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RESEARCH ARTICLE

Do farmers' risk perception, adaptation strategies, and their determinants benefit towards climate change? Implications for agriculture sector of Punjab, Pakistan

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Abstract

Due to global and regional climatic dynamics for a couple of decades, agricultural productivity, rural livelihood, and food security have been badly affected in Pakistan. This study was conducted in Punjab, Pakistan, to explore the farmers' understanding of the impacts of climate change, adaptation strategies, determinants, and benefits on agriculture using data from 1080 respondents. Perceived risks by the farmers in the rice-wheat cropping system and the cotton-wheat cropping system were weed infestation, seed rate augmented, low-quality seeds, infestation of crop diseases and pests, change of cropping pattern, increase of input use, decrease of cropping intensity and productivity, decreasing soil fertility, increasing irrigation frequency, and increase of harvesting time. To alleviate the adverse influences of climate change, the adaptation strategies used by farmers were management of crop and variety, soil and irrigation water, diversification of agriculture production systems and livelihood sources, management of fertilizer and farm operations time, spatial adaptation, access to risk reduction measures and financial assets, adoption of new technologies, institutional support, and indigenous knowledge. Moreover, the results of Binary Logistic Regression indicate that adaptation strategies are affected by different factors like age, education, household family size, off-farm income, remittances, credit access, information on climatic and natural hazards, information on weather forecasting, land acreage, the experience of growing crops and rearing of livestock, tenancy status, tube well ownership, livestock inventory, access to market information, agricultural extension services, and distance from agricultural input/output market. There is a significant difference between adapters and nonadapters. The risk management system may be created to protect crops against failures caused by extreme weather events. There is a need to develop crop varieties that are both high yielding and resistant to climate change. Moreover, cropping patterns should be revised to combat the effects of climate change. To enhance farmers' standard of living, it is necessary to provide adequate extension services and a more significant number of investment facilities. These measures will assist farmers in maintaining their standard of living and food security over the long term to adapt to the effects of climate change based on various cropping zones.

Keywords Climate change · Perceived impacts · Adaptation strategies · Determinants · Benefits · Pakistan

Introduction

Agricultural development in less-developed nations faces significant obstacles due to predicted climate change and rising climatic dangers in the twenty-first century (IPCC 2014). When it comes to a wide range of agricultural insecurity issues, climate change is the most important (Ali et al. 2021; Sheikh et al. 2019). This is because climate change can disrupt major crops and the broader food supply chain, which can have disastrous consequences on farm production (Nazir et al. 2018). Climate change is persistent stress on natural and human resources, which has resulted in a challenge to the social, economic, and ecological sustainability of the resources that are already scarce in developing countries (Ali et al. 2021; Bokhari et al. 2018). Increasing quantities of greenhouse gases (GHGs; e.g., CO_2 and CH_4) in the atmosphere are expected to raise global temperatures by 2.5 to 4.5 degrees Celsius by the end of the 21st century (Porter et al. 2014; Wang et al. 2018). Aryal et al. (2020) noted that production of cereal crops in South Asia might

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be reduced by 4–10 percent if the average temperature rises by 1°C. An additional 19 percent fall in per capita water availability might result in food crop losses of 30 percent in 2050 (Aryal et al. 2020).

Temperature and water stress can directly impact the production of cereals. Still, climate change can also have an indirect impact on the availability of nutrients, diseases, and pests (Porter et al. 2014). The study by McCarthy et al. (2001) indicated that by the end of 2059, climate change might lead to a 30 percent decrease in the output of cereal crops, with South Asia having the most significant proportion of insecure food (Myeni et al. 2019). Researchers believe that global warming cannot be reversed in a short amount of time. A long-term shift in international policy and sustainable agriculture adaptation methods is necessary to limit and reverse the environmental damage (Wang et al. 2018). Pakistan is one of the most vulnerable countries to climate change because of its inability to adapt and lack of infrastructure (Stocker 2014). As projected by (Gorst, Dehlavi, & Groom 2018), Pakistan's temperature and rainfall distribution are expected to increase significantly by 2050. Temperatures in Pakistan are expected to climb by 2 to 3 degrees Celsius by 2050, which will have a negative impact on the distribution of precipitation and household income (Gorst et al. 2018). As of 2021 Global Climate Risk Index, Pakistan would be the 8th most vulnerable country to the long-term effects of climate change (Haider, 2021).

Every year, Pakistan is hit by numerous natural disasters, many of which result from weather-related events (Ullah & Takaaki 2016). Floods from the monsoon (such as the "Pakistan flood" of 2010) (Khan 2011), droughts (Anjum et al. 2012), storm cyclones, landslides (Farooqi et al. 2005), and heat strokes in Karachi (Ullah & Takaaki 2016) are just a few recent examples of how civilization has become more vulnerable to such disasters as they have become more frequent and intense.

Adaptation to climate change means making changes to natural or human systems in response to current or future climate stimuli and their impacts to lessen harm or take advantage of valuable opportunities (Tessema et al. 2013). In addition, adaptation can take place at other levels, including local, regional, subnational, and national. The most challenging level of adaptation is at the local level, where the harshness of climate change is most evident (Parry 2009). Since climate change threatens rural economies and food supplies, effective farm-level adaptation is necessary (Abid et al. 2015). One of the most challenging aspects of adaptation at the local level is that farmers will shoulder most of the costs. Even in perfect market conditions, farmers may still be better off because of the higher prices they receive for their products (Abid et al. 2016a). That is not necessarily the case in developing countries like Pakistan, where nonmarket forces (imperfect conditions) heavily govern prices, and farmers may see higher production costs and lower profits. Because of this, farmers' intents and adaptive capacity must be considered in public policy. Since the impact of farmers' adaptation options on farm productivity may differ across geographies and scales, it is crucial from a policy viewpoint to understand the elements that influence farmers' decisions (Niles et al. 2015).

As a result, there is a pressing need for a new agriculture policy that emphasizes technical advancement, rural development, and a climate change awareness campaign. An adaptation policy to climate change may include farmers' planning, investment in stress-resistant cultivars and social awareness, and crop insurance and food security programs (Schlenker and Lobell 2010). Therefore, adaptation research should focus on how farmers perceive climate change, how they adapt to it, and how these factors influence their adaptive behavior (Mertz et al. 2009; Weber 2016).

The country has a low adaptation capacity, primarily due to poverty and lack of resources, such as physical and financial deficiencies, limiting Pakistan's ability to adjust to climate change (Abid et al. 2015; Adger et al. 2005). To add to the problem, there was a lack of research on environmental vulnerability and local level risk perceptions and stimuli that sparked adaptive capability (Ahmed and Schmitz 2011; Hanif et al. 2010). Individual farmer reactions and adaptability are also influenced by various internal elements, such as personal attributes, farming techniques, and specific conditions (Abid et al. 2016b). Interactions within the farming community can also affect farm-level adaptive capability. Sharing information or resources could also have a good impact on the adaptive ability of a farm, whereas disagreement at the farm level could result in low adaptive capacity (Abid et al. 2016a). In addition, making decisions on climate change adaptation at the farm level is highly complicated and depends on socioeconomic, demographic, institutional, and economic issues, among other things (Ali 2017). Adaptation strategies and plans that do not consider local concerns and behaviors are doomed to fail if they are not developed with this knowledge in mind (Khan et al. 2020a; Ward et al. 2013). Farmers' socioeconomic and institutional data can significantly add to climate change data and may indicate important underlying drivers or processes that specific environmental indicators fail to uncover (Mulwa et al. 2017).

The area under cultivation in Pakistan is 22.54 million hectares. Overall, 56.2% (12.67 million hectares) of the total cultivated area accounts for the Punjab province. The agricultural areas under cotton-wheat and rice-wheat systems are 7.1 million hectares and 4.25 million hectares, respectively, in Pakistan. Further, Punjab has 5.5 million hectares under the cotton-wheat system and 2.8 million hectares under the rice-wheat system (FAO, 2004). In Pakistan, Punjab is the most populated province and contributes 53 percent to total agricultural gross domestic product (PBS, 2020). Major agroecological zones in Punjab-Pakistan are cotton-wheat, rice-wheat, mixed-cropping, low-intensity, and rain-fed (FAO, 2004).

