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RESEARCH PAPER

Farmers' Perceptions of Climate Change and their Adaptation in a semi-Arid Region in India

Pradeep Mehta [*]

Abstract: Climate change is emerging as a significant threat to farmers in semi-arid rural areas in India, where agricultural livelihoods are primarily dependent on rainfall. The effect of climate change on farmers' social and economic well-being depends not only on their awareness of shifting climatic patterns but also on their responses to such changes. This study aims to examine farmers' perceptions of climate change, analyse their responses to it, and identify factors contributing to farmers' choice of anticipatory or reactive adaptation strategies. It was conducted in Nuh district in Haryana, a semi-arid region. The study comprised a primary survey of 384 farmers, with the sample size determined using probabilistic sampling method. It reveals that farmers have observed long-term changes in climatic factors (temperature and rainfall) and have adopted strategies to deal with them. In Nuh, the current institutional policy and knowledge mechanisms primarily focus on addressing short-term climate risks. As a result, farmers' adaptive strategies tend to be reactive in nature, primarily focused on mitigating immediate losses in agricultural productivity. There is a critical need to address the differential vulnerabilities of farming communities and build their capacity to absorb risks through institutional and technological interventions.

Keywords: Climate Change Adaptation; Perception; semi-Arid; Hazard.

1. INTRODUCTION

Climate across the globe is changing; this is emerging as a significant hindrance to promoting sustainable livelihoods and economic development (Guo *et al.* 2022; Adger *et al.* 2002; Harvey *et al.* 2018; Baede et al. 2001). Climate change encompasses alterations in both, average conditions and variability in climate patterns over extended periods. It also includes the

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phenomenon of global warming (Matthews et al. 2021).[1] Rising global temperatures pose unprecedented hazards for vulnerable communities, as they can disrupt natural systems, leading to more frequent and intense droughts, floods, and other extreme weather events. They also accelerate the rise in global sea levels and biodiversity loss (IPCC 2022; Shivanna 2022). Such changes are anticipated to exacerbate the pressure on water resources, food production, public health, and ecosystems (IPCC 2022; Mathews *et al.* 2021).

Semi-arid regions are among the most vulnerable to climate change.[2] This is because the ecosystems in these regions are fragile and sensitive to interactions between human activities and the climate (Huang *et al.* 2016). Given the prevalence of rain-fed agricultural practices and the lack of adequate irrigation infrastructure in these regions (Mitra *et al.* 2021), shifts in the state of the climate can lead to hazards,[3] such as prolonged droughts and increased groundwater salinity (Aryal *et al.* 2020; Mehta 2015; Kumar and Gautam 2014; Singh *et al.* 2019).[4] This study was conducted in Nuh, a semi-arid region in India, and one of India's most backward districts despite its proximity to the national capital. In this region, shifts in climate in the last 30 years (1988–2018) have led to escalating levels of aridity (Mitra *et al.* 2021). Both, climatic factors, such as increased temperature and reduced precipitation, which lead to more frequent droughts, and human-induced factors, such as the extraction of groundwater during prolonged droughts, have resulted in elevated levels of groundwater salinity. This has become a significant threat to the well-being of people in Nuh, as most of the population is unskilled, illiterate, and engaged in agriculture (Mehta 2015). Currently, more than two-thirds of Nuh district has saline groundwater,[5]

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[1] Statistically significant variations in the mean state of the climate or in its variability, typically persisting for decades or longer, are referred to as "climate change" (Baede *et al.* 2001).

[2] Long-term global warming leads to longer and more severe droughts in semi-arid regions because of enhanced evaporation and reduced precipitation (Dai 2013).

[3] A hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage to or loss of property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (Matthews *et al.* 2021).

[4] Groundwater salinity is more directly influenced by geological and hydrological factors than short-term variations in climate conditions. However, it is closely linked to broader climate change–related processes and can be exacerbated by climate-related factors (Dao *et al.* 2024).

[5] Nuh district grapples with a severe salinity problem owing to its distinctive geoclimatic context. Its bowl-shaped terrain, devoid of natural drainage, facilitates the accumulation of salts from the Himalayan and Shivalik ranges. In the late 1990s, a prolonged period of inadequate rainfall led to consecutive droughts, triggering intense groundwater extraction. This extraction exacerbated the presence of excessive saline water in the district. Currently, only 22% of the groundwater remains non-saline, significantly impacting the welfare of the

which poses a significant challenge to farmers who are dependent on agriculture for their livelihoods (Mehta 2020).

At the micro or farm level, it is generally argued that the extent of the impact of a change in climate on farmers' social and economic well-being hinges on their awareness or perception of such changes and their response to it (Fierros-González and Feldman 2021; Deressa *et al.* 2011; Feola *et al.* 2015).[6] Furthermore, their observations of climate change may include not just variability or shifts in key climatic parameters, such as temperature and rainfall (Deressa *et al.* 2009; Olabanji *et al.* 2021), but also the tangible impacts of climate change on their farming and livelihood resources, which can manifest as hazards. Further, they may experience anxiety regarding future climate-related risks (Howden *et al.* 2007; Arbuckle *et al.* 2015; Debela 2017). In other words, farmers' adaptation is not solely driven by their perception of changes in climatic factors—it is also influenced by their observations of the impacts of climate change and the perceived risk of future climate-related challenges.

Further, not all measures adopted by farmers reduce their vulnerability[7] to future climate change. Farmers in marginal regions are often compelled to alter agricultural practices, and such changes may not necessarily reduce their vulnerability to future climate change. Instead, they often exacerbate their vulnerability. For instance, due to climatic changes, farmers may be compelled to either reduce the land under cultivation or use degraded land (which is less productive). Climate-proof development involves reducing vulnerability and not merely identifying a response to climate change (Magnan *et al.* 2020; Schipper 2007). In other words, climate change adaptation[8] is more effective if livelihoods are adapted in response to

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predominantly agrarian populace (Mitra *et al.* 2021).

[6] Expecting respondents to have enough experience to have observed changes in climatic factors over 30 years is impractical. Therefore, we regard climate change as alterations in key climatic factors, including temperature and precipitation, as observed and reported by farmers. Our objective is not to distinguish between perceptions of long-term climate change and short-term variability; instead, it is to capture farmers' perceptions of changes in climatic factors, which can aid them in recognizing their vulnerability and help them act accordingly (Datta *et al.* 2022).

