°C. Eastern Uttar Pradesh districts such as Ballia, Mau, Jaunpur, and Varanasi were relatively warmer than western districts such as Ghaziabad, Gautam Buddha Nagar, Meerut, and Baghpat. This east–west contrast likely reflects continentality, land-use differences, and regional meteorological influences.
Similarly, Madhya Pradesh displayed moderate to warm conditions with clear intra-state variability. Western and southern districts such as Barwani, Dhar, Dewas, Harda, and West Nimar recorded higher mean temperatures above 24°C, whereas northern districts such as Datia, Morena, Bhind, and Shivpuri remained comparatively cooler. This suggests a north–south and east–west climatic gradient within the state.

Overall, the results indicate that coastal and western districts, especially in Gujarat, experience substantially warmer wheat seasons, while northwestern districts of Punjab and Haryana remain coolest. Such thermal contrasts are important for wheat productivity, as warmer districts may face earlier crop maturity and greater heat stress, whereas cooler districts may benefit from longer grain filling duration and more favorable winter temperature

5.2. State-wise Winter Warming Patterns and the Role of Night-Time Temperature Rise

The state-level district trend analysis revealed that winter warming across major wheat-growing states of India was primarily driven by stronger increases in minimum temperature compared with maximum temperature. In Gujarat, the average temperature increased at a rate of 0.037 °C year^{-1}, while maximum temperature rose by 0.023 °C year^{-1} and minimum temperature increased more rapidly at 0.063 °C year^{-1}. This indicates that warming in Gujarat was mainly associated with higher night-time temperatures rather than daytime heating.

In Haryana, one of the highest overall warming rates was observed, with average temperature increasing by 0.056 °C year^{-1}. The maximum temperature trend was 0.069 °C year^{-1}, while minimum temperature rose slightly faster at 0.074 °C year^{-1}, suggesting that both day and night temperatures increased substantially, with night warming remaining dominant. Similarly, Punjab showed strong warming trends, where average temperature increased by 0.053 °C year^{-1}, maximum temperature by 0.061 °C year^{-1}, and minimum temperature by 0.064 °C year^{-1}. These results highlight considerable warming across this important wheat-producing region.

In Madhya Pradesh, the average temperature trend was comparatively lower at 0.024 °C year^{-1}, while maximum temperature increased by 0.023 °C year^{-1} and minimum temperature by 0.065 °C year^{-1}, indicating a clear dominance of night-time warming. Uttar Pradesh exhibited one of the most pronounced minimum temperature increases among all states, with average temperature rising by 0.032 °C $year^{-1}$, maximum temperature by 0.038 °C $year^{-1}$, and minimum temperature by 0.076 °C $year^{-1}$. This suggests substantial winter night warming across districts of the state.

Overall, the results demonstrate that minimum temperature increased faster than maximum temperature in all selected states, implying a widespread reduction in winter cooling and increasing night-time warmth. Such asymmetric warming patterns may reduce the diurnal temperature range and can have important implications for wheat growth, particularly through reduced cold exposure and increased night respiration during sensitive crop stages.

Table 6: Temperature Trends Across States

State	Avg Trend	Max Trend	Min Trend	Drivers
Gujarat	0.04	0.02	0.06	Minimum temperature
Haryana	0.06	0.07	0.07	Minimum temperature
Madhya Pradesh	0.02	0.02	0.06	Minimum temperature
Punjab	0.05	0.06	0.06	Minimum temperature
Uttar Pradesh	0.03	0.04	0.08	Minimum temperature

Source: ERA5

5.3. State-wise Comparison of Winter Warming Trends Across Major Wheat-Growing States of India

The state-wise warming trend analysis for the wheat growing season (October–April) during 2011–2025 revealed clear differences in the rate of temperature increase across the major wheat-producing states of India. Among the selected states, Haryana experienced the highest warming rate, with temperature increasing at 0.056 °C $year^{-1}$, followed closely by Punjab at 0.053 °C $year^{-1}$. These results indicate that the northwestern wheat belt has undergone the most rapid winter warming during the study period.

At the other end, Madhya Pradesh recorded the lowest warming trend, with an increase of 0.024 °C $year^{-1}$, suggesting relatively slower warming compared with the northern plains. Uttar Pradesh exhibited a moderate warming rate of 0.032 °C $year^{-1}$, while Gujarat showed a slightly higher trend of 0.037 °C $year^{-1}$. Thus, Gujarat and Uttar Pradesh represent intermediate warming conditions between the highly warming northwestern states and the relatively slower warming central Indian region.

When ranked from highest to lowest warming, the order was: Haryana > Punjab > Gujarat > Uttar Pradesh > Madhya Pradesh. The difference between the highest warming state (Haryana) and the lowest warming state (Madhya Pradesh) was approximately 0.033 °C $year^{-1}$, equivalent to about 0.33 °C per decade. This substantial regional contrast indicates that winter warming has not been spatially uniform across India's wheat-growing states.

The stronger warming observed in Haryana and Punjab may have important agricultural implications, as these states form the core of India's high-productivity wheat belt. Faster warming during the crop season may increase the risk of shortened growth duration, heat stress during reproductive stages, and potential yield reductions. In contrast, the relatively lower warming in Madhya Pradesh may provide comparatively favorable thermal conditions, although continued warming could still influence crop productivity in the long term.

