Ecological Indicators 154 (2023) 110637

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Passive adaptation to climate change among Indian farmers

Shubhi Patel [a,b,c], R.K. Mall [b,*], Abhiraj Chaturvedi [b], Rakesh Singh [a,b], Ramesh Chand [b,d]

[a] Department of Agricultural Economics, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India
[b] DST-Mahamana Centre of Excellence in Climate Change Research, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[c] Department of Agricultural Economics, Narain College, Shikohabad, India
[d] Department of Mycology and Plant Pathology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India

ARTICLE INFO

Keywords:
Perception
Climate change
Agriculture
Adaptation
Uttar Pradesh

ABSTRACT

Effective adaptation is crucial for building climate resilience in agriculture. This study attempted to understand the perception of farmers about changing climate and its impact on agriculture, its consistency with observed trends. It further assessed the major adaptation strategies opted-in by the farmers along with the identification of the motivation that led to opt-in or opt-out. Multi-stage sampling was used to collect responses from farmers (n = 300) of eastern Uttar Pradesh, India. The validity of responses was verified through secondary data analysis. The findings revealed that 82% farmers perceived rise in temperature, 85% believed that the rainfall has altered, and 95% believed that the intensity of rainfall has changed. More than 60% of the farmers agreed that alterations in temperature and precipitation reduce the production as well as the revenue. A large fraction of farmers opted-in strategies like shifting of sowing dates (87%), change of variety (86%), and increase in irrigation (83%). While, resource saving strategies like conservation agriculture, water harvesting, were not considered (<25%). Interestingly, the motivation behind opting-in was not the knowledge but the monetary benefit generated by doing so i.e., passive adaptation. Among the non-adopters, a large fraction opted-out because they believed that 'It is not needed'. Constructive policies need to prioritize generation of awareness and sensitization of farmers for active adaptation preferably through participatory approach.

1. Introduction

Adapting to climate change is irrevocably one of the last-mile solutions for insulating agriculture against the impacts of climate change. However, understanding and desired behaviour change are the major prerequisites for an effective adaptation. Because, adaptation is a two-step process, first, the perception of climate change, followed by the adaptation decisions taken to minimize the possible losses (Maddison, 2007; Deressa et al., 2009). There are pieces of evidence of adaptation gaps i.e., the difference between actual adaptation and recommended adaptation (IPCC, 2022). Possible reasons are a misinterpretation of climate trends, and barriers like social, institutional, individual, technological, and economical at different levels (Mall et al., 2019; Singh, 2020; Mall et al., 2021). It may also be influenced by external factors that develop a biased belief (Myers et al., 2013). For example, a belief that global warming is happening may influence people to judge a rise in temperature in their surroundings while same may not be felt by those who do not believe so (Howe and Leiserowitz, 2013; Mall et al., 2018). There is available literature that indicates that farmer's perceptions are not consistent with the climate records (Niles and Mueller, 2016) while, in other regions, they mirror the trends in meteorological variables (Ayanlade et al., 2017). Sometimes, farmers have the knowledge and, adaptation take place at the farm level but, unknowingly i.e., passive adaptation (Tripathi and Mishra, 2017). On the other hand, despite accurate perception recommended adaptations may not take place (Gandure et al., 2013).

There is a wide conundrum of factors that shape the adaptation decisions ranging from perceptions of farmers, education, farming experience to infrastructural support available, as well as awareness activities. At individual level for example, low income, small landholding, lack of education can limit the adaptive capacity (Singh, 2020). Young generation of farmers who are risk-takers are more likely to adapt as education, and accessibility to information increases the chances of adaptation (Jha and Gupta, 2021). The adaptation strategies are often costly and a lack of finance and, information of weather act as a barrier (Pandey et al., 2018). A study by Swami and Parthasarathy (2020) showed that challenges vary as per preference of the strategy as well as the particular strategy itself. For example, the availability of kisan credit

* Corresponding author.
E-mail address: rkmall@bhu.ac.in (R.K. Mall).

https://doi.org/10.1016/j.ecolind.2023.110637
Received 4 January 2023; Received in revised form 5 July 2023; Accepted 6 July 2023

cards, soil health cards, crop insurance among the institutional factors are the major challenges for adoption of strategies which are more preferred by the farmers. It is noteworthy that, institutions have a crucial role to play in build-up of perceptions and decisions of adaptations by farmers, they make the adaptation process easier and seamless through provisions of facilities that support adaptation (Niles and Mueller, 2016). For example, technical and financial assistance promote the adaptation ability of the farmers (Chen et al., 2014). Awareness about the cost-benefits of adaptation, and use of extension activities, is also crucial (Singh et al., 2018). It is not only the government but private sector also that can help increase the adaptive capacity. For example, public private partnership has been identified to be useful for enhancing adaptation for drought (Zhang et al., 2018). In case of markets, reduced production due to climate change combined with the existence of market imperfections at domestic and international trade intensifies the income losses for farmers (Mendelsohn 2006). While sometimes the facilities also influence the perceptions viz., availability of irrigation has the potential to direct the perceptions of farmers in a different direction altogether (Niles and Mueller, 2016; Patel et al., 2022). This is where mainstreaming i.e., integration of adaption with other policies comes into play, emphasising that one solution fits all or running only specific policies will not bring the solution but an integrated approach will (Singh et al., 2018). Recently participatory action research has emerged as an option to improve the development of localised adaptations (Hochman et al., 2017). Growing body of literature has cited different barriers to adaptation in different fragments. However, current literature does not address the thought process behind the barriers as faced by the farmers to practice a given adaptation strategy. This study attempts to fill the research gap by assessing the motives behind opting for an adaptation strategy, what are the reasons for opting out, the consistency of perceived climate change with the observed records and how the external factors influenced the adaptation decisions to be intentional or unintentional in Uttar Pradesh state of India. Since this state is endowed being the leading producer of foodgrains while 89% of the farmers are small and marginal farmers. The outcome of the study will help shape the policy framework for effective adaptation at local levels, overcome the barriers stated by the farmers and, transfer knowledge for supporting active adaptation.

2. Material and methods

2.1. Study area

The study was undertaken in three districts of Uttar Pradesh state. Uttar Pradesh, one of the largest states in India, is located between 23° 50′ – 30° 45′ N latitude and 77° 04′ – 84° 38′ E longitudes. It covers an area of 2,43,286 sq. km. which is 7.4% of the total geographical area of India. The state is endowed with ample alluvial soil along with a diverse agro-climatic profile which can support the cultivation of a variety of crops. Due to this reason, it is distinguished as the" agricultural state" of the country. It is a leading producer of wheat and food grains. The state is the second most populous state with a dominating share of the farmers. The average size of holdings in UP is around 0.76 ha and the per capita land area is 0.14 ha, less than half of the national average of 0.32 ha. 92.81% of the farming population is small and marginal farmers (Agriculture Census 2015–16). The economy of Uttar Pradesh is