[7] Vulnerability generally refers to susceptibility to harm. In the climate change literature, vulnerability is often understood to be a function of exposure and sensitivity to a hazard and adaptive capacity, or the ability to respond. In the biophysical conception of vulnerability, exposure and sensitivity represent the risk that a physical hazard poses to a population; this risk is seen as exogenous to society (Matthews *et al.* 2021).

[8] Climate change adaptation involves the process of adjusting to present or expected climate conditions and their impacts, with the aim of moderating or preventing harm and seizing opportunities (Matthews et al., 2021). These adjustments are made to improve the sustainability of social and economic activities and to decrease their susceptibility to climate-

climate change such that they provide sufficient flexibility in terms of food security and income (Adger 1996 and Schipper 2020). For this, farmers must adopt strategies—such as water conservation and crop diversification—to reduce their vulnerability. We differentiate these two kinds of adaptation as responsive and anticipatory adaptation[9] (Adger *et al.* 2005). Responsive adaptations are coping or reactive strategies undertaken primarily to deal with past or current events. In contrast, anticipatory adaptation is long term and is undertaken to deal with anticipated climate change and hazards (Binternagel *et al.* 2010). Anticipatory adaptation reduces farmers' vulnerability to future climate change more effectively than responsive adaptation (Baede et al. 2001). Many studies have examined the role of farmers' perceptions of climate change in their decision to implement adaptation strategies, but there is a dearth of studies on the role of farmers' observations about the impacts of climate change in their decision-making around adaptation. In this study, we explore the role of perceptions, observed impacts, and anxiety about future climate-related risks in the kind of adaptation strategy farmers choose to implement, rather than merely the response to climate change alone.

We examine the pattern of climate change in Nuh, a semi-arid region, and explore farmers' perceptions of changes in climatic factors, its tangible impacts on their livelihoods, and their apprehensions regarding future climate change. Subsequently, we assess an array of response and adaptation strategies adopted by farmers and evaluate the factors that drove them to adopt either anticipatory or responsive adaptation strategies. The specific objectives of the study are (1) to map changes in significant climate variables within Nuh district in Haryana; (2) to assess the community's perceptions of changes in climate variables and their consequent outcomes; and (3) to examine the strategies implemented by farmers and the factors that lead them to adopt different adaption measures. The study is organized into seven sections, of which this is the first. The second section outlines the methodology. The subsequent section details the mapping of climate change in Nuh district, Haryana. Section 4 covers community perceptions of changes in climatic factors, its observed impacts, and farmers' concerns

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related risks, including current variability, extreme events, and longer-term climate shifts (Smit *et al.* 2000).

[9] Adaptation strategies in the context of climate change are often classified as reactive or proactive. Reactive adaptation occurs after experiencing negative climate change effects, while proactive adaptation aims to anticipate and prevent potential damage. However, the classification of specific practices, such as adjusting the timing of sowing and harvesting, can vary among scholars based on local conditions and farming systems. The distinction between reactive and proactive strategies depends on whether a measure is a response to observed changes (reactive) or a proactive coping mechanism (Engler *et al.* 2021).

about future climate-related risks. Sections 5 and 6 explore adaptive strategies employed by farmers in Nuh and the factors influencing these strategies, respectively. We conclude with a summary of our key findings.

2. METHODOLOGY AND FRAMEWORK

We carried out this study in Nuh district, Haryana, which is situated in a semi-arid region. We used both primary and secondary data sources. According to the World Meteorological Organization (WMO), climate is defined as the average weather or, more rigorously, as the statistical description of weather in terms of the mean and variability of relevant quantities such as precipitation and temperature over a period of time—typically a decade or longer.[10] In this paper, climate change refers to a change in the state of the climate that can be identified (for instance, using statistical tests) by changes in the mean and/or variability in its properties and which persists for an extended period of 30 years. For the Nuh region, we capture long-term trends in major climatic factors—such as temperature and rainfall—through secondary data from the Indian Meteorological Department (IMD) and the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) for the last 30 years (1986–2015).

We collected the primary data from households in March–October 2019. Based on the probabilistic sample formula,[11] our sample size is 384 farmers. They were selected from each block based on proportionate stratified random sampling, as in Table 1.

Table 1: Sample Size of the Study

Blocks	Number of Households	Proportion of Households	Sample Size
Tauru	20,117	14.37	55
Nuh	38,714	27.66	106
Punhana	36,531	26.10	100
Firozpur Jhirka	44,613	31.87	122
			384

Source*:* Census of India (2011).

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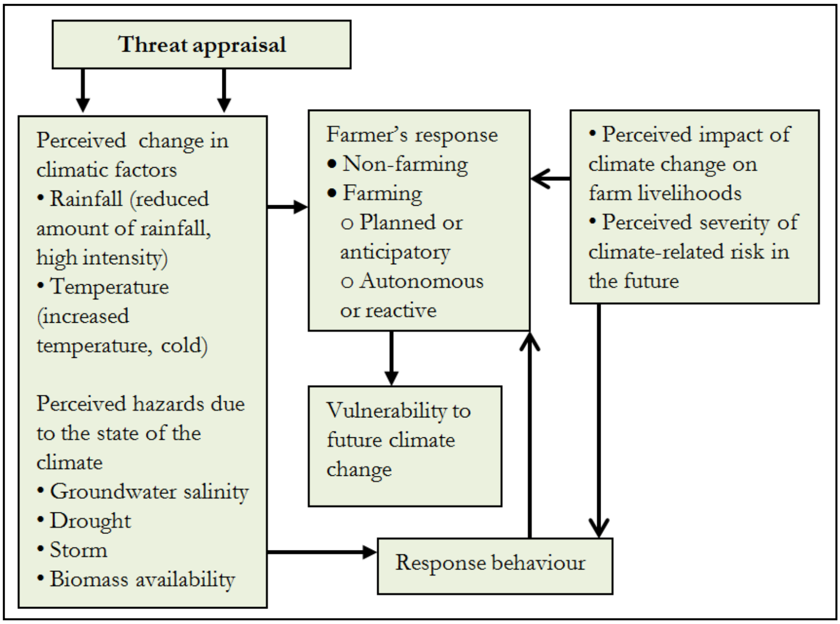
[10] The World Meteorological Organization timeline is a minimum of 30 years for delineating the climate of an area; we use this standard in this paper.

