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Rice farmers' perceptions about temperature and rainfall variations, respective adaptation measures, and determinants: Implications for sustainable farming systems

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In Pakistan, climate change is adversely affecting agricultural production and undermining the food security and subsistence of millions of farm households. Farmers' understanding of climate change and their adaptation strategies can serve as a useful step to help minimize climate risks. This study explores farmers' perception of and adaptation strategies to climate change and their determinants in the rice-growing zone of Punjab province, as this region of the country is highly vulnerable to climate change impacts. The multistage stratified-random sampling method was used to select 480 farmers from the four rice districts of the region, and data were collected using a structured questionnaire. Logistic regression and contingency tables are used to analyze the determinants of farmers' adopted strategies and adaptation extent (number of adopted strategies). Results show that farmers perceived significant changes in the climate, including the rise in average summer and winter temperatures and the decline in overall precipitation. The study further found that farmers' adopted adaptation strategies include supplementary irrigation, adjustments in rice cultivation dates, crop diversification, use of climate-smart varieties, better fertilizer management, and farm resizing. Logit model showed that farmers' age, primary occupation, income, landholding, access to irrigation, credit, climate information, and farm advisory appeared to be the significant determinants of their adaptation decision. The adaptation extent strongly correlates with farmers' education and access to climate information and credit services. Based on these findings, this study suggests the relevant institutions improve farmers' access to irrigation water, credit, farm advisory, and climate information to improve their adaptation extent and hence resilience of the rice-farming system.

KEYWORDS

Climate change, awareness, adaptation, socio-economic analysis, agriculture, Pakistan

1 Introduction

Inter-Governmental Panel on Climate Change (IPCC) predicts more frequent and severe climate events in the near future (Field et al., 2014). These indications will have severe consequences for different sectors of the global economy, including agriculture, and may undermine socio-economic development across the globe (Masud et al., 2017). The impact of climate variability and change on agriculture in the form of reduced crop yields, soil degradation, and water scarcity has posed a significant threat to livelihood and food security at both regional and global scales (Knox et al., 2012; Alauddin and Sarker, 2014). These impacts disproportionally affect developing countries' socio-economic development owing to their higher dependence on agriculture and related sectors (Fahad and Wang, 2018). South Asia is counted among the world's most vulnerable regions to climate change due to its high exposure to climate-induced risks and disasters (Field et al., 2014; Aryal et al., 2020). It is reported that a one-degree Celsius temperature rise may reduce cereal production in South Asia between 4%–10% by 2,100 (Aggarwal and Sivakumar, 2010; Lal, 2011). It is further shown that declining crop production may severely harm the food security of the region, where food production needs to be doubled by the end of this century (FAO FAOSTAT, 2016). The recent droughts in Nepal and Sri Lanka (Chandrasekara et al., 2021) are giving us a taste of what is to come when the consequences of climate change will be more widespread and more noticeable.

Like many countries in the region, Pakistan is facing the alarming challenge of climate-induced catastrophes. Pakistan is reportedly the world's fifth most vulnerable nation in terms of the long-term impacts of climate-induced disasters (Eckstein et al., 2019). This is caused by a significant temperature rise in the country during the past 6 decades; the average temperature has risen to half a degree Celsius (Chaudhry et al., 2009), triggering several disastrous events, such as floods, droughts, and biological hazards. Series of extreme droughts in the late 1990s to early 2000s (Khan et al., 2020a), four deadly floods between 2010–2014 and disastrous floods of 2022 (Shah et al., 2021; Sarkar, 2022), and a recent climate-led locust outbreak (Khatri, 2019) are a few examples. Such catastrophes are alarming for a developing nation like Pakistan, which mainly relies on agriculture and associated sectors that are highly sensitive to climatic variations.

In Pakistan, the agriculture sector contributes over 20% of the total Gross Domestic Product (GDP) and employs over 40% of its total labor force (Khan et al., 2020b). During the floods of 2010, Pakistan's agriculture sector faced a loss of over one million hectares of unharvested crops and 1.5 million livestock resulting in a loss of over US$10 billion to the poor economy (Shah et al., 2018). The recent flood of 2022 that wreaked havoc in Pakistan, washing out one-third of the country, displacing three million people, and causing unprecedented loss of human lives, crops, and livestock, is believed to be more disastrous than the historic 2010 floods, which is mainly caused by unexpected monsoon rainfall in the country (Sarkar, 2022). Such calamities are significant threats to people's livelihoods as agriculture provides subsistence to the millions of farm households in Pakistan. Among many crops, rice is reported as the most vulnerable food crop, facing a major yield decline due to the impacts of climate change and variability (Ahmad et al., 2015; Ali et al., 2017). In Punjab province alone, rice yield has declined by nearly 7% during the past decade (AMIS, 2018), mainly due to climate change-led water scarcity, increasing average temperature, and declining average precipitation. Studies have shown that rice production in Punjab is likely to decline further by up to 36% by the year 2099 if the current trend of climate change continues (Ahmad et al., 2015) and if farmers do not adequately adapt to the resultant impacts. Given the challenges to cereal crops, food security is being seen as an emerging challenge (Khan et al., 2021a). In this scenario, adapting agriculture to climate change is imperative to avoid existing and potential risks of yield decline.

Climate change adaptation is considered a useful strategy to address climate risks and their impact on the agriculture sector (Khanal et al., 2018a; Khan et al., 2021b). Farming systems and communities may adopt various adaptation strategies in the form of adjustments in cropping operations (Arunrat et al., 2017), adoption of improved farm management practices (Di Falco and Veronesi, 2013), and use of climate-smart seeds (Zhai et al., 2018; Sertse et al., 2021) to avoid the adverse effects of changing climate. The literature widely advocates the effectiveness of climate change adaptation measures in agriculture, making it one of the effective ways of tackling climate risks in agriculture (Khanal et al., 2018b; Sertse et al., 2021). For instance, studies in Africa widely report the use of climate-smart seeds, shuffling in crop planting dates, and water management practices among key strategies; Sertse et al. (2021) report climate-smart seeds to be one of the most useful strategies, and Amare et al. (2018) stated positive contribution of adaptation in terms of improving household food security. Similarly, a number of studies in Asia also suggest that farmers' adaptation measures are positive contributors to crop productivity; Khanal et al. (2018a) report rice farmers' adaptation strategies in Nepal which include soil and water management practices, shuffling of cultivation dates as effective strategies to deal with the variation of temperature and precipitation and a study in China (Cui and Xie, 2022) concludes that adjustments in crop planting dates can significantly avoid crop damages caused by climate change. Many types of adaptation strategies are widely discussed in both empirical and theoretical studies, such as ex-ante and ex-post adaptation (Abid et al., 2020) or autonomous and planned adaptation (Mersha and van Laerhoven, 2018; Khan et al., 2021c). Some studies distinguish adaptation in terms of time (anticipatory or reactive), type (technical, behavioral, or institutional), planning (short term or long term), and sector involved in managing or implementing it (Private or Public) (Bastakoti et al., 2017). Among various types, farm-level autonomous adaptation strategies are the most common form of adaptation that farming communities consider while facing climate risks (Arunrat et al., 2017; Masud et al., 2017). Previous studies (Adarsha et al., 2017; Khatri-Chhetri et al., 2017; Shah et al., 2022) show that the adoption of such adaptation strategies is mainly shaped by various attributes associated with farm households. These attributes include farmers' education, farming experience, farm assets, access to farm inputs, and, most importantly, availability of credit and information. Recent studies revealed that adaptation is largely shaped by farmers' contact with extension officers, daily media usage, availability of farm machinery, and membership in farmers' associations (Shahbaz et al., 2021; Ul Haq et al., 2021). Although a range of factors is discussed in these studies, important farm and economic attributes, such as farm labor availability, canal water availability, and primary income source, are not included in terms of their relationship with adaptation decisions, which this research intends to explore.

In Pakistan, the literature on climate change adaptation and agriculture is continuously growing, given the country's vulnerability to climate variations (Ali and Erenstein, 2017; Fahad and Wang, 2018; Hussain et al., 2020). For instance, Abid et al. (2015) conducted a study in the three agroecological zones of Punjab province and assessed that wheat farmers adopt a number of on-farm adaptation measures to cope with climate change, which are mainly associated with their socio-economic attributes. Similarly, Hussain et al. (2022), in their study in the southern part of Punjab province, assessed the impact of weather shocks on farmers' income and evaluated farm households' perceptions and coping strategies against weather shocks. Fahad and Wang (2018), on the other hand, assessed the vulnerability of farming communities in the Khyber Pakhtunkhwa province of Pakistan by exploring farmers' exposure to climate risks and their adaptive capacities. Similarly, some studies have also evaluated the efficacy of adaptation strategies; for instance, Ali et al. (2017) assessed the impact of climate change adaptation practices on household food security and poverty levels in different provinces in Pakistan. Despite the growing literature, empirical research still remains scarce, particularly, in the case of the major rice-growing region of the country, regarding the assessment of farm households' climate change perception, adaptation strategies, and socio-economic drivers of adaptation. Such empirical research on climate change adaptation and its determinants holds a fundamental significance in policy and action frameworks, as it outlines the current state of adaptive capacities of the farming systems and plays a pivotal role in designing relevant policies (Bonzanigo et al., 2016). Therefore, considering the research gap and significance, this study is particularly focused on the rice-growing zone of Punjab province, a region facing a decline in rice yield, and intends to explore how farmers perceive and adapt to climate change. Specifically, the study has three research objectives: 1) to assess rice growers' perceptions of climate change in the study area, 2) to explore farmers' adaptation strategies in the rice-farming systems, and 3) to analyze the factors affecting farmers' adoption of adaptation strategies.