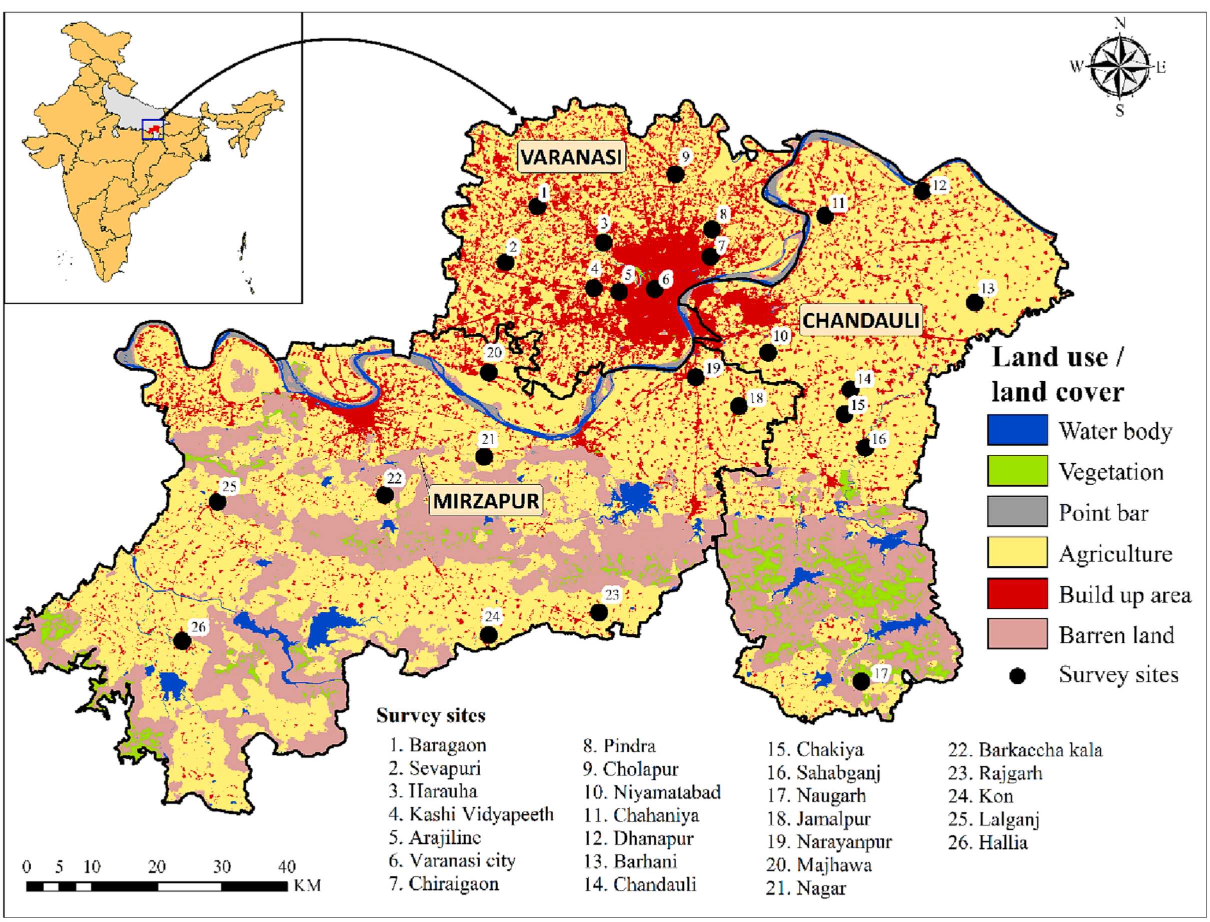

Fig. 1. Representation of the study area depicting the three districts of Uttar Pradesh on the Map. The numbers represent the survey sites which are the blocks (district subdivision) from where farmers of different villages were interviewed. The land use/land cover shows the distinction of each district. Source of map: Author's preparation. *Source of land use/land cover data* – ESRI (2022).

predominantly agricultural with heavy dependence on Monsoon. This sector employs about two-thirds of the workforce and contributes about one-third of the State's income. Dependence on agriculture combined with population pressure and low-income makes this region vulnerable to climate change. There have been few studies in the Indian region and also Uttar Pradesh.

These districts were Varanasi, Chandauli, and Mirzapur. All the districts have distinct farming practices and cropping patterns as well as topography. Varanasi falls in Eastern Plain Zone, and Chandauli and Mirzapur fall in the Vindhyan zone (Fig. 1).

Varanasi, considered the oldest city, is situated on the banks of the river Ganga. It holds a 1535 sq. km. area in Uttar Pradesh and part of the great Ganga River basin. Due to this reason, most of the area is exhibited under flat topography with a gentle slope and fertile soil. Active & Older flood plain of river Ganga and its tributaries and Older Alluvial Plains are the three morphological classifications of this district. It is a major pilgrim and an attraction for tourists as well as it is well-known as a knowledge, cultural and educational center of India. The cropping pattern of Varanasi is dominated by vegetables with Raja Talab being the biggest vegetable producer. This city has also benefited from the Indian Institute of Vegetable Research. Varanasi is divided into 8 blocks.

Mirzapur is the south-eastern district of Uttar Pradesh. The extension of the Mirzapur district is in the mountainous region of the Vindhyan ranges. It is situated at the junction of the Vindhya and Middle Ganga plain basins. Mountains, plateaus, and plains are characteristic of the district and it reflects in the land use of the area. It covers an area of about 4521 sq. km. Mirzapur has rich alluvial soil in the part of the Ganga plain basin and major crops are rice–wheat but other major crops are also grown. Soil of Vindhyan ranges, is degraded with shallow depth for cultivation. Therefore, farmers are practicing rain-fed/ dry crops, and vegetables. Mirzapur is divided into 12 development blocks.

Chandauli is a south-eastern district in Uttar Pradesh, which is situated on the UP and Bihar border. It is geographically divided into three major parts- Chakia Plateau, Chandauli Plain, and Ganga Khadar. The district is well drained in the Chakia plateau part but there is certainly water logging, and water erosion in the rainy season in Chandauli plain and Ganga Khadar. Chandauli plain and Ganga Khadar get new soil every year with floods which are highly fertile for paddy and wheat. Chandauli district is rich in paddy cultivation so it is called the paddy bowl in eastern Uttar Pradesh. Chandauli covers 2485 sq. km. area in Uttar Pradesh and is constituted by 9 blocks.

2.2. Data

The study is based on both primary and secondary data. The primary data was collected using a pre-designed survey schedule. The secondary data on climate and crop production statistics was used to verify the perceptions of farmers.

2.2.1. Survey design and data collection

The awareness and perception along with adaptation options were collected at three stages through a pre-designed survey schedule. In the first stage, the questions were framed based on the available literature. In the second stage, the preliminary survey schedule was tested by doing pilot interviews and focused group discussions with two climate experts, two experts working in farmer's advisory services, 5 researchers, and 7 farmers. In the third stage, the schedule was modified and finalized as per the response of the participants, incorporating the required questions and removing the unnecessary parts. This was again tested on 10 laborers working in the university agriculture research farm. A representative, multi-stage sampling was done. Firstly, for the selection of farmers a list of farmers from each block of the district was obtained, then, villages were selected from each block of the district to cover the whole area. The farmers were interviewed from the selected villages on a random basis. Finally, a total of 310 farmers were interviewed in 2020 out of which 300 responses (100 each in Chandauli, Varanasi and Mirzapur) were used for the analysis. The survey schedule is provided in the supplementary data (Table S1).

A team of trained researchers was assigned the task of interviewing the farmers. The survey schedule began with a general description of the farmer and his farming practice which act as a confounding factor for awareness and perception build-up. Farmers were asked about their knowledge on weather and climate. Then based on their long-term experience with the weather variables for 10–15 years the questions were asked. The perception towards climate change and its likely impacts was assessed using a three-point Likert scale. The last section of the questionnaire was the innovative where the novelty of this study lies. First, the farmers were asked whether they have taken some adaptive measures against the changing climate. Then they were asked about each possible adaptive practice suitable for their region along with the reason behind doing so and if not, why? This helped to identify the different constraints related to non-adoption at the farmer's level. Each interview lasted for about 40 min. The conceptual diagram of associations, influences between perception and adaptation is presented in Fig. 2.