Many studies were conducted on the link between climate change and agriculture in Pakistan from adaptation studies (Anser et al. 2020; Arshad et al. 2017; Elahi et al. 2021; Gorst et al. 2018; Khan et al. 2020b) to mitigation studies (Abid et al. 2015; Hussain et al. 2018) to income and food security assessment (Abid et al. 2016a; Ali and Erenstein 2017), impact assessment (Abbas et al. 2017; Ali et al. 2017; Aslam et al. 2017; ur Rahman et al. 2018). However, most of these studies mainly focused on one aspect or one agriculture production system. Empirical estimates of the integrated research on the impact of climate change on the rice-wheat cropping system (RWCS) and cotton-wheat cropping system (CWCS) and adaptation strategies and their determinants and implications of determinants are not thoroughly considered in ant research. In addition, this research has used partial least squares structural equation modeling (PLS-SEM) in SmartPLS to examine the impact of adaptation strategies on the agriculture sector in Punjab, Pakistan. Hence, this study also adds a new methodology to determine the effects of climate change adaptation strategies on agriculture. Given this knowledge gap, this study takes the case of the RWCS and CWCS farmers and investigates the impact of climate change on these cropping systems. The study tests the hypothesis that perceived impact of climate change, adaptation strategies, and their determinants are beneficial to mitigate the impact of climatic and natural hazards. This study determined the perceived effects of climatic and natural hazards on agriculture in Punjab, Pakistan. Furthermore, the adaptation strategies used at the farm level in response to perceived impacts of climatic hazards were also identified. Moreover, the factors affecting the determinants of adaptation strategies were also examined. Finally, the effects of adaptation practices were also estimated.

Literature review

Seo and Mendelsohn (2008) explored how farmers in South America can adjust to climatic conditions by shifting crops. Multinomial logit models were employed to understand farmers' crop choices. Furthermore, Seo et al. (2009) examined that climate change consequences threaten Africa's sixteen agroecological zones (AEZs). Regression analysis was used to study the effect of climate change on crops, livestock, and net income earned (i.e., income from crops and livestock). Deressa et al. (2009) identified strategies that growers in the Nile Basin of Ethiopia used to mitigate the influence of climate change, benefits of adaptation strategies, and constraints in the adaptation. Adaptation strategies like tree planting, soil conservation, changing crop types, early and late planting, and irrigation were adopted by farmers to alleviate the impact of climate change on agriculture. In another study of Ethiopian Nile River Basin, Deressa et al. (2010) used the multinomial logit model to investigate the variables that influence adaptation strategies used in response to severe climatic events. Socioeconomic and environmental variables influence farmers' ability to cope with climatic extremes. But higher education of the household head, gender of the head of household being male, livestock ownership, an increase in agricultural revenue, and better-quality housing significantly affected adaptation decisions.

The impact of climate change on food crops (wheat, rice, and maize) was examined by Ahmed and Schmitz, (2011), in Pakistan's four provinces (i.e., Punjab, Sindh, Balochistan, and NWFP). A panel data was used to examine the impact of climate change vulnerability on the crop production. In addition, the study of Siddiqui et al. 2012) in Punjab, Pakistan, indicated that temperature rise has a favorable effect on wheat production. The study's main results were the influence on the timing and production phases of temperature and precipitation on selected crops. In addition, there are considerable changes in agricultural productivity between crops and districts due to climate change. According to Moyo et al. (2012), perceptions of local farmers regarding climate risk substantially affect the decision-making of investments in agriculture in the semi-arid region of Zimbabwe. FGDs were conducted to account for farmers' views of climate fluctuation and their corresponding to historical climate data. The study demonstrated that farmers have seen changing climate and weather patterns in the last decade or two as shown by unpredictable climatic patterns, lower rainfall, and higher temperatures, resulting in declines in agricultural output and increased illness and death. The study suggested that farmers should modify their production methods to improve agriculture production in unpredictable patterns of climate change. Legesse et al. (2013) used a multistage stratified random sampling approach to collect primary data from 160 households in Doba District, West Hararghe, Ethiopia, to measure farmers' understanding of and adaptability to climatic variation. Additionally, multinomial logit model (MNL) was employed to determine the factors affecting strategies of adaptation taken in response to climate change. It was found that gender and social groups have almost the same understandings on climate change vulnerabilities. The diversification of crops, soil, and water conservation measures, as well as integrated crop and animal diversification, was employed in the MNL model.

Ahmad et al. (2014) evaluated the effect of climatic change on productivity of wheat in Pakistan, using data from 1981 to 2010 on the district level. Production function was used for data analysis purposes. The impact of global climatic variability on the output of major crops in Pakistan was estimated by Baig and Amjad (2014). A VAR (Vector Auto Regression) model was employed for time series data analysis collected from 1966 to 2009. Global warming would raise the incidence and austerity of events such as floods, droughts, and cyclones that would damage farm productivity and, in the future, disrupt the water balance. Abid et al. (2015) collected data from 450 farm households in 3 districts of 3 agroecological regions of Pakistan's Punjab to analyze how farmers observe climate change and acclimate their agriculture to climate change perceptions. The results of the binary logistical model demonstrated that level of education, agriculture land area, household size, the tube well, information on the market, weather predictions, and extension services all affect adaptation likelihoods. The consequences also revealed that climate change adjustment was constrained by a number of reasons, like low level of awareness, lack of money, limits on resources, and paucity of irrigation water within the area investigated.

The productivity of adaptation measures and their effect of the reduction on output loss were studied by Ahmed and Schmitz (2015) in Pakistan. Simulations were carried out to analyze if losses and damages are probable to occur in the future and to examine whether crop growers have reacted successfully. It was observed that farmers adapt their crop choices to the environment and projected income. If farmers adopt, gains in the crops exceeding $300 million are possible. In the normal company situation, losses were discovered between $4 and $12 million (2030/2090). The findings suggested well-directed farmers' adaptations to climate change in Pakistan, which reduce loss and harm. In Ethiopia's Central Rift Valley, Belay et al. (2017) examined how smallholders perceive climate change, what adaptation techniques they use, and the variables that impact their decisions on adaptation. The econometric model reveals that the key drivers of farmers' adaptation strategies include education, household size, age, gender, possession of animals, farming experience, frequency of interaction extension officer, farm size, market access, access to climate information, and farm income. In addition, it is also vital to create possibilities for nonfarm income sources since this allows farmers to participate in activities that are less prone to climate change. Furthermore, it is imperative to provide knowledge on climate change, extend services, and create market access.

Abid et al. (2017) used the social network technique to assess institutional assistance from the farm level and detail any current structural weaknesses in change to climate change in Pakistan's agricultural area. This study offered an integrated framework to promote networking among stakeholders through various partnerships and improved adaptation to climate change. Just and Pop (J-P) production functions were employed by Arshad et al. (2017) to data collected from 240 farm households to compute the effects of climate change on rice and wheat production in eight of Pakistan's twelve agroecological zones. Findings signposted that climate change had a significant impact on rice and wheat yields for both cultivations. The study's findings revealed the necessity of evaluating current programs of adaptation to increase the resilience of farmers in Pakistan and, more generally, throughout South Asia. The Auto-Regressive Distributed Model was used on time series data (from 1985 to 2015) by Kayani et al. (2018) to calculate the influence of climate change on agriculture in Punjab, Pakistan. It was estimated that increased average temperature and precipitation and two nonclimatic factors, i.e., fertilizer and loan distribution, considerably impact agricultural production. The policy measures to minimize the harmful effect of climate change on agricultural production must thus be formulated. Plant breeders should concentrate on developing drought and heat-resilient seed varieties to reduce the consequence of snowballing average temperatures and rainfall fluctuations.

Abid et al. (2020) studied farmers' opinions on climate change, using data gathered from 450 respondents from 3 agroecological zones in Pakistani, Punjab. The study results showed that the views of farmers' on rising average temperature are consistent with local realities. However, there was a discrepancy between farmers' assessments of fluctuations in rainfall and local climate data in certain cases. Furthermore, the three adaptive stages affected formation, expertise, land holdings, tenancy status, expansion, collaboration, access to weather predictions, and marketing knowledge. There was a significant relationship between the three stages of adaption. In particular, the study validated the prediction that correct perceptions led to higher intentions of adaptation than understated or no perceptions. In addition, farmers favor fundamental adaptation methods like crop type's change, input and planting dates, shade planting, crop diversification, and soil conservation. The research advocated access to institutional services, information, and training for farmers, especially small farmers and renters, to utilize modern production practices to decrease the detrimental effects of climate change.

Bakhsh and Kamran (2019) examined different farmers' adaption methods, by means of cross-sectional data gathered in the semi-arid area of Punjab, Pakistan. The study likewise evaluated the influence of farmers' socioeconomic features on climate change adaptation. The study suggested that legislators should examine the possible discrepancy in private advantages and public benefits arising from private climate adaptation regarding human capital, family assets, and agricultural tools in the formulation of climate change policy interventions. Proper policy actions should foster private modification of public assets. Rapid urbanization and population expansion have caused a disastrous shift in land use, leading to higher land surface temperatures and fewer water bodies (Khan et al. 2019).

Iqbal et al. (2020) studied drivers of perception on different hazards and the corresponding solutions for mitigation and adjustment. To do this, 480 farmers were randomly picked from the agricultural-dominant Punjab region to analyze their levels of consciousness, the socioeconomic dynamics influencing their views, and different elements influencing their perceptions. The PFA (principal factor analysis) technique determined key sources and strategies based on the farmer's views and planned/practiced alternatives. Furthermore, regression analysis was used to assess the variables impacting farmers' perception of risk sources. The results revealed that most farmers encountered different hazards and adapted crop farming to these perceived dangers. Changes in agricultural policy were the biggest risk source, while small dams/turbine systems were the top priority for risk management strategies.