2 Research methodology

2.1 Research site

This study was conducted in the Punjab province of Pakistan, which is a leading agricultural province in the country. Punjab contains over half of Pakistan's total cultivated land area and produces 70% of its cereal crops, generating over half of its agricultural GDP (Khan et al., 2020c). Punjab province is situated in the eastern part of the country, bordering India from the east, Sindh province from the South, and the provinces of Khyber Pakhtunkhwa and Baluchistan from the northwest and southwest. This study further chose the rice-growing zone of Punjab province as a specific focus of this research due to its agricultural significance and vulnerability to climate change (Khan et al., 2020d). The region produces over 60% of the country's total rice, an important food crop and an essential element of Pakistan's agricultural exports (IRRI, 2013; Khan et al., 2021a). Rice growing region is located in the irrigated plains[1] of Punjab province, consisting of over ten districts specializing in rice production (Ahmad et al., 2019). The region is globally famous for its aromatic rice varieties and is known as the *Kollar track*. However, during the last decade, the rice-growing zone has faced a substantial decline in rice yield, mainly due to climate change and its associated hazards. These climate hazards and risks include droughts of the late 1990s and early 2000s, extreme floods of 2010 and 2022, and depletion of water resources (Xie et al., 2013; MA and Mugera, 2016; Khan

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[1] Irrigated plains are one of three Agro-ecological zones (AEZs) of Punjab province.http://www.fao.org/3/ca6938en/CA6938EN.pdf.

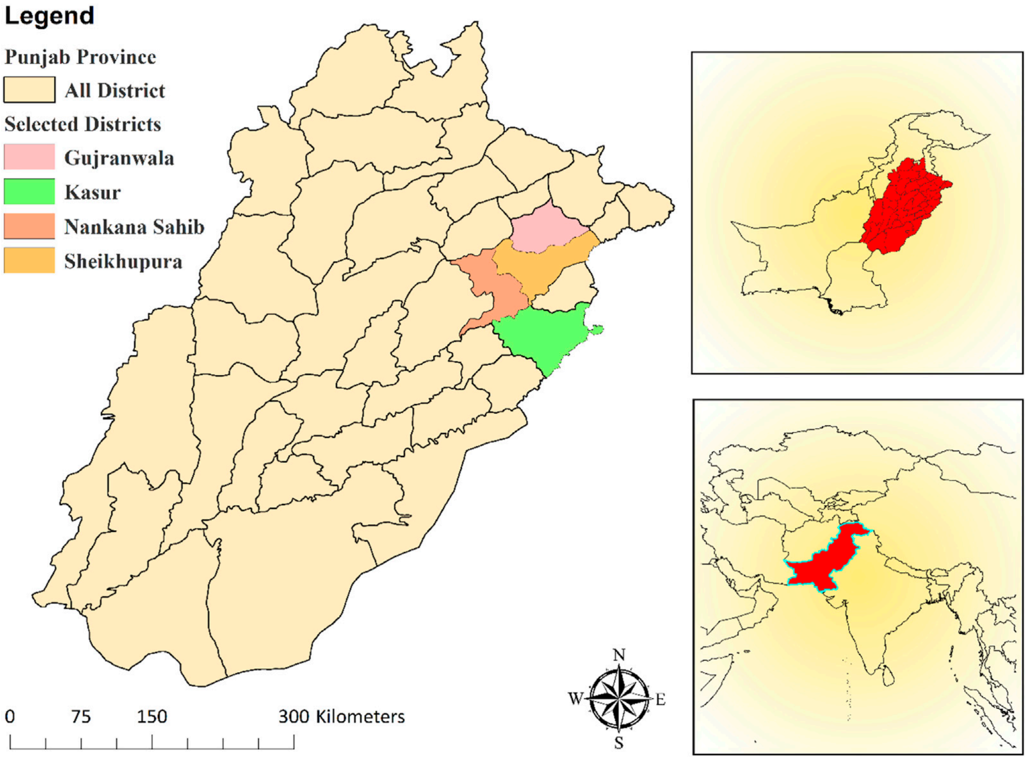

FIGURE 1
Pakistan in South Asia and Punjab on Pakistan's map (right), selected districts of Punjab (left).

et al., 2020a). The flood of 2010 affected eleven districts of Punjab, including the study area (PDMA, 2014). Such risks and uncertainties have made the cultivation of crops such as rice extremely susceptible. For instance, between 2009–2017, rice production declined by nearly 7% due to a 10% decline in land area under rice cultivation (AMIS, 2018). Studies show that the decline in rice production and cultivation area is mainly due to increasing average temperature, declining precipitation, and shrinking water resources of the region (Ahmad et al., 2015; Ali and Erenstein, 2017). Given these challenges, this research is conducted in the rice production zone of Punjab to investigate how farmers perceive changes in climate and what adaptation strategies they adopt. Specifically, four rice-growing districts are selected for this study, shown in Figure 1.

2.2 Sampling method and data collection

There are various methods of determining sample size available in the literature; this study, however, used the formula by Teddlie and Yu (2007), given the nature of the population. This approach is employed if the exact population of farmers is unspecified. In the current study, the exact population of rice farmers was unknown; thus, a sample size of 480 farmers was generated with an estimated proportion of the attribute in population $p = 0.5$, ±4.475% margin of error, and 95% confidence level, calculated as follows:

$$n_0 = \frac{Z^2 \rho q}{e^2} = \frac{(1.96)^2\ (0.5)\,(0.5)}{(0.04475)^2} = 480 \qquad (1)$$

where: n_0 indicates sample size, the Z-value at 95% confidence level is 1.96, e is the margin of error (4.475%), p is the (estimated) proportion of the attribute in population $p = 0.5$, $q = 1\text{-}p$, hence $q = 0.5$.

This study considered a random-stratified, multistage sampling approach, where the sample was drawn in the following six steps. The reason for employing this sampling method is owing to the different hierarchical levels of the local population living in an area. Studies support the use of this approach if the population is distributed at different levels (Allen, 2017). Then the sample is determined by selecting farmers from each stage. The major benefits of this method include flexibility in determining the number of stages, sampling units, and methods at each stage, which make this approach more suitable for fulfilling survey requirements (Steel and Lovric, 2011). Therefore, following previous research (Shah et al., 2017; Khan et al., 2021c), we have chosen the farmers involving six stages. In the first step, using stratified sampling, the rice production region was divided into two groups, i.e., high production districts

TABLE 1 Sample distribution across the study area.

Stage 1		Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Production categories	Production range	Districts	Sub-districts	Union council	Villages	Farmers selected
High Production districts	300–500 metric tonnes	Gujranwala	2	4	8	120
		Sheikhupura	2	4	8	120
Low Production districts	100–300 metric tonnes	Nankana Sahib	2	4	8	120
		Kasur	2	4	8	120
Total	2	4	8	16	32	480

Land unit in Pakistan (1 ha = 2.47 acre);^{2fn2} PKR = Pakistani rupees (1USD = 163 PKR on 30 June 2019), source: (Field survey, 2019)

and low production districts, given each district's share of the total provincial rice yield. Our logic behind using the districts' total production instead of per hectare yield as the basis of categorization is because the per hectare yield is affected by several factors such as land productivity, input use efficiency, and technology adoption (irrigation, type of variety, etc.). Besides, in the study area, farmers grow different types of rice, such as long-duration rice and short-duration rice, which largely differ in terms of yield and market value; hence, considering per hectare yield could be misleading. Therefore, following Iqbal et al. (2016), who also adopted a similar sampling strategy, we considered the total production of the districts and categorized them into two groups, i.e., high production districts and low production districts, and selected two from each category. Table 1 shows the production range for categorizing the region. Following that, the second step involved the random selection of two districts from each yield group. Specifically, districts Gujranwala and Sheikhupura were selected from the high production zone, while districts Nankana and Kasur were selected from the low production zone. In step three, we randomly selected eight sub-districts (Tehsils) from both regions by choosing two from each district. In the fourth stage, using random sampling, we selected four union councils (UC, the second-smallest administrative unit of Pakistan's local government system) from each sub-district, making a total of sixteen UCs. In the fifth step, we randomly chose eight villages from one district (two from each UC), comprising a total of 32 villages. In the sixth and last step, we randomly chose fifteen farmers per village, making a total sample of 480 rice farmers. A list of farmers of the villages was obtained from the district agriculture department, and following that, farmers were randomly chosen from each village.

Data were collected using a predesigned structured questionnaire to obtain farmers' perceptions of and adaptation strategies to climate change. All the farmers were face-to-face interviewed, given their low literacy levels. The questionnaire was developed in the English language (see questionnaire in annexure); however, the questions were translated to the local language (Punjabi) during the interviews. A pre-test was also conducted on thirty farmers (outside the sample) to ensure the reliability and validity of the questionnaire. To facilitate the data collection process, two enumerators from a local university were hired and trained. The data collected was completed between June-August 2019.