2.3. Data analysis

The socio-economic characteristics and perceptions of farmers and adaptation practices responses were quantified using simple descriptive statistics. The awareness of farmers was also displayed using the same.

2.3.1. Climate data analysis

The agreement between farmers' perceptions and observed climate trends was assessed to check whether the perceptions are drawn from experience or general knowledge and awareness. The long term observed climate data of the three districts was obtained from IMD Pune for a period of 1951 to 2021. This period of 69 years was taken to cover the range of farming experience of the respondent farmers. The weather variables included Maximum temperature (T_{max}), minimum temperature (T_{min}), and precipitation.

The trend in Tmax, Tmin, and precipitation was analysed using ordinary least squares. Modified Mann-Kendall trend (MMKT) analysis was used to determine the change in trends at 95% confidence interval i.e., $p < 0.05$. MMKT was preferred over Mann Kendall (MK); it takes into account the problem of autocorrelation, and thus, the tau and slope values are free of autocorrelation and data normalization reducing the type I error (Hamed and Rao, 1998). MMKT performs better in the case of non-Gaussian datasets. This test maintains distribution free characteristics with the normalisation pre-treatment of datasets (Hu et al., 2020). So, this test is widely used for long term climate data. For the transformation of observational data into the normal Gaussian datasets the following equation has been used:

$$Zi = \varnothing^{-1}\left(\frac{Ri}{(N+1)}\right) \tag{1}$$

Here, R_i is the rank of normal distribution series x_i, N is the length of the series, and −1 is inverse function of standard normal distribution. Now, both of the series are similar because the series Z is created based on the ranks of the series X. As the MK test is essentially a test for the rank sequence, X and Z must have the same significance for the statistic S in the MK test. As a result, it is suggested that Z replace X in the MK test. Instead of using X, apply H estimation and trend detection to Z. As an overview, the MMKT data scaling process is as follows:

- First, calculate the Mann Kendall statistics (S).
- Second, Get the similar standard normal series Z with the use of equation (1).
- Third, Hurst coefficient or scaling coefficient (H) has been estimated with the equation (1).
- After it, obtain variance of S of given N and H.

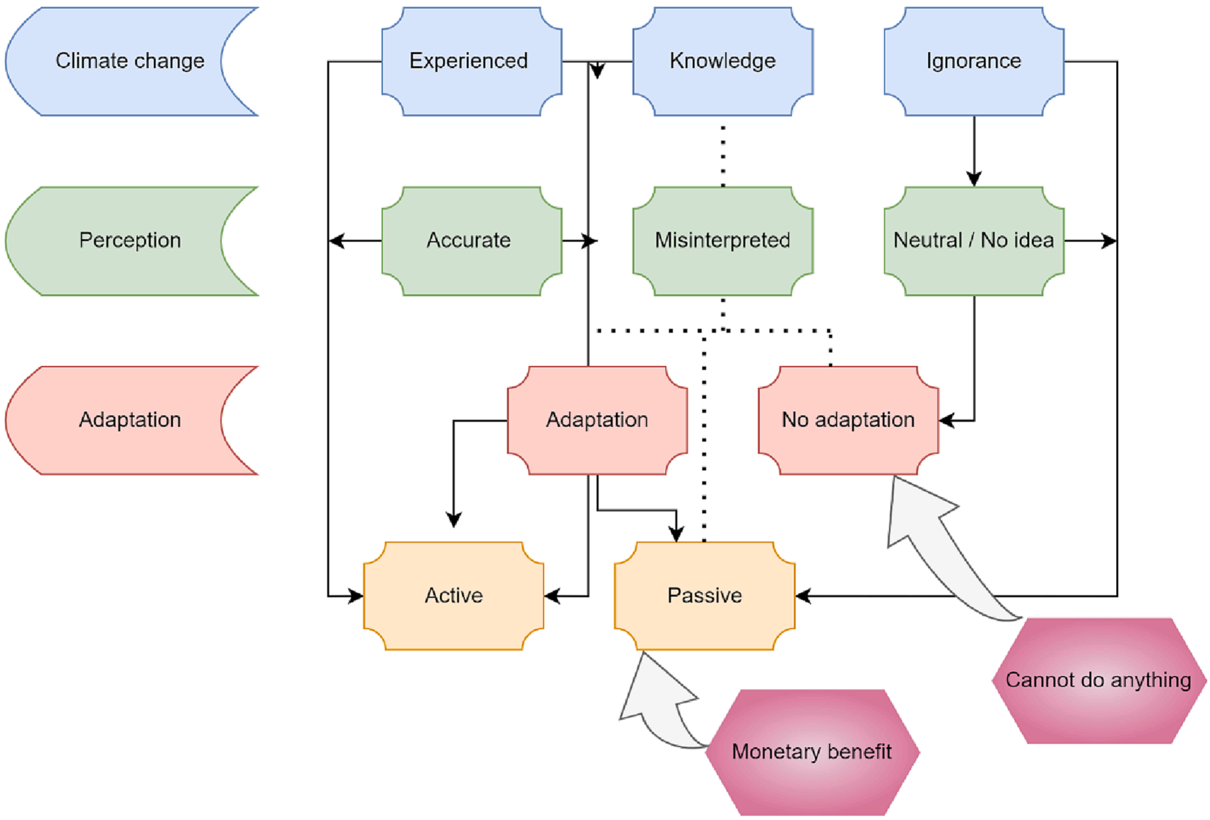

Fig. 2. Conceptual description of the perceptions and adaptations by farmers and their associations with each other. The diagram shows that there is downward movement i.e., adaptation is followed by perception. The solid lines represent the greater association and the dotted lines represent the possibilities of such associations. The bold arrows represent the driving force behind such decisions.

$$V(S) = \eta\frac{N(N-1)(2N+5)}{18}$$

$$\eta = 1 + \frac{2}{N(N-1)(N-2)} X \sum_{i=1}^{n-1} (N-i)(N-i-2)Ri$$

- Lastly, to calculate the statistic Z (Z_s) with this equation and also compare with Z_{tab} on certain significance level (**α**). The Z_s is calculated as follows:

$$Zs = \begin{cases} \frac{S-1}{\sqrt{V(S)}} S > 0 \\ 0 S = 0 \\ \frac{S+1}{\sqrt{V(S)}} S < 0 \end{cases}$$

R software was used for these calculations. According to the positive and negative value of Z_s, depict the positive and negative trend for the parameters respectively. The null hypothesis H_0 was assumed that there is no significant trend. Details of the MMKT method can be found in Hamed and Rao, 1998.

2.3.2. *Crop production analysis*

To understand the extent of changes in cropping patterns as an adaptation towards climate change, the yearly data of the area, production, and yield of major crops were collected for the period of 1980–2018 from dacnet.gov. The decadal average was calculated for the area under crops, and production and yield of crops were calculated for two decades i.e., 1980–2008 and 2009–2018. The comparison of the change in these aspects was then done to identify the extent of adaptation as said by the farmers and statistical records.

3. Results

3.1. *General profile of the respondents*

Perception determines the extent of adaptation. The extent of adaptation is however also determined by the socio-economic characteristics of the respondents. The socioeconomic characteristics of the farmers are given in Table 1. The majority of the farmers are of age 41–60 years and are educated. The landholding of a majority of farmers is <1 ha but they have access to credit. The farmers have a considerable experience of 15–30 years in farming.

3.2. *Farmers' perception of climate change*

It was observed that 82% of the farmers believed that they have

Table 1
General characteristics of respondents.

