Farmers' Perception, Adaptation to Groundwater Salinity, and Climate Change Vulnerability: Insights from North India

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ABSTRACT: Groundwater salinity, caused by overextraction and aggravated by climate change, negatively affects crop productivity and threatens global food security. Poor farmers are vulnerable because of low adaptive capacity. A better understanding of their perceptions and adaptation is important to inform policies for successful adaptation. This paper represents an important study by exploring the same in Mewat, a salinity-affected socioeconomically disadvantaged district of northern India. The study uses a mixed-method approach with both secondary data and a primary survey of 250 farmers. A large number of farmers perceived negative impacts on water, crop, income, and assets, and they adapt in various ways such as water, crop, and land management; livelihood diversification; and a shift toward surface water irrigation. Perceived impacts differed between richer and poorer farmers, whereas adaptation measures varied across the educational, social, and economic backgrounds of farmers. Lack of awareness, education, skill development, and livelihood opportunities are found to be hindrances, whereas institutional and infrastructural support are facilitators of adaptation. In comparing the findings with global experiences, we argued that developed countries intervene more in the policy level and infrastructure, whereas in developing countries, adaptation strategies are local, context specific, and low cost. The insights from our study will be useful for intervention in Mewat and similar areas across the developing world. We further argue that farmers make adaptation decisions on the basis of perceived impacts and cost–benefit analysis. Therefore, future research work on quantifying the negative impacts and cost–benefit analysis of various adaptation measures will be useful to ensure successful adaptation in the region and beyond.

KEYWORDS: Climate change; Salinity; Statistical techniques; Adaptation; Agriculture

1. Introduction

Groundwater depletion and increase in salinity are serious threats to the future of sustainable agriculture (Pulido-Bosch et al. 2018). Nearly 70% of global extractions take place only for irrigation purposes (Birkenholtz 2017). Apart from the increased extraction, another major reason behind groundwater salinity is climate change (Akbari et al. 2020; Earman and Dettinger 2011). Thus, in the future, the problem can act as a major threat to global food security. The largest number of food-insecure people live in South Asia (IPCC 2014). The problem is crucial for India, the biggest country in South Asia, where food security is to date a major issue, and around 55% of the workforce is directly dependent on the sector (Government of India 2021). Moreover, according to the Global Climate Risk Index 2021, India is among the 10 most affected countries. Therefore, adapting the agricultural sector to the negative effects of climate change is necessary to ensure the food and livelihood security of the country.

The groundwater salinity problem is not new in India, and it has been there since a century ago along the coasts and in island systems. However, the inland groundwater salinity problem is increasing in recent times in arid and semiarid regions of northern India (Krishan et al. 2020a). Back in the mid-1960s a new agricultural strategy, popularly known as the "Green Revolution," was implemented in north India to attain self-sufficiency in food grain production. This new agricultural strategy was implemented with intensive agriculture practices—use of high-yielding variety (HYV) seeds, chemical fertilizers and pesticides, and irrigation facilities. As a result, agricultural productivity increased significantly, but at the cost of soil degradation due to excessive use of fertilizers and pesticides and overexploitation of groundwater (Singh 2000). For example, in India, almost 90% of groundwater is extracted for irrigation purposes only (Shah 2009). At the same time, approximately 7 million hectares of land have been affected by salinity (Shrivastava and Kumar 2015). Unless mitigating attempts are taken, the area is estimated to increase from 7 to 16 million hectares by 2050, making large areas of cultivable land completely barren (Mandal et al. 2018).

Haryana, the northern state of India, which has been one of the implementing states of the Green Revolution, is suffering from the depleting table of fresh groundwater and increasing table of saline groundwater. Nearly 60% of areas of the state fall in the category of overexploited and critical zones (Mehra et al. 2012). The application of saline groundwater for irrigation is one of the major constraints of agriculture in the state in recent times (Mandal et al. 2016). It is causing economic losses to the farmers as well. Datta and De Jong (2002) estimated economic loss to be around USD 37 million for Haryana due to waterlogging and salinity. Smallholder farmers of the state are more vulnerable to adapt to the changing situation. A better understanding of their perceptions is important to inform policies aimed at promoting successful adaptation.

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This paper presents an empirical study in the Mewat (recently renamed as Nuh) district of Haryana. Mewat is one of the most socioeconomically disadvantaged districts of not only Haryana but also of the country, despite its proximity to the national capital New Delhi. Among other factors, the impoverishment of the district is largely due to groundwater salinity (Mehta 2015). Although the entire Haryana state is facing salinity issues, the excessive problem in this southern district of Haryana has its distinct geoclimatic history. Since long ago, salts have been drained from the Himalayas and Shivalik ranges through rivers/streams and accumulated at the alluvial plains, particularly in the southern and western parts of Haryana, where the Mewat district is located (Tanwar and Kruseman 1985). The digital elevation data shows depressions in the central part (Krishan et al. 2020b), giving a unique bowl shape to the district. Moreover, due to the lack of any natural drainage outlet, the salt settled at the lower level of the groundwater table at the bottom of that bowl. In the late 1990s, three consecutive droughts took place, which resulted in rapid extraction of the groundwater. Soon after that, farmers witnessed excessive saline groundwater coming out in many parts of the district. Presently, only 22% of the district has nonsaline groundwater, whereas 78% area has saline groundwater (Borana 2012). The increasing groundwater salinity has become a major threat to the well-being of people in the region at present, as 88% of the population is still engaged in agriculture (Mehta 2015). In this background, the present paper explores how farmers perceive salinity-related socioeconomic impacts, and what are the strategies and extent of adaptation in the district. Despite growing behavioral and attitudinal data on climate change in developed countries, less is known about the determinants of climate behaviors in developing countries. This paper is an attempt to add value to the existing literature in that direction. The findings of this paper offer insight into necessary interventions to ensure effective and efficient adaptation strategies in the region and beyond.

2. Conceptual framework

Groundwater is generally considered to be saline when the contents of dissolved solids are above 1000 mg per liter of water (Pulido-Bosch et al. 2018). With repeated irrigations with saline groundwater, the salts get accumulated in the soil. According to Ayers and Westcot (1985), the soil salinity is generally 1.5 times irrigated water salinity. Since the plant has to use more energy to absorb relatively salt-free water instead of using it for growth, flowering, or fruiting, it limits the plant's ability to grow (Blaylock 1994). Increased salinity not only reduces yield but also nutritional and economic value, cumulatively resulting in a reduction in farmers' revenue (El-Fadel et al. 2018).

The salinity problem gets aggravated by climate change. Climate change affects both the quality and quantity of available groundwater, directly through impacts on recharge and evapotranspiration, and indirectly via an increase in extraction (Earman and Dettinger 2011). Climate change affects both precipitation amounts and intensity, which result in increased runoff and low recharge (Gosain et al. 2011). An increase in temperature and shortening of monsoon results in higher potential evapotranspiration, which leads to a lack of soil moisture and reduced groundwater recharge (Acharyya 2012; Carter and Parker 2009). Further, the increased frequency of droughts also increases the growing concern of salinity (Corwin 2021).