2.3 Data analysis and empirical model

Farmers' perceptions of climate change were recorded using a Likert scale, where farmers were asked to indicate the changes in temperature and precipitation over the past 1–2 decades. Given that the average temperature in the country has increased by half a degree Celsius during the past 6 decades (Chaudhry et al., 2009), it is relevant to ask how farmers perceive temperature and precipitation changes at the local level. In this way, researchers intended to find whether farmers' perceptions are in line with the actual trends. The collected response was analyzed using simple percentages. Similarly, farmers' responses to adopted adaptation measures were recorded in the form of a binary variable, which takes a value of one if farmers adopt a certain adaptation measure and zero if they do not adopt that measure. While to determine the factors affecting farmers' adoption of various adaptation strategies, a regression analysis was conducted.

2.3.1 Binary logit model

This study chose a binary regression model given the binary nature of the dependent variables. Specifically, a binary logit model was employed to analyze the factors determining farmers' adaptation decisions, which is commonly used in similar studies (Kato et al., 2011; Bryan et al., 2013). This model gives relatively more precise estimates than similar models like the Linear Probability Model (LPM), which has certain limitations in heteroscedasticity and distribution abnormality of the error term (Iqbal et al., 2016). In this model, we assume that a farmer adopts an adaptation measure that has the maximum outcome in terms of reducing the adverse effects of changing climate (Kato et al., 2011).

Specifically, an assumed latent binary variable (Y_{ij}) equal to the expected outcome of adopted measures can be interpreted as:

TABLE 2 Descriptive statistics of explanatory variables.

Variable name	Description	Mean
Farmers' age	Age in years	47.25
Farmers' education	Acquired schooling in years	7.53
Household size	Total family members	6.58
Primary occupation	1 = farming, 0 = otherwise	0.78
Landholding	Total cultivated land in Acres[1]	8.07
Land ownership	1 = farmer is the owner of the land, 0 = tenant	0.88
Tube well	1 = farmer has irrigation borewell, 0 = No	0.64
Canal irrigated land	The percentage of land irrigated by canal water	14.33
Livestock units	Number of animals owned by HH	4.59
Farm labor	Continuous number of farm laborers	1.98
off-farm income	Continuous monthly income from non-farm sources, 000 PKR[2]	11.05
Access to farm advisory	1 = farmer received, 0 = No	0.42
Access to credit services	1 = farmer availed, 0 = No	0.32
Access to climate info	1 = if farmer access, 0 = No	0.61
Farm location	1 = farmer belongs to high yield zone, 0 = No	0.50

$$Y_{ij} = \alpha + \sum X_k \beta_k + \varepsilon_{Y_{ij}} \tag{2}$$

where, subscript i indicates a farmer whose crop is exposed to climate change, and subscript j indicates response measures (adaptation strategies) that farmers adopt to avoid the potential risks. The symbols a and β indicate the intercept and coefficients of the binary regression model. X_k refers to the vector of exogenous explanatory variables that influence farmers' selection of adaptation strategies, while the subscript k indicates a particular explanatory variable (Table 2). $\varepsilon_{Y_{ij}}$ is an error term, homoscedastic and normally distributed, with constant variance and zero mean (Schmidheiny, 2013).

A binary variable cannot be observed directly; however, it is observed as:

$$Y^*_{ij} = \begin{cases} 0, & Y \le 0 \\ 1, & Y > 0 \end{cases} \tag{3}$$

where, Y^* is an observed variable, indicating a farmer i will only adopt certain measure j if the expected benefit is more than zero ($Y > 0$), and will not adopt the adaptation measure if the expected benefit is below or equal to zero ($Y \le 0$). Eq. 3 can be reinterpreted in terms of an observed binary variable (Y^*_{ij}), where G refers to the specific binomial distribution (Eq. 4) (Fernihough, 2011).

$$Pr\left(Y^*_{ij} = 1\right) = Y^*_{ij} = G\left(\beta_k X_k\right) \tag{4}$$

2.3.2 Marginal effects

Parameter estimates of the logit model only give the direction of impact (βk) and the level of significance (p-value) of correlation between dependent and independent variables. However, they do not measure the magnitude of effects or the relationship between the dependent (adaptation) and independent variables (socio-economic explanatory). To do so, marginal effects ($Y^{*'}_{ij}$) were calculated to quantify the impact of per unit change in the explanatory variable (Xk) on the probability of unit change in the dependent variable Pr(Yij = 1) (Fernihough, 2011). The marginal effects equation for a binary logit model can be interpreted as follows:

$$\frac{\partial \mathrm{Y_i}}{\partial \mathrm{x_k}} = Pr\,(1 - Pr)\beta_\mathrm{k} \tag{5}$$

2.3.3 Evaluation of model fitness

Before estimating binary logistic regression, we checked the multicollinearity effect between the explanatory variables using the variance inflation factor (VIF) and did not find a high pairwise correlation among the selected variables. Further, to evaluate the *goodness of fit* of the developed models (seven models of farmers' adaptation measures), we adopted the commonly used null hypothesis approach. In this approach, all the models' coefficients (β_k) were assumed to be zero as null hypotheses, while alternative hypotheses with at least one value as non-zero.

$H_{1:}$ at least one $\beta_k \neq 0$

H_0: $\beta_k = 0$

Table 3 shows test statistics for model fitness. Pseudo R-square values ranged between 0.15 and 0.32, showing the model's strength in assessing determinants of adaptation decisions. Further, LR chi-square values for all logit models ranged between 17 and 99 and were significant at less than 1% probability level. Based on these indicators, we reject the null hypothesis and accept the alternative hypothesis (as at least one value of β_k is non-zero). Hence it can be concluded that all the models fit significantly and can accurately estimate the

TABLE 3 Test statistics for model fitness.

Models	-2 log likelihood	Prob > chi^2	Pseudo R^2	LR chi^2 (13)
Supplementary irrigation	−183.03	0.00	0.30	77.20
Irrigation time changes	−184.97	0.00	0.28	23.12
Short-duration rice	−220.69	0.00	0.15	12.97
Climate-smart rice varieties	−165.75	0.00	0.22	92.31
Cultivation date changes	−121.81	0.00	0.21	42.22
Fertilizer management	−201.39	0.00	0.32	99.06
Farm resize	−200.78	0.00	0.23	17.27

Prob > chi^2 indicates the significance level ($p< 0.01$) to accept the alternative hypothesis (H_1).

determinants of adaptation decisions (Peng et al., 2002; Stephenson et al., 2008).

2.3.4 Adaptation extent across different types of farmers: Three-way contingency table analysis

In addition to binary logistic regression, a three-way contingency table analysis was also used to understand the adaptation extent across the various regions and categories of the farmers. This method involved the division of variables into groups. For instance, in terms of adaptation extent, farmers were divided into four categories (from non-adaptation to high adaptation). A similar categorization was done for the selected explanatory variables. The contingency table analysis was done on three explanatory variables, i.e., farmers' education, access to climate information, and credit utilization status, to assess their adaptation extent across both study zones separately and in total. This is a descriptive analysis using cross-tabulation to complement the results of regression analysis.

A three-way contingency table analysis is a cross-classification of observed values *x_ijk, i = 1, . . . , I, j = 1, . . . ,J, k = 1, . . . , K of I×J×K* random variables, arranged in I rows, J columns, and K layers (Andersen, 1997). The interpretation of corresponding random variables could be as follows:

$$X_{111}, \cdots, X_{ijk} \sim M\left(n; \pi_{111,L}, \pi_{ijk}\right) \tag{6}$$

It is a multinomial distribution with number parameter n and probability parameters π_{ijk}Where; $n = x\ldots = \sum_i \sum_i \sum_i xijk$

After conducting contingency table analysis, the results were presented as line graphs (Figures 4–6) to better understand and compare farmers' adaptation extent across socio-economic and regional attributes.

3 Results and discussion

3.1 Farmers' perception of climate change in the study area

Initially, farmers were assessed on their perception of climate change considering primary climate indicators, i.e., temperature and rainfall. Results (Figure 2) showed that farmers reported significant changes in the climate, which mainly included increased temperature and declined precipitation throughout the year. Specifically, results showed that over 80% of the farmers reported an increase in summer temperature in comparison to 60% who indicated an increase in winter temperature. Notably, 30% of farmers indicated a significant increase in the summer temperature. These findings show that temperature in general and summer temperature, in particular has increased according to farmers' perceptions. Similarly, regarding rainfall, results show overall rainfall has also decreased throughout the year. In particular, most farmers reported that rainfall has decreased during the summer and monsoon months compared to the previous 1–2 decades. Our findings are consistent with another study conducted in the southern part of Punjab province, where Hussain et al. (2020) reported that farmers perceived a rise in temperature; however, on the contrary, farmers in south Punjab reported an increased incidence of heavy rainfall. The perceived variation in rainfall could be due to the fact that both regions fall in different agroecological zones.