Climate Change Vulnerability Index (CCVI) was developed in areas of rice growing of Punjab, Pakistan (Khan et al. 2020a). CCVI was developed using the IPCC's (Intergovernmental Panel on Climate Change) approach of three indicators (i.e., sensitivity, exposition, and adaptive capacity). The findings indicated that farmers in the study region are particularly vulnerable to CC. These findings imply that regional diversity in farm performance, a local emphasis on decreasing output losses should be placed. CSA (Climate Smart Adaptation) efforts should be supported at the farm and local levels through apposite plans and investment strategies.

Shahzad and Abdulai (2020) analyzed farmers' adaptability to harsh weather, utilizing climate-smart farm practices (CSFP) and their influence on farm performance using current farm-level data from three Pakistani agroecological zones. The empirical results indicated that CSFP adoption correlates to greater returns on net farm income. The results further showed that adjusting such techniques considerably decreases the volatility of farm net returns and the vulnerability of farmers to downside risks. Access to family education and extension services had a favorable effect on the likelihood of CSFP adaptation to harsh weather conditions. The study of Imran et al. (2020) examined the degree of concordance between farmers' perception and real climatic patterns in Pakistan's three irrigated Punjab areas. The results showed that farmers' perception of precipitation patterns is not in keeping with current trends, mostly due to the processing of climate information among farmers and the scientific community. However, farmers' perception of temperature increases reflected meteorological evidence throughout chosen irrigated cultivation areas. Extension services together with revenue and landholding size have been significant variables in the farmers' view of climate change adaptation.

According to Khan et al. (2021a), a 2-year flood has a 50% chance of occurring in any given place without flood protection and may have no noticeable effect on gross domestic product (GDP), population, or urban damage. A five-year flood has a 20% chance of occurring, which could cost the country's GDP roughly \$20.4 billion, putting 8.4 million people in danger and causing \$1.4 billion in urban damage. A 10-year flood has a 10% chance of occurring, which could have a \$28.9 billion impact on Pakistan's GDP, impact 11.9 million people, and cause \$2.4 billion in urban damage. Content analysis of Shahid and Adnan (2021) showed a considerable disparity between climate change facts and values and their consequences on developing nations. Pakistan is already confronting numerous challenges as a developing country, while the catastrophic impacts of climate change further aggravate it. As an economy centered on agriculture, the consequences of climate change on Pakistan are particularly severe. After the coronavirus, there is a frantic economic emphasis. Pakistan and the rest of the globe are placing second-priority measures to handle climate change. Communicating plans and effective governance would assist in reducing climate change issues. This study used novel approach SmartPLS to examine the benefits of adaptation strategies. Moreover, the two cropping systems were also compared in the study.

Materials and methods

Study area

The Punjab province is approximately positioned between 30°00 N and 70°00 E on a geographical map Ahmed and Schmitz (2011). This rich land is critical for Pakistan' economy since it pays a significant share of the country's GDP through agriculture (Ali and Rose 2021). Due to more than fifty percent contribution in agricultural GDP, the Punjab province was chosen purposively. It also accounts for almost 75 percent of the country's total grain production, with rice accounting for more than 60 percent of total production (GOP 2021). With a total land area of more than 20 million hectares, approximately 60% of which is under cultivation. In Pakistan, Punjab is in the semi-arid lowland region (PMD, 2017). Because of their significant contribution in maintaining the country's food security, the rice-wheat and cotton-wheat zones were explicitly chosen for this study (Fig. 1).

Sampling and data collection

The population of agriculture is heterogeneous; therefore, MSRS (Multistage Random Sampling) methodology was utilized to accumulate primary data. Punjab, Pakistan, was selected in the first stage. In the second stage, the rice-wheat cropping system (RWCS) and cotton-wheat cropping system (CWCS) of Punjab province were selected purposely for this study due to their importance in ensuring food security and contribution to the national

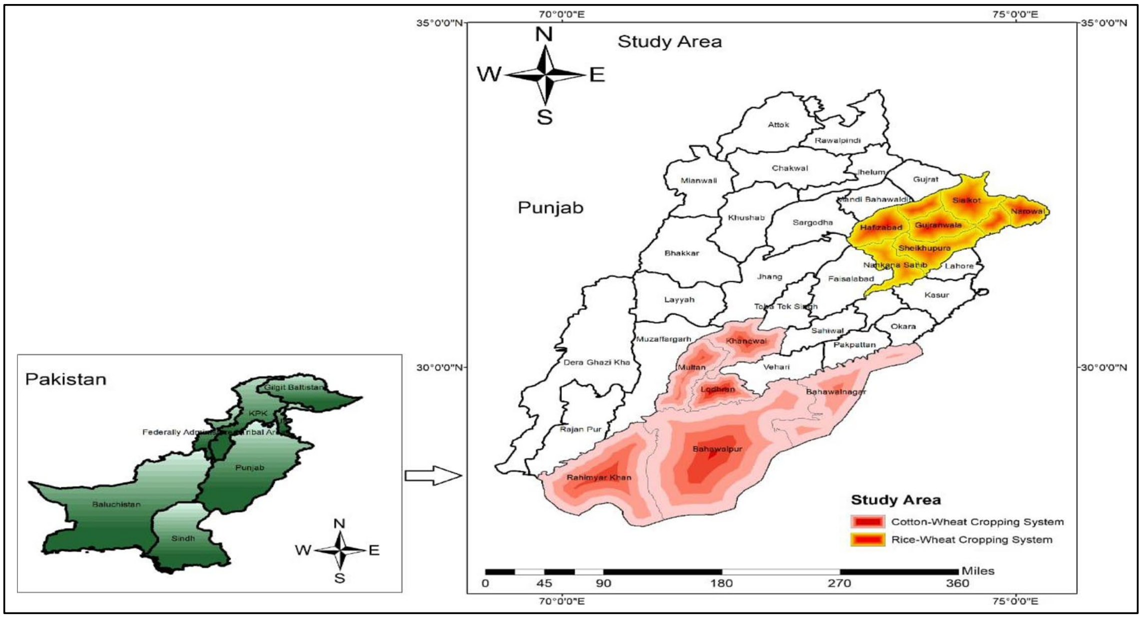

Fig. 1 Study area

exchequer. The third stage was selecting districts from RWCS (Gujranwala, Sialkot, Narowal, Sheikhupura, Hafizabad, and Nankana Sahib) and CWCS (Bahawalpur, Bahawalnagar, Khanewal, Rahim Yar Khan, Lodhran, and Multan). At stage four, one canal distributary irrigating major RWCS and CWCS of selected districts was chosen. From the head, middle, and tail of each selected distributary, one village was designated at the fifth stage (Fig. 2). The sample households from each village were selected by using Yamane's formula (Yamane 1967) represented as follows:

$$n = \frac{N}{1+Ne^2}$$

where,

n = sample size in each village

N = total number of farming households in a village

e = precision which is set at 10%(0.10)

Finally, 30 farmers from each village were interviewed randomly involved in the production of crops and rearing of livestock. Ninety farmers from one district and thus a total of 1080 farmers were interviewed. The first-hand information was gathered on climate change, irrigation water, crops, livestock production, socioeconomic characteristics of the

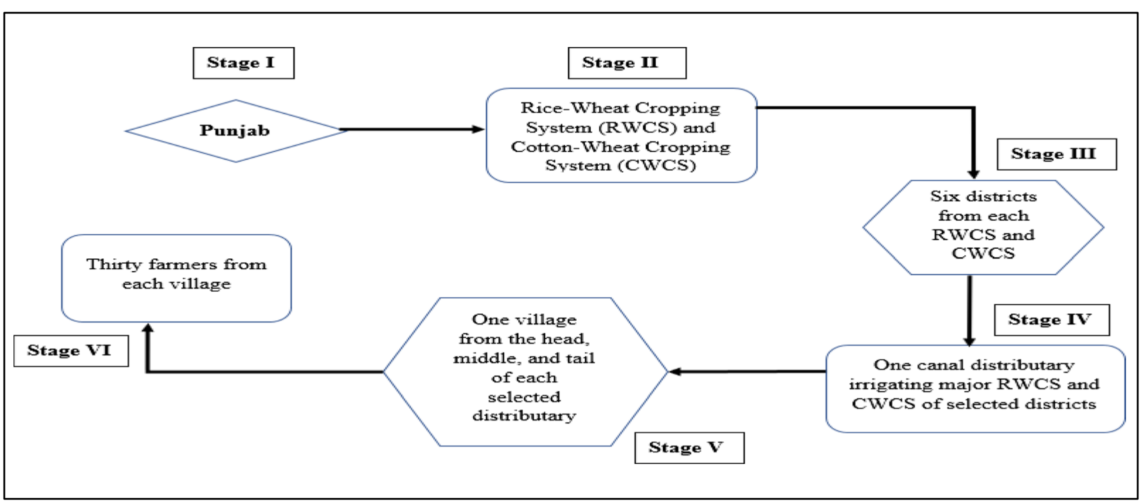

Fig. 2 Sampling framework

farmers, levels of farm income, and food security status. Secondary data regarding all relevant variables were collected from published sources, i.e., PMD (Pakistan Meteorological Department 2020), PBS (Pakistan Bureau of Statistics), ESP (Economic Surveys of Pakistan), AMIS (Agriculture Marketing Information Service), and Soil Surveys.