Farmers are the most important stakeholders, and a better understanding of their perception is important since adaptation is largely dependent on it (Deressa et al. 2011; Feola et al. 2015). Adaptation at the farmers' level is a two-step process: first, perceiving climate change and its associated risks; second, responding to perceived changes to minimize their adverse impacts (Tripathi and Mishra 2017). Existing literature has focused largely on farmers' perception about climate change and climate variability but relatively less on perceived impacts (Debela et al. 2015; Madhuri and Sharma 2020). Farmers' perceptions of climate risk and their approaches to adaptation are also influenced by various socioeconomic–political factors (Gandure et al. 2013). Smallholder farmers of developing countries often become more vulnerable due to their low adaptability. According to the IPCC (2014), a system is vulnerable if it has more exposure, is more sensitive to climate-related risks, and has limited adaptive capacity. According to Füssel (2005), the extent of vulnerability is context specific.

3. Study area

The Mewat district was carved as the 20th district of Haryana state on 4 April 2005, from erstwhile Gurgaon and Faridabad districts. Mewat district has a geographical area of 1507 km^2 with a projected population of 1 249 359 in 2020.[1] The Mewat district is inhabited primarily by Meo-Muslims, a unique ethnic group that has been categorized as one of the other backward castes (OBCs) in India. The health and education scenario, particularly that of females, is poor, with only 37.6% of female literacy and nearly 60% of the child deliveries taking place at home (Ministry of Health and Family Welfare 2013). According to the Vision 2030 document of Haryana, Mewat has positioned among the bottom three districts as per the human development index (including health, education, and income) (Government of Haryana 2017). Agriculture is the primary occupation of the population of the Mewat district. It falls under the subtropical, semiarid climatic zone with extremely hot temperatures in summer. May and June are the hottest months of the year with the temperature ranging up to 48°C. The annual rainfall varies considerably from year to year, but almost 80% of the precipitation occurs during the monsoon (June–September). The total average annual rainfall during 2013 through 2017 was 548.3 mm (Government of Haryana 2019). Aravalli hill is spread over 199.65 km^2 in the district, separating it from the Thar Desert of neighboring state Rajasthan.

Mewat district comprises five blocks: Taoru, Nuh, Nagina, Punhana, and Firozpur (FP) Jhirka. There seems to be a direct correlation between groundwater availability and quality, and the economic development of blocks. For example, Mehta (2015) found substantial intradistrict diversity with Taoru

[1] Projected on the basis of 1 089 406 as per the latest census (Office of the Registrar General and Census Commissioner 2011).

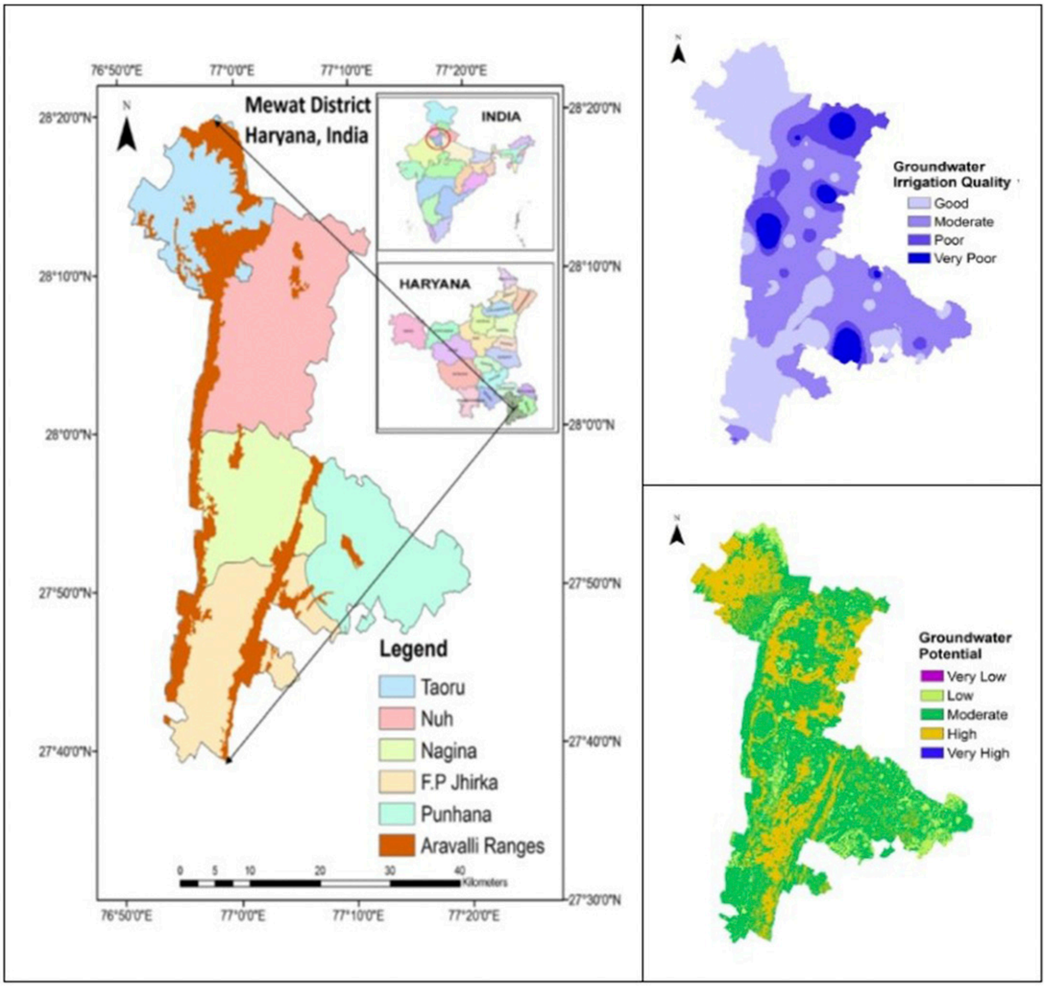

FIG. 1. Mewat district and its groundwater irrigation quality and potential, as compiled from Mehra et al. (2017; written consent to use these maps has been obtained by the corresponding author through email).

being the most developed and Punhana the least developed block. Now, Taoru and FP Jhirka are the two blocks that have a high potential of good quality groundwater, as compared with the Punhana, Nagina, and Nuh blocks (Fig. 1).

Interestingly, according to Mehta (2015), Nuh is the second-best developed block just after Taoru, despite its low potential and low quality of groundwater. This is because of the availability of canal water in Nuh block. In the Taoru and Nuh blocks, farmers can produce high-value crops like onion and tomato because of the availability of freshwater and can meet the demand of the national capital and surrounding rich neighborhood. This is not possible in the Punhana and Nagina blocks, particularly where high salinity has negatively impacted crop yield.