These findings suggest increasing vulnerability of rice crops as it is one of the crops facing significant yield decline due to temperature rise and shrinking precipitation. We further cross-checked farmers' perceptions with the actual temperature and precipitation trends in the study area, which revealed that the increase in mean annual temperature for north-eastern Punjab (the rice-growing districts) is mostly non-significant, while a significant temperature increase in mean temperature for winter is observed. Similarly, Syed et al. (2021) report that annual mean precipitation has not changed significantly; however, a significant change was observed in autumn. A study by Ahmad et al. (2015) states shrinking precipitation and rising temperature as the two major challenges to rice crops in Punjab province, projecting nearly a 35% decline in rice production by the end of this century if the temperature and precipitation variability continues. Such figures are alarming for the food security and livelihoods of the rural population as over one million farm households in the study

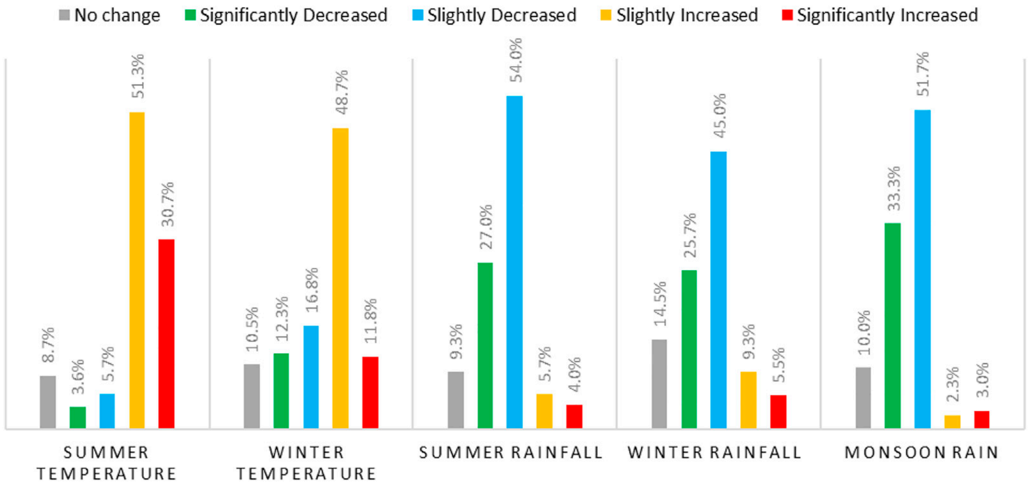

FIGURE 2
Perceived variability in temperature and rainfall.

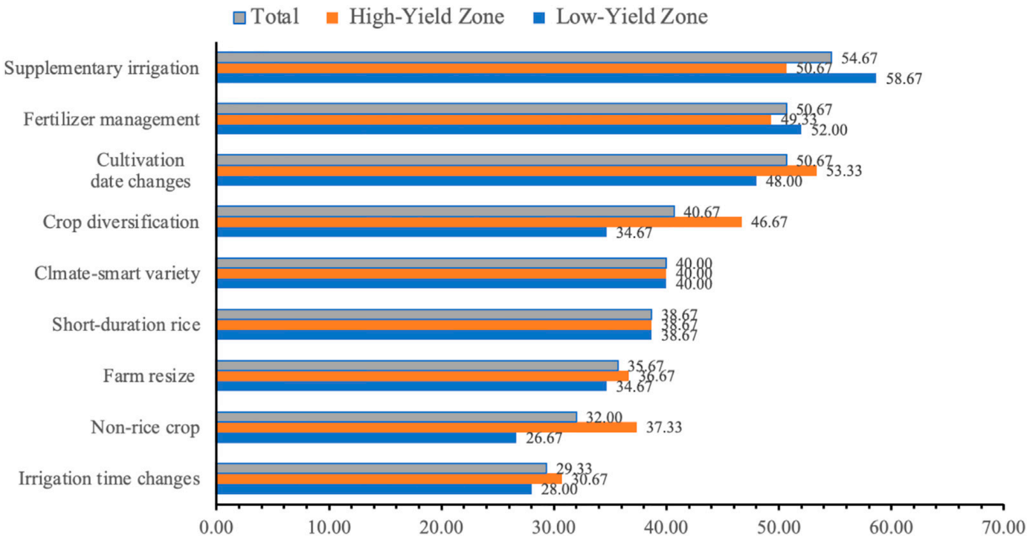

FIGURE 3
Farmers' adaptation strategies to cope with temperature and rainfall variability.

area depend on rice farming for their subsidence. It is, therefore, imperative to adapt rice farming to these changes in climate to avoid potential yield losses.

3.2 Farmers' adaptation strategies to climate change

Farmers in the study area were asked to indicate the respective adaptation measures which they adopt in their farming operations as a response to the changes in climate. During the interviews, the sampled farmers were requested to state only the strategies they adopted in response to their perceived impacts of climate change and variability. Findings (Figure 3) show that supplementary irrigation (55%), changes in rice cultivation dates (51%), and better fertilizer management (51%) were the major adaptation strategies adopted by the farmers. Further, farmers also reported use of crop diversification (41%), cultivation of climate-smart seeds (40%), cultivation of short-duration rice (39%), farm resizing practice (35%), shift to non-rice crops (32%), and altering irrigation time (29%) as key measures to cope with effects of changing climate.

These findings revealed that farmers implement a range of adaptation measures to adapt their rice farming to climate change in the study area.

3.2.1 Supplementary irrigation

Many studies show that the adaptation of agriculture to climate change is mainly the adaptation to water scarcity and shortage (Khanal et al., 2018a; Abid et al., 2020). Similar are the findings of this study as over half of the farmers considered the application of supplementary irrigation, making it the most adopted adaptation measure. This could be due to the rising irrigation requirement, mainly because of rising temperature, long and frequent droughts, and declining precipitation, which compel farmers to apply more irrigation to rice fields to mitigate temperature shocks. These findings are supported by a study in Bangladesh (Alauddin and Sarker, 2014), where rice farming communities apply additional irrigation to the rice field in order to avoid heat stress during extremely hot days. Similarly, in India (Dhanya and Ramachandran, 2016; Narayanan and Sahu, 2016), farmers also consider water application to the field when it is faced with the hot summer wind. However, in African countries (Thinda et al., 2020), the trend is slightly different as farmers' do not adopt supplementary irrigation as the most adopted strategy; rather, they mostly shift seed varieties. The possible difference between African and South Asian farmers' adaptation could be due to many factors, including different climate conditions and agroecological features. As temperature rise is more severe in south Asia than in Africa, farmers tend to rely more on additional irrigation.

3.2.2 Fertilizer management

Making crops physiologically healthy and resistant to environmental changes is another key measure adopted by farmers. This is done by using a good combination of fertilizers, which not only makes plants healthy and generates higher yields but also avoids the extra cost of non-required nutrients and fertilizers. According to Stuart et al. (2014), better management of fertilizers not only reduces climatic shocks and input costs but also enhances soil fertility. Half of the farmers in the study area adopted this measure, where some used a smart combination of fertilizers while some managed the plants' nutrients requirement by adjusting the supply of organic fertilizers obtained from the farmyard manure. Farmers reported that it is one of the good ways of improving plant health, given the negative impacts of climate change on plant growth. Our findings are similar to the study of Khanal and Wilson (2019), who also reported that Nepalese farmers use a proportionate combination of organic and chemical fertilizers to cope with climate change. These findings, however, contradict the case of Thailand (Arunrat et al., 2017), where farmers do not mostly rely on fertilizer management as an alternative strategy for climate change adaptation. The difference in the adoption of this strategy is mainly due to the variation of agroecological characteristics and farming culture of both countries, which are developed based on local knowledge.

3.2.3 Cultivation date changes

The change in crop cultivation dates is another strategy used by the rice farmers of Punjab. In this strategy, farmers shuffle the sowing and harvesting dates to avoid the expected occurrence of an unfavorable event. More than half of rice farmers adopted this strategy as a response to temperature and rainfall variability. This is mainly based on farmers' understanding of local climate patterns, where they may consider early sowing or transplanting if the temperature has risen before the usual time. This strategy also appears to be the most cited and commonly adopted measure among farmers in Africa and Asia (Cooper et al., 2008; Masud et al., 2017). However, the extent of reliance and adoption varies from region to region. For instance, in Malaysia (Masud et al., 2017), farmers rely more on crop planting and harvesting date adjustment compared with the case in Pakistan, where over half of the farmers were found altering rice cultivation dates in response to climate variability. In a South Asian country like Nepal (Khanal et al., 2018a; Khanal et al., 2018b), studies support these findings stating that rice farmers largely rely on crop operation adjustment in response to changes in cropping cycles and temperature and precipitation fluctuations.

3.2.4 Climate-smart varieties

Several farmers (40%) also adopted climate-smart varieties to cope with the changing climate. Change of crop varieties was done mainly in areas where previous varieties were highly vulnerable to temperature changes or could not give good yields. It was found that most farmers were looking mainly for those rice varieties which consume less irrigation water. However, no such varieties are available; rather, the farmers are provided with a few new varieties that are slightly heat-resistant and tolerant to climate shocks compared with the previous variety. Still, a considerable portion of the 60% of farmers cultivates old varieties because they are not familiar with the production technology and input requirement for new varieties. These findings are parallel with the study of Khanal and Wilson (2019), where a similar rate of new varieties' adoption is reported while contradicting the case of Nile Basin, Ethiopia, where farmers' adoption of improved seed variety is relatively higher. Mersha and van Laerhoven (2018) argue that the adoption of climate-smart variety is mainly led by institutions or planned adaptation where the local government contributes to the development and adoption of climate-smart technologies. However, in Pakistan, still, the planned adaption is at a nascent stage, and farmers are only open to very limited choices of seeds regarding a highly vulnerable crop like rice.

3.2.5 Cultivation of short-duration rice

Besides the adoption of climate-smart seeds, some farmers (32%) were found shifting to the cultivation of short-duration rice. Short-duration rice cultivation is a common practice in South Asian rice farming systems, where few varieties are harvested within 3 months of the cultivation cycle, compared to long-duration rice, taking over 4 months to be harvested. These findings are supported by the results of Alauddin and Sarker (2014), who also reported that most Bangladeshi rice farmers are shifting to short-duration rice, given the increased input cost needed for regular rice varieties.