Analytical framework

Description of variables

The reliability and consistency of the data were checked by Cronbach's alpha (α), and it was greater than 0.7. The dependent and independent variables used in Binary Logistic Regression to identify determinants of climate change adaptation are presented in Table 1.

Perceived impacts of risks of climatic and natural hazards (CNHs)

The influences of climatic discrepancies fluctuate by region. Still, farm households in developing regions are expected to agonize the most for a variety of reasons, including lack of awareness, lack of diversification capacity, dearth of adaptive capacity, nonexistence of skills, absence of education, nonexistence of infrastructure, deficiency of economic resources, and an inability to forecast extreme climatic events (Kurukulasuriya 2007). A Likert scale was utilized to determine farmers' perceptions of the influence of CNHs on irrigation water, crops, livestock, rural livelihood, and food security. Descriptive statistics were employed to compute the effects of CNH perceptions on nexus components. Frequencies of the answers were summarized as percentages to establish graphs.

Table 1 Description of variables

Variable	Description
Dependent variables	
Soil and water management	Binary: 1 if a farmer adapts soil and water management practices and 0 otherwise
Diversification of agriculture practices and income sources	Binary: 1 if a farmer is involved in diversification of agriculture practices and income sources and 0 otherwise
Farm operation time management	Binary: 1 if a farmer is using farm operation time management and 0 otherwise
Fertilizer management	Binary: 1 if a farmer is involved in fertilizer management and 0 otherwise
Spatial adaptation	Binary: 1 if there is spatial adaptation (migration, selling of land, shifting to another business) by the farmer and 0 otherwise
Risk mitigation and financial resources	Binary: 1 if a farmer have access to risk mitigation and financial resources and 0 otherwise
Adoption of new technologies	Binary: 1 if a farmer adapts new technologies and 0 otherwise
Crop and varietal management	Binary: 1 if a farmer is involved in crop and varietal management and 0 otherwise
Institutional/governmental support	Binary: 1 if a farmer has access to institutional/governmental support and 0 otherwise
Indigenous knowledge	Binary: 1 if a farmer adapts indigenous knowledge and 0 otherwise
Explanatory variables	
Age	Age of the farmers in year (continuous)
Education	Education years of the farmer (continuous)
Household family size	Number of family member of the farmer (continuous)
Off-farm income	Binary: 1 if a farmer has off-farm income sources and 0 otherwise
Remittances	Binary: 1 if a farmer receives remittances and 0 otherwise
Credit access	Binary: 1 if a farmer has access to credit and 0 otherwise
Information on climatic and natural hazards	Binary: 1 if a farmer has knowledge about climatic and natural hazards and 0 otherwise
Information on weather forecasting	Binary: 1 if a farmer has information on weather forecasting and 0 otherwise
Cropping system	Binary: 1 if rice-wheat cropping system and 0 otherwise
Land area	Land area in acres (continuous)
Farming experience	Farmer experience of growing crops (continuous)
Tenancy status	Binary: 1 if a farmer is owner and 0 otherwise
Tube well ownership	Binary: 1 if a farmer has tube well ownership and 0 otherwise
Livestock/animal inventory	The number of livestock (dairy) animal owned by household (continuous)
Access to market information	Binary: 1 if a farmer has access to information about market and 0 otherwise
Agricultural extension services	Binary: 1 if a farmer has access to agricultural extension services provider regarding crop production and 0 otherwise
Distance	Distance of the farmer from the agriculture input and output market in kilometer

Adaptation strategies to mitigate the adverse effects of climate change

Adaptation to climate variability is the process of adapting agricultural production systems and on-farm activities to be more in line with variability of climate change (Shaffril et al. 2018). It is often considered the most effective method of addressing climate effects in agriculture (Field et al. 2014; Masud et al. 2017). The Likert scale was used to evaluate farmers' adaptation measures to alleviate the risks of CNHs on irrigation water, crops, livestock, rural livelihood, and food security.

Determinants of climate change adaptation strategies

A Binary Logistic Regression (BLR) model was used to identify the behaviors that led to the farmers adopting different adaption techniques in their respective fields. Farmers frequently adopted more than one adaptation strategy simultaneously, making the application of a multinomial logit model superfluous. The multinomial logit model is in contrast to many studies in which farmers were only allowed to choose one adaptation strategy from a set of different adaptation strategies provided (Acquah and Onumah 2011; Fosu-Mensah et al. 2012; Bryan et al. 2013; Mabe et al. 2014; Abid et al. 2016a, 2016b; Alemayehu and Bewket 2017b; Fadina and Barjolle 2018; Wetende et al. 2018; Bate et al. 2019; Khan et al. 2020b). In contrast, binary regression offers the capability to understand variables affecting each adaptation strategy's decision separately and independently. This model has several advantages in that it allows individuals to evaluate the farmer's actions and calculate the relevant probability for each choice they make (Ali and Rose 2021; Ali et al. 2021). It is possible to circumvent several limiting assumptions of linear regression by plan, such as normality, linearity, and same variances. It is also not required that the error term variance is distributed normally, which is a common assumption in linear regression (Ali and Rose 2021).

Farmers were thought to confront a set of discrete equally incompatible adaptation choices, which were expected to depend on various climatic variables, socioeconomic characteristics, and other factors. Farmers must first identify temperature and rainfall patterns before acclimatizing (Bryan et al. 2013). This study also accepts that farmers adapt only if they notice danger in output of crop (Kato et al. 2011; Bryan et al. 2013). In this investigation, the study used a latent variable (Y^{*}_{ij}) that corresponds to the estimated benefits of using guaranteed adaptation techniques.

$$Y^{*}_{ij} = \alpha + \Sigma\beta_k X_k + \varepsilon_{Y^{*}_{ij}} \tag{1}$$

It can be seen from the preceding equation that Y^{*}_{ij} is a binary latent variable, with the subscripts I and j denoting the farmers who were able to adjust to climatic randomness and the diverse types of adaptation techniques used in this research. Meanwhile, X_k is a vector of variables impacting farmers' preference for adopting specific adaptation actions for k's predictor variables, a represents the model intercept, k represents the vector of binary regression coefficients, and Y^{*}_{ij} is the error term. A vector of binary regression coefficients is represented by Schmidheiny (2013). As a result of this investigation, we do not detect the latent variable (Y^{*}_{ij}) in any way. Our perceiving is like

$$Y_{ij} = \begin{cases} 1 = if \;\; Y_{ij} > 0 \\ 0 = if \;\;\; Y_{ij\leq 0} \end{cases} \tag{2}$$

In the overhead equation, Y_{ij} is a perceived variable that indicates that farmer I will choose procedures j to adapt to observed climatic change ($Y_{ij} = 1$) if the projected benefits are more than zero ($Y_{ij} > 0$) and that farmer I will not choose adjustment action j if the expected returns are equivalent to or less than zero ($Y_{ij} \leq 0$). In the overhead equation, Y_{ij} is a perceived variable that indicates that farmer I will choose methods j to adapt to as a result; the perceived binary variable (Y_{ij}) is represented by Eq. (2) expressed as

$$P\left(Y_{ij} = 1\right) = Y_{ij} = G\left(\beta_k X_k\right) \tag{3}$$

In above equation, $G(.)$ is binomial distribution (Fernihough 2011).

Hypothesis testing for model significance

The study tested all models were to see if they were statistically significant and accurate in their predictions. There are several methods for determining the quality of fit of logistic models. The classification table approach was used in the first phase to assess how well our models forecast the dependent variable (in this study, adoption of the specific adaptation strategy by the rural farm household). The classification table is constructed by equating the projected scores of observations based on our model's predictor variables to their real replies in the data Hosmer Jr. and Lemeshow (2004). In the current study, all models had a higher accuracy of over 71%, confirming the well fit of all models employed. We utilized a global null hypothesis technique in the second stage to evaluate the total significance of models. The study developed a null hypothesis for this investigation by counterfeit and setting all the logistic model regression coefficients to zero versus the alternative that at least one of the regression coefficients (β_k) is not zero (Peng et al. 2002):

$$\left.\begin{array}{r} H_0 : \beta_k = 0, \\ H_1 : \text{at least one } \beta_k \neq 0. \end{array}\right\} \quad (4)$$

In OLS (Ordinary Least Square) regression, the similar method is adopted as the *F* test for model testing. This test checks whether the model with independent variables, i.e., Eq. (3), fits more significantly compared to the model with only an intercept, i.e., a model with intercept only:

$$Y^*_{ij} = \alpha \quad (5)$$

The test statistic is obtained by subtracting the null deviation of an intercept-only model from the residual deviance of a model, including independent or predictor variables. The DF (degree of freedom) of the test statistic is measured as the difference in the number of variables in the model with predictors and the intercept-only model (Stephenson et al. 2008).

