Environmental Science and Pollution Research (2021) 28:14844–14853
https://doi.org/10.1007/s11356-020-11472-x

RESEARCH ARTICLE

Farmers' perception and adaptations to climate change: findings from three agro-ecological zones of Punjab, Pakistan

Muhammad Faisal Ali [1] · Sobia Rose [2]

Received: 25 March 2020 / Accepted: 28 October 2020 / Published online: 21 November 2020

Abstract

The main objective of this study was to capture farmers' perceptions and adaptations to climate change in agriculture sector. Along with this, it also identified farmers' adaptations to perceived climate change. Binary logit models were applied on data of 386 farmers, collected from three different agro-ecological zones of Punjab, Pakistan, to present a comprehensive analysis of different adaptation strategies missing in the existing literature. The coefficients of a binary logit model only explain the direction of change; therefore, to see the magnitude of change, marginal effects were also estimated. Findings revealed that farmers perceived climate change and opted different adaptation strategies. Results of binary logit models described age, education, farming experience, landholding, access to climate information, access to credit facilities, and access to extension services as important determinants of adaptation. This research also found lack of access to climate information, lack of irrigation resources, and knowledge about appropriate adaptations as key constraints in adaptation process. This situation can be improved by enhancing institutional support and capacity. It is suggested that improved agricultural education with better access to climate information and extension services affects the farmers' well-being directly and hence is good for the economy of Pakistan.

Keywords Perception · Climate change · Adaptation · Agriculture · Pakistan

Introduction

This is now an undeniable truth that the climate is changing and Pakistan is among one of the countries extremely in danger due to climate change (CC). Pakistan had to bear total of US $ 3792.52 million losses from 1999 to 2018 due to climate change. That is why findings of the long-term global climate risk index has placed Pakistan as the 5th most affected country in the world (Eckstein et al. 2019). A 0.6 to 1.0 °C rise in temperature coupled with rising precipitations from 18 to 32% in the monsoon zone during the last century can devastate the productivity of agriculture sector in an agriculture-dependent economy like Pakistan (Asif 2013). Different studies and reports have projected that the situation will become more severe in future creating serious future concerns for Pakistani agriculture (Shakoor et al. 2011).

The varying climate affects both developed and developing nations, but its effects are felt more severely in developing countries due to their low adaptation capacity (IFAD 2010). Although the mitigation effort is no doubt a best way to deal the challenge of changing climate, but it is time taking and requires many financial resources. To save the agriculture sector of a developing country like Pakistan, adaptation according to changing climatic situations is the finest approach to minimize the damaging effects of CC. (Adger et al. 2003; Kurukulasuriya et al. 2008). The economy of Pakistan is hugely dependent on agriculture sector with a bigger share in annual GDP that is 18.9%. Agriculture sector is also providing 42.3% share in labor force (GOP 2019). Despite its high importance, agriculture sector is confronted with a number of other issues, but the climate brought disasters, i.e., rainfall and flood, are the key factors (Nomman and Schmitz 2011).

The imminent risks that are allied to climate change are no doubt apparent and real, but regarding the agriculture sector, they are quite uncertain; therefore, adaptations is not only an effective way but inevitable to limit the undesirable effects of

Responsible editor: Philippe Garrigues

✉ Muhammad Faisal Ali
faisalaliuaf@gmail.com

[1] Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad, Pakistan

[2] Planning and Development Department, Government of Punjab, Punjab Economic Research Institute, Lahore, Pakistan

varying climate (Nastis et al. 2012). It is generally argued that every society is fundamentally adaptive, but the perception about CC plays an important role, while the capacity to adapt is sturdily linked to education, access to resources, and awareness, but these components are not available to small growers in Pakistan. A larger population share (29.5%) is living under poverty line, which is affecting the capacity of growers to tackle CC (Indexmundi 2019). Hence, for developing countries, adaptation is a difficult process where exposure to CC is high, while poverty and lesser adaptation capacity at farm level further aggravate the situation (Hassan and Nhemachena 2008; Ayers and Huq 2009; M Abid et al. 2015; Gorst et al. 2015). In addition to lower technological and financial capacity of the farmers, ineffective climate policy is also limiting the current support for adapting to CC (OECD 2011). Hence, for a well-targeted adaptation policy, there is a need to understand the factors shaping the farmers' perception and their adaptive responses (Bradshaw et al. 2004; Below et al. 2015). Although growers' adoptions of different adaptation measures are connected to various aspects, i.e., social, environmental, and economic (Deressa 2007; Bryan et al. 2013), perception about CC is key determinant. Therefore, it is indispensable to explore how growers notice climate changes and how they respond. Moreover, type and extent of adaptation methods applied are crucial for future perspectives (Abid et al. 2015).