4. Method

The study has been conducted through a mixed-method approach using both primary and secondary data. To understand whether there has been a significant change in the actual trend of temperature, rainfall, evapotranspiration rate, and groundwater level in the region, secondary data was collected from the Indian Meteorological Department (IMD 2020) and Central Groundwater Board (2016). Mann–Kendall trend analysis (Karmeshu 2012) of long-term rainfall and temperature data has been done. Rainfall and temperature affect crop yield directly, as well as indirectly through a change in potential evapotranspiration (PET) and soil moisture. Based on the average monthly rainfall and temperature data, PET was calculated using the Thornthwaite method (Hamon 1960). Groundwater availability over 10 years from 2006 to 2016 has been captured by plotting groundwater levels in the region over the period using the geographical information system (GIS) tool. The study employed both quantitative and qualitative tools to collect primary data.

In India, the term "farmer" is not very clearly defined. Since adaptation measures are generally adopted by farmers who have their land, therefore, we purposely surveyed those farmers only. According to Government of Haryana (2019), there are around 76 000 landholders in Mewat district (including five blocks). Around two-thirds of them are marginal and small farmers (having up to 2 ha of land) and the remaining one-third are medium and large farmers (having more than 2 ha of land). We used a balanced random sampling by including 50 farmers from each block randomly. Five villages were selected from each block using random sampling. Ten farmers were selected from each village using a purposive stratified sampling technique to ensure the inclusion of different groups, such as women and farmers with different land sizes. Thus, a total of 250 landholding farmers were surveyed. Our sample size is justified with a 95% confidence interval and a 6% margin of error.

The survey was conducted during March–July 2019. To avoid the language barrier, the schedules were translated into the local language Hindi. The surveyors were from the same region and the pilot testing was done to ensure the use of the right words/language in the survey schedules. Since human participants were involved in the primary survey, we first introduced the study to them and then collected their consent before beginning the individual interview. The consent form was prepared in English as well as in Hindi. For the illiterate participants, it was read out in the local language before taking their thumb impression in the consent form.

During the survey, the farmers' perceived impacts of climate change-induced groundwater salinity were captured through the 5-point Likert scale, ranging from "strongly agree" to "strongly disagree." This was done to generate quantitative values at a comparable scale, for analyzing their perceived impacts over the last several years. The survey also explored various adaptation strategies used by these farmers. For analyzing the quantitative data, first, we did socioeconomic profiling of the surveyed farmers across the five blocks. Statistical significance of difference among the categorical variables was analyzed through chi-square techniques, whereas the mean difference of average income and the family size was explored through Student's t test. "Chi-square test for independence" is often used to explore whether distributions of categorical variables differ from each another or not. Student's t test is a type of inferential statistic used to decide if there is a significant difference between the averages (means) of two comparable groups.

Next, the impact perceptions, as well as adaptation strategies, were linked with their actual socioeconomic backgrounds. To analyze the vulnerability of the system, the significance of the difference of both the perceived impacts and adaptation strategies was tested in the context of the socioeconomic and educational background of the farmers, using chi-square techniques.

Further, four case studies were captured in four different sites across the Mewat district through in-depth interviews, to understand how perceived impacts, socioeconomic context, technology interventions, and institutional support determine adaptation and impact farmers' welfare. The case study method is often advocated to investigate a contemporary phenomenon when the research questions focus on the reasons and process, rather than only counting numbers (Yin 2017). Field observations and these four case studies substantiated and supplemented our survey data and statistical analysis. Narrative analysis of the case studies was done, and findings were assimilated under broad themes of determinants and impacts of adaptation.

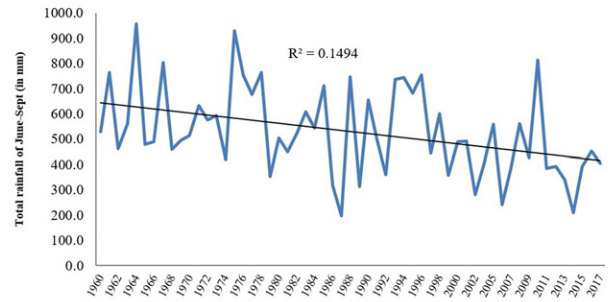

FIG. 2. The declining trend of monsoon rainfall of the Gurgaon region, as prepared by the authors using IMD data.

5. Findings

The findings on climate change and groundwater, socioeconomic profiling of the surveyed farmers, their perceived impacts, adaptation strategies, and impacts of adaptation on farmers' well-being are presented in the following subsections.

a. Trend of temperature, rainfall, evapotranspiration rate, and groundwater level

Climate change is generally referred to as environmental change for at least 30 years. Since the Mewat district was separated from the Gurgaon district recently in 2005, we have analyzed the rainfall of the entire Gurgaon region based on secondary data collected from IMD. Over the last six decades, monsoon rainfall has declined in the region. Figure 2 shows a mild downward trend (correlation coefficient squared $R^2 = 0.1494$) of monsoon rainfall (i.e., total rainfall of 4 months from June to September) from 1960 to 2017. The statistical significance of this downward trend is established by the Mann–Kendall test result, with both Kendall's tau (-0.265) and Sen's slope (-3.920) statistically significant at 1% level (significance p value: 0.004).

Although the average temperature was available for recent years, the maximum and minimum temperature was accessible only up to the year 2000. Therefore, we put the decadal trend of maximum–minimum temperature from 1965 to 2000 in Table 1. It shows that, although monthly maximum temperature remained more or less the same over the four decades, the monthly minimum temperature has increased over time. Figure 3 shows an increasing trend of potential evapotranspiration that indicates an increasing loss in soil moisture and rising dryness in the region.

The Mewat district is presently facing two challenges related to groundwater: first, the occurrence of the extreme salinity of groundwater in three blocks, particularly centrally situated Nuh and Nagina blocks between the Aravalli ranges, and Punhana block at the extreme right; second, the overextraction

TABLE 1. Decadal maximum–minimum temperature of the Gurgaon region, as calculated by the authors from IMD data.

	1965–75		1975–85		1985–95		1996–2000	
	Monthly max	Monthly min	Monthly max	Monthly min	Monthly max	Monthly min	Monthly max	Monthly min
Mean	31.8	16.7	31.6	17.0	32.2	18.1	31.2	18.9
Std dev	6.31	8.30	6.29	7.79	6.70	7.68	6.51	7.58

of the limited availability of fresh groundwater in a few of the pockets[2] of Taoru and FP Jhirka blocks.