This study considered the cultivation of short-duration rice as a separate adaptation measure because it is not a climate-smart variety (heat or drought-tolerant) but rather a risk-aversion response. Farmers relied on this strategy because they were not able to cultivate long-duration rice varieties like *BASMATI, SUPER,* and *SELLA* (local rice varieties in Pakistan) as they were unable to afford the cost of irrigation water and other inputs. The adoption of short-duration rice provides smallholder farmers with an alternative way to sustain their food and nutritional requirements by cultivating short-duration seeds such as *SUPRI, KAINAT* (rice varieties in Pakistan). However, the short-duration rice does not provide equal crop return as obtained through the long-duration rice because of the lower market value of short-duration rice. This is mainly because the long-duration rice has a special aroma[2], which is a distinctive feature of the rice of this region, while the short-duration rice is not that aromatic; hence people tend to prefer aromatic varieties more, which leads to a higher market value of the long-duration rice.

3.2.6 Crop diversification

Crop diversification refers to the cultivation of more than one crop species at the same time. It also means allocating some land area for another crop to diversify cropping systems to reduce the expected losses. Various studies alternatively use the term crop combination as well. Some scholars (Lim, 2018) argue that crop diversification is a livelihood adaptation rather than a farming adaptation because farmers reduce the land of a particular crop, affecting its production on a larger scale. We argue in support of the scholars that crop diversification is actually on the margins of farming adaptation and livelihoods adaptation, which shows both aversion[3] and response at the same time, as farmers respond with an alternative crop, but at the same, they reduce the crop's cultivation area which adversely affects production.

A considerable portion of the farmers was found shifting to other crops by reducing the cultivation area under rice crops. Specifically, 26% of the farmers were shifting to non-rice crops as they reported that rice is not a profitable business anymore in certain types of farms, making most farmers think about the alternative crops of the summer seasons such as pulses (moong, mash), maize, sugarcane, which relatively are less labor-intensive and input consuming. Farmers' diversification of crops and cultivation of non-rice crops could be the leading factors in declining rice cultivation area in Punjab province; for instance, provincial agricultural statistics show that from 2009–2018, the land area under rice cultivation has declined by 10%, causing a 7% reduction in rice yield (AMIS, 2018). These findings imply that farmers should be equipped with contemporary farming methods to sustain rice farming, as it is an important element of the country's agricultural exports.

3.2.7 Farm resizing

Farm resizing indicates a distinctive practice of rice farmers of Punjab province, which they usually adopt before the start of every rice cultivation season. This refers to the enlargement of rice plot size to over an acre[4], while usually, the plot sizes are one or half an acre for other crops. Farmers' expansion of plot size is coupled with land laser leveling, which makes a long plain plot for rice cultivation. In the study area, farmers irrigate their rice fields through a flooded irrigation method, where they have to spend long irrigation hours of electric or fuel-run tube wells. In this context, farmers' expansion of plot sizes is based on the notion that long smooth plots decrease the time and cost of irrigation. These findings are unlike the adaptation reported in other countries of Africa (ZY AmareAyoade et al., 2018), and Southeast Asia (Arunrat et al., 2017), where farmers do not make such changes in farm size. This could possibly be due to different irrigation methods practiced in different countries. In contrast, similar findings are reported in India, where land leveling for effective water harvesting is reported as a climate-smart measure (Khatri-Chhetri et al., 2017).

Over one-third of the farmers' adoption of such a strategy to cope with climate-induced water shortage indicate its usefulness, which implies the adoption of similar measures in other regions to cope with the climate-induced water-related issues in agriculture. Farmers largely advocated using this adaptation measure to reduce input costs spent on irrigation water.

3.2.8 Irrigation time changes

Change in irrigation application time to counter the heat waves and sun intensity was also found to be one of the adaptation measures of rice farmers. Over one-quarter of the sampled farmers indicated that they shuffle the times of irrigation application to avoid water loss. Farmers reported that they usually avoid irrigation at such time of the day when sun/heat intensity is high, which leads to higher evapotranspiration[5]. Hence irrigation application at certain times of the day (when evapotranspiration is minimum) reduces the irrigation costs. These indigenously developed adaptation measures may bring great benefits, particularly to those farmers

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[2] Aromatic rice of Pakistan https://www.cabi.org/GARA/FullTextPDF/2010/20103160491.pdf.

[3] Risk aversion means changing farming decision under fear of risk. https://core.ac.uk/download/pdf/206245143.pdf.

[4] Land unit in Pakistan, 1 ha = 2.4 acres.

[5] A process when irrigation water evaporates from field to air.

who have fewer resources to adopt other adaptation measures, such as climate-smart varieties or supplementary water application.

3.3 Factors affecting the farmers' adaptation decisions

3.3.1 Farmers' age

The results of the binary logit model (Table 4) indicate that farmers' age has a significant positive effect ($p < 0.01$) on the probability of changing irrigation application time and cultivation dates while a significant negative effect on the adoption of climate-smart varieties. Marginal effects (Table 5) further show that a 1-year increase in farmer's age increases the likelihood of changing irrigation time and cultivation dates by 0.016% points and 0.001% points, respectively, while it decreases the likelihood of cultivation of climate-smart seeds by 0.005% points. The lower inclination of old farmers towards new crop cultivars could be due to their lack of knowledge or more reliance on conventional seed varieties, which led them not to cultivate new rice seeds. Similarly, more possibility of changing irrigation timing and cultivation times among the aged farmers could be due to their more farming experience and understanding of farming operations, which enable them to adopt these measures to avoid the negative effects of changing climate.

3.3.2 Household size

The size of a farm household, which represents the number of family members, is assumed to be an essential attribute associated with farm-related decisions. Our findings show that household size has a significant positive correlation ($p < 0.05$) with irrigation time changes, while there is a significant negative correlation between supplementary irrigation ($p < 0.01$) and crop variety ($p < 0.01$). The magnitude of the relationship further indicates that a one-member increase in household size decreases the likelihood of application of supplementary irrigation and changing crop variety by 0.048% points and 0.027% points, respectively, while it increases the likelihood of changing irrigation timing by 0.03% points. The negative relationship could be due to the farmer's lack of financial resources, which may limit their capacity to invest more money in buying new varieties and applying more irrigation. These findings are supported by Akhtar et al. (2018), who advocate that large farm households have fewer financial constraints as they have more human resources that improve their adaptive capacity. Likewise, the positive association with changing irrigation time could also be due to the availability of more family members to work as on-farm labor to make changes in irrigation application timings.

3.3.3 Primary occupation

It is further found that farmers who mainly rely on farming as their primary source of family income are more likely to apply supplementary irrigation, irrigation time changes, do better fertilizer management, and cultivate climate-smart varieties compared with those not relying entirely on farming. A strong relation among these strategies is because the farmers who have a greater dependence on farming are more concerned about climate risks and hence adopt major adaptation strategies. As they have relatively few or do not have an alternative source of income, hence adopt strategies to minimize the risks of climate change to their livelihoods. This proves that farmers take risks and apply new technologies to save themselves from climate change when their sole income source is their rice farm.

3.3.4 Landholding

Farm size, which indicates farmers' total cultivated land, showed a significant positive correlation with farm resizing ($p < 0.01$), better fertilizer management ($p < 0.1$), and climate-smart seeds cultivation ($p < 0.01$). In contrast, it has a significant negative relationship with irrigation time changes ($p < 0.01$) and the cultivation of short-duration rice ($p < 0.05$). This shows that big landlords adopted those measures that required higher input costs and resources such as farm machinery, income, and skills, given the fact the big farmers have more land assets. On the other hand, the lower likelihood of irrigation time changes and short-duration rice cultivation shows that farmers having large land assets are financially stable and are not concerned about resource-saving measures. Our results are similar to a study conducted in China (Zhai et al., 2018) reporting that peasants who cultivate larger land areas are more likely to adopt climate-smart measures than farmers with less farmland.

3.3.5 Land ownership

The negative coefficients of farm ownership status indicate its significant negative relationship with the farmers' application of supplementary irrigation ($p < 0.05$) and the cultivation of climate-smart seeds ($p < 0.1$). The values of marginal effects show that farmers who owned the farmland have respectively 0.14% points and 0.11% points less probability of applying supplementary irrigation and adopting climate-smart varieties compared to tenant farmers. The higher trend of adopting these measures tenants could be due to their more concerns about farm produce and crop return to meet the additional burden of the land fee. Fosu-Mensah et al. (2012) also argued that farmers' land ownership largely improves their adaptation intentions.

3.3.6 Tube well

Availability of tube well, which indicates farmers' access to an irrigation source, showed a significant positive correlation with supplementary irrigation application ($p < 0.01$), irrigation time changes ($p < 0.01$), and fertilizer management ($p < 0.05$). The marginal effects indicate that farmers having a personal tube well have, respectively, 0.16% points, 0.30% points, and 0.08% points more likelihood of applying supplementary irrigation, changing irrigation time, and managing fertilizer application. It is reported that water management measures are among the most effective adaptation strategies against climate change (Alauddin and Sarker, 2014); hence farmers' ownership of a personal irrigation source is a

TABLE 4 Parameter estimates of logit models.