[11] A standard sample size formula is used to determine the sample size:
Sample Size = $N * [Z2 * p * (1-p)/e2] / [N - 1 + (Z2 * p * (1-p)/e2]$
Where N is the population size (1,089,000), z is the z-score with a 95% confidence level (z = 1.96), e is the margin of error with 5% (.05), and p is the standard of deviation, where p is assumed to be 0.5 as it is unknown.

We employed quantitative and qualitative tools, including a questionnaire, focus group discussions, historical mapping, climate mapping, and resource mapping. We captured farmers' adaptation to climate change through anticipatory and responsive strategies and examined how their awareness or perception of changes in climatic factors, anxiety about future climate change, and observations regarding the impacts of climate change (hazards) affect these choices (Figure 1).

Figure 1: Strategies for Adaptation to Climate Change



Source: Prepared by Author

We have also explored the factors explaining farmers' choice of adaptation strategies using a binary logit model. This model incorporates climate change adaptation strategies as a dummy, and dependent variables with binary choices. Farmers are differentiated by their adoption of anticipatory strategies versus reactive ones (we assign the value 1 to farmers with at least one anticipatory strategy and 0 to those who have not adopted any anticipatory strategies). The logistic distribution function for the decision to adopt adaptation measures can be specified as follows:

$$Logit\ (P) = \log \left(\frac{P}{1-P}\right)$$

$$Let\ P_i = Pr\ (\underline{Y = 1})$$

$$X = x_i$$

then the model can be written as

$$Pr\,(y = 1/x) = \frac{exp^{x'b}}{1 + e^{x'b}} = log\left(\frac{P_i}{1-Pi}\right) = Logit\,(P_i) = \beta_0 + \beta_1 x_i$$

where P_i is the probability of deciding to adopt anticipatory adaptation strategies (dependent variable), x are the independent variables, β_0 is the intercept, and β_1 is the regression coefficient.

We can present the model in terms of odds as follows:

$$\frac{P_i}{(1-P_i)} = exp\,(\beta_0 + \beta_1 x_i)$$

The binary logit model examines the correlation between socioeconomic characteristics and farmers' choice of either adaptive or responsive adaptation strategies. The dependent variables—which represent the adoption of anticipatory adaptation strategies, including soil conservation techniques, crop diversification, saline crop varieties, agro-forestry, and water conservation technologies—were formulated as a binary, with a value of 1 assigned to farmers employing at least one listed anticipatory strategy and 0 to those employing none of these within the study. This binary classification distinguishes farmers who have adopted anticipatory strategies from those who have not. The independent variables, hypothesized to influence farmers' adoption of anticipatory strategies, encompass the combined effects of various factors, including psychological, demographic, socioeconomic, and institutional characteristics. Drawing on insights from past studies on adaptation strategies, we considered the explanatory variables detailed in Table 2 and scrutinized them for their impact on the typology of farmers' adaptation strategies.

Nuh is a semi-arid region with hot temperatures during the summer. May and June are the hottest months, with temperatures ranging from 30–48°C. January is the coldest month, with temperatures in the range of 2–25°C (Government of Haryana 2022). About 80% of the annual precipitation is received during the monsoon season, with a peak in July. The annual rainfall varies considerably from 300–500 mm.

Nuh has experienced 18 moderate and 8 severe droughts in the last 100 years (Kumar NS *et al.* 2016). Due to these extreme events and the region's high dependence on groundwater for irrigation, the groundwater table in Nuh is declining rapidly (Mehta 2020). Changes in long-term temperature and rainfall patterns hold critical significance for this agriculturally dominant

Table 2: Variables Hypothesized to Affect Farmers' Adaptation Decision

Variable	Description	Value	Adoption Typology Decision (Sign)
Household size	Number of family members	Number	−
Gender	Gender of household head	1= Female, 0 = Male	+/−
Age	Age of household head in years	Years	+/−
Experience	Farming experience of household head	Years	+/−
Farm size	Total landholding	Hectare	+
Access to formal credit	Access to formal credit	1 = Yes, 0 = No	+
Perception of change in climatic factors (temperature and rainfall)	Perception of change in climatic factors	1 = Yes, 0 = No	+
The severity of the impact on livelihoods due to the change in the state of the climate*	Severe impact of climate change and associated hazards	1 = Yes, 0 = No	+
Anxiety about future climate-related risks **	Concerned about future changes in climate	1 = Yes, 0 = No	+
Institutional affiliation	Association with government or private institution (NGO)	1=Yes, 0 =No	+

Notes:

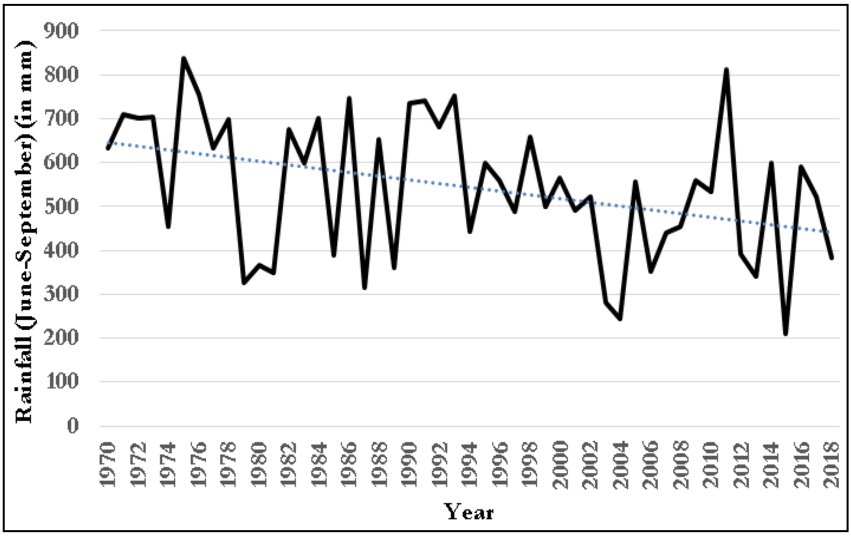
* The data on the severe impacts of climate change were obtained from the farmers on the Likert scale (strongly agree, agree, indifferent, disagree, and strongly disagree) but recoded as binary variables for the analysis of its role in adaptation—we marked responses with "strongly agree" or "agree" as 1 and "indifferent", "disagree", or "strongly disagree" as 0. The variables considered for the severe impact of climate change include a decline in farm income, reduction in crop productivity, and loss of indigenous crops.