5.3. Month-wise Comparison of Warming Rates During the Wheat Growing Season (2011–2025)

The month-wise warming trend analysis for the wheat growing season (October–April) during 2011–2025 revealed substantial seasonal differences in the rate of temperature increase. Among all months, February experienced the highest warming rate, with temperatures increasing at 0.069 °C $year^{-1}$, followed closely by April at 0.066 °C $year^{-1}$ and March at 0.058 °C $year^{-1}$. These results indicate that late winter and early spring months have warmed most rapidly during the study period.

Moderate warming trends were observed during October (0.024 °C $year^{-1}$) and January (0.022 °C $year^{-1}$), while December showed a relatively smaller increase of 0.018 °C $year^{-1}$. In contrast, November was the only month to exhibit a slight cooling trend, with a temperature change of −0.009 °C $year^{-1}$, suggesting little to no warming during the early sowing period.

The concentration of stronger warming during February to April is agriculturally significant because these months correspond to critical wheat growth stages such as flowering, grain filling, and maturity. Rising temperatures during this period may accelerate crop development, shorten grain filling duration, and potentially reduce wheat yield.

The pronounced warming in February suggests that the transition from winter to spring is occurring under increasingly warmer conditions, while strong warming in March and April indicates growing risks of terminal heat stress before harvest. Overall, the findings demonstrate that warming is not uniform across the wheat season but is heavily concentrated in the later crop growth months, which are highly sensitive for wheat productivity.

5.4. Unseasonal Rainfall Patterns

The rainfall trends across major wheat-growing states indicate a noticeable shift in rainfall occurrence from the traditional winter months (November–February) toward the harvest period (March–May) over the last 15 years. While winter rainfall continues to remain important for rabi crop growth, several recent years show unusually high rainfall during the harvesting window, particularly after 2014. For instance, Haryana recorded only 37 mm rainfall during November–February in 2015 compared to nearly 137 mm during March–May, while Punjab received about 147 mm rainfall during March–May in the same year. Similar spikes were observed in Uttar Pradesh in 2021 (111 mm), Punjab in 2023 (154 mm), and Madhya Pradesh in 2023 (75 mm), suggesting that unseasonal rainfall events during harvest months have become more frequent and intense. The increasing variability and extreme rainfall during March–May can be partly attributed to changing patterns of Western Disturbances, which traditionally bring rainfall to northern India during December–February. However, recent climatic changes have led to delayed and more intense Western Disturbances extending into March and April, often interacting with higher atmospheric moisture and triggering untimely rainfall events. This emerging shift poses significant risks for wheat harvesting through crop lodging, grain quality deterioration, and post-harvest losses, particularly in Punjab, Haryana, and Uttar Pradesh where wheat production is highly concentrated.

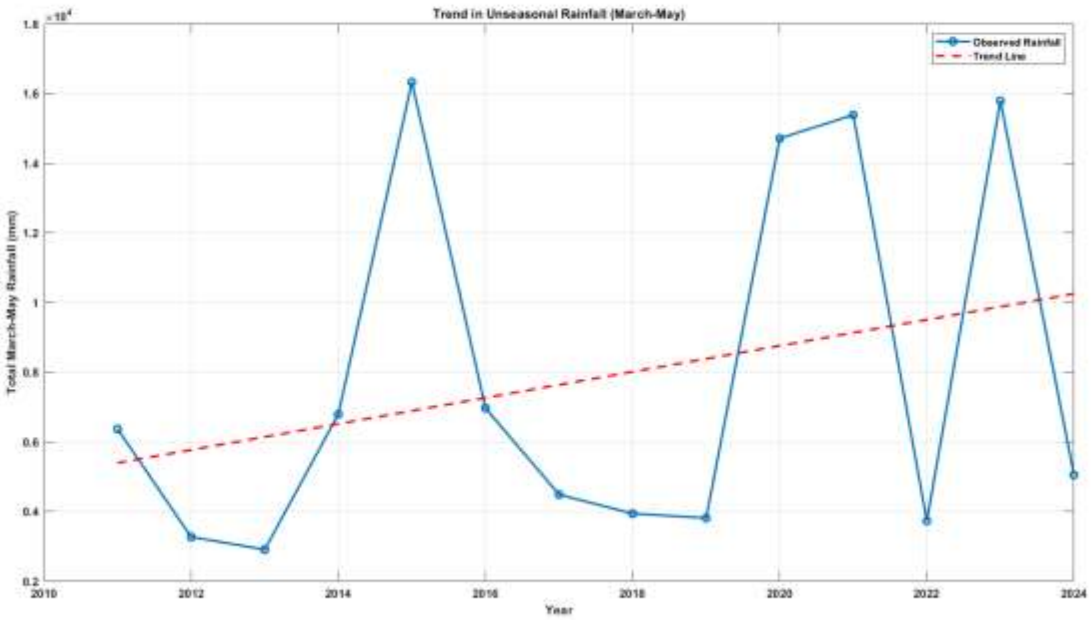

Figure 1: Trend in Unseasonal Rainfall (March-May) between 2010 and 2024
Source: Indian Meteorological Department

5.5. Trends in Wheat Cultivation

Table 7: Decadal Growth Rate (in %) of Wheat Yield in Major Producing States of India

Year	Uttar Pradesh	Punjab	Madhya Pradesh	Haryana	Gujarat
1966-75	41	54	69	39	
1976-85	48	45	54	52	
1986-95	27	31	36	30	
1996-2005	-2	-1	-10	-1	11.8
2006-2015	-3	9	63	4	4.1
2016-2024	21.3	8.8	1.1	-2.6	15.9

Source: Unified Portal for Agriculture Statistics

The decadal growth of wheat exhibits a declining trend in the last three decades for almost all the states. Madhya Pradesh saw a 63% rise in yield between 2006 and 2015 while Uttar Pradesh witnessed 21.3% rise in yield between 2016 and 2024. Based on available data for the past three decades, Gujarat has improved its yield in the last decade.