Explanatory variable	Supplementary irrigation	Change irrigation time	Short duration rice	Climate-smart variety	Change cultivation dates	Fertilizer management	Farm resize
Farmer's age	0.0093 (0.0200)	0.15921*** (0.0253)	−0.0119 (0.0161)	−0.0668*** (0.0231)	0.0900*** (0.0205)	0.0201 (0.0226)	−0.0185 (0.0169)
Farmer's education	0.1065 (0.0788)	0.0589 (0.0701)	−0.0040 (0.0601)	0.0862 (0.0806)	0.0291 (0.0702)	0.1126 (0.0882)	−0.0201 (0.0649)
Household size	−0.4976*** (0.1418)	0.3198** (0.1420)	0.0687 (0.1233)	−0.3558** (0.1710)	0.0162 (0.1264)	−0.1927 (0.1545)	−0.0886 (0.1374)
Primary occupation	2.4313*** (0.6700)	2.4020** (0.9388)	−0.7289 (0.4985)	2.3912*** (0.7995)	0.8142 (0.6151)	1.5045** (0.6902)	−0.2443 (0.5729)
Landholding	0.0411 (0.0357)	−0.1170*** (0.0442)	−0.0821** (0.0381)	0.1602*** (0.0440)	−0.0550 (0.0357)	0.0676* (0.0392)	0.1196*** (0.0319)
Land ownership	−1.4999** (0.6644)	−1.1034 (0.7183)	−0.2245 (0.5342)	−1.4859* (0.8409)	0.7139 (0.6463)	−0.2824 (0.7782)	0.9105 (0.7352)
Tube well	1.7587*** (0.4579)	3.0284*** (0.6226)	−0.5502 (0.3479)	−0.4596 (0.5542)	0.5537 (0.4032)	1.0032** (0.5103)	0.2986 (0.4603)
Canal irrigated land	0.0401** (0.0158)	−0.0047 (0.0158)	0.0077 (0.0127)	−0.0048 (0.0165)	0.0156 (0.0145)	0.0190 (0.0168)	−0.0199 (0.0142)
Livestock units	0.2432* (0.1194)	0.0241 (0.0923)	−0.3083*** (0.0958)	0.1141 (0.0920)	−0.0854 (0.0643)	0.2373** (0.1208)	0.1949** (0.0901)
Farm labor	0.1567 (0.2418)	0.2723 (0.2328)	0.3859** (0.1971)	−0.0902 (0.2934)	0.4336** (0.2120)	0.0753 (0.2607)	0.3938* (0.2268)
Off-farm income	0.0592** (0.0267)	−0.0629*** (0.0234)	−0.0092 (0.0217)	0.0559* (0.0293)	0.0043 (0.0221)	0.1117*** (0.0308)	−0.0066 (0.0213)
Access to farm advisory	1.9060*** (0.5786)	2.4454*** (0.6154)	−0.8764 (0.4640)	2.7622*** (0.5492)	2.7973*** (0.4692)	3.1887*** (0.6198)	2.6097*** (0.4856)
Access to credit service	1.4816** (0.6285)	0.0377 (0.6162)	−1.2516** (0.5734)	1.4925*** (0.5721)	1.8337*** (0.6025)	1.6042** (0.7153)	0.5942 (0.5014)
Access to climate information	0.3227 (0.4553)	−0.0480 (0.4642)	−1.0305*** (0.3508)	1.4171** (0.6590)	0.7087* (0.4140)	0.6832 (0.4860)	−0.1701 (0.4929)
Farm location	0.5278 0.4496	0.01967 (0.3996)	−0.1484 (0.3496)	0.0526 (0.4837)	0.1344 (0.3856)	0.2782 (0.5085)	0.3076 (0.3760)
Constant	−3.7745** (1.7114)	−15.1729*** (2.4336)	3.0779** (1.3016)	−1.1961 (1.8402)	−8.7196*** (1.6713)	−7.1797*** (1.9848)	−3.7501** (1.4885)

*, **, *** indicates significance level at $p < 0.1$, $p < 0.5$, and $p < 0.01$, respectively, and the values in parentheses are standard errors.

TABLE 5 Marginal effects of logit models.

Explanatory variable	Supplementary irrigation	Change irrigation time	Short duration rice	Climate-smart variety	Change cultivation dates	Fertilizer management	Farm resize
Farmer's age	0.0009 (0.0019)	0.0160 (0.0017)	−0.0016 (0.0022)	−0.0051 (0.0017)	0.0105 (0.0021)	0.0015 (0.0018)	−0.0021 (0.0019)
Farmer's education	0.0102 (0.0075)	0.0059 (0.0070)	−0.0005 (0.0085)	0.0066 (0.0062)	0.0034 (0.0082)	0.0089 (0.0069)	−0.0023 (0.0075)
Household size	−0.0480 (0.0125)	0.0321 (0.0137)	0.0097 (0.0174)	−0.0275 (0.0128)	0.0019 (0.0148)	−0.0152 (0.0121)	−0.0102 (0.0158)
Primary occupation	0.2345 (0.0591)	0.2413 (0.0905)	−0.1033 (0.0695)	0.1849 (0.0581)	0.0955 (0.0716)	0.1193 (0.0527)	−0.0283 (0.0661)
Landholding	0.0039 (0.0034)	−0.0117 (0.0042)	−0.0116 (0.0052)	0.0123 (0.0031)	−0.0064 (0.0041)	0.0053 (0.0030)	0.0138 (0.0033)
Land ownership	−0.1447 (0.0616)	−0.1108 (0.0710)	−0.0318 (0.0756)	−0.11490 (0.0645)	0.0837 (0.0752)	−0.0223 (0.0616)	0.1054 (0.0846)
Tube well	0.1696 (0.0399)	0.3042 (0.0509)	−0.0780 (0.0485)	-0.0355 (0.0425)	0.0649 (0.0467)	0.0795 (0.0400)	0.0345 (0.0531)
Canal irrigated land	0.0038 (0.0014)	−0.0004 (0.0015)	0.0010 (0.0018)	−0.0003 (0.0012)	0.0018 (0.0016)	0.0015 (0.0013)	−0.0023 (0.0016)
Livestock units	0.0234 (0.0112)	0.0024 (0.0092)	−0.0437 (0.0126)	0.0088 (0.0070)	−0.0100 (0.0074)	0.0188 (0.0094)	0.0225 (0.0102)
Farm labor	0.0151 (0.0232)	0.0273 (0.0231)	0.0547 (0.0272)	−0.0069 (0.0226)	0.0508 (0.0243)	0.0059 (0.0206)	0.0456 (0.0258)
Off-farm income	0.0057 (0.0024)	−0.0063 (0.0022)	−0.0013 (0.0030)	0.0043 (0.0022)	0.0005 (0.0026)	0.0088 (0.0022)	−0.0007 (0.0024)
Access to farm advisory	0.1838 (0.0519)	0.2457 (0.0545)	−0.1242 (0.0642)	0.2135 (0.0334)	0.3280 (0.0415)	0.2528 (0.0384)	0.3022 (0.0460)
Access to credit service	0.1429 (0.0586)	0.0037 (0.0619)	−0.1774 (0.0797)	0.1154 (0.0417)	0.2150 (0.0679)	0.1272 (0.0557)	0.0688 (0.0576)
Access to climate information	0.0311 (0.0436)	−0.0048 (0.0466)	−0.1461 (0.0467)	0.1095 (0.0500)	0.0831 (0.0476)	0.0541 (0.0379)	−0.0197 (0.0570)
Farm location	0.0509 (0.0431)	0.0020 (0.0401)	−0.0210 (0.0495)	0.0041 (0.0374)	0.0158 (0.0452)	0.0221 (0.0403)	0.0356 (0.0433)

Average marginal effects (standard errors).

pivotal factor in determining their adaptation decision. More likelihood of shuffling irrigation application time basically shows that farmers have options in irrigation application times, i.e., they may water the field at a certain time when evapotranspiration rate, the process of evaporating water to air, is minimum. Moreover, fertilizer is usually applied during irrigation; hence personal tube well possession also enables farmers to better manage their fertilizer application. A study by Kelkar et al. (2008) also reported ownership of borewells to be a vital asset of Indian farmers to manage farm-level adaptation.

3.3.7 Canal irrigated land

In the study area, on average, farmers have had a 14% share of surface water (canal water) in meeting their irrigation needs. This secondary source of irrigation has a significant role in meeting farmers' irrigation needs, especially in the rice zone, which is facing severe water scarcity. Studies found that in Punjab province, the groundwater table has significantly depleted, increasing irrigation costs for many farmers (Bell et al., 2014). Our findings show that despite the trivial share in overall irrigation needs, canal water has a significant positive relationship with water management strategies. For instance, it appeared to have a significant positive effect on supplementary irrigation ($p < 0.05$). These findings revealed that farmers with improved availability of canal water are more likely to meet their irrigation needs which is the key determinant of higher rice yield.

3.3.8 Livestock

The size of the livestock herd (i.e., cattle, sheep, and goats) is considered farmers' important assets and income other than crop production. The results of our study also show a significant positive influence of farmers' livestock holdings on supplementary irrigation application ($p < 0.1$), better fertilizer management ($p < 0.05$), and farm resizing, with a magnitude of 0.02% points, 0.018% points, and 0.02% points, respectively. This indicates that farmers having large livestock herds are more likely to adapt to climate change. In the study area, people usually keep livestock as a reserved asset to generate additional income by selling milk and its products or save house expenditure by consuming them at home. Further, owning livestock also enables the farmer to make better use of fertilizers with an abundant supply of farmyard manure which improves soil quality and rice yield. Sertse et al. (2021) also report that livestock is an important asset for farmers in developing countries, which helps them cope with climate change.