Partial least squares structural equation modeling (PLS-SEM)

The statistical foundations of PLS-SEM were established by Swedish econometrician Herman O. A. Wold (Wold 1974, Wold 1982, Wold 1985). PCA (Principal Component Analysis) and OLS (Ordinary Least Squares) regressions to compute partial model structures are combined in PLS-SEM (MateosAparicio, 2011). PLS-SEM is a regression-based approach that assesses connections in path models with latent and manifest variables. It is frequently used in marketing and other social sciences disciplines (Wold 1985; Lohmoller, 1989; Hair et al. 2017b).

PLS-SEM is used to investigate the comparison effect and determine if it is moderating, the invariance of its measures must be calculated (Measurement Invariance Assessment) prior to the multigroup analysis using PLS-SEM. The PLS-MGA (partial least squares multigroup analysis) may be used to see if groups of specified data have substantial variations in their estimations of particular group parameters. PLS-MGA is a nonparametric test for the significance of differences in particular group findings based on PLS-SEM results (Sarstedt et al. 2011; Henseler et al. 2016). Moreover, unlike a conventional moderation analysis, where the moderator is anticipated to have an influence on a single structural route, MGAs look at whether two or more factors have the same connection across groups. The MGA approach evaluates and contrasts the impact of each structural route on different groups (Memon et al. 2020; Ghazali et al. 2020). Impact of Climate Change Adaptation Strategies rice-wheat cropping system and cotton-wheat cropping system was estimated using PLS-SEM. A bootstrapping algorithm with 500 resample technique was run in PLS-SEM, and results are extracted to compare the difference between adapter and nonadapter.

Results and discussions

The average age of the sampled farmers was about 42 years. The age of a farmer is a significant component in determining their inclination for creativity and change and other characteristics (Amir et al. 2020). Education is thought to be essential for accessing creative knowledge about enhanced agricultural output and new, improved agricultural technology (Elahi et al. 2015). The average age of the respondents was 8 years. Education of the household head is significantly allied with CC adaptation strategies (Abid et al. 2015). The minimum farming experience of the farmers was one year and a maximum of 37. The mean farm experience of the sample respondents was about 19 years. Farmers with greater experience adopted more adaptation techniques than those with lower education and less expertise. In addition, experienced farmers were better able to adjust to climatic vulnerability Table 2 (Abid et al. 2016a; Khatri-Chhetri et al. 2017).

Household size has an important beneficial link with perception of climate change risks and adaptation (Deressa et al. 2009). The average household size was 6 with a minimum of two and maximum 12. The average landholding of the respondents was around 9 acres with a minimum of one acre and maximum of twenty-nine acres. Farmers' total landholding has a considerable impact on their decision to reduce the vulnerability of climate change (Khan

Table 2 Socioeconomic characteristics of the respondents

Variable	Minimum	Maximum	Mean	Std. deviation
Age (year)	19	70	41.52	10.803
Education (year)	0	18	8.31	5.109
Farming experience (year)	1	37	19.40	10.582
Household size (no.)	2	12	6.34	1.905
Operational land holding (acre)	1	29	9.19	5.464
Distance from input-output market (km)	1	30	10.25	6.684

et al. 2021a). Market access had a beneficial impact on the food security of household. There is significant relationship between family food security and distance to major marketplaces (Kassie et al. 2013; Alhassan 2020). The average distance from input-output market was 10 kilometers.

Perceived impacts of climate change

Findings revealed that there was higher weed infestation due to climatic and natural hazards in cotton-wheat cropping system (CWCS) than rice-wheat cropping system (RWCS). The *T* value (−2.303) and *P* value (0.021) revealed significant difference. Moreover, there was a higher use of more and less quality seed in CWCS than RWCS, proved by T value (−38.469) and P value (0.000). The CWCS has more infestation of crop diseases and pests than RWCS. It was estimated that CWCS is experiencing significant changes in cropping pattern than RWCS. Moreover, both systems have increased the use of inputs due to climatic vulnerability. In addition, the cropping intensity and crop productivity were also declined in CWCS and RWCS.

Moreover, the farmers perceived that climatic vulnerability had significantly deteriorated soil fertility. The farmers' perception about the impacts of climate change on CWCS and RWCS reported an increased number of irrigations in the study area. Likewise, the severe climatic conditions have also significantly increased the harvesting time of the crops in both systems. All the perceived impacts of the sampled farmers were significant in CWCS and RWCS. But, CWCS has more impacts on CNHs than RWCS, proving the *T* value and *P* value (Table 3).

Adaptation strategies to mitigate the impacts of climate change

The crop and varietal management as an adaptation strategy is used in both RWCS and CWCS, as 54.8% of farmers in RWCS and 36.9% in CWCS used crop and varietal management. The percentage of the farmers who used crop and varietal management was less in CWCS than RWCS because there is the absence of new varieties for cotton that can effectively mitigate the severe effects of CNHs. So, the area and production of cotton in Pakistan declined significantly. 36.3% of the respondents in RWCS used soil and water management strategy while it was adopted by 37% in CWCS. Diversification of income sources and agricultural practices is useful to reduce the adversaries of the CNHs on crop production. The study findings indicated that around 28.1% and 35.5% of households in RWCS and CWCS used diversification of income sources and agriculture practices to tackle the impacts of CNHs (Table 4).

Table 3 Perceived impacts of climatic and natural hazards

Impact of climate change	Cropping system	Mean	S.D.	S.E. mean	*T* value	*P* value
Weed infestation	RWCS	3.84	1.406	0.061	−2.303	0.021*
	CWCS	4.02	1.144	0.049		
Seed rate increased	RWCS	2.84	1.153	0.050	−38.469	0.000**
	CWCS	4.85	0.389	0.017		
Low-quality seeds	RWCS	2.93	1.167	0.050	−35.620	0.000**
	CWCS	4.83	0.417	0.018		
Infestation of crop diseases and pests	RWCS	2.95	1.102	0.047	−37.561	0.000**
	CWCS	4.84	0.392	0.017		
Change of cropping pattern	RWCS	3.10	1.032	0.044	−34.783	0.000**
	CWCS	4.81	0.477	0.021		
Increase of input use	RWCS	3.11	1.026	0.044	−35.127	0.000**
	CWCS	4.82	0.476	0.020		
Decrease of cropping intensity	RWCS	3.10	1.026	0.044	−36.125	0.000**
	CWCS	4.83	0.424	0.018		
Decreasing soil fertility	RWCS	3.10	1.031	0.044	−34.695	0.000**
	CWCS	4.81	0.491	0.021		
Decrease crop productivity	RWCS	3.10	1.018	0.044	−35.585	0.000**
	CWCS	4.82	0.472	0.020		
Number of irrigations increased	RWCS	3.10	1.008	0.043	−36.504	0.000**
	CWCS	4.82	0.427	0.018		
Increase of harvesting time	RWCS	3.12	1.019	0.044	−36.243	0.000**
	CWCS	4.84	0.412	0.018		

Author's own survey results (2020)

Table 4 Adaptation practices to mitigate the impact of climate change

Adaptation practices	RWCS		CWCS	
	Yes (%)	No (%)	Yes (%)	No (%)
Crop and varietal management	54.8	45.2	36.9	63.1
Soil and water management	36.3	63.7	37.0	63.0
Diversification of income sources and agriculture practices	28.1	71.9	33.5	66.5
Farm operation time management	35.4	64.6	41.4	58.6
Fertilizer management	27.0	73.0	30.6	69.4
Spatial adaptation	25.4	74.6	37.0	63.0
Access to risk reduction measures and financial assets	34.3	65.7	46.7	53.3
Adoption of new technologies	37.4	62.6	26.1	73.9
Institutional/governmental support	28.6	71.4	26.2	73.8
Indigenous knowledge	31.1	68.9	33.7	66.3

Author's own survey results (2020–21)

Moreover, 35.4% and 41.4% respondents of RWCS and CWCS used farm operation time management. Fertilizer management was adopted by 30.6% farmers in CWCS, while in RWCS 27% of the respondents adopted it. The spatial adaptation like migration, selling of land, and shifting to another business was adopted by 25.4% and 37% of farmers in RWCS and CWCS, respectively. There are frequent floods in the CWCS cropping system, so most of the farmers adopted spatial adaptation in this system than RWCS. Moreover, access to financial resources and risk reduction measures 34.3% and 46.7% of respondents in RWCS and CWCS, respectively. The farmers are poor in CWCS than RWCS due to higher impacts of CNHS. Therefore, only 37.4% farmers in RWCS and 26.1% in CWCS adopted new technologies for CNHs. The respondents who adopted institutional/governmental support strategy were 28.6% and 26.2% in RWCS and CWCS. Finally, 31.1% farmers in RWCS adopt indigenous knowledge and of 33.7 % in CWCS. All indicators of adaptation strategies of crops were found of different adoption in the rice-wheat growing areas and cotton-wheat growing areas (Table 4).