** The data on anxiety or concern about future climate change was obtained from farmers on the Likert scale (strongly agree, agree, indifferent, disagree, and strongly disagree) but recoded as binary variables for the analysis of its role in adaptation—we marked responses with "strongly agree" or "agree" as 1 and "indifferent", "disagree", or "strongly disagree" as 0.

Source*:* Authors' analysis

region. To comprehend rainfall trends in Nuh district, we use data sourced from the Indian Meteorological Department (IMD) for the four primary months of June, July, August, and September, when the most precipitation occurs. The data unveils a declining trend in rainfall,[12] characterized by a coefficient of variation of 29% (Figure 2).

Figure 2: Trends in Rainfall in Nuh



Source: Author, using Indian Meteorological Data (2023)

To analyse the change in long-term temperature patterns, we measured changes in the mean of the maximum and minimum values over the last three decades, i.e., 1986–2015.[13] The data revealed a consistent rise in minimum temperature values and little change in the maximum temperature values during this period (Figure 3). The shifts in the long-term rainfall and temperature patterns signify climate change in the region; they carry potential implications for cropping cycles, water availability, and cropping patterns.

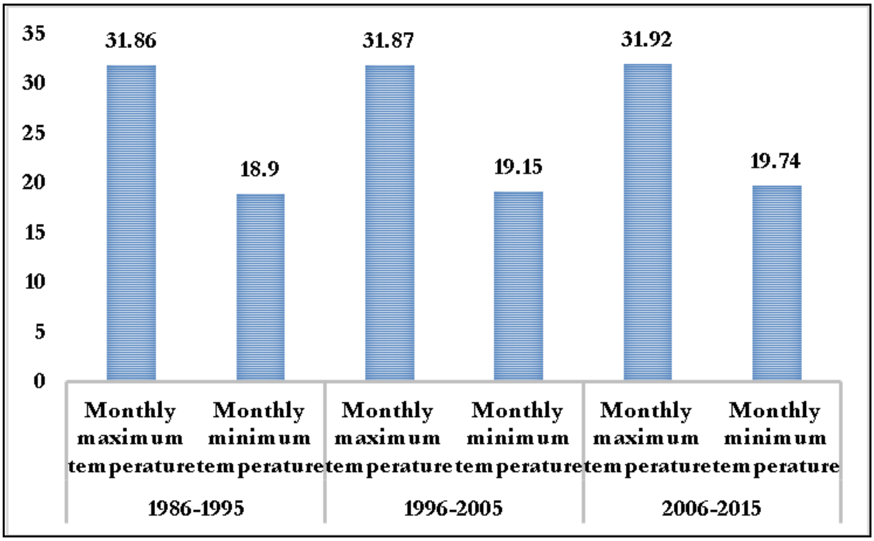
Rainfall and temperature affect crop yield directly and indirectly through changes in potential evapotranspiration (PET) and soil moisture. Soil moisture content (SMC) is directly connected with the process of evapotranspiration (ET)—a process by which water is transferred from the

[12] In Nuh district, the average rainfall (a five-year moving average) in the 1970s was 650 mm over four months (June, July, August, and September). It declined to a five-year moving average of 450 mm over the same four-month period by the end of 2018.

[13] The IMD data is available only until the year 2000. For 2001–2015, we used data from ICRISAT. No reliable source contains data for 2015 and onwards.

soil compartment and vegetation layer to the atmosphere (Verstraeten *et al.* 2008). Mitra *et al.* (2021) calculated PET for the Nuh district using the Thornthwaite method and demonstrated an increasing PET trend, indicating the loss of soil moisture and rising dryness in the region (Figure 4). The trend in climatic factors at the district level indicates that over this period, the temperature increased along with declining precipitation, resulting in an increase in dryness and loss of soil moisture.

Figure 3: Temperature (in °C) Pattern Change in Nuh

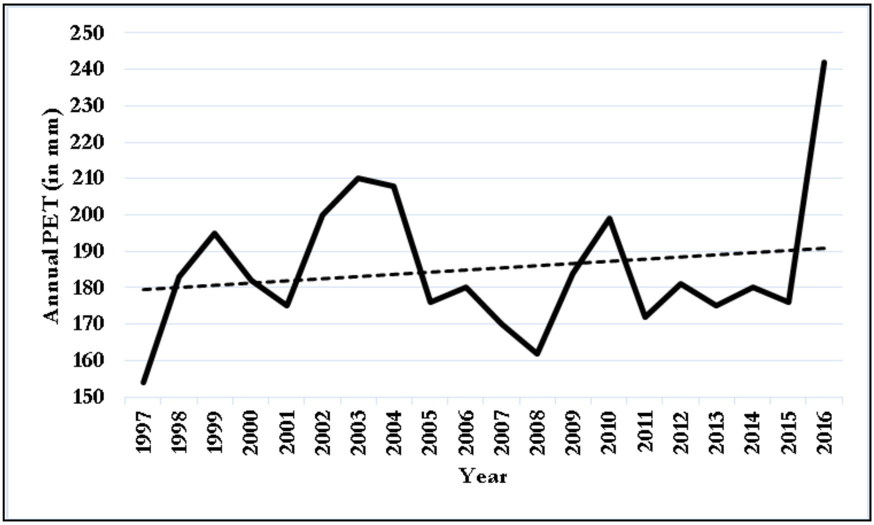


Source: Authors using IMD and ICRISAT (2023).