Variables	Descriptions	Percentage (%)
Age	19–40 years	35
	41–60 years	44
	>60 years	21
Education	Upto high school	18
	Higher secondary	26
	UG and above	56
Land holding	Marginal	31
	Small	29
	Semi-medium	21
	Medium	15
	Large	3
Farming experience	<15 years	27
	15–30 years	46
	>30 years	27

experienced an increase in temperature (Fig. 3). While for precipitation, 85% and 95% agreed upon altered timings and variation in the intensity respectively. Pest & diseases, occurrence in crops is influenced by climate change (Luck et al., 2011; Ghini et al., 2011). In our study it was found that, 93% of the farmers agreed that incidence of pest & diseases has increased over the years. They have also experienced rise in temperature, change in rainfall and this negatively impacts production as well as returns.

Majority of farmers believed that the results of climate change have an adverse impact on production and revenue generation (Fig. 4). More than 60% of the farmers agreed that temperature changes, precipitation reduce the crop yield as well as the revenue while 13–17% were neutral about this fact.

3.3. Observed climate trends

The analysis of the weather variables of the region for the period of 1951–2021 showed that there was an increase in maximum temperature and the rainfall has shown a decrease in intensity (Fig. 5). The maximum temperature has shown an increasing over the period. Thus, the perception of farmers about the temperature rise is based on their experience. Additionally, if we see the trend of minimum temperature, it has shown a negative trend over the years. The rainfall trend analysis showed that there has been a negative trend in the study region. However, this was not significant.

3.4. Adaptation to changing climate

The findings of this study showed that farmers have opted for few strategies but their driving force is monetary benefits and not just their knowledge (Table 2). Among the 15 adaptation strategies, change of variety (86%), shifting of sowing dates (87%), and increased irrigation (83%) was the most adopted ones. Literature has also shown that the majority of researchers suggest these strategies to reduce losses and escape heat stress (Tooley et al., 2021; Gardi et al., 2022; Gunawat et al., 2022). What is more striking is that the reasons for opting for new variety (46%) and shifting of sowing dates (46%) are primarily due to monetary benefit. However, the farmers have the knowledge of climate change also. While for increased irrigation, farmers had knowledge that when heat increases, more irrigation helps to bring the cooling effect and thus reduce the losses. Change in the crop, shift to non-agriculture, soil testing, and mixed farming was the other strategies opted by around 50% of the farmers. And, the reason they did so was that same, i.e., monetary benefit. For obvious reasons, crop change, and mixed farming increases the income from the field while the centrally sponsored Govt schemes like Soil Health cards provided an opportunity to use balanced fertilizer and reduce the input cost of fertilizer and hence increasing the net income. Opting for non-agricultural activities (51%) serve as a reliable source of income for the farmers. This shows evidence of passive adaptation by the farmers as the motive behind adoption is not their knowledge on changing climate but to generate more income. Studies have shown that passive adaptation is common among farmers (Apata et al., 2009). The fact that farmers have gone for a change of crops, change of crop area, and also variety change in the study area was established with the secondary data analysis. The secondary data on area, production, and productivity showed that there is change in the crop area of many crops specially mustard, wheat, rice and masoor in recent decade of 2009–18 as compared to 1998–2008 (Supplementary Table S2). While in general there is a rise in production of the crops in 2009–18 despite area reduction. This is because the use of high yielding varieties that compensated the reduction in area and increased the production (Supplementary Fig. S1). Very few farmers have opted for conservation agriculture, water harvesting, and even crop insurance. The positive sign here is that although only 10% of the farmers opted-in water harvesting the motive was driven by their knowledge (74%).

3.5. Barriers for non-adoption

A deeper insight is also important to identify the farmer's point of view for opting-out or not adopting a given strategy. The analysis shows that the one of biggest reasons for not adopting a given strategy is that the farmers feel that it is not required (Table 3). Majority (10 out of 15) of the strategies were opted-out because farmers responded that it was not needed in their fields. Other reasons were also reported like, when farmers were asked about mixed farming, opting for dairy or poultry at a commercial level, they were unable to do it alone. Other activities like crop insurance faced the issue that their crop was not notified under the scheme followed by it being faulty.

3.6. Is it just the farmers or other factors also involved?

The study has clearly reported passive adaptation among farmers. But it is not only the perception of farmers but other external factors that shape adaptation decisions and beliefs. Identification of these factors help the research community and policy makers develop solutions for inducing active adaptation among farmers. Deriving the concept from IPCC 2007 where the adaptation strategies can be divided on the basis of - type of action, by actor, by spatial scale, by baseline income, by sector or a combination of these and other categories for understanding purpose (Adger et al., 2007). Giving an explicit focus on the type of action taken by the farmers we divided the strategies into four major categories i.e., Physical, technological, risk transferring and diversification. Physical strategies comprised of shifting in sowing dates, increase in irrigation, change in crop area, change of crop and change of variety. These are changes which can be done in short term and have immediate results. Technological strategies comprised of conservation agriculture, soil testing, water harvesting and use of new technology. These are the options that support resource conservation like water, soil and nutrients

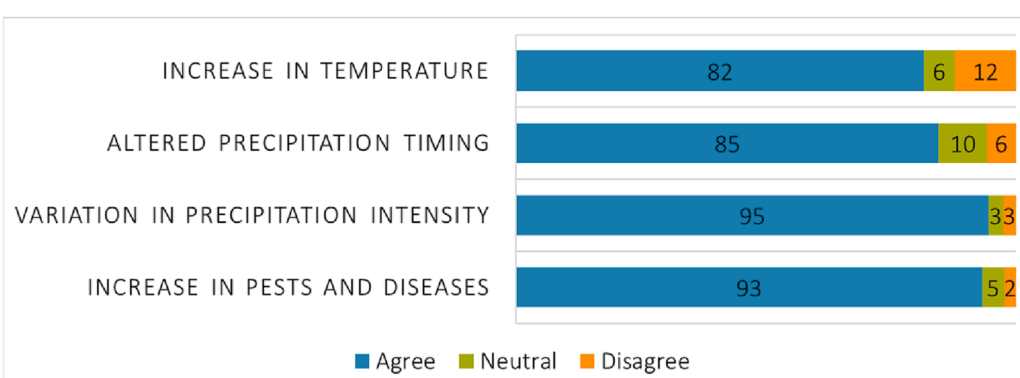

Fig. 3. Farmers' perception of climate change in (%).

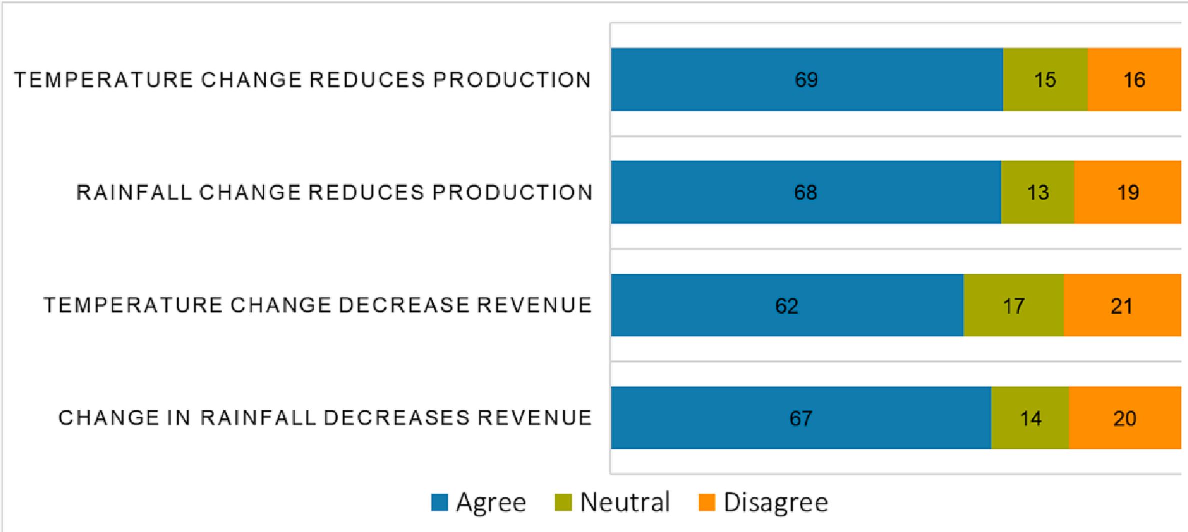

Fig. 4. Farmers' perception on negative impacts of climate change on production, revenue, pest & diseases (%).