Determinants of adaptation strategies of climate change

The impacts of climate change are becoming more noticeable every day. Climate change disrupts weather patterns throughout the world, causing temperature swings and irregular precipitation patterns (Savo et al. 2016). Climate change (CC) is now having an enormous impact on several emerging Asian countries like Pakistan (Khan et al. 2020a). Most nations with a low income, especially those in the tropics, are vulnerable to climate change because rising temperature drives them further away from the zones with the most comfortable temperature (Khan et al. 2020b).

Pakistan is particularly vulnerable to climate change as a developing country because of its fewer resources and arid topography (Schilling et al. 2020). Rural areas, particularly those in developing nations, are vulnerable to CC (Dumenu and Obeng 2016). Adaptation techniques are required to make rural areas more climate-resilient (Ndamani and Watanabe 2016). Local socioeconomics, agricultural systems, existing infrastructure, and climate change consequences affect climate change adaptation plans to some degree (Alam et al. 2016). The results of Table 5 showed that all the hypotheses were tested significantly.

Age of the farmer

The age of a farmer is a significant component in determining their inclination for creativity and change and other characteristics (Amir et al. 2020). Age has not been closely linked to all crops' adaptation measures such as management of crop, variety, soil and irrigation water, diversification of agricultural production systems and livelihood sources, management of fertilizers and farm operating time, access to risk reduction measures and financial resources, and spatial adaptation. It indicates that every age group had about the same crop adaptation measures (Table 6).

Education

Farmers' education level had a positive and significant relationship with all crop adaptation measures, including management of soil and irrigation water, crop type and variety, diversification of agricultural and livelihood sources, farm operation time management, fertilizer management, spatial adaptation, access to risk mitigation measures, and financial resources. This indicates that educated farmers possessed a greater capacity for crop adaptability. Education is thought to be essential for accessing creative knowledge about enhanced agricultural output and new, improved agricultural technology (Norris and Batie 1987; Elahi et al. 2015). Previous research (Maddison 2007; Deressa et al.

Table 5 Testing of hypothesis for predictive power and model significance

Models	Chi-squared	DF	P level	Model correctness (%)	−2 Log likelihood	Cox & Snell R square	Nagelkerke R square
Crop and varietal management	583.48	17	0.000	80.6	902.489	0.417	0.558
Soil and water management	722.76	17	0.000	85.4	773.238	0.488	0.651
Diversification of income sources and agriculture practices	731.72	17	0.000	85.5	750.740	0.492	0.659
Farm operation time management	728.78	17	0.000	86.2	768.358	0.491	0.654
Fertilizer management	739.83	17	0.000	85.8	756.742	0.496	0.661
Spatial adaptation	721.71	17	0.000	85.3	774.866	0.487	0.650
Access to risk decrease measures and financial assets	571.95	17	0.000	80.3	916.342	0.411	0.550
Adoption of new technologies	520.48	17	0.000	78.6	972.181	0.382	0.511
Institutional/governmental support	725.39	17	0.000	86.0	771.800	0.489	0.652
Indigenous knowledge	518.47	17	0.000	78.7	974.689	0.381	0.509

Author's own survey results (2020)

2009; Bryan et al. 2013; Abid et al. 2015) indicated that education of the household head was found to be significantly allied with CC adaptation.

Experience

Farmers' crops and dairy farming experience had a positive and significant relationship with all adaptation measures, management of crop, variety, soil, and irrigation water, diversification of agriculture production systems and livelihood sources, management of fertilizer and farm operation time, spatial adaptation, access of financial resources, and risk management measures. According to the study, farmers with greater experience adopted more adaptation techniques than those with lower education and less expertise (Abid et al. 2016a). In addition, the study by Khatri-Chhetri et al. (2017) found that experienced farmers were better able to adjust to climatic vulnerability.

Household size

Household size had significant and negative relation with adaptation strategies such as crop and varietal management, access to risk mitigation strategies and financial resources, management of soil and irrigation water, diversification of agriculture production systems and livelihood sources, management of fertilizer and farm operations, spatial adaptability, and institutional assistance. It has been observed that household size has an important beneficial link with adaptation to CC (Croppenstedt and Colleagues, 2003; Deressa et al. 2009; Abid et al. 2015).

Land area

Land area had significant and positive relation with adaptation strategies related like management of soil and irrigation water, diversification of agricultural production systems and livelihood sources, management of fertilizer and farm operations, spatial adaptation, access to monetary resources and risk reducing measures, adoption of new technologies, and institutional support except crop and varietal management and indigenous knowledge. The study by Khan et al. (2021b) shows that farmers' total landholding has a considerable impact on their decision to reduce the vulnerability of climate change.

Tenancy status

It is found that tenancy status had significant and negative relation with all adaptation measures used in this study. However, owner cultivators had less adaptation measures as compared to tenant and owner-cum-tenant cultivators. Past studies have found a link between land ownership and CC adaptation (Fosu-Mensah et al. 2012; Iheke and Agodike 2016), while others have found a negative association (Nabikolo et al. 2012; Iqbal et al. 2020; Javed et al. 2015; Abid et al. 2015, Abid et al. 2016a), with the latter being linked to the need for tenants to pay land rent.

Tube well ownership

Climate change adaptation will be a major concern for farmers that use tube wells for irrigation water supply (Khan et al. 2021b). Farmers that use canal water in addition to tube well water have chosen drought-tolerant cultivars Ali and Erenstein (2017). The study's findings indicated that farmers' tube well ownership had no significant relationship with all crop adaptation measures, including management of crop and variety, soil, irrigation water management, diversification of agriculture production systems and livelihood sources, management of fertilizer and farm operations,

Table 6 Models of farm-level climate change adaptation measures and parameter estimates of the logistic regression

Independent variables	Adaptation strategies (dependent variable)																			
	Crop and varietal management		Soil and water management		Diversification of agriculture practices and income sources		Farm operation time management		Fertilizer management		Spatial adaptation		Access to risk reduction measures and financial resources		Adoption of new technologies		Institutional/governmental support		Indigenous knowledge	
	B	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.	*B*	Sig.
Age (year)	0.001	0.847	−0.006	0.436	−0.007	0.371	−0.006	0.491	−0.006	0.507	−0.009	0.292	−0.001	0.946	−0.002	0.780	−0.005	0.510	0.001	0.931
Education (year)	0.267	0.000	0.052	0.005	0.063	0.001	0.067	0.000	0.056	0.002	0.059	0.001	0.259	0.000	0.232	0.000	0.069	0.000	0.231	0.000
Crops and dairy farming experience (year)	0.064	0.000	0.030	0.000	0.030	0.001	0.033	0.000	0.031	0.000	0.032	0.000	0.061	0.000	0.057	0.000	0.032	0.000	0.055	0.000
Household size	−0.165	0.000	−0.034	0.489	−0.068	0.169	−0.025	0.610	−0.025	0.613	−0.035	0.476	−0.138	0.003	−0.133	0.003	−0.026	0.602	−0.123	0.005
Land area	0.009	0.558	0.049	0.004	0.056	0.001	0.045	0.009	0.034	0.046	0.048	0.005	0.009	0.558	0.004	0.799	0.041	0.016	0.002	0.873
Dummy tenancy status owner (1=owner; 0=otherwise)	−0.504	0.017	−1.03	0.000	−0.891	0.000	−0.940	0.000	−0.879	0.000	−1.010	0.000	−0.540	0.009	−0.475	0.017	−0.916	0.000	−0.517	0.009
Tube well ownership (1=owner tube well; 0=otherwise)	−0.776	0.065	0.068	0.868	0.215	0.585	0.126	0.754	0.027	0.945	0.084	0.836	−0.080	0.822	−0.116	0.733	0.142	0.722	−0.093	0.785
Livestock	0.137	0.000	0.150	0.000	0.350	0.000	0.159	0.000	0.170	0.000	0.153	0.000	0.117	0.000	0.092	0.000	0.161	0.000	0.093	0.000
Distance from market (km)	0.006	0.650	0.007	0.627	0.030	0.049	0.007	0.646	0.006	0.656	0.005	0.708	0.002	0.892	0.005	0.703	0.001	0.929	0.004	0.776
Market access information	0.699	0.002	−0.149	0.568	0.553	0.034	0.704	0.004	−0.153	0.560	−0.045	0.861	0.604	0.007	0.531	0.015	0.624	0.009	0.542	0.013
Credit access	0.507	0.253	0.095	0.831	−0.179	0.683	0.229	0.596	0.483	0.274	0.112	0.801	0.030	0.935	−0.025	0.943	0.232	0.590	−0.017	0.961
Agricultural extension services provided for crop production	0.435	0.010	0.473	0.015	0.526	0.007	0.457	0.019	0.646	0.001	0.498	0.010	0.394	0.020	0.284	0.083	0.531	0.006	0.290	0.077
Access to information on climatic and natural hazards	1.045	0.000	1.500	0.000	1.592	0.000	1.403	0.000	1.432	0.000	1.526	0.000	0.969	0.001	1.002	0.000	1.442	0.000	1.023	0.000
Information on weather forecasting	0.434	0.016	−0.036	0.856	0.301	0.133	0.198	0.322	0.341	0.087	0.025	0.900	0.568	0.001	0.519	0.003	0.258	0.195	0.547	0.002
Dummy cropping system (D = 1 if rice-wheat cropping zone; 0 = otherwise)	−0.374	0.037	−3.402	0.000	−3.116	0.000	−3.22	0.000	−3.170	0.000	−3.344	0.000	−0.391	0.028	−0.568	0.001	−3.153	0.000	−0.542	0.002
Dummy remittances	0.105	0.622	−0.236	0.348	0.489	0.040	0.297	0.227	−0.204	0.406	−0.229	0.358	0.032	0.882	0.126	0.540	0.322	0.188	0.143	0.486
Dummy off-farm income	0.399	0.072	0.011	0.966	−0.161	0.530	0.519	0.034	0.850	0.000	−0.068	0.790	0.672	0.003	0.490	0.023	0.459	0.059	0.492	0.022
Constant	−4.55	0.000	2.657	0.000	0.932	0.170	1.551	0.017	1.058	0.105	2.461	0.000	−4.423	0.000	−3.372	0.000	1.359	0.036	−3.536	0.000