To tackle challenges arising from climate change, the state of Haryana formulated a comprehensive climate change plan applicable to all 22 of its districts, including Nuh.[14] The climate change policy encompasses a range of programmes that address environmental issues, with a focus on water resources, forestry, agriculture, and animal husbandry (Government of Haryana 2011). Key initiatives include the development of a state water policy, schemes for enhancing land productivity, and the implementation of the National Agricultural Insurance Scheme. The Haryana Forest Department initiated an extensive afforestation programme in line with its comprehensive State Forest Policy, 2006. Forestry initiatives encompass both adaptation and mitigation projects, incorporating practices such as the

[14] Nuh does not have a district-specific climate change policy. The district is part of Haryana, which introduced a comprehensive state climate change policy in 2011 that covers all 22 districts, including Nuh.

Figure 4: Increasing Trend of Annual PET (in mm) of Nuh



Source*:* Author, using data from Mitra *et al.* (2021)

adoption of short-rotation species and sustainable harvesting. The Departments of Agriculture and Animal Husbandry identified research areas to strengthen climate resilience. The Haryana Irrigation Department proposes measures such as establishing a water database and implementing real-time water quality monitoring. The Integrated Watershed Management Programme focuses on micro-watershed projects, demonstrating a significant financial commitment to addressing climate change in Haryana (Government of Haryana 2011).

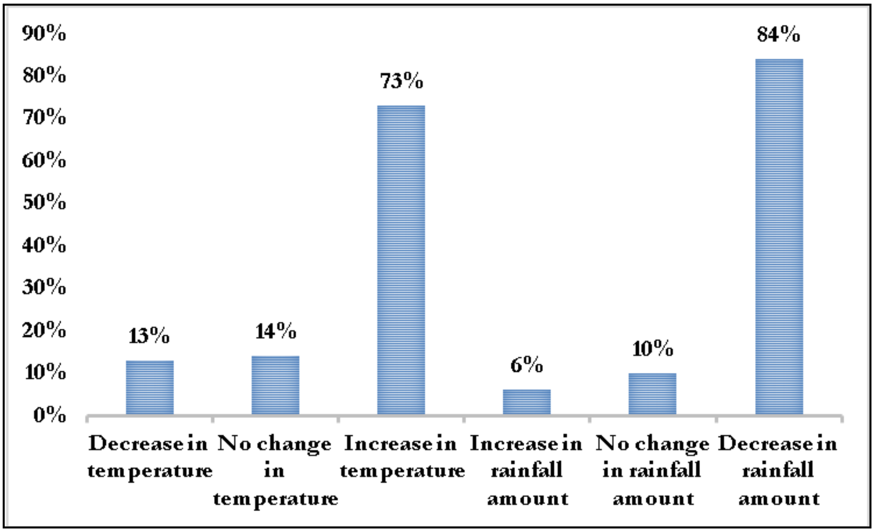
4. FARMERS' PERCEPTIONS OF CLIMATE CHANGE AND ITS OBSERVED IMPACT

Farmers perceive climate change by observing variations in climatic factors (Alam *et al.* 2017; Banerjee 2015; Datta *et al.* 2022). In the previous section, we revealed that there have been climatic changes in Nuh in terms of a rise in the minimum temperature and a downward trend in rainfall. In this section, we delve into farmers' perceptions[15] of temperature and rainfall variations, their observation of the impact of climate change manifested through hazards, and their anxiety regarding future climate-related risks.

[15] The Cambridge Dictionary describes the meaning of perception as "a belief or opinion, often held by many people and based on how things seem".

The variables used to capture farmers' perceptions of climatic change related to changes in temperature and rainfall patterns over the last 30 years. The responses reveal that 86% of the farmers noticed changes in the trend of climatic factors—temperature and rainfall—while 14% did not observe any such changes. Among those who perceived shifts in climatic factors, the majority (84%) reported a decreasing trend in rainfall, while 73% observed an increase in temperature (Figure 5). While farmers in the district have not encountered any flood-like situations, they observed an increase in rainfall intensity. This means that more rainfall occurs over shorter durations, accompanied by a decrease in the number of rainy days per year. The information on rainfall and temperature collected from farmers corroborates macro- and district-level trends. In Nuh, community radio disseminates daily and long-term information on climatic factors, accompanied by periodic discussions on the issue. We observed that a substantial majority of farmers (more than 90%), who perceived a change in climatic factors, regularly access such information through the community radio.

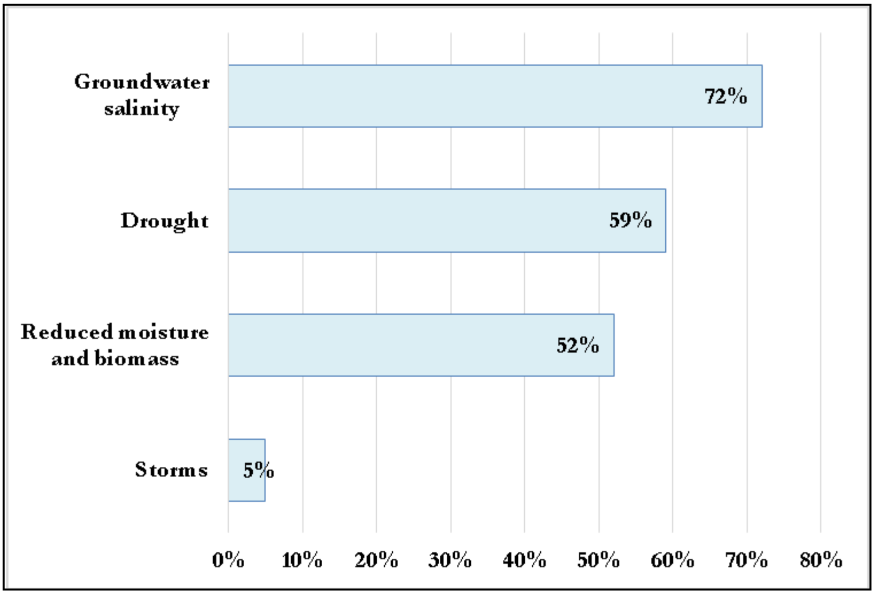
Figure 5: Farmers' Perceptions of Changes in Climatic Factors



Source: Author, using data from primary survey

Long-term changes in temperature and rainfall may lead to various hazards, prompting farmers in dryland areas to undertake responsive measures (Jodha *et al.* 2012). We obtained information from the sampled farmers about the hazards they have encountered over the past 30 years. The results indicate that farmers have witnessed several hazards, such as droughts, storms, an increase in groundwater salinity, and the loss of soil moisture and biomass (Figure 6), with groundwater salinity emerging as the predominant issue. Following this, over 50% of the farmers reported having experienced droughts and a decline in soil moisture. Incidents of storms are infrequent.