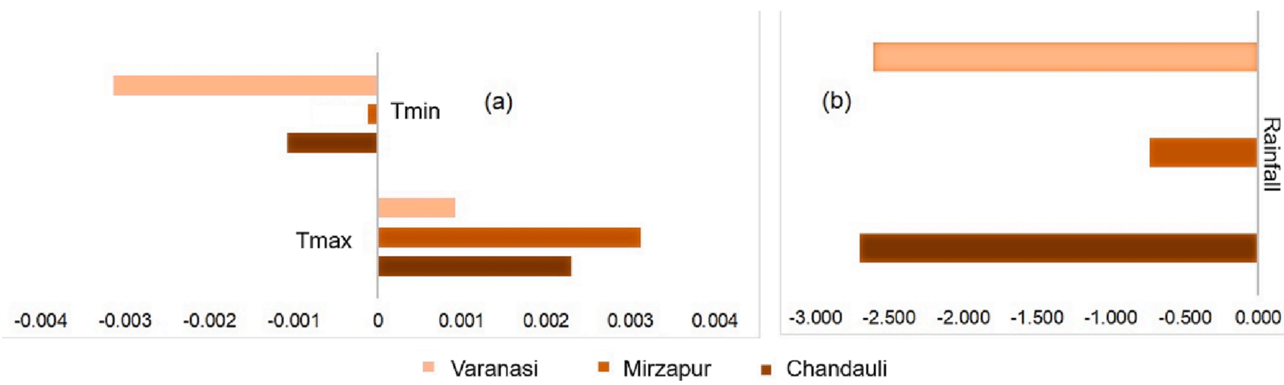

Fig. 5. Trend of (a) maximum temperature and minimum temperature (°C/year) and (b) rainfall (mm/year) in Chandauli, Mirzapur and Varanasi for a period of 1951–2021 at 95% confidence interval.

Table 2
Adaptation strategies opted by respondents and reasons of adoption (values in %).

Adaptation strategy	Adopted	Reasons for adoption		
		Knowledge	Monetary benefit	Both
Shifting of sowing dates	87	28	46	26
Increase irrigation	83	46	43	11
Mixed farming	47	35	53	12
Contract farming	12	3	77	20
Shift to non-agriculture	51	8	87	5
Conservation agriculture	24	37	59	4
Opted dairy/poultry	31	34	60	7
Change in crop area	38	36	55	10
Variety change	86	37	46	17
Soil testing	49	30	59	11
Crop insurance	37	23	71	5
Water harvesting	10	74	19	6
Agro-forestry	37	36	59	5
New technology	29	25	57	17
Crop change	56	43	45	12

and also show results in the long run and also capital intensive. Opting these is easier when the farmer is educated and know the importance of resource conservation. The risk transferring strategies included contract farming and crop insurance. Crop insurance is a risk transferring technique in case of crop failure and contract farming ensures assured price during price volatility. The last category diversification strategy comprised of agro-forestry, mixed farming, shift to non-agriculture and opting livestock/poultry. These options diversify the sources of income and hence stabilize the farmers income. Descriptive approach was used to identify the external factors that might have relation with the opting-in decision of the farmers. The prevailing government policies, market infrastructure, have a role in altering the adaptation beliefs for example if the farmer is unaware of the ways and need to adapt in changing climate his farm level decisions will be driven by income generation motive and resource conservation or other strategies will not be opted until his farm requirements are being fulfilled through infrastructural facilities.

From Table 2 it was revealed that risk transferring strategies were the least adopted ones. Farmers stated that it was not required but also, there is a possible reason that, contract farming is not popular in the area. While, it is noteworthy that, to avail the indemnity in crop insurance the crop grown by the farmer must be notified by the insurance company for the given area. The unavailability barrier shows that the insurance was not available for the crops grown by those farmers and faulty facility shows that despite crop losses, indemnity was not paid. While, most widely adopted strategies were the physical strategies (~80%). These strategies require credit for purchasing seeds and fertilizers and increase irrigation. It was found that 97% of the farmers had access to irrigation, 78% had access to credit thus easing the opting-in option (Table 4). The technological strategies also had a low adoption

Table 3
Barriers stated by respondents who didn't adopt the adaptation strategy (values in %).

	Don't know about it	It is not needed	Cannot do alone	Faulty facility	No awareness	Schemes not known	Not available	Lack of credit	Costly measure	Neel gai
Shifting of sowing dates	13	73	8	8	0	0	0	0	0	0
Increase irrigation	8	71	15	2	4	0	0	0	0	0
Mixed farming	2	34	39	6	1	3	1	1	11	1
Contract farming	6	35	6	28	8	0	0	14	1	2
Shift to non-agriculture	7	49	19	5	3	5	10	1	0	0
Conservation agriculture	15	26	7	22	4	1	9	2	0	14
Opted dairy/poultry	0	38	38	4	1	6	9	2	0	1
Change in crop area	2	51	6	2	0	3	32	1	3	0
Variety change	0	51	5	17	2	5	0	5	2	12
Soil testing	3	11	10	34	5	3	11	2	0	22
Crop insurance	2	15	1	32	6	2	40	3	0	0
Water harvesting	15	45	6	22	2	4	4	1	0	0
Agro-forestry	8	46	12	10	3	0	4	1	5	11
New technology	5	15	4	2	4	10	20	2	38	0
Crop change	3	46	23	5	1	2	3	0	16	2

Table 4
Availability of various institutional facilities in the study area.

Attribute	Yes/No	Percentage of farmers
Access to credit	Yes	78
Access to irrigation	Yes	97
AGROMET advisory	Yes	70
Weather information	Yes	88
Source of information	Mobile	49
Reduced surface water sources	Yes	75
Associated with kisan club/ NGO etc.	Yes	76

rate (<40%) despite the fact that 75% of the farmers have experienced a reduction in surface water sources. Pointing out two issues first farmers are not aware of the need to saving water and second, how water harvesting and agro-forestry play a crucial role in water cycle. Conservation agriculture in one way promotes integrated pest management and hence reduce the use of pesticides but, it was not adopted by the farmers. The secondary data showed that the pesticide consumption in the study area has increased since last two decades thus deteriorating soil and ground water (Supplementary Fig. S2). Again, indicating the lack of extension activities or specifically the programmes focusing on resource conservation in the long run.

4. Discussion

4.1. Farmers' perception and climate trends

Perception analysis showed that the more than 80% of the farmers agreed that they have experienced changes in temperature and rainfall patterns. Notably, the farmers perceived that a temperature rise reduced production as well as revenue. The farmers have experienced losses in yields, shrivelling of grains, death of flowers due to high temperatures at critical stages, and drop of fruit. The rainfall intensity and change in timing also had a similar impact on the production and revenue generated. It delayed the sowing of crop and destroys the standing crops, washes away the pollen, and flowers. The trend analysis showed that there has been a rise in maximum temperature over the years and a reduction in rainfall. Farmers' perception in the region is consistent with the trends of observed meteorological variables, indicating that, their perception is built upon their own experience.