5.6. Correlation between Meteorological Variables and Wheat Yield

Table 8: Correlation between Temperature, Rainfall and Wheat Yield

States	Maximum Temperature	Minimum Temperature	Average Temperature	Rainfall
Punjab	0.26 (weak)	0.03 (negligible)	0.20 (weak)	-0.52 (moderate)
Gujarat	-0.24 (weak)	-0.03 (negligible)	-0.18 (weak)	0.21 (weak)
Madhya Pradesh	0.21 (weak)	0.26 (weak)	0.22 (weak)	-0.13 (negligible)
Uttar Pradesh	-0.20 (weak)	-0.37 (moderate)	-0.37 (moderate)	-0.09 (negligible)
Haryana	0.26 (weak)	0.06 (negligible)	0.19 (weak)	-0.43 (moderately negative)

The relationship between temperature and wheat productivity varies significantly across major wheat-growing states in India, revealing how regional climatic conditions shape crop responses to warming. In warmer states such as Gujarat, wheat yield shows a weak negative relationship with temperature, particularly with maximum temperature, suggesting that rising daytime heat may slightly suppress productivity. A similar pattern emerges in Uttar Pradesh, where wheat yields are moderately negatively correlated with both average and minimum temperatures. This indicates that increasing temperatures, especially warmer nights, may adversely affect wheat production, while the relationship with maximum temperature remains negative though comparatively weaker. These findings suggest that persistent warming, particularly elevated nighttime temperatures, could reduce crop performance in these regions.

In contrast, Punjab presents a more nuanced response to warming. Wheat yield in the state shows a positive relationship with maximum temperature, implying that moderately warmer daytime conditions during the growing season may support productivity up to a certain threshold. However, minimum temperature has a negative effect on yield, indicating that warmer nights may harm crop development by increasing plant respiration and limiting grain formation. Haryana exhibits a somewhat similar trend, where wheat yield has a weak positive relationship with both maximum and average temperatures, suggesting that moderate warmth may slightly benefit production. At the same time, the findings imply that excessive heat could eventually become detrimental to yields.

Madhya Pradesh also demonstrates a relatively positive association between temperature and wheat productivity. Wheat yield in the state shows a weak positive relationship with minimum, average, and maximum temperatures, indicating that moderate warming may support crop growth under existing climatic conditions. The climate coefficients further suggest that warmer nights may benefit wheat production, as minimum temperature has a positive effect on yield. However, higher daytime temperatures appear to reduce productivity, highlighting the risk of heat stress during the day. Overall, the findings suggest that while moderate warming may provide limited benefits in some regions, rising temperatures—especially excessive daytime heat and warmer nights—pose growing risks to wheat productivity across India.

Overall, wheat production is highly vulnerable to rising temperatures, although non-climatic factors remain the dominant drivers of long-term changes in yield. Temperature is the most important climatic driver of wheat yields in Punjab, but non-climatic factors still play an even larger role in explaining productivity changes over time. Temperature and rainfall together explain about 35% of yield variation in Punjab, 24.9% in Uttar Pradesh, and 20.6% in Haryana. However, climate variables explain very little variation in wheat yields in Madhya Pradesh and Gujarat, where non-climatic factors—such as soil quality, irrigation access, and farming practices—as well as broader changes over time, including policy shifts, technology adoption, and input availability, play a much greater role in determining yield.

6. Wheat Under Stress — Insights from Gujarat and Punjab and Pathways for Scalable Adaptation

6.1. Gujarat

6.1.1. Background and Objectives

Two focus group discussions were conducted with 20 small and marginal women farmers in Vadu village in Mehsana district of Gujarat to examine climate change impacts on wheat cultivation. Facilitated by the Self-Employed Women's Association, this case study documents lived experiences of climate stress, agrarian vulnerabilities, and locally grounded adaptations relevant for programmatic effort. These findings were supplemented with contextual insights and scientific inputs received from Krishi Vigyan Kendra, Mehsana and SEWA's district team in Nandasan, Mehsana.

- **District Profile:** Mehsana district is located in northern Gujarat and is characterized by semi-arid climatic conditions, flat to gently undulating terrain, and alluvial to sandy loam soils. Wheat is a major rabi crop, grown primarily for self-consumption among smallholders. Surplus produce is marketed locally or through Agricultural Produce Marketing Committee (APMC) run mandis by larger farmers with higher quantum of produce. Borewells are the primary source of irrigation, supplemented by canals in some areas.