Figure 6: Hazards Experienced by Farmers in Nuh



Source: Author, using data from primary survey.

The perceptions of farmers are shaped by both changes in macro-climatic factors and the critical levels and productivity of resources essential for their livelihoods and families (Niles and Mueller 2016). We used the Likert scale to collect data on select parameters from farmers based on their perceived changes in resource levels and productivity. The results indicate that climate change has had a significant impact through changes in climatic factors and hazards that have affected resources, particularly the loss of indigenous crops (Table 3). In the past, farmers could cultivate a variety of commercial crops, primarily pulses, with sufficient rainfall and non-saline groundwater. However, successive droughts in the late 1990s led to increased groundwater salinity, compelling farmers to stop producing most indigenous commercial crops, especially pulses. Currently, farmers are only cultivating commercial crops such as mustard, wheat, and some vegetables, with pulses scarcely grown in the region. Over 70% of farmers believe that indigenous crops have disappeared primarily due to groundwater salinity.

Table 3: Key Outcomes of Climate Change and Farmers' Concerns about Future Climate Change Impacts

	Strongly Agree	Agree	Indifferent	Disagree	Strongly Disagree
Key Outcomes of Changes in the State of the Climate					
Decline in productivity of major crops	54%	10%	14%	16%	06%
Loss of indigenous crops[1]	73%	8%	02%	12%	05%
Decline in the availability of fresh drinking water	58%	10%	10%	17%	05%
Increase in the cost of production	32%	16%	18%	25%	09%
Decline in farm income	35%	10%	25%	14%	16%
Decrease in the number of livestock	26%	12%	19%	27%	16%
Increase in the incidence of pests and diseases	52%	10%	13%	16%	9%
Increase in land degradation	37%	8%	15%	28%	12%
Concern about Climate Change in the Future					
Extreme weather events will happen more frequently in the future	34%	20%	25%	19%	2%
Concerned about the potential impacts of climate change on the farm operation	30%	22%	34%	13%	1%

Source*:* Authors' analysis

Moreover, groundwater salinity has contributed to a decline in the availability of potable water and has reduced crop productivity. In general, farmers assert that groundwater salinity is the primary hazard impacting their incomes and lives. Other hazards, such as intense rainfall, have a comparatively lower impact on key outcomes related to their livelihoods.

Climate change is already underway; it is anticipated to continue affecting society in the coming decades (Schipper 2007). Concerns about future climate change and its potential effects were found to influence farmers' responses (Howden *et al.* 2007). Drawing from Arbuckle *et al.* (2015), we consider two questions regarding farmers' climate concerns: whether farmers believe that extreme weather events will occur more frequently in the future and whether the individual farmer is concerned about the potential impacts of climate change on their farm operations. We used the Likert scale to obtain data from farmers on these two parameters. A majority of farmers expressed concerns about the future impact of climate change (Table 3), with over 50% either strongly agreeing or agreeing on these two aspects. Farmers exhibiting greater concern about future climate change are expected to adopt anticipatory strategies to address its effects.

5. FARMERS' RESPONSES TO CLIMATE CHANGE IN NUH

Farmers' perceptions of climate change serve as a precursor to their adaptation efforts (Alam *et al.* 2017). Once farmers recognize climate change and observe its impact on their incomes and risk, they respond in various ways (Adger *et al.* 2003; Levina and Tirpak 2006). The responses depend on several factors, including farmers' perception of changes in climatic factors and their impact on key resources, social conditions, and the support provided by local institutions, among others (Datta *et al.* 2022).

In Nuh, farmers confront several challenges, including groundwater salinity, water scarcity, and a marked decline in crop productivity. These challenges have not only resulted in a decline in farm incomes but have also affected their overall livelihoods. In an effort to grapple with these adversities, farmers have resorted to an array of adaptive strategies—intensification of fertilizer use, seasonal and distress-led out-migration, augmentation of irrigation practices, crop diversification,[16] integration of saline-resistant crop varieties, adoption of soil and water conservation techniques, and reclamation of degraded land (Figure 7).

When presented the twelve adaptation strategies,[17] Nuh farmers often replied that they have adopted multiple strategies to address the emerging challenges. Notably, the most prevalent adaptation strategies in Nuh are intensification of fertilizer use, seasonal migration, and adjusting the timing

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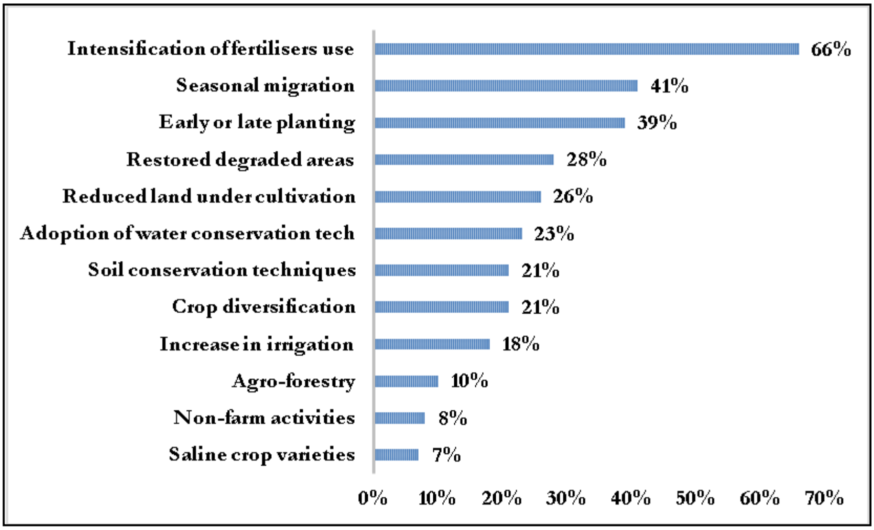
[16] Crop diversification refers to the agricultural practice of cultivating a variety of crops instead of relying on a single crop or a few crops. Crop diversification has the potential to mitigate risks associated with environmental factors, market fluctuations, pests, and diseases. By cultivating different crops, farmers aim to enhance resilience to adverse conditions and improve overall farm sustainability.