4.2. Adaptation, motives and barriers

The adoption of several adaptation strategies motivated by monetary benefit emphasized that they are unaware of what they can do from their end to cope with it. This showed that passive adaptation was observed in the region i.e., the farmers know the climate is changing but they are unaware of the strategies they can practice for minimizing the losses or what they are doing is adaptation.

Interestingly, we found that among those who had not adopted the given strategy, the biggest barrier was their belief that it was not required. This response is driven by the perception of farmers that "we cannot do anything" about the changes in weather variables. For example, more than 80% farmers have experienced rise in temperature and more than 60% agree that this causes losses in production and revenue but, <40% of them could identify that the adaptation strategy opted by them was due to their climate knowledge. Again, showing passive adaptation and elucidating harmony between perception and active adaptation is challenging. Similar findings of passive adaptation have been documented by and Tripathi and Mishra, 2017; Apata et al., 2009.

While studies have emphasised that farmers with institutional connection are better in adaptation (Islam & Nursey-Bray, 2017), the role of government is important for ante-adaptation (Mendelsohn, 2000) and the need of active adaptation (Bradshaw et al., 2004). In our study also, the declaration by farmers that 'it is not needed' and 'it is for more income' demonstrates that at present institutional involvement in generating knowledge about sincere steps that can be taken is lacking. Accessibility to credit and irrigation has made it easier to adopt new varieties, change the crop, increase the irrigation but strategies that are more influenced by knowledge were not opted despite the fact farmers are members of Kisan clubs, NGOs and have access to consultancy.

Institutions, market, community have a role in adaptation decisions as seen. Policies like MGNREGA that guarantee 100 days' work to rural has contributed to the reduction in agricultural labour (Agarwal et al., 2015). There is migration of rural youth from agriculture to other income sources majorly because of the poor income generation from farming (Chandrasekhar and Sharma 2014). This leads to preference of less labour-intensive farming practices. To address the importance of weather information, Agromet Advisory services were started to ensure a weekly weather forecast sent to farmers individually. While for credit facilities, Kisan Credit Card was introduced in 1998 that provides credit to farmers to meet credit need with interest subvention option. At present Prime Minister Crop Insurance Scheme, Soil Health Card scheme are active for insuring income and reducing input costs. Recently Kisan drones have been introduced in the budget 2022 for crop assessment, digitization of land records, plant protection measures etc. Also, National Innovations on Climate Resilient Agriculture, a network project was launched by the Indian Council of Agricultural Research to promote climate resilience through research & development, extension and capacity building.

There are several studies which have examined the perceptions of farmers and the adaptation strategies opted by them in Indian region (Table 5). The body of literature showed that across India effects of climate change have been experienced by the farmers in form of elevated temperatures, irregular rainfall and increased incidence of climate extremes. Regional variations were observed in the adaptation strategies opted by the farmers. However, increased irrigation and change in crop varieties were the most common while migration was majorly seen in Himalayan regions.

5. Policy implications

The findings of the study provide an approximate roadmap for framing and implementing policy to stimulate active adaptation. With immediate effect the following policy initiatives can be taken-.

- Constructive initiatives like utilizing folklores, proverbs, riddles that are intricately interwoven in the traditional-religious beliefs or rural community. Use of folklores for generating awareness and cope up with climate change has been highly beneficial (Paulraj and Andharia, 2015; Gupta and Singh, 2011).
- Utilizing the kisan clubs, NGOs existing in the villages for extension of knowledge, gender sensitization to improve awareness and adaptation rate.
- Connect all the farmers through mobile phones and disseminate the AGROMET advisory, with more precise suggestions and possibly in regional languages also.
- Start customised extension activities, awareness programmes for knowledge of resistant varieities, harnessing the recent event of International Year of Millets that is giving boost to millet production and use, as this crop is climate resilient and highly nutritious.

Long run-.

- Updating of the crop insurance facility by use of real time data about the cropping pattern of the district, now use of kisan drones can be done for digital data collection about the crops grown and losses occurred. This will ease the insurance claim process and bring transparency, thus remove the existing lacunae.
- There is need to study the projections for the climate trend in the area and frame policy for introducing new cropping pattern, new crops

Table 5
Studies on perception and adaptation towards climate change in India.

Study	Region	Findings	
		Perception	Adaptation
Vedwan & Rhoades 2001	Kullu valley, Himachal Pradesh	Reduction in snowfall, no change in rainfall, increase and shift in temperatures and increased extreme events like cloud bursts	–
Dhaka et al., 2010	Bundi, Rajasthan	Increase and shift in temperatures, decrease in rainfall	Integrated farming system, crop rotation, intercropping, change in time of farm operation
Basannagari et al., 2013)	Kinnaur, Himachal Pradesh	Increase in temperature, decrease in snowfall.	Experienced change in land use practices, replacement of apple withcoarse cereals.
Sahu and Mishra 2013	Kendrapara, Odisha	Almost 98% of farmers believed that there is change in temperature and rainfall patterns.	Only 59% of the farmers have opted for adaptation strategies
Banerjee 2015	Nasik, Maharashtra and Guntur, Andhra Pradesh	Increase in summer temperature, fluctuations in winter temperatures, late rainfall onset and increased pest & disease incidence.	Diversification, shift to commercial crops, use of drip irrigation, creation of surface pond.
Dhanya & Ramachandran 2016	Kancheepuram, Tamil Nadu	Increase in temperature, decrease in rainfall, increased dry spell	Short duration crops like pulses, vegetables, perennial crops like coconut, banana.
Hussain et al., 2016	Eastern Brahmaputra (Hindukush Himalaya region)	Increased occurrence of floods, landslides, drought, livestock diseases and crop pest.	New off-farm activities, out migration, changes in farming practices.
Panda, 2016	Balangir and Nuapada, Odisha	Changes in temperature and rainfall pattern	–
Shukla et al., 2016	Kanchandzonga biosphere reserve, Sikkim	Increasing temperature and unpredictable pattern of rainfall, warmer and stronger winds	Use of locally available materials as mulches, agroforestry, intercropping
Dubey et al., 2017	Sunderban, West Bengal	Changes in temperature, rainfall, and also tropical cyclones & sea level rise.	Adopted short term coping measures.
Negi et al., 2017	Uttarakhand (Western Himalaya region)	Increase in temperature, decrease in snowfall, irregular rainfall, change in agrobiodiversity	Change in cropping pattern, livestock integration, protected cultivation, high yielding varieties, migration
Tripathi and Mishra 2017	Faizabad, Uttar Pradesh	There is change in temperature, rainfall.	Passive adaptation through timing changes of sowings and harvesting, short-duration varieties, inter-cropping, changed cropping pattern, agroforestry and irrigation.
Dey et al., 2018	Chilapata reserve forest, West Bengal (Eastern Himalaya region)	increasing temperature, decrease in winter spell, low amount of rainfall, uneven distribution of rainfall, intensification of drought and flood	Pre-monsoon seeding, agroforestry, crop rotation, short duration crop varieties and use of organic/inorganic products
Shukla et al., 2019	Dehradun, Almora, Uttrakhand (Indian western Himalaya region)	83% farmers not know the term 'climate change'. Decrease in summer and winter rainfall. Increase in summer temperature.	–
Singh, 2020	Bundelkhand region, Central India	Changes in temperature and rainfall leading to food insecurity.	Early maturing seed varieties and less water consuming crop varieties
Baruah et al., 2021	Assam	Increased temperature, no change in rainfall intensity	Use of resistant varieties, application of fertilizers and pesticides, crop diversification, changes in sowing dates, irrigation, soil conservation, changes in cropping pattern.
Jha and Gupta 2021	Bihar	Increase in number of hot days, decrease in number of cold days, changes in rainfall	Irrigation, migration to urban area, change in crop area, change in crop variety, crop insurance, vegetable cultivation
Kundu & Mondal 2022	Maldah, West Bengal	Increase in annual summer temperature while decrease in winter temperature, decrease in rainfall	Change in cropping pattern, change in sowing dates, organic farming, crop diversification, conversion of cropland into orchard and crops and livestock
Datta and Behera 2022	Coochbehar, West Bengal (Sub Himalayan region)	Increase in temperature and decrease in rainfall.	Irrigation, high value crops and high yielding varieties, mechanisation

suitable for the elevated temperatures, introduction of resistant varieties in the region.