3.3.9 Farm labor

This study further took farm labor, the number of available laborers for farm work, as an important factor to explore its correlation with farmers' adaptation decisions. We found a significant positive effect of farm labor on short-duration rice cultivation, cultivation date changes, and farm resizing. Specifically, the findings show that a one-laborer increase in farm labor increases the probability of short-duration rice cultivation, changing planting and harvesting dates, and farm resizing up to 0.05% points. This indicates that with the availability of laborers, households are more likely to shuffle rice cultivation operations and expand the sizes of the plots, which are mainly the labor-oriented adaptation strategies.

3.3.10 Off-farm income

We further considered farmers' non-farm income to see its relationship with adaptation strategies, as these income sources play a vital role in households' farming decisions. We found that farmers' non-farm income is significantly positively correlated with supplementary irrigation application, climate-smart seeds cultivation, and fertilizer management, while it is negatively significantly correlated with altering irrigation time. These results imply that farmers with more off-farm income are more intended to invest in supplementary irrigation in the form of separate groundwater irrigation or its conjunctive use with canal water. Further, the off-farm income also enables farmers to often change crop varieties and better manage fertilizer for improved yields and better resistance to changes in climate. These findings indicate that farmers with diverse livelihood options are more likely to adapt to changes in climate, possibly because they usually keep off-farm employment as precautionary savings to use in needy times. Further, the negative effect of more off-farm income on irrigation time changes shows that financial well-being which enables farmers to rely more on groundwater without being worried about the evapotranspiration of the field water. Another study (Akhtar et al., 2018) also found that farmers with more non-farming income have a positive attitude towards implementing new strategies compared to those who only rely on agriculture as their primary income source.

3.3.11 Access to farm advisory

Farm advisory services are the provision of farm management information by public or private sector extension agencies, and it has shown a significant positive impact on farmers' adaptation decisions. For example, results show that farmers' access to farm advisory improved their likelihood of changing irrigation timing, changing cultivation dates, fertilizer management, and farm resizing by 0.24% points, 0.32% points, 0.25% points, and 0.30% points, relatively. This shows that access to agricultural extension services not only improves farmers' understanding of local climate variabilities but facilitates them in adopting suitable measures to cope with changing climate effects by adjusting irrigation application time, transplantation and harvesting dates, better managing fertilizer, and expanding their plots. Various studies (ZY AmareAyoade et al., 2018; James et al., 2020; Kamruzzaman et al., 2022) have also found that agricultural extension is the key determinant of farmers' ability to adapt to climate change. This shows that farm advisory is an important factor in the decision-making process for rice farmers.

3.3.12 Access to credit services

This study further shows that farmers' credit access has a positive and significant correlation with supplementary irrigation application ($p < 0.05$), climate-smart varieties cultivation ($p < 0.01$), cultivation date changes ($p < 0.01$), and fertilizer management ($p < 0.05$), while a significant negative correlation with short-duration rice cultivation ($p < 0.05$). Marginal effects further show that farmers who accessed credit were 0.14% points more likely to apply supplementary irrigation, 0.11% points more likely to cultivate climate-smart rice varieties, 0.21% points more likely to shuffle cultivation dates, and 0.12% points more likely to do better fertilizer management. These findings basically show that access to financial capital improves farmers' adaptive capability and decision-making in choosing various adaptation measures. However, access to credit services reduced the likelihood of short-duration rice cultivation, inferring that the availability of finance enables farmers to consider regular or long-duration rice varieties, which generate higher income. Masud et al. (2017) have also indicated that Malaysian farmers having access to credit adapt their farming in a timely manner, which reduces the adverse effects of changing climate on farming. A study in Bangladesh (Sarker et al., 2013), however, contradicts our findings, stating that access to credit services increases the likelihood of short-duration rice cultivation. This variation could be due to the difference in the agroecological conditions of both countries.

3.3.13 Access to climate information

Information about potential climate events, i.e., unexpected rainfalls or temperature fluctuation, is among the key factors influencing farmers' adaptation intentions. We found a significant positive impact of such information's access on farmers' cultivation of climate-smart seeds and changes in rice cultivation dates. These findings show that information about weather forecasts increases farmers' adaptation likelihood, particularly in cultivating climate-smart seeds and shuffling cultivation time as per the potential weather changes. However, access to climate information is negatively associated with the adoption of short-duration rice. The lower probability of cultivating short-duration rice may be due to their informed decisions-led preparedness, which may lead to making savings or certain arrangements to afford the adaptation cost for long-duration rice cultivars. These findings imply that farmers' access to climate information, directly and indirectly, improves farm-level adaptation to climate change.

3.4 Adaptation extent across regional and socio-economic attributes

A contingency table analysis was used to understand the adaptation extent among different categories of farmers

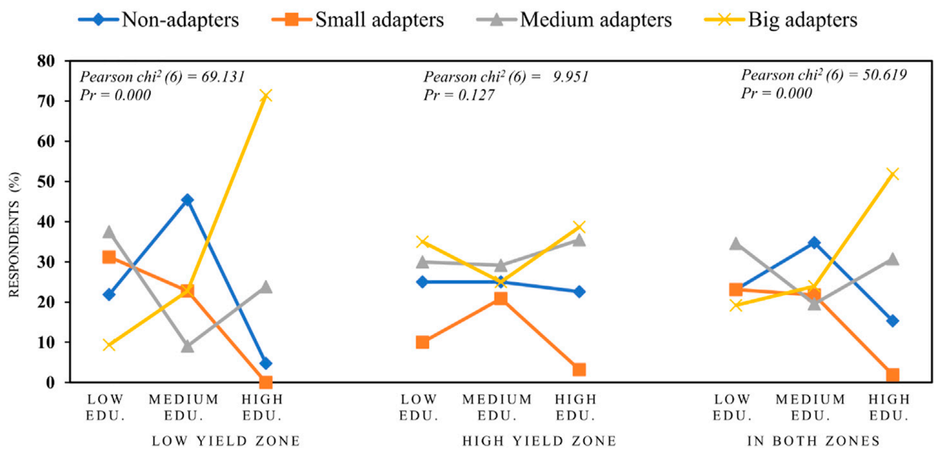

FIGURE 4
Climate change adaptation across farmers' education level.

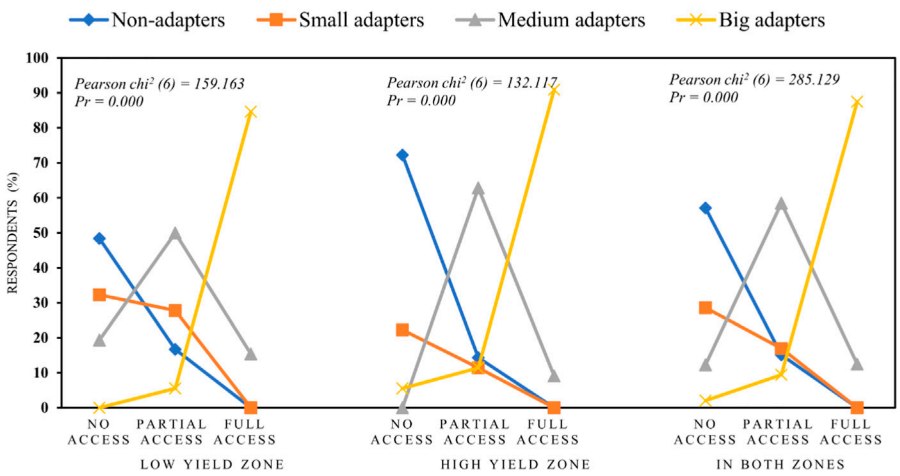

FIGURE 5
Climate change adaptation across climate information access.

based on socio-economic and regional attributes. Initially, farmers were categorized into four groups according to their adaptation level, i.e., non-adapters (no adaptation measure), small adapters (at least two measures), medium adapters (3–4 adaptation measures), and big adapters (over four adaption measures). Similarly, concerning socio-economic and institutional services, farmers were also categorized into different groups. For instance, in terms of education, there were three groups of farmers, i.e., low education (below 5 years of schooling), medium education (between 5 and 10 years of schooling), and high education (over 10 years of schooling) were made. A similar categorization was made based on farmers' access to climate information, i.e., no access, partial access[6], and full access[7]. The last category of farmers was regarding their credit utilization status, i.e., whether they had utilized credit or loans offered by public or private institutions.

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[6] Partial access means access to weather forecast only.

[7] Access to forecast of weather and climate risks.