Figure 4 shows that where groundwater has already become saline and difficult to use for irrigation or drinking purpose, the water level has increased over time. In some of the aquifers, the groundwater level has increased to such an extent that it often leads to a waterlogging problem. On the other hand, in the freshwater pockets in Taoru blocks, groundwater is depleting continuously over the last decade. The color legend of Fig. 4 has captured this drastic shift (from blue to red). The other freshwater pocket of FP Jhirka got recharged due to good rainfall in 2011, but once again moved toward rapid depletion in the next 5 years between 2011 and 2016.

b. The socioeconomic profile of the surveyed farmers

The descriptive statistics of the socioeconomic data of the 250 farm households, disaggregated by blocks, are presented in Table 2.

In the two developed blocks, namely, Taoru and Nuh, more than 60% of household heads are at least primary school educated, whereas in the rest of the blocks nearly half of the surveyed household heads are illiterate. In all five blocks, around 95% of families are headed by male members. The average annual household income is USD 1,086.67,[3] which is comparable to some economically disadvantaged regions of the country, but it is even less than half of the average annual household income of the state of Haryana (USD 2,363.15) (Ranganathan 2015). Nearly 90% of the surveyed farm households possess marginal to small landholding (up to 2 ha of land). Only in Nuh block, nearly 20% of farm households have farm size more than that. Moreover, the average family size is 7.03, which is much higher than the average rural family size of India (4.9) and Haryana (5.4) (Office of the Registrar General and Census Commissioner 2011). The average family size is lowest (6.03) in Taoru followed by Nuh (6.91), the two comparatively developed blocks. However, neither the t test nor the chi-square test shows a significant difference in these cases. The only significant difference is found in the case of social categories. In the total sample, nearly 80% of the farm households are Meo-Muslims (which fall under the OBC category). The share of Meo-Muslims is less than 60% in the comparatively developed Taoru block, and this difference is significant at 1% level, in the chi-square test.

c. Farmers' perceptions of socioeconomic impacts

Various types of socioeconomic impacts of climate change-induced groundwater salinity have been identified in the Mewat district. We captured farmers' perceptions on those different types of impacts through the Likert scale and broadly clubbed those as water, crop and income, and assets related impacts (Table 3). The total number of responses exceeds 250 since multiple responses were allowed.

1) WATER-RELATED SOCIAL IMPACTS

Nearly 80% of farmers agreed that there has been an increase in cost and time to arrange drinking water. Increased groundwater salinity in the Mewat district has caused the community to shift its source of water from local wells to distant water storage units. These storage units draw water from limited sweet groundwater pockets located in the foothills of Aravallis. Drinking water is supplied to some of the nearby villages by the government through underground pipes. However, the treated government water supply is accessed by around 20% of households in the district. For the rest of the residents, buying water through local water merchants is the only option. The water price is USD 12–13 per tank. For an average family size of 6–7 people, this amount is sufficient for 15 days. Therefore, an average family spends around USD 25 only on drinking water per month. This is almost one-quarter of the monthly average income. Moreover, the price charged by private tankers varies depending on the distance traveled to deliver water and also increases during summers due to high demand.

In the backdrop of low household income, it is difficult to spend nearly 25% of the monthly income only on purchasing drinking water. For nondrinking use, inhabitants rely on scattered sources such as water from untreated sources, uncovered wells, tube wells, and ponds. The young girls and women in the economically weaker households (mainly landless laborers and

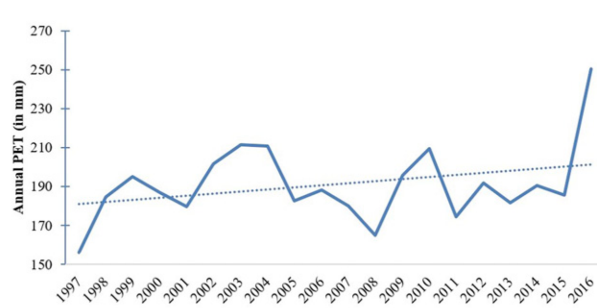

FIG. 3. Increasing trend of annual PET of the region, as prepared by the authors using IMD data.

[2] Pockets refer to "tract in an underground layer of water-bearing permeable rock (aquifer)."

[3] At the exchange rate of USD 1 = INR 73.70 on 26 September 2020.

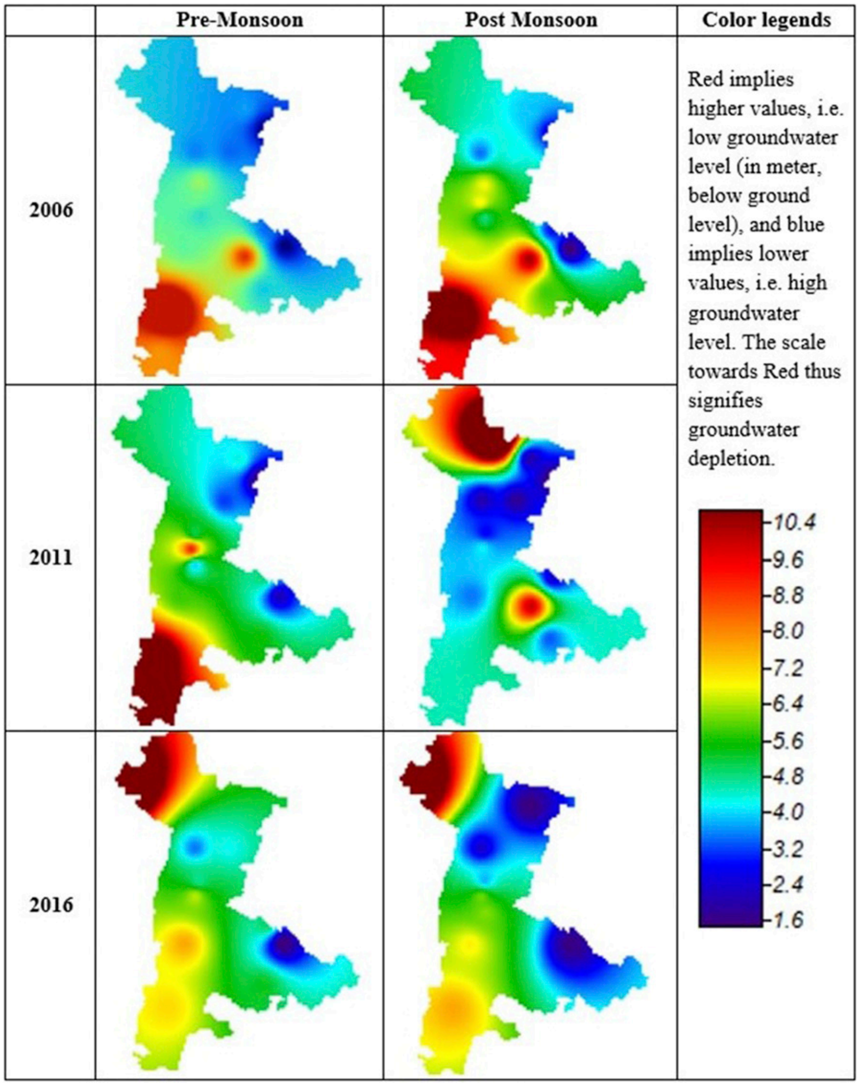

FIG. 4. Decadal trend of groundwater level in the Mewat district, as prepared by the authors using data collected from the Central Groundwater Board.

marginal farmers) spend enormous time fetching drinking water from far-off sources. This has significant repercussions for girls' education and the overall development of women in this region.