- Mainstreaming of policies like water management, dams, road plans, drainage plans, market infrastructure that can withstand weather extremes like floods in the long run.
- Promotion of research and development through institutional support, budget allocation to identify vulnerable regions and develop customised plans for upliftment of the affected communities in the vulnerable regions preferably through participatory approach.

6. Limitations

The research findings always inherit a conundrum of some limitations. For example. the findings from this study are based on only two Agro-climatic Zones (ACZs) of Uttar Pradesh. More detailed research can be conducted to assess responses from different ACZs addressing the heterogeneity among local climate, cropping system, socio-economic status of farmers, institutional support, and culture. Second, female farmers can also be included and a gender-based study can be done to identify variability if any. It is noteworthy that females have a greater role as agricultural laborers on the farms and handle both agricultural and domestic responsibilities. It is noteworthy that perceptions are influenced by multiple factors like education, awareness, and local or short-term experiences. A more detailed understanding of the responses with a larger sample size, careful framing of questions and scale, and consideration of the complex division of society can contribute to better response collection. Hence, there lies the scope for future research on farmers' perception and adaptation strategies, their adoption & barriers.

7. Conclusion

Adaptation to climate change is crucial for income security of the stakeholders and food as well as nutrition security of the nation. This study attempted to fill the research gap in literature for addressing the driving force of adaptation and non-adoption in context with the response of farmers directly. The wide spectrum of literature has identified various factors affecting adaptation, barriers to adaptation but few studies have reported evidences of passive adaptation. Present study used a combination of primary and secondary data to demonstrate the first step of adaptation i.e., perception and then reported the psychological factor impeding the behaviour change. It was revealed that despite knowledge of climate change the monetary aspect drives the adaptation decisions and farmers still believe that they don't need to adapt as it is beyond their capacity. This evidence of passive adaptation is important for researchers and policymakers to develop awareness or sensitization programmes that educate farmers about active adaptation. Uttar Pradesh is vulnerable to climate change, and the findings of this study can be instrumental in uplifting the development of agriculture in the upcoming future.

CRediT authorship contribution statement

Shubhi Patel: Methodology, Investigation, Formal analysis, Data curation, Validation, Visualization, Writing – original draft. **R.K. Mall:** Conceptualization, Supervision, Methodology, Resources, Funding acquisition, Data curation, Project administration, Visualization, Writing – review & editing. **Abhiraj Chaturvedi:** Visualization, Data curation, Formal analysis, Investigation. **Rakesh Singh:** Supervision, Writing – review & editing. **Ramesh Chand:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Authors wish to thank the Climate Change Programme, Department of Science and Technology, New Delhi for providing financial support (Award no.: DST/CCP/CoE/ 80/2017(G)). The authors wish to thank the India Meteorology Department (IMD) for making available the observation dataset.

Funding

Authors thank the Climate Change Programme, Department of Science and Technology, New Delhi, for financial support (DST/CCP/CoE/ 80/2017(G)).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2023.110637.

References

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 717-743.

Agarwal, P.K., Nagrale, B.G., Chandel, B.S., 2015. Is mnrega affecting availability, wages and cost of labour in Indian Agriculture? Discerning quantitative evidences. Ind. J. Econ. Dev. 11 (4), 967–974.

Agriculture Census 2015-16. All India Report on Number and Area of Operational Holdings. Ministry of Agriculture & Farmers Welfare, Government of India 2019. http://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf.

Apata, T.G., Samuel, K.D., Adeola, A.O., 2009. Analysis of Climate Change Perception and Adaptation among Arable Food Crop Farmers in South Western Nigeria. Contributed Paper prepared for presentation at the International Association of Agricultural Economists' 2009 Conference.

Ayanlade, A., Radeny, M., Morton, J.F., 2017. Comparing smallholder farmers' perception of climate change with meteorological data: A case study from southwestern Nigeria. Weather Clim. Extremes 15, 24–33.

Banerjee, R.R., 2015. Farmers' perception of climate change, impact and adaptation strategies: a case study of four villages in the semi-arid regions of India. Nat. Hazards 75 (3), 2829–2845.

Baruah, U.D., Saikia, A., Robeson, S.M., Mili, N., Chand, P., 2021. Perceptions and adaptation behavior of farmers to climate change in the upper Brahmaputra Valley, India. Environ. Dev. Sustain. 23 (10), 15529–15549.

Basannagari, B., Kala, C.P., Convertino, M., 2013. Climate Change and Apple Farming in Indian Himalayas: A Study of Local Perceptions and Responses. PLoS One 8 (10), e77976.

Bradshaw, B., Dolan, H., Smit, B., 2004. Farm-level adaptation to climatic variability and change: crop diversification in the Canadian prairies. Clim. Change 67 (1), 119–141.

Chandrasekhar, S., Sharma, A., 2014. Internal migration for education and employment among youth in India. Indira Gandhi Institute of Development Research, Mumbai.

Chen, H., Wang, J., Huang, J., 2014. Policy support, social capital, and farmers' adaptation to drought in China. Glob. Environ. Chang. 24, 193–202.

Datta, P., Behera, B., 2022. What caused smallholders to change farming practices in the era of climate change? Empirical evidence from Sub-Himalayan West Bengal, India. GeoJournal 87 (5), 3621–3637.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Chang. 19 (2), 248–255.

Dey, T., Pala, N.A., Shukla, G., Pal, P.K., Das, G., Chakarvarty, S., 2018. Climate change perceptions and response strategies of forest fringe communities in Indian Eastern Himalaya. Environ. Dev. Sustain. 20 (2), 925–938.

Dhaka, B.L., Chayal, K., Poonia, M.K., Kendra, K.V., 2010. Analysis of farmers' perception and adaptation strategies to climate change. Libyan Agric. Res. Center J. Int. 1 (6), 388–390.

Dhanya, P., Ramachandran, A., 2016. Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi arid region of south India. J. Integr. Environ. Sci. 13 (1), 1–18.