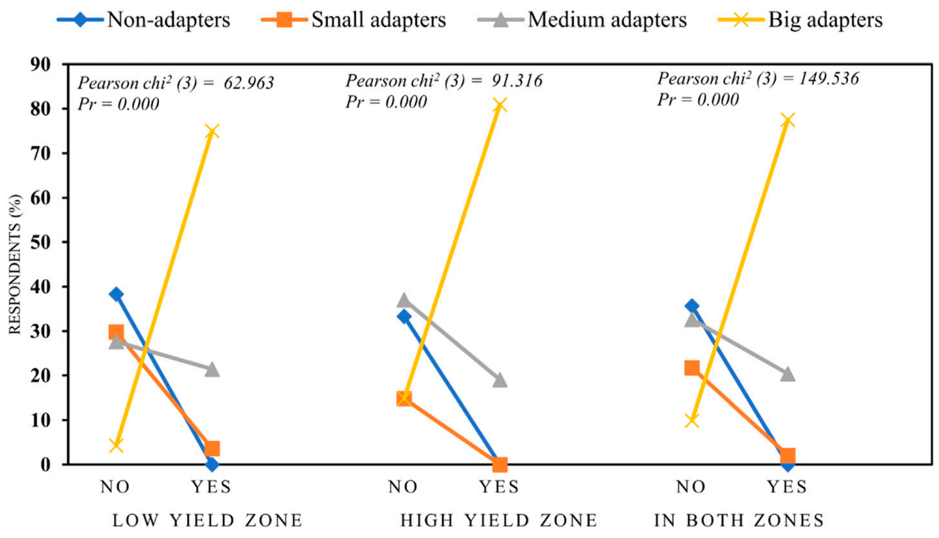

FIGURE 6
Climate change adaptation across farmers' credit access.

According to the results, the values of *Pearson chi-squared* and the significance level indicate a strong relationship with the adaptation extent and selected variables (Figures 4–6). This shows that the extent of adaptation significantly improves with increases in farmers' education levels and access to credit and climate information services**.** Specifically, in terms of education (Figure 4), the majority of the big adapters fall in the higher education category. In contrast, the non-adapters and medium adapters are comparatively less educated. Secondly, adaptation categories across farmers' climate information access (Figure 5) indicate that moving from no access to full access, the extent of adaptation also increases. For instance, in total, the majority of the big adapters have full access to climate information. In contrast, most small adapters and non-adapters have partial or no access to climate information services. This shows that access to climate and weather forecasts facilitates the farmers' adaptation extent due to farmers' better understanding of any changes that happen in local climate patterns.

Thirdly, in terms of credit services, results (Figure 6) show that, in total, most big adapters have utilized credit services, while the medium and small adapters did not indicate the utilization of credit services. Notably, none of the non-adapter farmers has utilized credit services, which infer that credit services increase the farmers' likelihood of adopting a large number of adaptation measures. This means farmers who utilize the credit services have a greater extent of adopting multiple adaptation measures. Studies show that adopting a diverse combination of adaptation measures helps to improve farmers' resilience compared to relying on single or very few measures (Teklewold et al., 2019). Hence farmers' access to these important institutional services has the potential to uplift the farming systems' resilience by increasing the extent of adaptation measures.

4 Conclusion and implications

Rice farming systems in Pakistan are highly vulnerable to climate change. This study aims to evaluate the farm-level perception of and adaptation strategies to climate change and its determinants in the rice-growing zone of Punjab province, a region highly vulnerable to climate change. A multistage sampling approach is used to select 480 farmers from the four rice-growing districts. Face-to-face structured interviews were conducted to collect data, and the collected data were analyzed using descriptive statistics and a logistics regression model.

The study found that farmers indicated significant changes in the local climate, reporting a significant increase in both summer and winter temperatures and a decline in precipitation. Farmers adopted various adaptation measures as a response to cope with the adverse effect of climate change on their rice crops. Among many, supplementary irrigation, better management of fertilizer, and adjustment in cultivation dates are appeared to be common adaptation strategies adopted by the farmers. Logistics regression analysis further showed that important attributes associated with farmers are the key determinants of the adoption of various adaptation strategies. Specifically, farmers' age, land size, access to irrigation water, credit service, farm advisory, and climate forecasts are major factors shaping their adaptation decisions. The study further found that adaptation extent (the number of adaptation measures) also improves with the increase in farmers' education levels and their access to important institutional services such as climate information and credit.

These findings conclude that these institutional services can play an important role in enhancing farmers' adaptive capacities and hence their resilience to climate change risks. Therefore, relevant institutions, concerned ministries, and policymakers are advised to improve farmers' access to these services. Specifically, credit and farm advisory services are the most critical determinants of both the adaptation decision and adaptation extent. Therefore, efforts should be made by agricultural banks to improve credit services provision on easy conditions, so farmers' adaptation levels could be enhanced. Similarly, the directorate of agriculture (extension) Punjab and other private advisory providers are recommended to provide farmers with climate-specific advisory so they could be well aware of the existing or potential variabilities in the climate and hence adapt their rice farming to it. Besides institutions, farmers should also make efforts to access relevant advisory services and implement them on their farms in order to cope with climate change.

This study has empirical, methodological, and policy contributions. Although climate change is a global phenomenon, the impacts of climate change are observed and realized at the local level. In this context, this study contributes to understanding how local people perceive changes in climatic conditions. Moreover, the study identifies location-specific adaptation strategies that can be further promoted. Furthermore, socio-economic factors affecting adaptations have been identified that are critical in implementing future adaptation actions. Thus, this research directly contributes to the United Nation's SDG13 (Climate action), which highlights the development of innovative solutions to adapt to climate change. Given the fact that Pakistan is a country that pays a huge toll due to climate change events, the findings of this study play an important role in designing and implementing robust climate change adaptation actions, programs, and policies in the agricultural sector. Rice is considered among the staple foods in Pakistan (and other south Asian countries) and is reported to be more vulnerable to climate risks compared to other food crops. The current study findings imply that farm-level adaptation can serve as a useful strategy to address the yield losses by positively impacting rice yield; hence, it can play a vital role in local food security. Finally, the methodology employed is relevant to many developing countries to identify location-specific adaptation strategies and determinants of adoption. This study does have limitations; it only deals with the farmers of the rice growing zone of Punjab province and cannot necessarily be generalized to other crops and regions of the country. Besides, this research only considered farm-level adaptation measures; thus, future studies should also investigate farmers' non-farm adaptation measures, i.e., livelihood adaptation strategies. Moreover, this research considered a small sample size compared to the on-ground farming activities; therefore, future research should consider a larger sample. Further, this research only focuses on farmers; therefore, future research should include office bearers of agricultural institutions to discuss the climate challenges faced by the local communities.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Publisher's note

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Appendix

TABLE A1 Rice production statistics for year 2018–2019.

District name	000 metric tonnes
Gujranwala	470.04
Sheikhupura	376.80
Hafizabad	301.30
Sialkot	241.88
Nankana Sahib	239.27
Kasur	149.53
Narowal	130.96
M.B. Din	125.66
Lahore	71.47
Gujrat	54.39

Source (AMIS, 2018).

TABLE A2 Questionnaire used for the study.

1	Question	Response
2	District	
3	City (Tehsil)	
4	Village ID	
5	Date of Survey	
6	Enumerator Name	
SECTION B. SOCIO-ECONOMIC, LAND, AND RELATED CHARACTERISTICS		
1	What is your age	
2	What is your education?	
3	What is your primary occupation? 1) Farming 2) Employment 3) Own off business	
4	Experience in rice farming?	
5	Household size (numbers of family members)	
6	Landholding Size (acres)	
	1) Owned 2) Share cropping 3) Tenant 4) Leased land 5) Owned + leased	
7	What kind of ownership does your household have on most of your land?	
8	Irrigation source 1) Electric tube well 2) Engine tube well 3) Canal 4) TW + Canal	
9	Do you own a tube well?	
10	Proportion of rice land that is irrigated by the canal water (%)	
11	Numbers of livestock that you have?	
12	What is your average monthly income in PKR	
13	Family members working as active labor on farm (numbers)	
14	How many family members are involved in non-farm job	
15	What is your average off-farm income/month	
16	Do you have access to farm advisory services?	
17	What type of organization is it? A. Government B. Non-government	
18	What is the frequency of contact with advisory services, particularly in rice cultivation season?	
19	Do you have access to the weather forecast	
20	Have you received credit during the rice cultivation (number)	
21	Are you an active member of any group/organization/farmers' cooperation/farmers' club?	
SECTION C. PERCEPTIONS OF CLIMATE CHANGES		
22	Have you noticed/perceived any changing climate in your locality over last 10–20 years?	
23	Observed variation in summer temperatures (choose from the following)	
24	Observed variation in winter temperatures (choose from the following)	
25	Observed variation in summer rainfall	
26	Observed variation in winter rainfall	
27	Observed variation in rainfall during monsoon months	
28	Drought (Khushksali)	
29	Frequency of observed drought in numbers	
30	Floods	
31	Avail. of surface water	
32	Availability of groundwater	
33	Length of the Rabbi cropping season (winter)	
34	Length of the Kharif cropping season (summer)	
1). Significantly decreased 2). Slightly decreased 3) No change 4). Slightly increased 5). Significantly increased		

(Continued on following page)

TABLE A2 (*Continued*) Questionnaire used for the study.

SECTION D. CLIMATE CHANGE ADAPTATION			
35	Do you believe that adaptation minimizes the negative impacts of climate change in rice production		
	Adaptation strategy	**Adopted**	**Constraints**
36	More irrigation		
37	Cultivation short duration rice		
38	Changed crop variety (climate-smart seeds)		
39	Changed crop type (non-rice crop)		
40	Changing planting and harvesting dates		
41	Planting trees (Agro. forestry)		
42	Fertilizer management		
43	Changes in farm size (plots resizing)		
44	Crop diversification		
45	Changed irrigation application times		

Constraint 1 = Financial constraints, 2 = shortage of labor 3 = lack of information, 4 = expensive irrigation5 = Power cut (load shading) 6 = No access to the market service 7. Other (please specify).