2) Crop and income-related impacts

Climate change and lack of freshwater for irrigation have resulted in a reduction in crop productivity. Around 70% of farmers agreed that their land has been degraded. According to the farmers, before two to three decades there was no need for irrigation at all. However, in recent times due to delay or inadequate rainfall, they often apply saline groundwater knowing fully well that the productivity will be comparatively less. If there is sufficient rainfall in the following year, the accumulated salt in the soil gets washed away and productivity is restored. However, if there is low rainfall in the next year also, productivity is further reduced. In some of the fields, with repeated use of saline water farmers have witnessed that some fields have become completely barren. However, on the other hand, 30% of farmers, who have access to canal water, even witnessed a rise in productivity.

Salinity has also resulted in a substantial loss of crop varieties. Almost all the farmers feel that most indigenous crops have now vanished due to climate change [e.g., chickpea, green pea, split red gram, red lentil, and *gwar* (a local vegetable)]. Moreover, due to increased salinity farmers hardly cultivate vegetables now. Since salt tolerance level is high for tomatoes, only that is cultivated in limited parts of their land. More than 80% of farmers believe that due to declined rainfall over the years, now they can produce one crop per year (or a maximum of two crops in few years), in sharp contrast to producing three crops up to the early 1990s. Moreover, 85% of farmers agreed about the increase in incidents of pests and diseases. More than three-quarters of the farmers strongly agreed that their cost of

TABLE 2. The descriptive statistics of the socioeconomic data of the 250 farm households. Here and in subsequent tables, Pr indicates probability.

Socioeconomic details/blocks	FP Jhirka	Nagina	Nuh	Taoru	Punhana	Mewat district (total)	Test statistics
Households	50	50	50	50	50	250	
Education of household head: illiterate/no schooling	24	23	19	18	25	109	Chi-square: 3.16; Pr: 0.53
Education of household head: at least primary school educated	26	27	31	32	25	141	
Gender of household head: female	2	2	3	5	1	13	Chi-square: 3.73; Pr: 0.44
Gender of household head: male	48	48	47	45	49	237	
Social category: Meo-Muslim (OBC)	43	41	38	29	44	195	Chi-square: 17.02; Pr: 0.00
Social category: other	7	9	12	21	6	55	
Landholding category: marginal and small farmers	45	43	41	47	46	222	Chi-square: 4.67; Pr: 0.32
Landholding category: medium and large farmers	5	7	9	3	4	28	
Avg family size	7.6	7.54	6.91	6.03	7.05	7.03	t stat: −0.01; $P(T \leq t)$: 0.49; t critical: 2.13
Avg annual household income (INR)	74,085	81,925	88,352	91,153	64,921	80,087	t stat: 4.17×10^{-5}; $P(T \leq t)$: 0.50; t critical: 2.13

production has increased. Farming practices have changed drastically in the last two to three decades. Earlier rainwater was the prime source of irrigation, but since the late 1990s cost of input in farming increased especially the irrigation cost. The local seeds have been substituted by hybrid seeds. The use of organic manure like cow dung has been substituted by chemical fertilizers like urea, potash, boron, and zinc. Around 90% of farmers agreed that the productivity of their major crops has declined due to climate change, and almost 95% of farmers mentioned a decline in income.

3) ASSETS RELATED IMPACTS

Because of the water scarcity problem, the scope of mixed farming of food crops and fodder crops has been restricted, which affects farmers' decisions to keep livestock (mainly buffalo). More than 85% of farmers agreed that their livestock has declined over time. In earlier times, every household used to have 5–15 cattle on average. Now the number has reduced drastically. Water and shade, the two crucial items for cattle rearing became scarce. As pointed out by some of the villagers in Sultanpur of Nagina block, "we have to purchase water for our own family, how can we arrange water for the cattle?"

4) FARMERS' PERCEPTIONS ACROSS SOCIOECONOMIC CATEGORIES

For the farmers either agreeing or strongly agreeing to the impacts, responses have been cross tabulated against the educational background, economic, and social categories of the respondents (Table 4). Among farmers who perceived crop and income-related impacts, more than 80% were either illiterate or studied up to secondary school (class 10), and less than 20% of farmers were educated beyond secondary school. Similarly, around 80% of respondents belong to the Meo-Muslim (OBC) category, and the other 20% belong to other categories. However, educational or social category differences were not statistically significant. On the other hand, the

TABLE 3. Farmers' perception on socioeconomic impacts of climate change (%).

Impacts	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Water-related social impacts					
Increase in cost and time to arrange fresh drinking water	58	20	10	7	5
Crop and income-related impacts					
Increase in land degradation	52	18	7	8	15
Loss of indigenous crops	95	5	0	0	0
Loss of more than one crop in a year	80	6	0	6	8
Increase in incidence of pest and diseases	72	13	0	6	9
Increase in cost of production	76	6	8	5	5
Decline in productivity of major crops	70	20	4	6	0
Decline in farm income	85	10	0	4	1
Impact on asset					
Decline in number of livestock	74	12	0	7	6

TABLE 4. Farmers' perception on impacts across socioeconomic backgrounds of farmers.

		Crop- and income-related impacts							
	Water-related social impacts: increase in cost and time to arrange drinking water	Increase in land degradation	Loss of indigenous crops	Loss of more than one crop in a year	Increase in incidence of pest and diseases	Decline in productivity of major crops	Decline in farm income	Impact on asset: decline in number of livestock	Test statistics between water-, crop-, and assets-related impacts
Educational background of the respondent									
Illiterate	90	70	115	95	90	101	106	110	Chi-square: 5.01; Pr: 0.29
Up to secondary	70	80	90	80	86	82	88	67	
Above secondary	35	25	45	40	39	42	41	38	
Test statistics (within crop- and income-related impacts)				Chi-square: 5.92; Pr: 0.82					
Economic categories (annual household income)									
Up to INR 50,000	120	75	135	130	128	126	130	125	Chi-square: 3.28; Pr:0.19
Above INR 50,000	75	100	115	85	87	99	105	90	
Test statistics (within crop- and income-related impacts)				Chi-square: 15.01; Pr: 0.01					
Social categories									
Meo-Muslim (OBC)	160	145	195	185	181	188	190	183	Chi-square:1.00; Pr:0.61
Others	35	30	55	30	34	37	45	32	
Test statistics (within crop and income related impacts)				Chi-square: 6.41; Pr: 0.27					

difference of perceived impacts (on crop and income) was significant (at 5% level) for respondents/farmers of different economic categories. Comparatively richer farmers mentioned land degradation, whereas comparatively poorer farmers spoke more about the loss of more than one crop a year and increased incidence of pests and diseases. This implies that rich farmers, who have more land, are concerned about land degradation, whereas farmers having less land are facing the risk of losing the benefits of multiple crops. However, for the loss of indigenous crops and the decline in farm income, the risk perceptions were similar across economic categories. The difference among three broad categories (i.e., water-related social impacts, crop, and income-related consequences as a whole, and impact on assets) is not statistically significant across the socioeconomic backgrounds of farmers.

d. *Adaptation practices across various socioeconomic groups of farmers*

Farmers in the Mewat district have been found to act in various ways to respond to climate change. Those responses can be broadly categorized as 1) water management, 2) crop and land management, 3) livelihood diversification and out-migration, 4) shift from saline groundwater to surface water irrigation due to proximity of canal, and 5) no adaptation at all (Table 5).