Dubey, S.K., Trivedi, R.K., Chand, B.K., Mandal, B., Rout, S.K., 2017. Farmers' perceptions of climate change, impacts on freshwater aquaculture and adaptation

strategies in climatic change hotspots: A case of the Indian Sundarban delta. Environ. Dev. 21, 38–51.
ESRI Inc, 2022. Esri land Cover. Available online: https://www.arcgis.com/home/item.html?id=cfcb7609de5f478eb7666240902d4d3d (accessed on 22 October 2022).
Gandure, S., Walker, S., Botha, J.J., 2013. Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. Environ. Dev. 5, 39–53.
Gardi, M.W., Memic, E., Zewdu, E., Graeff-Hönninger, S., 2022. Simulating the effect of climate change on barley yield in Ethiopia with the DSSAT-CERES-Barley model. Agron. J. 114 (2), 1128–1145.
Ghini, R., Bettiol, W., Hamada, E., 2011. Diseases in tropical and plantation crops as affected by climate changes: current knowledge and perspectives. Plant Pathol. 60 (1), 122–132.
Gunawat, A., Sharma, D., Sharma, A., Dubey, S.K., 2022. Assessment of climate change impact and potential adaptation measures on wheat yield using the DSSAT model in the semi-arid environment. Nat. Hazards 111 (2), 2077–2096.
Gupta, A.K., Singh, A., 2011. Traditional intellect in disaster risk mitigation: Indian Outlook-Rajasthan and Bundelkhand Icons. Indian J. Tradit. Knowl. 10 (1), 156–166.
Hamed, K.H., Rao, A.R., 1998. A modified Mann-Kendall trend test for autocorrelated data. J. Hydrol. 204 (1–4), 182–196.
Hochman, Z., Horan, H., Reddy, D.R., Sreenivas, G., Tallapragada, C., Adusumilli, R., Roth, C.H., 2017. Smallholder farmers managing climate risk in India: 1. Adapting to a variable climate. Agr. Syst. 150, 54–66.
Howe, P.D., Leiserowitz, A., 2013. Who remembers a hot summer or a cold winter? The asymmetric effect of beliefs about global warming on perceptions of local climate conditions in the US. Glob. Environ. Chang. 23 (6), 1488–1500.
Hu, Z., Liu, S., Zhong, G., Lin, H., Zhou, Z., 2020. Modified Mann-Kendall trend test for hydrological time series under the scaling hypothesis and its application. Hydrol. Sci. J. 65 (14), 2419–2438. https://doi.org/10.1080/02626667.2020.1810253.
Hussain, A., Rasul, G., Mahapatra, B., Tuladhar, S., 2016. Household food security in the face of climate change in the Hindu-Kush Himalayan region. Food Security 8 (5), 921–937.
IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.
Islam, M.T., Nursey-Bray, M., 2017. Adaptation to climate change in agriculture in Bangladesh: The role of formal institutions. J. Environ. Manage. 200, 347–358.
Jha, C.K., Gupta, V., 2021. Farmer's perception and factors determining the adaptation decisions to cope with climate change: An evidence from rural India. Environ. Sustain. Indic. 10, 100112.
Kundu, S.K., Mondal, T.K., 2022. Farmers' perception of climate change and adaptation strategies: a study of the Lower Gangetic Plain in India. Arab. J. Geosci. 15 (1), 1–17.
Luck, J., Spackman, M., Freeman, A., Tre¸bicki, P., Griffiths, W., Finlay, K., Chakraborty, S., 2011. Climate change and diseases of food crops. Plant Pathol. 60 (1), 113–121.
Maddison, D., 2007. The perception of and adaptation to climate change in Africa, Vol. 4308. World Bank Publications.
Mall, R.K., Singh, N., Singh, K.K., Sonkar, G., Gupta, A., 2018. Evaluating the performance of RegCM4.0 climate model for climate change impact assessment on wheat and rice crop in diverse agro-climatic zones of Uttar Pradesh, India. Clim. Change 149 (3-4), 503–515.
Mall, R.K., Srivastava, R.K., Banerjee, T., Mishra, O.P., Bhatt, D., Sonkar, G., 2019. Disaster risk reduction including climate change adaptation over south Asia: challenges and ways forward. Int. J. Disaster Risk Sci. 10 (1), 14–27. https://doi.org/10.1007/s13753-018-0210-9.
Mall, R.K., Chaturvedi, M., Singh, N., Bhatla, R., Singh, R.S., Gupta, A., Niyogi, D., 2021. Evidence of asymmetric change in Diurnal Temperature Range in recent decades over different Agro-climatic Zones of India. Int. J. Climatol. 41 (4), 2597–2610. https://doi.org/10.1002/joc.6978.
Mendelsohn, R., 2000. Efficient adaptation to climate change. Clim. Change 45 (3), 583–600.
Mendelsohn, R., 2006. The role of markets and governments in helping society adapt to a changing climate. Clim. Change 78 (1), 203–215.
Myers, T.A., Maibach, E.W., Roser-Renouf, C., Akerlof, K., Leiserowitz, A.A., 2013. The relationship between personal experience and belief in the reality of global warming. Nat. Clim. Chang. 3 (4), 343–347.
Negi, V.S., Maikhuri, R.K., Pharswan, D., Thakur, S., Dhyani, P.P., 2017. Climate change impact in the Western Himalaya: people's perception and adaptive strategies. J. Mt. Sci. 14 (2), 403–416.
Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: Associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob. Environ. Chang. 39, 133–142.
Panda, A., 2016. Exploring climate change perceptions, rainfall trends and perceived barriers to adaptation in a drought affected region in India. Nat. Hazards 84 (2), 777–796.
Pandey, R., Kumar, P., Archie, K.M., Gupta, A.K., Joshi, P.K., Valente, D., Petrosillo, I., 2018. Climate change adaptation in the western-Himalayas: Household level perspectives on impacts and barriers. Ecol. Ind. 84, 27–37.
Patel, S., Mall, R.K., Jaiswal, R., Singh, R., Chand, R., 2022. Vulnerability Assessment of Wheat Yield Under Warming Climate in Northern India Using Multi-model Projections. Int. J. Plant Prod. 16, 611–626. https://doi.org/10.1007/s42106-022-00208-1.
Paulraj, J., Andharia, J., 2015. Resilience of Indigenous Peoples To 236 Disasters: an Exploration of Practices of Konyak Community, Nagaland. Eur. Sci. J. 11 (10), 147–160.
Sahu, N.C., Mishra, D., 2013. Analysis of perception and adaptability strategies of the farmers to climate change in Odisha, India. APCBEE Proc. 5, 123–127.
Shukla, R., Agarwal, A., Sachdeva, K., Kurths, J., Joshi, P.K., 2019. Climate change perception: an analysis of climate change and risk perceptions among farmer types of Indian Western Himalayas. Clim. Change 152 (1), 103–119.
Shukla, G., Kumar, A., Pala, N.A., Chakravarty, S., 2016. Farmers perception and awareness of climate change: a case study from Kanchandzonga Biosphere Reserve, India. Environ. Dev. Sustain. 18 (4), 1167–1176.
Singh, S., 2020. Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region, India. Ecol. Indic. 116, 106475.
Singh, N.P., Anand, B., Khan, M.A., 2018. Micro-level perception to climate change and adaptation issues: A prelude to mainstreaming climate adaptation into developmental landscape in India. Nat. Hazards 92 (3), 1287–1304.
Swami, D., Parthasarathy, D., 2020. A multidimensional perspective to farmers' decision making determines the adaptation of the farming community. J. Environ. Manage. 264, 110487.
Tooley, B.E., Mallory, E.B., Porter, G.A., Hoogenboom, G., 2021. Predicting the response of a potato-grain production system to climate change for a humid continental climate using DSSAT. Agric. For. Meteorol. 307, 108452.
Tripathi, A., Mishra, A.K., 2017. Knowledge and passive adaptation to climate change: An example from Indian farmers. Clim. Risk Manag. 16, 195–207.
Vedwan, N., Rhoades, R.E., 2001. Climate change in the Western Himalayas of India: a study of local perception and response. Clim. Res. 19 (2), 109–117.
Zhang, L., Hu, J., Li, Y., Pradhan, N.S., 2018. Public-private partnership in enhancing farmers' adaptation to drought: Insights from the Lujiang Flatland in the Nu River (Upper Salween) valley, China. Land Use Policy 71, 138–145.