Table 9: District Profile: Mehsana

Location	Northern Gujarat
Climate	Semi-Arid and sub-tropical, characterized by hot summers and cool winters. Average monsoon rainfall is 668 mm.
Soil	Alluvial to sandy loam soils
Crops Cultivated	wheat, paddy, bajra, jowar, cotton, castor, cumin, fenugreek, fennel, isabgul, mustard, potato, tomato

Net cropped area	350,000 hectares
Size of land holding	81% of land holdings are held by **small and marginal farmers**; average holding size <1.5 ha
Economy	**Primary Sector:** Agriculture **Secondary Sector:** Small scale manufacturing, dairy and agro-processing, oil & gas extraction

- **Crop Cycle of Wheat in Mehsana**
  Typically, wheat sowing begins between 15–25 November. Farmers commonly apply flood irrigation before sowing to ensure soil moisture, followed by seed sowing using cultivators. Germination begins within a week. The first major irrigation and fertilizer application takes place around 21 days after sowing, followed by up to four rounds of irrigation and three rounds of fertilizer application (Di-Ammonium Phosphate,humic acid and urea etc). The first and fifth rounds of irrigation are crucial for the proper fruiting stage of wheat. The crop matures by February, with field drying in March–April and harvesting thereafter.

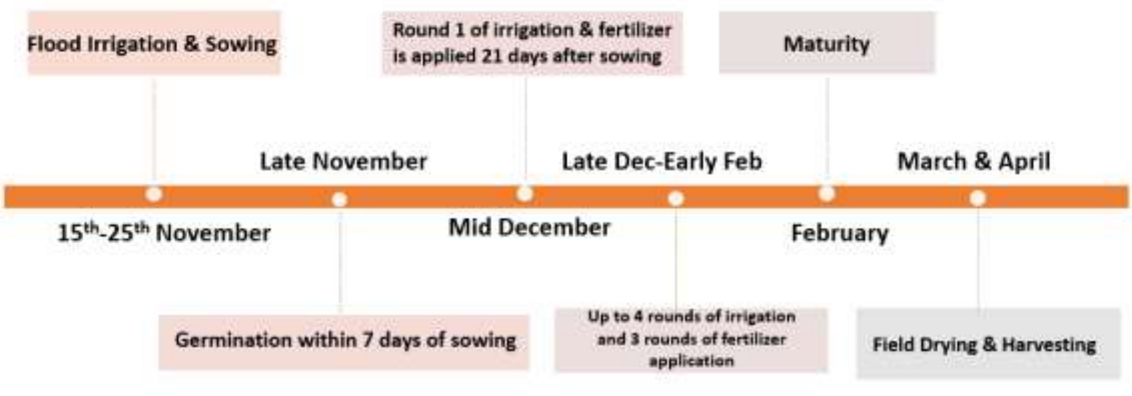

Figure 2: Crop Cycle of Wheat in Mehsana

- **Popular Wheat Varieties in Mehsana:** Wheat varieties in Mehsana include GW 451, GW 496, GW 513, and GW 476 which are normal duration crops with a cycle of 110-115 days sown between 15th November to 25th November. Another short duration variety called GW 451 with a cycle of 95 days is bio-fortified and is being promoted by KVKs for their nutritional value. Each variety differs in yield, grain quality, fodder value, and market preference.

6.1.2. Climate Change Impacts on Wheat Production in Mehsana: Perspectives from the Ground

Farmers unanimously reported that climate change impacts have intensified over the past three to five years, directly affecting wheat productivity, quality, and livelihoods.

- **Erratic and Unseasonal Rainfall**

Rainfall has become increasingly erratic, with shorter but more intense spells followed by prolonged dry periods. Unseasonal rainfall during March–April, coinciding with crop maturity, drying, or harvest, has caused severe grain damage, discoloration, and quality loss. Even one or two rainfall events after harvest, when wheat is lying in open fields, can be catastrophic, as farmers lack means to cover or protect the crop. In 2023, heavy rains during flowering and harvest stages led to widespread losses. Excess moisture has also reduced fodder availability and increased post-harvest storage losses.

- **Rising Temperatures and Heat Stress**

Farmers reported unprecedented heat, with real-feel temperatures reaching 47–48°C during April–May. Winters have become shorter and warmer, with fewer cold days, an essential requirement for wheat growth. Wheat germination ideally requires temperatures below 22–25°C, but high daytime temperatures in October and November, combined with sharp diurnal fluctuations, are increasingly disrupting germination. Germination requires adequate soil moisture. When high daytime temperatures rapidly dry the soil, seeds fail to germinate even after pre-sowing flood irrigation, forcing farmers to re-sow the seeds. Rising temperatures during tillering and milking stages (January–February) lead to poor tiller formation, early maturity, reduced grain filling, and lower yields. If temperatures in the range of 18–22 °C are not maintained after 25 days of sowing, tillering is adversely affected. In recent years, only a few days in December have recorded temperatures as low as 18 °C.

Heat stress also affects labour productivity and health during harvesting, causing dehydration, heat strokes, and increased health risks, particularly for women and elderly farmers.

- **Pest and Disease Pressure**

Changes in temperature and humidity have altered pest and disease cycles. Farmers reported increased incidence of rust and aphids, which degrade grain quality and taste. Higher humidity during harvesting and storage has further exacerbated pest infestation, reducing storage life from one–two years earlier to less than six months in recent years.