For crop and land management practices, every two out of three farmers either use crop intensification with the increased use of fertilizer or change the calendar of planting. Among other crop and land management practices, farmers put less land under cultivation than before, use soil moisture and biomass conservation practices, plant more trees, practice crop diversification, or plant more salt-tolerant crops (particularly tomatoes). Few farmers (less than 20%) practice restoration of degraded areas, use salinity-resistant seeds, or employ technologies such as land leveling. Around 30% of the farmers have shifted from using saline groundwater for irrigation to surface water irrigation due to the proximity of the canal. Few farmers (20%), particularly those who have access to institutions (government and nongovernment), use water conservation strategies like sprinklers by taking that on a rental basis. As a result of the increased financial cost of arranging drinking water and reduction in farm income, several resource-poor farmers are forced to find avenues to earn cash to sustain their lives. Nearly 40% of the farmers mentioned income diversification or out-migration as a coping strategy. Nearly 15% of the farmers mentioned doing no adaptation at all.

The difference between various types of crop and land management practices across the educational backgrounds of the respondents is significant (at 1% level). Illiterate farmers mentioned more about putting lesser land under cultivation than before or increase in the use of fertilizers, whereas more educated farmers practiced crop diversification, agroforestry or planting more trees, shifting to salinity resistant varieties, and restoring degraded areas. The difference between social and economic categories is also significant (at a 1% level). Comparatively richer farmers practiced more of soil moisture and biomass conversion, agroforestry, crop diversification, restoration of degraded areas, and adoption of climate-resilient varieties, whereas comparatively poorer farmers reduced their land under cultivation, changed the cycle/calendar of planting, and increased the use of fertilizers. Educational background and economic classification of respondents seem to be correlated with educated respondents belonging to economically better-off respondents. However, no such prominent correlation was present with social categories. The majority of the respondents were Meo-Muslims, and they were spread across educational and economic backgrounds. For livelihood diversification and out-migration, there has been a significant difference across the educational background and economic categories of farmers. Out-migration was common among less educated and comparatively poorer farmers whereas income diversification was common among comparatively richer farmers.

For the difference between broad strategies of adaptation practices, we found significant (at 1% level) differences among educational backgrounds, economic as well as social categories of farmers. Water management practices (particularly water conservation technologies such as sprinklers) are common among more educated and comparatively richer farmers, whereas ''no adaptation'' is particularly common among illiterate and less educated as well as comparatively poorer farmers. The shift from saline groundwater to surface water irrigation due to the proximity of the canal is relatively lower among the majority social category of Meo-Muslims.

e. *Determinants and impacts of adaptation*

To explore the forces behind adaptation strategies and the resulting impact on the welfare of the adopters, we captured four case studies across the Mewat district. The four case studies represented four types of adaptation strategies: 1) water management through the adoption of sprinklers, 2) land management through laser leveling, 3) out-migration and livelihood diversification, and 4) community initiative to bring canal water from the nearby village through the pipe. The findings are presented below by assimilating under different subheadings.

1) PERCEIVED IMPACTS: A MAJOR DETERMINANT

One of the residents of the Sounk village in Nuh block adopted a sprinkler irrigation system. According to the resident, the groundwater level of the village declined sharply from 30–35 ft (1 ft = 30.48 cm) in the early nineties up to 80–85 ft at present. Similarly, one of the residents of the Mundaka village in FP Jhirka block witnessed a water scarcity problem in his village after the devastating drought of 1996. He recalled that water was abundantly available in the village before the drought and agriculture was primarily rain fed. Since the drought, almost all the village lands get irrigated through bore wells that run either through diesel or electric pumps. It has resulted in overexploitation of groundwater, and presently groundwater is available at 70–80 ft. In 2015, this resident of the Mundaka village adopted digital leveling in 2 acres of his land. Similarly, a 70-year-old resident of Patan Udaypuri village in FP Jhirka block felt the gradual change of the groundwater from sweet to saline. The depletion of groundwater has forced him and many villagers to depend on purchase

TABLE 5. Adaptation strategies across socioeconomic backgrounds of farmers.

		Crop and land management									Livelihood diversification and out-migration				
	Water management: Water conservation technologies such as sprinkler	Increase in the use of fertilizers	Change in cycle/ calendar of planting	Reduced land under cultivation	Soil moisture and biomass conservation practices	Agroforestry/ planting more trees	Crop diversification/ planting new crops	Restored degraded areas	Shift to salinity-resistant seeds	Adoption of climate-resilient technologies such as laser leveling	Income diversification	Out-migration	Shift to canal water irrigation	No adaptation	Test statistics
							Educational background of the responders								
Illiterate	10	86	75	60	30	8	5	2	5	4	30	49	36	17	Chi-square: 29.40; Pr: 0.00
Up to secondary	12	68	54	12	8	12	18	13	6	9	25	37	21	17	
Above secondary	28	21	36	10	22	37	29	30	31	27	40	19	18	3	
Test statistics						Chi-square: 223.26; Pr:0.00					Chi-square: 13.90; Pr: 0.00				
							Economic categories (annual household income)								
Up to INR 50,000	11	77	85	69	12	5	6	12	18	10	20	87	59	30	Chi-square: 73.9; Pr: 0.00
Above INR 50,000	39	98	80	13	48	52	46	33	24	30	75	18	16	7	
Test statistics						Chi-square: 133.54; Pr: 0.00					Chi-square: 74.116; Pr: 0.00				
							Social categories								
Meo-Muslim (OBC)	43	110	133	70	45	40	42	40	38	30	72	80	43	30	Chi-square: 17.30; Pr: 0.00
Non-OBC	7	65	32	12	15	17	10	5	4	10	23	25	32	7	
Test statistics						Chi-square: 33.39; Pr: 0.00					Chi-square: 3.40×10^{-31}; Pr: 1				

water for drinking and irrigation. To cope up with the increasing cost of cultivation, this old resident of Patan Udaypuri village has to migrate more often. Earlier he was migrating once a year, but now he migrates twice a year. He stated that earlier due to water availability he used to produce wheat and mustard in his small patch of land, but due to water scarcity, presently he produces only mustard, and hence he migrates during the wheat cutting season as well.