Author's own survey results (2020–21)

spatial adaptation, access to hazard mitigation measures and financial resources, adoption of new technologies, and institutional support.

Livestock

It was estimated that the number of livestock owned by farmers had a significant and positive relationship with adaptation measures like management of crop, variety, soil and irrigation water, diversification of agriculture production systems and livelihood sources, management of fertilizer and farm operations, spatial adaptation, financial resources access, and risk reduction measures having a bigger herd of animals reduces farmers' financial strain when trying to cover the costs of resource-intensive adaptation methods like longer-term rice planting and farm downsizing. There is evidence to substantiate these conclusions from a research conducted in Bangladesh, which found that livestock production was a key factor of farmers' adaptability (Alauddin and Sarker 2014). The socioeconomic conditions of the research region are significantly influenced by livestock ownership. It significantly impacts how respondents see government and nongovernmental organizations in terms of financial and technical aid (Amir et al. 2020).

Distance

There were not enough agricultural inputs and food commodities purchased by farmers who had difficulty in accessing markets. Likewise, they were unable to boost their earnings by selling their goods at a profit. As a result, they struggled to maintain a diverse diet. As a result, the problem of market access had a detrimental impact on the food security of their household (Alhassan 2020). There is significant relationship between family food security and distance to major marketplaces Kassie et al. (2013). It was found that distance from market had nonsignificant relation with all adaptation measures related to crop in this study. It means that distance from market had no impact on adaptation measures.

Market access

Market access has a significant and positive association with adaptation measures like crop and varietal management, diversification of agriculture production systems and livelihood sources, management of farm operations time, access to risk mitigation measures and financial resources, adoption of new technologies, institutional support, and indigenous knowledge. On the other hand, market access had insignificant relationship with soil and irrigation water management, fertilizer management, and spatial adaptability. Familiarity with the market can support as a means of apportioning and substituting thoughts and evidence among growers and other service provision workers (Maddison 2007; Ali et al. 2021).

Credit access

It was found that respondents' credit access had nonsignificant relation with all adaptation measures related to crop. Credit availability has a considerable impact on climate change adaptation (Ali et al. 2021). Access to financing and subsidies take prompt actions to limit the detrimental impact of climatic variability on their crops (Masud et al. 2017).

Agricultural extension services

Agricultural extension services were found to have a significant relationship with adaptation measures such as crop, variety, soil and irrigation water management, diversification of agriculture production system and livelihood sources, management of fertilizer and farm operations time, access to financial resources, risk decreasing measures, institutional support, and spatial adaptation. Different research findings established a link between agricultural institutions' efforts and rural communities' ability to adapt to CC (Maddison 2007; Nhemachena and Hassan, 2007; Deressa et al. 2009; Ali and Erenstein 2017, Ali et al. 2017).

Information about climatic and natural hazards

It was found that access to information about climatic and natural hazards (CNHs) had a significant and positive relationship with adaptation measures like management of variety, soil, irrigation water, diversification of agricultural production systems and livelihood sources, management of fertilizer, farm operation time, spatial adaptation, and risk management. It has been shown that access of farmers to knowledge of climate change aids the adaptation process both directly and indirectly (Mulwa et al. 2017; Abid et al. 2020; Khan et al. 2021b).

Information on weather forecasting

Information on weather forecasting had significant and positive relation with crop and varietal management, access to risk reduction measures and financial resources, adoption of new technologies, and indigenous knowledge. A strong correlation exists between farmers' ability to adapt and their availability to farm advisory services and farm administration information from governmental or agriculture extension departments Khan et al. (2021c). In addition, agricultural extension was identified by Amare et al. (2018) as one of the most important factors of farmers' capacity for climate adaptation and risk management.

Dummy cropping system

The dummy variable cropping system had significant and negative relation with all adaptation measures related to crop. It means respondents of cotton-wheat zone had more adaptation measures as compared to those respondents who belonged to rice-wheat cropping zone.

Remittances

Foreign remittances contribute to rural households' income from out-migration (Thapa and Hussain 2021). Remittance from out-migrated small business owners, wage labor and tourism, and harvesting of medicinal herbs and plants contributes to communities' livelihood and food security (Hussain et al. 2016). The results of the findings revealed that dummy variable "remittances" had nonsignificant relation with all adaptation measures related to crop except one variable "diversification of agriculture practices and income sources".

Off-farm income

Off-farm income exhibited a strong and favorable relationship with several adaptation measures, including time management, fertilizer management, access to climate risk reducing measures and financial resources, adoption of new technology, institutional support, and indigenous knowledge. Other factors, on the other hand, exhibited no meaningful relationship with off-farm income. The sources of income and market access have an impact on the way people make a living. Farmers who make a living from various sources are well equipped to deal with extreme weather and climate change. Furthermore, they have the financial means to keep their agriculture land fallow for around a year (Amir et al. 2020).

Impact of climate change adaptation strategies on the rice-wheat cropping system (RWCS)

The results of SmartPLS revealed that in RWCS for adaptation strategy crop and varietal management, the coefficient of β for nonadapter and adapter was −0.291 and −0.161, and it was significant. There was a reduction of −13.00% in the impacts of climatic and natural hazards (CNHs) using crop and varietal management adaptation strategy. Soil and irrigation water management has a significantly beneficial role in coping with the risks of climate vulnerability. There was a reduction of −5.80% in the impacts of CC by adopting management of soil and irrigation water. Diversification of agriculture production systems and livelihood sources is essential to improve rural livelihood and ensure food security in the prevalence of CC. Therefore, this variable has declined −10.10 percent the effects of CC in the RWCS. In addition, a −10.50 percent reduction occurred due to using the farm operation time management strategy of CC. The result revealed that fertilizer management had decreased the impacts of CC by −9.80 percent.

There was a −11.50 percent decline in the impacts of CC by spatial adaptation strategy. Risk reduction measures and access to financial resources played a vital role in enhancing crop production, improving rural livelihood and food security. About 10 percent reduction was achieved by the risk reduction measures and access to financial resources to cope with CC vulnerability. Agriculture is now in the modern era of globalization; hence, adopting new technologies is crucial to achieving the goal of food security in a gigantic population explosion and climate change. The result of the study purported that a −12.20% reduction in the impacts of CC was achieved by adopting new technologies in crop production. The institutional/governmental support had a significant impact on managing the adversaries of CC on crop production. There was a reduction of −9.60% in the impacts of CC due to the access to institutional support. Moreover, the farmers' indigenous knowledge related to CC reduced the impact by −10.20% (Table 7).

Impact of climate change adaptation strategies in the cotton-wheat cropping system (CWCS)

All the coefficients of the adaptation strategies of the adapter and nonadapter in the cotton-wheat cropping system (CWCS) were significant. It was estimated that the crop and varietal management strategy mitigated the impacts of climatic and natural hazards (CNHs) of −4.20 percent. The soil and water management coefficient was −0.397 for nonadapter and −0.274, while a net reduction of CC impacts was −12.30 percent. Moreover, −11.70% and −11.70% risks of CC were declined by diversification of agriculture practices and income sources and time management in farm operations (Table 8). In addition, fertilizer management and spatial adaptation reduced −6.70% and −6.60% impacts of CC. It was estimated that −10.10 percent reduction of CC risks was reduced due to risk reduction measures and access to financial resources, while −6.60 percent was due to adopting new technologies for the production of crops. Similarly, institutional/governmental support and indigenous knowledge reduced the impacts of CC by −6.60% (Table 8).

According to Zahid and Ahmed (2018), the profit efficiency of Punjab's agriculture sector was 0.72 percent.