- **Water Woes in Mehsana: Declining Ground Water Amidst Flooded Fields**

A canal from the Narmada River has altered natural drainage patterns in Mehsana over the past 10 years. Lack of proper subsurface drainage, causes canal water to stagnate in fields and villages, a situation further exacerbated by increasingly intense rainfall events. As a result, large tracts of land remain waterlogged for extended periods, making it difficult to cultivate crops other than paddy. In several instances in the past, excess water could not be drained, leading to complete crop loss. Many cotton farmers have been forced to shift to paddy cultivation in recent years to cope with this problem. Shallow digging of 3–4 feet now yield water in some areas due to raised water levels from canal seepage. However, often described by farmers as '*khar wala pani*'—this hard water is of poor quality, adversely affecting soil health and crop quality.

In contrast, deeper "sweet" groundwater suitable for irrigation, which was earlier accessible at depths of around 100 feet, is now found at 800–1,000 feet in downstream areas, making it increasingly inaccessible and expensive for small farmers. Traditional village ponds that once captured rain water runoff and enabled groundwater recharge have been lost to concretization associated with roads, buildings, and industrial expansion. Farmers note a clear difference in crop quality: wheat grown using borewell water produces better grain and softer rotis, while wheat irrigated with canal (hard surface) water results in inferior quality grain and harder rotis. While excess water damages fields at the surface, yet usable groundwater continues to decline—undermining agricultural productivity and long-term water security.

In some villages, emissions from tiles manufacturing units result in ceramic dust deposition, severely damaging crops within a 100-metre radius of the factory. Persistent dust accumulation reduces sunlight exposure and contaminates water, adversely affecting crop growth and yields. Incessant waterlogging, soil degradation, industrial pollutants, and dwindling agricultural productivity have pushed many households to sell off their lands and seek wage labour in factories for livelihood insecurity.

6.1.3. Socio-Economic Vulnerability of Small and Marginal Farmers

Climate impacts interact with existing structural vulnerabilities, disproportionately affecting small and marginal farmers. Smallholders often cultivate leased land under fixed-rent or sharecropping arrangements, meaning they must pay rent even in years of crop failure.

Small and marginal farmers lack permanent irrigation infrastructure and depend largely on rainfall or rented borewell water. Most do not own borewells and face rising irrigation costs, with water charges increasing from about ₹120 to ₹230 per hour, while electricity subsidies remain inaccessible and are tied only to micro-irrigation systems. Shared borewells serve multiple farmers and cater large areas, resulting in delayed access and untimely irrigation. Farmers often do not receive water when crops require it, despite waiting for their turn. Falling water tables have further reduced borewell reliability, contributing to declining yields and crop quality despite rising production costs.

Lack of storage facilities, high transportation costs to wholesale markets, and declining grain quality reduce market participation. Crop insurance and institutional credit remain limited due to lack of awareness, complex procedures, and inadequate triggering of payouts. Rising costs, poor output, lack of institutional support has led many farmers to abandon agriculture and seek employment in industries.

6.1.4. Local Adaptation Strategies

Despite constraints, the path to long term climate resilience lies in reducing vulnerability and enhancing adaptive capacity of small farmers. Operating across 310 villages in Mehsana district, SEWA works on employment, livelihoods, and social security for smallholder women farmers, supporting women farmers through training, access to inputs, finance, insurance, and market linkages.

- **Climate information and early warnings:** SEWA, in collaboration with the Indian Meteorological Department disseminates weather advisories through voice messages in Gujarati, enabling farmers to adjust irrigation and harvesting decisions to protect crops from adverse weather conditions.

- **Capacity Building:** SEWA supports smallholder farmers in adapting to climate change by providing training on water-efficient and climate-resilient farming practices, and livelihood diversification. These efforts are complemented by village-level capacity building conducted in collaboration with institutions such as the Krishi Vigyan Kendra (KVK), where faculty deliver hands-on training on agriculture and livestock management.
- **Strengthening Local Agricultural Value Chains:** Through its Rural Urban Distribution Initiative (RUDI) initiative, established in 2004, SEWA has created a localized, women-led value chain that reduces market risks and transaction costs. Through RUDI, SEWA acquires local produce such as rice, bajra, wheat, chillies, and turmeric directly from small farmers at prices higher than those prevailing in wholesale markets. The products, once cleaned, processed, packaged, are sold locally. This ensures fair and quicker payments to farmers while eliminating transport and intermediary costs, augmenting their adaptive capacities.
- **Input access and subsidies:** SEWA facilitates access to critical inputs for smallholder farmers by enabling loans and machinery support, and providing parametric insurance. In addition, it operates seven agri-input centres across the district that supply low-chemical inputs and locally produced biofertilizers and biopesticides, ensuring affordable inputs for small farmers.
- **Adjustments in crop varieties and calendars:** Farmers are experimenting with short-duration and stress-tolerant varieties such as GW 499, GW 11, and Bhalia-13, which require less irrigation and perform better under heat stress. Sowing calendars are being adjusted, and seed rates increased to compensate for poor germination. Rising temperatures interfere with the growth of wheat at different stages of cultivation often resulting in inadequate germination or fruiting. To compensate for higher such losses, farmers now increase seed rates from about 20 kg to 30 kg per sowing.
- **Water and nutrient management:** Improved nutrient management, including potash and zinc application, is used to enhance stress tolerance. Some farmers are reviving organic and natural farming practices, though labour and cost constraints limit widespread adoption.
- **Adaptation Strategies to Reduce Post Harvest Losses:** Households could earlier store their wheat for one-two years. However, high humidity in summers have reduced this duration to less than six months by increasing pest infestations and rotting. Farmers adopt multiple household-level practices to improve to address this problem. Grains are thoroughly sun-dried, periodically cleaned, and stored with neem leaves, castor oil coating, or boric powder to control pests. Wheat is kept in airtight tin drums or jute bags, raised on pallets to avoid contact with walls or floors and prevent moisture absorption. Storage rooms are fumigated, kept closed to direct sunlight and airflow disturbances, and opened infrequently.
- **Livelihood Diversification:** Households diversify livelihoods beyond farming and taking up livestock rearing, factory work, and services such as catering to avoid risking their income in the face of climate stressors.