Existing literature focused largely on farmers' perception about climate change and climate variability but relatively less on perceived impacts. We argue that perceived impacts are a stronger determinant than perceived climate change or variability, particularly for poor farmers.

2) Farmers do a cost–benefit analysis before adapting

According to the abovementioned resident of the Sounk village in Nuh block, before the drought of mid-1990s, agriculture was mostly rain fed and some of the lands were irrigating through bore wells. The average time of irrigation per acre was 6–7 h, which has increased up to 10–12 h at present because of the decline in water tables. To have efficient use of scarce groundwater, he adopted a sprinkler irrigation system. According to him declining groundwater level and the resulting increase in irrigation cost was a major force behind the adoption of new technology. Similarly, realizing the fact that the cost of irrigation is directly linked to the unevenness of the land, the abovementioned resident of the Mundaka village in FP Jhirka block adopted the method of digital leveling in 2 acres of his land during 2015. According to him, although technology adoption increased his costs, the benefits were even higher.

3) Access to information, infrastructure, and finance facilitate adaptation process

One of the residents of Sultanpur village in Nagina block is a beneficiary of canal water. Interestingly the canal is situated in Umra village, which is at a distance of 3 km from their village. Comparatively richer farmers of Sultanpur village (like this particular resident) put together personal funds to bring water to their village from the nearest canal in Umra village through pipelines during 2014–15. However, according to him, the canal water covers only 30% of the total land in the village, where cultivation is possible 2 times per year for both kharif and rabi seasons, whereas the rest of the villagers depend on rainfall only and cultivate once a year. Similarly, the resident of the Sounk village in Nuh block was able to install the sprinkler in his land because he got it at a subsidized rate from a private company.

4) Adaptation leading to several positive impacts

The resident of the Sounk village installed the sprinkler in his land in 2018. Within this short period, he realized that the installation of sprinklers proved beneficial for him in many aspects, for example, saving water, cost of irrigation, physical drudgery, and time required for irrigation, and also increasing yields.

Similarly, the resident of the Mundaka village has witnessed several economic benefits. There has been a decline in water requirements, a reduction in the electricity bill, and an increase in the yield. He informed that due to the constant failure of electricity during the daytime, all of the farmers in his village who irrigate the land through the electric pump prefer to do that at night. Before laser leveling, he had to spend the whole night in the field. In winters he had to sit in front of the fire for the entire night, to change the pipe from one place to another since the water did not spread over all of the farmland equally because of the unevenness. After implementing laser leveling, he generally goes to the field twice to shift the location of the pipe; and can have peaceful sleep the rest of the night.

The old resident of Patan Udaypuri village generally migrates to Hanumangarh (Rajasthan), Punjab, and Gujarat for cotton plucking, and Bilaspur and Rewari for wheat harvesting. The main incentive behind migrating to such a long distance is to receive a cash payment since in the local areas people pay him in kind. With the additional income, he has bought a *chaak* (electrical wheel) to make earthen pots for selling, alongside agricultural activities.

The resident of the Sultanpur village finds himself one of the blessed residents in the village whose entire 2.5 acres of land is irrigated through canal water. His per acreage yield has increased with the use of canal water. Moreover, he has even started growing cotton, which fetches him a good income to spend on children's education and save for their future as well.

6. Discussions

Our secondary data analysis established that in Mewat precipitation has declined, whereas temperature and potential evapotranspiration increased, resulting in increased dryness of the region. There has been a change in groundwater quantity (depth) and quality as well. A large number of farmers were able to perceive the negative impacts on water, crop, income, and assets. Farmers were found to adapt in various ways. Those responses can be broadly categorized as water management, crop and land management, livelihood diversification and outmigration, and shift to surface water irrigation due to proximity of canal. With regard to perceived impacts, and economic difference of farmers played a significant role. Our results confirmed that the farmers who perceived more adverse impacts were mostly from poor economic backgrounds. However, in terms of adaptation practices, a significant difference was found across the educational, social, and economic backgrounds of the farmers. Our findings corroborated that the vulnerability of the Mewat district is arising from exposure, sensitivity, and lower adaptability. From this microlevel study, we argue that although perceived impacts are affected by economic vulnerabilities only, however, in terms of adaptation practices, other vulnerabilities arising from educational and social backgrounds also do play a major role.

We found that the availability of infrastructure and support of institutions [both government and nongovernmental organizations (NGOs)] can facilitate adaptation. On the other hand, lack of awareness, education, skill development, and livelihood opportunities are major hindrances. In Mewat, lack