[17] The selection of strategies is based on our review of the literature and focus group discussions with farmers.

Figure 7: Adaptation Strategies Adopted by Farmers in Nuh[18]



Source*:* Author, using data collected through primary survey.

of crop seed planting. Intensification of fertilizer use stands out as the predominant strategy, as it has been adopted by a significant share (66%) of surveyed farmers. This underscores its significance as a primary response to the challenges posed by climate change and its repercussions for agricultural land. As rainfall dwindled and groundwater salinity levels surged, a significant number of farmers made the difficult decision to discontinue the cultivation of indigenous crops, particularly commercial crops such as pulses, as cultivation on the once-fertile land became unviable. Increasing groundwater salinity further compounded the predicament, forcing farm families to rely on purchased drinking water. The consequential reduction in the production of commercial crops, coupled with the heightened scarcity of drinking water, precipitated a dire situation for numerous resource-poor farmers, compelling them to explore alternative avenues of generating cash to purchase essential drinking water.

Given the centrality of farming to livelihoods, and the limited institutional support available in Nuh, farmers resorted to intensifying fertilizer use to augment crop productivity. While this approach can yield higher

[18] The farmers' response includes anticipatory strategies—including the use of saline crop varieties, agro-forestry, soil conservation techniques, water conservation techniques, and crop diversification—and reactive strategies, including restoring degraded land, reducing land under cultivation, intensifying fertilizer use, adopting non-farming activities, and opting for seasonal migration.

productivity for select crops, it is not without its caveats. There is tangible evidence of the potential long-term adverse impacts of fertilizer use on land productivity (Mehta 2020; Datta *et al.* 2022). In interviews, farmers candidly disclosed their conundrum—they grapple with an increase in agricultural pests and diseases coupled with persistently low crop yields, leaving them with little recourse but to lean on additional fertilizers to enhance the productivity of their crops. This underscores the complex trade-offs that farmers must navigate as they address immediate challenges while negotiating the need to sustain the long-term viability of their farming practices.

Moreover, a considerable number of farm families (41%) have opted for seasonal migration, with family members migrating to work as labourers in neighbouring districts and states. These seasonal migrants have also decreased their cultivated area, mainly due to a decline in the cultivation of indigenous commercial crops. Approximately 8% of farmers have diversified their income sources by incorporating non-farm activities, primarily by establishing shops or working in local organizations. Furthermore, in response to the reduced income, 28% of farming households have even restored to cultivating crops on degraded (less fertile) land. Roughly one-fifth of farmers have adopted water conservation technologies and soil conservation methods, while agro-forestry has been adopted by one-tenth of the farmers studied. Though groundwater salinity is a major hazard, only 7% of farmers use saline seed varieties. There is a lack of effort from the government and private institutions to promote saline crop varieties in the region. As a result, local farmers are compelled to travel to the neighbouring district of Karnal to acquire these seeds, which are only available for wheat and mustard crops.

6. TYPOLOGY OF FARMERS' ADAPTATION AND ITS DETERMINANTS

In the face of climate change and the associated hazards, farmer communities in Nuh find themselves consistently pressured to adjust and adapt to survive and sustain their incomes. However, it is also imperative for farmers to adopt anticipatory adaptive strategies that mitigate their vulnerability to future climate change (IPCC 2001; Baede *et al.* 2001). Reactive strategies are undesirable, as they may result in maladaptation and further increase farmers' vulnerability to future climate change (Schipper 2020).

We distinguish the sampled farmers based on the adoption of anticipatory and reactive strategies. Anticipatory measures encompass a spectrum of initiatives—water conservation techniques, agro-forestry, soil conservation practices, crop diversification, and the use of saline-resistant seed varieties. These forward-looking strategies, which are inherently long term, equip farmers to confront anticipated climate change and the associated hazards, thereby enhancing their resilience to future environmental shifts. Conversely, the remaining strategies predominantly fall under reactive or short-term approaches designed to address past or ongoing climate-related challenges.

The results indicate that 27% of the sampled farmers have adopted at least one of the outlined anticipatory strategies. The farmers' adaptive responses to climate change are influenced by myriad factors, including socioeconomic, psychological, institutional, and technological considerations. Our analysis specifically considers social, economic, psychological, and institutional factors. Among the 10 independent variables in the model, four variables, i.e., farm experience (coefficient = 0.451, $p < 0.10$), institutional association (coefficient = 0.970, $p < 0.10$), the severity of perceived impact of climate change (coefficient = 4.067, $p < 0.01$), and access to formal credit (coefficient = 1.777, $p < 0.01$) were significant, and all these factors were found to positively influence the adoption of anticipatory strategies (Table 4).

These findings suggest that farmers with more farming experience are more inclined to adopt anticipatory strategies in response to climate change. This inclination may stem from their exposure to a broader range of climate variability, leading them to place a higher value on the importance of proactive measures. The propensity to adopt anticipatory adaptation decisions is also closely linked to access to credit facilities, demonstrating a positive correlation with improved access to formal credit sources. Given the capital-intensive nature of many anticipatory strategies, such as water conservation technologies, it becomes pivotal to consider the financial constraints of most farmers. We underscore that access to credit not only alleviates the capital constraints associated with the adoption of costly technologies but also expands the range of adaptation options available, thereby diminishing farmers' reliance on coping mechanisms. Access to formal credit in the Nuh district of Haryana can be improved by enhancing the reach of the banking system.[19] This can be achieved through a

[19] Nuh has the fewest banks in Haryana, with an average of 26,600 people per bank, compared to 64,000 in other districts. Due to the reduced availability of banks, the proportion of households availing bank services is lowest in Nuh. Only 41% of all households in Nuh avail bank services, whereas other districts in Haryana have a slightly higher percentage (70%) of households accessing bank services (Mehta 2015). Also, due to the absence of a self-help group, people in Nuh are dependent on either banking or other

concerted government push to expand the accessibility and availability of banking services. Measures like establishing new bank branches, mobile banking units, and automated teller machines (ATMs) in key locations can significantly enhance financial inclusivity. Fostering collaboration among the government, financial institutions, and the community is crucial in establishing a more comprehensive and effective banking infrastructure in Nuh district, which can ultimately contribute to the socioeconomic development of the region.