Table 10: Climate Impacts and Adaptation Across Wheat Growth Stages

Stage of Growth	Observed climate stressors	Impacts on crop and farmers	Local adaptation responses
Sowing & germination (Nov)	High daytime temperatures, large diurnal fluctuations, inadequate moisture	Poor or uneven germination; need for re-sowing; higher seed costs	Pre-sowing flood irrigation; increased seed rates (20 kg to ~30 kg); adjusting sowing dates; use of short-duration varieties
Tillering (Dec–Jan)	Warmer winters; fewer cold days	Reduced tillering and biomass; lower yield potential	Nutrient management (NPK, potash, zinc); selection of varieties tolerant to warmer conditions
Flowering & milking (Jan–Feb)	Sudden rise in temperatures from mid-February; missing spring	Early maturity; poor grain filling; quality deterioration	Shift to short-duration or heat-tolerant varieties (GW 499, GW 11); careful irrigation scheduling
Maturity & drying (March)	Unseasonal rainfall; high humidity	Grain discoloration (black/white grains); fodder loss	Early harvesting when possible; use of tarpaulins (limited effectiveness); local weather advisories
Harvest & storage (March onwards)	Extreme heat; high humidity; pest pressure	Health risks for labour; storage losses; reduced shelf life	Night/early-morning harvesting; sun drying of harvest; use of neem leaves for storage to reduce pest infestation, storage in airtight drums to reduce moisture exposure, castor oil coating of grains; raised storage platforms to reduce moisture incursion from walls and floors

The Mehsana case illustrates how climate change—manifested through heat stress, erratic rainfall, and humidity—has begun to fundamentally alter wheat cultivation systems. These climatic stresses interact with socio-economic and institutional constraints, making small and marginal farmers, particularly women, highly vulnerable. Farmers are responding through changes in crop calendars, varietal choices, nutrient and water management, and collective strategies supported by SEWA. However, these adaptations remain largely incremental and constrained by scale, infrastructure, and resources. Grounded in farmer experiences, this case study underscores the importance of aligning climate programmes with local realities to safeguard livelihoods and food security.

6.2. Punjab

6.2.1. Background and Objectives

A field exploration was conducted in Abohar tehsil of Fazilka district, located in southwest Punjab, to understand how climate variability is shaping wheat cultivation across different stages of the crop cycle. Punjab, known as the food bowl of India, contributes 40% of wheat to the central pool (GOI, 2019).

The study was facilitated by Kheti Virasat Mission and included one focused group discussion with 10 organic farmers and interactions with Krishi Vigyan Kendra (KVK) officials and the owner of a wheat processing unit in Abohar.

- **Fazilka District Profile**

Fazilka district falls in the Malwa region of Punjab and is climatically similar to western Rajasthan due to its proximity to the Thar desert. Traditionally known as the cotton belt of southwest Punjab, the district has witnessed intensive chemical agriculture, resulting in polluted groundwater, environmental degradation, and serious public health impacts, including high cancer incidence.

In response, a section of farmers—particularly large landholders—have transitioned towards organic and natural farming. However, these farmers now report a steady decline in wheat quality and consistency of yields, largely driven by climate variability.

Farmers reported that groundwater levels in Abohar, which had earlier declined from about 7–8 feet to 1.5–3 feet, are now rising again following the introduction of a new canal in the area. Over-irrigation due to availability of water and canal seepage have contributed to this rebound in groundwater levels, and flooding making it difficult to cultivate cotton and kinnow in the area.

Table 11: District Profile: Fazilka

Location	South-western Punjab at the bordering Rajasthan
Climate	Tropical desert, arid and hot. The climate on the whole is dry and characterized by very hot summers, a short rainy season, and a bracing winter. Summer temperatures may reach 47 degrees Celsius and the area receives about 389 mm annual normal rainfalls.
Soil	Coarse to fine loamy soils, with sandy loam to clay textures
Crops Cultivated	The main crops grown during kharif are cotton and paddy and wheat in Rabi. The other crops grown in the area are Maize, Mustard, Sugarcane, Bajra, Guar seeds, Gram, Barley and Kinnow.
Production and Area under wheat cultivation (2022-23)	**Production**: 925000 tonnes **Area:** 200000 hectares (Department of Economics & Statistics, Government of India)
Size of land holding	Similar to Punjab's average operational holding is about 3.6 hectares (2015-16 trend)
Economy	**Primary Sector:** Agriculture and Livestock rearing. **Secondary Sector:** Small scale agro-based and cottage industry

Crop Cycle in Fazilka

Wheat sowing in Fazilka typically begins around 15 November and continues until 15 December. The crop requires 3–5 irrigations, primarily through canal water, as borewell access is uneven. A standard irrigation schedule includes:

- One pre-sowing irrigation
- Three critical irrigations at 25, 65 and 90–95 days after sowing
- Irrigation is stopped 20–30 days before harvest to allow grain drying

Germination occurs within 5–7 days under optimal conditions. The crop then moves through vegetative growth, tillering, reproductive stages, maturity, and harvest. During sowing Di-Ammonium Phosphate, zinc, sulphur and urea are added to the soil. Additionally, chemical farming requires 2-3 rounds of weedicide applications. Input use varies across chemical and organic systems, with chemical farming yielding 20–28 quintals/acre and organic systems averaging ~10 quintals/acre, though with higher nutritional quality.