Table 7 Impact of adaptation practices on the rice-wheat cropping system

Adaptation strategy	Path coefficients (nonadapter)	Path coefficients (adapter)	*P* value (nonadapter)	*P* value (adapter)	Impact reduction (%)
Crop and varietal management	−0.291	−0.161	0.000	0.055	−13.00%
Soil and water management	−0.254	−0.196	0.000	0.020	−5.80%
Diversification of income sources and agriculture practices	−0.282	−0.181	0.000	0.015	−10.10%
Farm operation time management	−0.285	−0.180	0.000	0.020	−10.50%
Fertilizer management	−0.282	−0.184	0.000	0.031	−9.80%
Spatial adaptation	−0.295	−0.180	0.000	0.008	−11.50%
Access to risk reduction measures and financial resources	−0.282	−0.182	0.000	0.009	−10.00%
Adoption of new technologies	−0.292	−0.170	0.000	0.077	−12.20%
Institutional/governmental support	−0.283	−0.187	0.000	0.001	−9.60%
Indigenous knowledge	−0.285	−0.183	0.000	0.023	−10.20%

Author's own survey results (2020–21)

Still, that figure could rise to 28 percent by implementing climate change adaptation measures and increasing production efficiency in the province. Adaptation methods must be put into action if the agriculture industry is to enhance its performance. Climate change has harmed Pakistan's agricultural productivity (Khan and Tahir 2018). Climate change adaptation techniques have a beneficial impact on the market in terms of net return volatility, kurtosis, and downside risk exposure. Farmers that use climate change adaptation measures have better net returns than traditional farmers. Traditional farmers can improve their net profits by adapting and mitigating to climate change (Shahzad and Abdulai 2019).

Compared to conventional farmers, farmers who use climate change adaptation measures get better returns (Shahzad and Abdulai 2019). Adaption measures such as shifting planting dates, improving fertilizer application, and increasing irrigation efficiency have decreased poverty in Peshawar and Dera Ismael Khan, respectively, from 28.62 to 19% and 28.90 to 23.0%. Similar to this, farmers that use risk-coping strategies for climate change had greater wheat yields (42–65 kg per hectare) and income (PKR 1658–2610 per month). With the adaption measure, household poverty decreases by 2–4 percent, and food security increases by 8–13 percent (Gul et al. 2019). Weather risk exposure is declining due to climate change adaptation strategies at the home level (Ali and Erenstein 2017). Improved food security and higher farmer income are also advantaging of farm-level adaptation (Abid et al. 2016a).

The ability of cotton farmers to adapt to CC has a large and beneficial influence on their productivity and net income. According to Ahmad and Afzal (2020), cotton farmers in Punjab, Pakistan, who are climate change adapters, produce 0.06 t/ha more cotton than those who are not, and their net income rises by PKR 5378 ($51) more due to the increase in cotton output. The beneficial impact of adaptation on Pakistan's food and cash crops has also been documented in research by Gorst et al. (2015) and Abid et al. (2016b).

Table 8 Impact of climate change adaptation practices on the cotton-wheat cropping system

Adaptation strategy	Path coefficients (nonadapter)	Path coefficients (adapter)	*P* value (nonadapter)	*P* value (adapter)	Impact reduction (%)
Crop and varietal management	−0.337	−0.295	0.003	0.000	−4.20%
Soil and water management	−0.397	−0.274	0.000	0.000	−12.30%
Diversification of income sources and agriculture practices	−0.393	−0.276	0.000	0.000	−11.70%
Farm operation time management	−0.396	−0.272	0.000	0.000	−12.40%
Fertilizer management	−0.357	−0.290	0.000	0.000	−6.70%
Spatial adaptation	−0.356	−0.290	0.000	0.000	−6.60%
Access to risk reduction measures financial resources	−0.336	−0.235	0.000	0.034	−10.10%
Adoption of new technologies	−0.357	−0.291	0.000	0.000	−6.60%
Institutional/governmental support	−0.356	−0.290	0.001	0.000	−6.60%
Indigenous knowledge	−0.356	−0.290	0.001	0.000	−6.60%

Author's own survey results (2020–21)

Conclusion and policy recommendations

The findings conclude that farmers perceived different impacts of climate change on the rice-wheat cropping system and the cotton-wheat cropping system in Punjab, Pakistan. Weed infestation, seed rate increased, low-quality seeds, infestation of crop diseases and pests, change of cropping pattern, increase of input use, decrease of cropping intensity and productivity, decreasing soil fertility, increasing irrigation frequency, and increase of harvesting time were the perceived risks by the farmers in the RWCS and the CWCS. There was more vulnerability of CC in CWCS than RWCS. To alleviate the adversative influences of climate change, the adaptation strategies used by farmers were management of crop and variety, soil, and irrigation water, diversification of agriculture production systems and livelihood sources, management of fertilizer and farm operations time, spatial adaptation, access to risk reduction measures and financial assets, adoption of new technologies, institutional support, and indigenous knowledge. Moreover, the results of Binary Logistic Regression indicate that adaptation strategies are affected by different factors like age, education, household family size, off-farm income, remittances, credit access, information on climatic and natural hazards, information on weather forecasting, land acreage, the experience of growing crops and rearing of livestock, tenancy status, tube well ownership, livestock inventory, access to market information, agricultural extension services, and distance from agricultural input/output market. The SmartPLS results demonstrated a considerable disparity in climate change adaptation techniques between adapters and nonadapters. Climate change adaptation methods positively influence Pakistan's food and cash crops. Farmers that adopt climate change adaptation methods outperform traditional farmers in terms of net returns. Conventional farmers' net earnings can be increased by adapting to and mitigating climate change. Farm-level adaptation also benefits from increased farmer revenue and food security.

Hence, the findings of the study complete the objective and answer all the research questions, i.e., farmers perceive the impact of climate change, use the adaptation strategies to mitigate the adverse effects, the adaptation measures are affected by socioeconomic and demographic characteristics. Finally, the adapters had less effect of climate change risks than nonadapters. The findings suggest that establishing policies and putting them into action at the grassroots level are necessary to consider these concerns. Additional investments in farmer education and improved access to public services such as farm advisory services and awareness programs could potentially assist farmers in managing the effects of climate change. Likewise, learning how to implement a variety of adaptation strategies to mitigate the adverse impact on the agriculture production systems process. Overall, these findings can assist other scientists and policymakers in recognizing such elements and how socioeconomic and demographic characteristics influence farmers' decision-making processes and attitudes toward climate change adaptation. The risk management system may be created to protect crops against failures caused by extreme weather events like floods and droughts. Develop crop types that are both high-yielding and resistant to climate change. New cropping patterns and schedules should be introduced to combat the effects of climate change on crops. Tree planting programs must be launched to increase the number of plants to lessen the danger of climate change.

Reforms need to be made to agricultural extension systems, and the government and politicians need to make it easier to obtain agricultural information. In addition, they need to devise education programs that are easily accessible about climate change. Concurrently, the government has a responsibility to disseminate the findings of thus research to local farmers and offer both institutional and financial sustenance, with a particular focus on assisting disadvantaged smallholder farmers. It is also proposed that methods of production that are more sustainable and up to date be included in farming livelihoods. Access to sufficient resources and information on how to adapt are two examples of techniques that may be employed as short-term tactics that can considerably enhance efforts to increase productivity and net income of agriculture. Using climate change potential level adaptation helps farmers improve their net financial status and quality of life. Still, it also boosts cotton-wheat and rice-wheat crop yields at the national level. For the adaptation advantages to be utilized appropriately, regionally customized strategies that take into account the particular climate risks and demands of each farming region are required. According to the study's empirical findings, utilizing adaptation techniques can result in significant benefits such as an increase in production and higher net revenue for the farm as a whole.

Limitations and future directions

The limitation of this research is that it is conducted in the rice-wheat cropping system and the cotton-wheat cropping system, so future studies may be conducted in other cropping systems like mixed cropping system and maize wheat cropping system. As this study is carried out only in the Punjab province, further studies may be conducted in other provinces, and a comparison may be conducted. Moreover, this study used only primary data; in future research, secondary data may be used with primary data.

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Author contribution Muhammad Usman, Asghar Ali, and Muhammad Khalid Bashir contributed in planning, conceptualization, conduct of the research, formal analysis, and writing—original draft. Magdalena Radulescu and Sajjad Ahmad Baig assisted in data analysis. Muhammad Usman and Khalid Mushtaq provided guidelines throughout research work and proofread the manuscript. Abdulazeez Hudu Wudil and Rimsha Akram contributed in review and editing.

Data availability Data may not be made public as it may violate research participants' privacy. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval This study has been approved by the Ethical Review Committee, Institute of Agricultural and Resource Economics, University of Agriculture Faisalabad, Pakistan.

Consent to participate Informed written consent was taken voluntarily from each eligible participant.

Consent for publication All authors approved the final version to be submitted for publication.

Conflict of interest The authors declare no competing interests.

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