Interestingly, we found no significant associations between farmers' perceptions of changes in climatic factors (temperature and rainfall), anxiety about future climate change, farm size, and adoption of anticipatory strategies. The findings indicate that farmers who have experienced severe impacts due to climate change and the associated hazards exhibit a greater inclination towards adopting anticipatory strategies. This suggests that the tangible impacts of climate change play a more pivotal role in influencing farmers' adoption of anticipatory measures rather than their subjective perceptions of climatic factors. Although approximately 50% of farmers expressed concerns about future climate change, we identified a noteworthy paradox—a significant portion remains unable to adopt planned strategies despite their apprehensions. The key drivers that support farmers' transition from reactive to proactive strategies also include collaborative partnerships with local NGOs or governmental organizations. Government extension services and partnerships with NGOs could have a dual impact: increased awareness among local communities about the significance of new sustainable technologies and the provision of practical support to local farmers in adopting these practices or new technologies. Such a collaborative approach not only empowers farmers with knowledge but also offers tangible assistance for the implementation of sustainable practices. This helps farmers better handle challenges resulting from climate change, reducing their vulnerability to future climatic changes. By working together with the government and non-governmental groups, farmers can more easily adopt proactive measures to deal with the changing climate.

Overall, the results highlight that upon perceiving changes in climate variables and experiencing hazards, farmers employ various adaptation measures. In Nuh, farmers are predominantly implementing strategies to combat groundwater salinity, a hazard that adversely affects farming outcomes and simultaneously necessitates a reliance on purchased drinking water for survival. Due to the absence of supportive mechanisms, most farmers adapt through the intensification of fertilizer use, out-migration, or

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informal sources for credit.

other coping mechanisms. A limited number of farmers choose to use saline seeds and climatic conservation technologies, which require additional investments and resources. While access to climate information is pivotal in influencing farmers' perceptions of climate change, mere access to information alone is insufficient for effective climate change management. It is crucial to comprehend the various associated hazards in the region and identify which ones prompt more responses from farmers and influence their adaptation patterns. This understanding can aid policymakers in identifying gaps in adaptations and addressing the situation through policy actions (McKinley *et al.* 2021).

Table 4: Determinants of Farmers' Choice of Anticipatory or Reactive Adaptation Strategies

Variables	Coefficient	Standard error	Wald	P-Value
Age	0.018	0.015	1.434	0.231
Gender	−0.909	0.482	3.552	0.159
Household size	0.004	0.008	0.001	0.975
Farm size	0.058	0.356	0.026	0.872
Experience	0.451	0.377	0.000	0.017**
Institutional association	0.970	0.388	6.244	0.012**
Perception of change in climatic factors	0.310	0.441	0.493	0.483
Severe impact of climate change and associated hazards	4.067	0.512	63.059	0.000*
Anxiety about future changes in climate	0.089	0.091	0.953	0.329
Formal credit	1.777	0.395	20.207	0.000*
Constant	−2.990	0.924	10.468	0.001
Notes: * and ** significant at $p < 0.01$; and $p<.10$ Log likelihood = 225.979; Pseudo R2 (Cox and Snell R2 = 0.370; Nagelkerke R2 = 0.569).				

Source: Authors' analysis

Furthermore, it is imperative that both the government and NGOs expand their outreach so that more farmers can respond to current changes in climate and enhance their resilience to future climate change. Additionally, access to formal credit is vital for farmers to adopt anticipatory strategies, which can be financially demanding. Even farmers with small farms can embrace anticipatory strategies given the availability of low-cost credit, especially when they perceive the high impact of climate change on their income and risks.

7. SUMMARY AND CONCLUSIONS

Nuh district, an aspirational district in India, faces severe challenges due to climate change—particularly its agricultural sector. The intrusion of salinity in the late 1990s initiated a chain of events that led to impoverishment. The meteorological data from Nuh highlights a reduction in rainfall, increased intensity of rainfall, and a rise in the minimum temperature, resulting in a significant decline in crop yield, soil erosion, and loss of indigenous crop varieties. This adversely affects the livelihoods of farmers who heavily rely on agriculture. In this paper, we explore the adaptive strategies employed by farmers in response to climate change and examine the role of perceptions vis-à-vis other institutional and socioeconomic factors in their choice of adaptation. Our findings underscore the need for comprehensive policies to promote sustainable practices.

Farmers in Nuh employ coping mechanisms and adaptations to optimize income and manage the risks arising from climate change and associated hazards. The adoption of anticipatory strategies, such as implementing soil and water conservation technologies or diversifying crops, contributes to environmental sustainability, incomes, and food security. However, certain responses to climate change that are mainly reactive in nature—such as intensifying fertilizer use—pose threats to land resource productivity. Existing policies that focus on short-term climate risks lead many farmers to adopt reactive strategies, with only 27% adopting anticipatory strategies. Factors that influence these strategies include the observed impact of hazards, affiliations with NGOs and governmental institutes, and access to formal credit. We find no significant associations between farmers' perceptions and the adoption of anticipatory strategies, emphasizing the tangible impact of lived experiences of climate change.

For Nuh district, comprehensive climate resilience policies addressing short-term risks and long-term challenges are crucial. We recommend integrating climate-resilient practices into agricultural policies, enhancing institutional support, and creating local resource centres for information dissemination. Increasing formal credit availability, fostering public–private partnerships, and promoting community engagement and awareness are essential. By implementing these recommendations, policymakers can empower Nuh's farmers to cope with immediate challenges and build resilience against future climate change, ensuring agricultural sustainability.

Ethics Statement: I hereby confirm that this study complies with requirements of ethical approvals from the institutional ethics committee for the conduct of this research

Data Availability statement: Sources for secondary data used have been given against respective figures and tables. Remaining data was collected through primary survey.

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