Figure 3: Crop Cycle of Wheat in Fazilka

- **Popular Varieties of Wheat in Fazilka:** Organic farming uses traditional seed varieties like bansi, sharbati, sonamati, chawalkantha and khapli. Other popular varieties include PB826, DBW227, DBW187, DBW3386, PBW872 and HD3086.

6.2.2. Climate Impacts Across Stages of Wheat Cultivation: Perspectives from the Ground

- **Sowing and Germination Stage (Mid-November to Early December)**

Wheat germination requires moderate daytime temperatures (around 25-28°C) and cool nights (12–14°C) with adequate soil moisture. Farmers report that November is no longer as cold as earlier, leading to delayed or uneven germination.

- **Vegetative Growth and Tillering (December–January)**

This stage requires stable cold conditions (10–12°C daytime and ~4°C at night). Farmers observed that while occasional extreme cold waves occur, the larger problem is temperature fluctuation rather than cold itself. Sudden drops due to northerly winds can cause frost injury, damaging leaf veins and reducing photosynthesis, though such events are short-lived.

More commonly, warmer-than-normal January temperatures (20–25°C) suppress tillering, directly reducing the number of productive spikes.

- **Reproductive and Milking Stage (February–Mid March)**

This stage has emerged as the most climate-sensitive phase. Wheat requires cool, stable conditions during grain formation, but farmers reported early onset of spring and rising temperatures in February and March. In several years, including 2022, temperatures rose by 5°C within two days, triggering terminal heat stress. High temperatures during the milking stage cause premature drying of grains, leading to shrivelled kernels, reduced grain weight, and lower market quality. Yield variability across years—even for the same variety—has increased significantly. Generally, there is 24 quintals /acre in a year but when temperatures are high after March 15th yield can fall to 16 quintals/acre. Humidity during this stage also raises the risk of aphids and sucking pests, particularly toward late March.

- **Maturity and Harvest (Late March–April)**

Wheat requires hot and dry weather during maturity and harvest, but farmers now experience unseasonal rainfall and elevated humidity, disrupting harvesting schedules. Westerly winds in March and April further affect standing crops, leading to lodging and grain losses. Erratic rainfall patterns—rain not occurring when required and sudden showers during harvest—add to uncertainty and post-harvest losses.

- **Post-Harvest Storage and Processing**

Post-harvest impacts have intensified due to high ambient humidity and changing moisture regimes. Farmers noted that wheat which earlier could be stored for 2–3 years now does not last beyond 6–12 months, even with traditional storage practices.

To adapt, farmers and processors rely on:

- Sun drying during the day and storing grain at night after cooling
- Mechanical blowers for moisture reduction

Processing units reported that moisture control is now critical for flour shelf life. Atta, which earlier lasted 30 days, can extend to 45 days only under controlled moisture conditions.

6.2.3. Adaptation Responses and Emerging Solutions

Farmers emphasized the need for real-time climate advisories, particularly on temperature fluctuations, rainfall, and frost events.

Other adaptive strategies include:

- Shift towards traditional and climate-resilient wheat varieties
- Move towards natural farming systems to reduce ecological damages
- Traditional practices such as smoke generation and light irrigation during frost are still used.

At the institutional level, KVK advisories, organic transitions, and moisture-controlled post-harvest handling are strengthening resilience, though unevenly across farmer categories.

6.3. Discussions

Wheat cultivation in India is increasingly shaped by climate variability. Despite contrasting agro-ecological and socio-economic settings, Mehsana and Fazilka show strikingly similar impacts. Both the semi-arid smallholder system of Mehsana (Gujarat) and the large-scale production landscape of Fazilka (Punjab) experienced pronounced yield fluctuations, declining grain quality, and higher post-harvest losses. In both regions, the reproductive (flowering–milking) and maturity–harvest phases were most climate-sensitive: terminal heat in Punjab caused shrivelled grains and poor grain filling, while unseasonal rainfall and humidity during drying and harvest in Gujarat caused discoloration, spoilage, and fodder loss. Early growth stages were also affected. Higher temperatures led to poor germination and re-sowing in

Gujarat, whereas delayed winter cooling and temperature variability in Punjab caused uneven germination and suppressed tillering.

The main difference lay in socio-economic context, which shaped vulnerability and adaptive capacity. Wheat cultivation in Mehsana is dominated by small and marginal farmers, many of them women, dependent on rented borewell water, rain-fed irrigation, and informal water-sharing arrangements. Limited capital, rising irrigation costs, and declining yields heighten their economic vulnerability. Fazilka, by contrast, has more medium and large landholders with greater financial and infrastructural capacity to test climate-resilient practices, though they still face yield and quality variability within commercial grain supply chains.