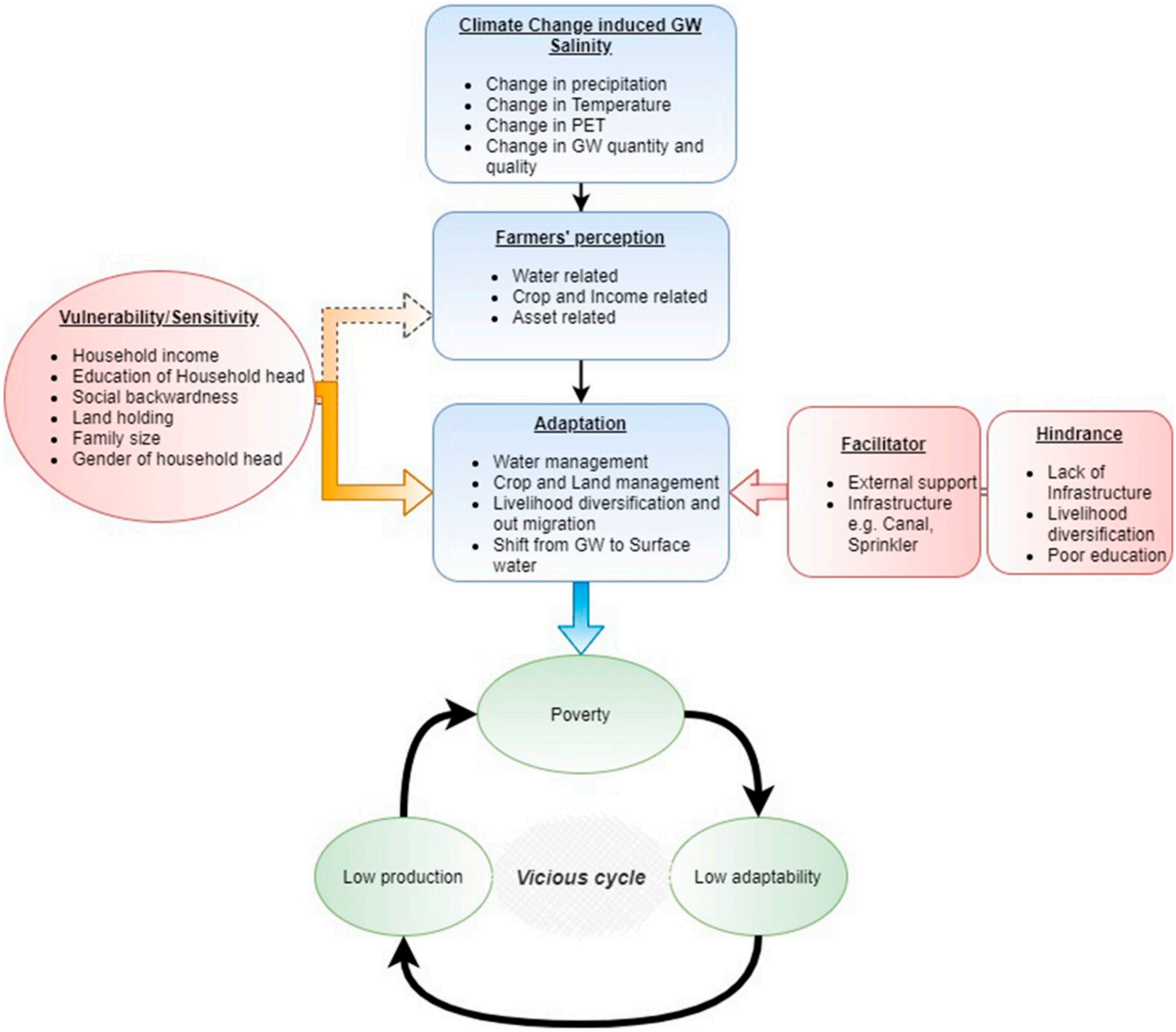

FIG. 5. Conceptualizing farmers' perception, adaptation, and vulnerability.

of adaptation measures is pushing already poor farmers into a deeper vicious cycle of poverty. Poor farmers have low adaptive capabilities, which result in low productivity and low income and make them poorer. We summarize our findings and conceptualize farmers' perception, adaptation, and vulnerability in Fig. 5.

Apart from summarizing the findings of our microlevel study, we also reference the results in the context of existing studies related to the salinity problem (Table 6). It reveals that in the developed parts of the world interventions are often at the policy level or involve infrastructure building, whereas, in the developing countries the coping mechanisms are local, context specific, and of low cost. According to Davidson (2000), soil reclamation and other advanced practices are rare in developing countries because of limited knowledge, the small size of landholdings, and lack of investment capacity. In India, a balanced approach between technology adoption and alternative land use has been found.

Several Indian studies suggest and recommend some simple alternative land use, which might also be replicated in the Mewat region and beyond. These include afforestation program, medical and aromatic crops, biofuel crops, fodder crops, fruits and vegetable trees, coconut plantation, prawn/shrimp cultivation, and integrated farming of crop and fish (Selvamurugan et al. 2017; Tomar and Minhas 1998; Singh and Dagar 1998; Kumar 1998; Patra and Singh 1998).

7. Conclusions and recommendations

Groundwater salinity, caused by overextraction and aggravated by climate change, negatively affects crop productivity. This is a major potential threat to global food security. The problem is crucial for India where food security is still a concern, and a large part of the workforce depends on the agricultural sector. Therefore, an adaptation of the sector is the need of the hour. A better understanding of community

TABLE 6. Successful interventions/adaptation practices across the globe to tackle salinity, as compiled from Ladeiro (2012), Shah (2005), Sharma and Singh (2015), and Abid et al. (2016).

Salinity-affected regions	Successful interventions/adaptation practices
Developed nations (Australia, Spain, and the United States)	a) Various incentives to increase water use efficiency; increase in irrigation efficiency; salt/water trade; soil reclamation and salt interception schemes (pumping boreholes); installation of small modular brackish-water desalination plants by farmers
Developing nations (Bangladesh, Pakistan, and Lebanon)	Improvement of crop production using farmyard manure; effective utilization of rainwater with very little application of brackish groundwater for irrigation; improved livestock management; diversification of livelihoods toward nonfarm activities; changing land-use patterns by switching to more salt-tolerant crops; managing irrigation patterns to improve water use and enhance drainage and leaching of salts
Different parts of India (Coastal Orissa, Andhra Pradesh, west Bengal, etc.)	Salt-resistant crop varieties; alternative land uses; use of technologies such as laser leveling and sprinkler irrigation; alternative livelihood in terms of small-scale fishing and plantation of eucalyptus trees; phytoremediation of salt-affected soils; postmonsoon (rabi) cropping in monocropped coastal saline soils; rainwater harvesting in dugout farm ponds

perceptions is important to inform policies aimed at promoting successful adaptation. There is a paucity of empirical studies conducted in developing countries and within local communities. This paper represents an important study by exploring the perceived impacts and adaptation by the farmers in one of the most socioeconomically disadvantaged districts of India, where groundwater salinity is a serious concern.

We found that a large number of farmers were able to perceive the negative impacts and were found to adapt in various ways. Our findings confirmed that the vulnerability of the Mewat district was due to exposure, sensitivity, and lower adaptability. However, the generalization of our findings is limited by the fact that Mewat is a special case with a very poor socioeconomic background. We found that perceived impacts varied with economic differences, whereas adaptation strategies varied with educational, social, and economic differences. So, the findings might not hold for comparatively better socioeconomic regions. However, about global experiences we found that developed countries intervened more in the policy level and infrastructure, whereas in developing countries, adaptation strategies are local, context specific, and of low cost. Thus, even with the limitation, the insights from our study are useful in making a few recommendations and suggestions for intervention and future research in Mewat and similar areas across the developing world.

As lack of education and vocational skills, absence of any rail network, poor road connectivity, lack of industries in the region, cumulatively limit the development of the area, investment in agriculture technology should receive attention to improve the well-being of the inhabitants of the Mewat district. Agriculture extension services, support of institutions (both government and NGOs), and credit facilities for low-cost technologies can facilitate adaptation. Awareness building and skill development are also needed. In the background of poverty, simple adaptive measures like saline-resistant crop varieties and alternative land uses suggested in the literature can be useful. The use of technologies like laser leveling and sprinkler irrigation can be scaled up in the region with credit support. As salinity is spreading in the region, alternative livelihoods in terms of small-scale fishing and planting eucalyptus trees can also be encouraged.

The existing literature focused largely on farmers' perception about climate change and climate variability but relatively less on perceived impacts. We argue that perceived impacts are a stronger determinant than perceived climate change and variability, particularly for poor farmers. Therefore, future research work on quantifying the negative impacts of salinity will be useful to motivate farmers to adapt. We also found that farmers do cost–benefit analysis at their level before adopting adaptation measures. Therefore, future research toward cost–benefit analysis and awareness building around the benefits will be beneficial for poor, illiterate, or less educated farmers to take a decision. Awareness building through various modes like storytelling, use of easy songs, and street plays can be used for Mewat and similar regions where a large percentage of the farmers are illiterate.

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