Adaptation responses differed in form but converged in principle. In Gujarat, they were community-centred and incremental—adjusting sowing dates, increasing seed rates, adopting short-duration varieties, improving nutrient management, building capacity, and diversifying livelihoods. In Punjab, they were more individualized and technology-driven—use of traditional heat-resilient varieties, organic or natural farming, moisture-controlled storage, and reliance on institutional advisories. Many of these practices are replicable and provide a template for strengthening resilience across India's wheat belt, including Haryana, Rajasthan, Madhya Pradesh, and western Uttar Pradesh. Effective adaptation ultimately requires combining locally grounded practices with institutional support.

Pathways to resilience: Best Practices from the Ground

Here is a compilation of best practices and adaptation strategies used by farmers in Gujarat and Punjab to improve long term resilience which are applicable to other crops and geographies.

- **Heat Tolerant and Short Duration Seed Varieties:** In Gujarat, farmers are experimenting with short-duration and stress-tolerant varieties such as GW 499, GW 11, and Bhalia-13, which require less irrigation and perform better under heat stress. Short duration varieties mature early and can avoid terminal heat stress that affect crops in late February and March.
- **Adjustment in Sowing Calendars:** Wheat germination ideally requires temperatures below 22–25°C along with adequate moisture. High daytime temperatures in October and November, rapidly dry the soil despite irrigation. Seeds fail to germinate forcing farmers to re-sow the seeds. Sowing calendars are being adjusted to avoid the October heat, and seed rates increased to compensate for poor germination. To compensate for such losses, farmers in Gujarat now increase seed rates from about 20 kg to 30 kg per sowing.
- **Timely Weather Advisories:** Indian Meteorological Department disseminates weather advisories through voice messages in local languages. Rainfall advisories enable farmers to adjust irrigation calendars and harvesting decisions to protect crops from adverse weather conditions.
- **Mulching Reduces Terminal Heat Stress and Improves Soil Health:** In Punjab, farmers in collaboration with Kheti Virasat Mission use an innovative, zero-tillage technique where wheat seeds are sown directly onto rice stubble and covered with another layer of crop residue. It acts as a natural "blanket" that retains moisture during the October heat, provides nutrients to the soil, reduces weed growth and eliminates

the need for stubble burning. Mulching with rise residue during the grain filling period also protects plants from terminal heat stress.

- **Water and nutrient management:** Improved nutrient management, including potash and zinc application, is used to enhance stress tolerance.
- **Shift to Organic and Natural Farming as a Sustainable Alternative:** Some farmers in Punjab are reviving organic and natural farming practices to adapt to rising temperatures, declining soil health and increasing input costs. By using biofertilisers, compost, farmyard manure and biopesticides such as neem-based formulations, they aim to improve soil moisture retention, enhance heat resilience and reduce pest outbreaks. However, labour requirements, transition costs and lower short-term yields continue to limit wider adoption, especially among smallholders. In Mehsana district of Gujarat, SEWA operates seven agri-input centres that supply low-chemical inputs and locally produced biofertilizers and biopesticides, ensuring affordable organic inputs for small farmers.
- **Adaptation Strategies to Reduce Post Harvest Losses:** Households in Gujarat could earlier store their wheat for one-two years. However, high humidity in summers have reduced this duration to less than six months by increasing pest infestations and rotting. Farmers adopt multiple household-level practices to improve to address this problem. Grains are thoroughly sun-dried, periodically cleaned, and stored with neem leaves, castor oil coating, or boric powder to control pests. Wheat is kept in airtight tin drums or jute bags, raised on pallets to avoid contact with walls or floors and prevent moisture absorption. Storage rooms are fumigated, kept closed to direct sunlight and airflow disturbances, and opened infrequently. Mechanical blowers are used for moisture reduction in processing units in Punjab.
- **Capacity Building:** Village level capacity building programs conducted by Krishi Vigyan Kendra (KVK) train farmers in water-efficient and climate-resilient farming practices, and livelihood diversification.
- **Parametric Insurance to Protect Farmers from Climate Shocks:** Organisations such as SEWA are helping farmers access parametric insurance in Gujarat to reduce financial risks from increasingly erratic weather. Under such arrangements, payouts are triggered automatically when predefined weather thresholds—such as extreme heat, rainfall deficits or delayed monsoons—are crossed, enabling faster compensation to farmers. This helps small farmers recover working capital, avoid distress borrowing and invest in the next cropping cycle.

7. Conclusion

Climate change is increasingly emerging as a major threat to wheat cultivation across India's key producing regions. The findings of this report show that rising temperatures—particularly warmer winters, increasing night-time temperatures, and terminal heat stress during reproductive stages—are already affecting wheat growth, grain quality, and yield stability. These impacts are further intensified by erratic rainfall, humidity, and post-harvest losses, especially during harvest and storage periods. Projections consistently indicate major yield declines across the Indo-Gangetic Plain if current trends continue. Farmers are responding through altered sowing dates, seed choices, improved storage, water-management practices, and collective or institutional support systems, yet these remain insufficient without wider structural backing. Ensuring India's wheat-based food security will require coordinated adaptation—timely sowing, heat-tolerant cultivars, improved irrigation and advisories, and strengthened extension systems that integrate local knowledge with scientific guidance.

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