Although internationally extensive research is available on perceptions, adaptation behavior of farmers under climate variability, the determining factors that shape adaptation behavior but most of the work done belongs to Africa (Makate et al. 2017; Gorst et al. 2015; Deressa et al. 2009; Bryan et al. 2009; Hassan and Nhemachena 2008; Thomas et al. 2007) this research is also carried out by Mase et al. (2017) in USA; Alam et al. 2017in Bangladedesh ; Niles et al. (2016) in New Zeland; Jorgensen and Termansen (2016a, b) in Denmark, and a little work is done in Pakistan (Gorst et al. 2018; Abid et al. 2015;). The research conducted on the issue of CC is restricted to only the impacts of CC and their projections for specific crops and sectors. Therefore, this research was planned to clear the current research gap in agriculture sector.

This research focuses primarily on two research questions. Firstly, farmers' perception about long-term changes in local climate based on the past 20 years of experience was analyzed. Secondly, farmers' adaptations in farming to perceived climate change were assessed in detail, although factors explaining adaptation behavior under varying climate are similar and recognized already. However, the impacts are different in different regions because of many environmental and socio-economic aspects. Further barriers in the process of adaptations were also explored.

Methodology

Elucidating the site of study

This study was conducted in three different agro-ecological zones of the most populous and second largest (79,284 square miles) province of Pakistan, Punjab (Britannica 2016). The Punjab province is geographically located approximately at 30° 00 N and 70° 00 E (Ahmed et al. 2012). This fertile land is important for the economy of Pakistan because it is contributing a large share through its agriculture. The Punjab province has about 29% of the total area reported, 57% of total area cultivated, and about 70% of cropped area of Pakistan (GOP 2012) (Fig. 1).

Sampling and data collection

A multistage sampling method was adopted while selecting study sites and respondents. At the first stage, the whole study area was indicated, i.e., Punjab province of Pakistan. At the second stage, 3 districts from three agro-ecological zones of Punjab province was selected purposively, based on agricultural contribution in GDP and exposure to varying climate. At the third stage, 6–8 union councils were selected randomly from each subdivision (Tehsil) of the district subject to counting of union councils in tehsil. At the fourth stage, 7–10 respondents were selected randomly from each union council.

The study was conducted for the cropping years 2014–2015 that includes Rabi 2014–2015 (winter) and Kharif 2015 (summer). The major crops under study were wheat, sugarcane, and cotton. The collection of data was accomplished in December 2015. For this purpose, 386 farmers' interviews were conducted with the help of a well-structured pretested questionnaire that includes information on farmers' socio-economic characteristics, perception about varying climate, perceived adaptations, adaptations undertaken, and barriers to adaptations.

Binary logit model

The factors that influence adaptations were analyzed by using a binary logit model. The decision to adapt necessitates farmer to recognize the changes in long-term climate (Bryan et al. 2013). Following previous studies, we assumed that farmers adopt different adaptation practices if they perceive CC, and further CC is a risk to future crop production (Kato et al. 2011; Bryan et al. 2013; Abid et al. 2015).

It was assumed that farmers face a set of discrete mutually exclusive choices of adaptations that were assumed to depend on number of climate attributes, socio-economic characteristics, etc.:

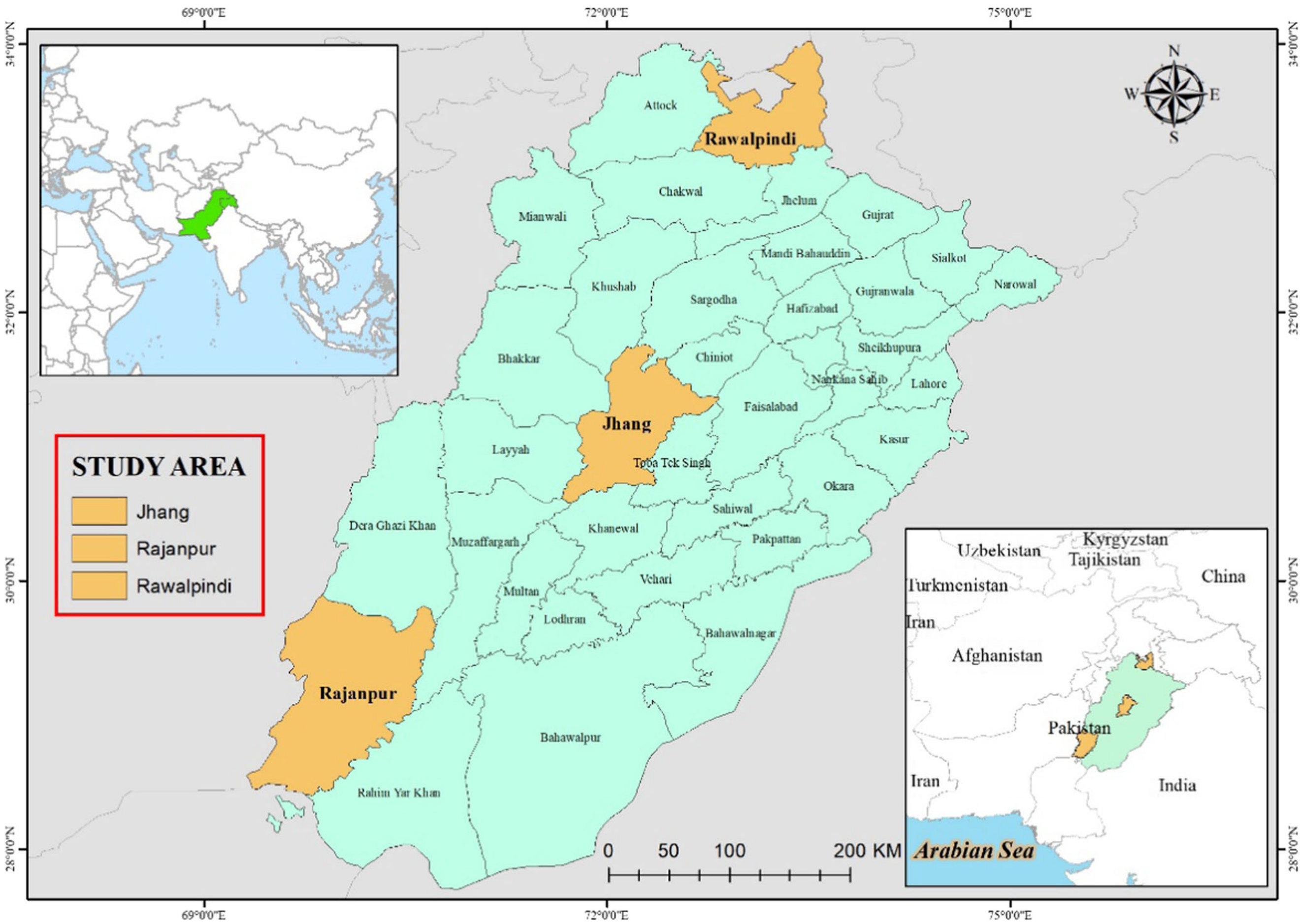

Fig. 1 Description of study sites

$$Y_{ij} = \alpha + \sum \beta_k X_k + \mathcal{E} Y_{ij} \tag{1}$$

where Y_{ij} is a dichotomous outcome with subscript i demonstrating farmer, who is adapting to long-term climate changes, and j represents different adaptation measures undertaken, whereas X_k specifies the vector of various factors that affects the growers' choices of different adaptations and k is the subscript showing particular independent variable. The symbol α is the model intercept, β_k is the vector of binary coefficients, and $\mathcal{E}Y_{ij}$ is the error term which is normally distributed and homoscedastic, zero mean, and constant variance (Schmidheiny and Basel 2013).

The parameters β_k of a binary logit model only explain the direction of the effect of explanatory factors on dichotomous outcome and associated level of significance. Hence, a positive coefficient of the parameter means that the likelihood of the particular adaptation measure increases due to the explanatory factor X_k, and a negative coefficient means that the likelihood of the particular adaptation measure decreases due to the explanatory factor X_k.

The endogenous variable is a twofold option, so the farmers have two options to decide: 1 means if the respondent adapted a particular adaptation strategy in response to climate change and 0 means if the respondent had not adapted. Consider a case where response Y_{ij} is binary, assuming only two values coded as one and zero for convenience.

$$Y_{ij} = \begin{cases} 1 = \textit{if the farmer i adapted Jth adaptation stratgy} \\ 0 = \textit{if the farmer i had not adapted Jth adaptation stratgy} \end{cases}$$

Why binary logit model?

It was frequently observed that farmers adopt more than one adaptation strategies simultaneously, so a multinomial logit model application becomes irrelevant in contrary to many studies, where farmers were controlled to one adaptation strategy out of a provided set of different adaptation methods (Deressa et al. 2009; Hassan and Nhemachena 2008; Hisali et al. 2011; Belay et al. 2017). While binary regression provides the facility to understand factors influencing the decision of each adaptation strategy individually and independently.

One way to study adaptation decisions was to cartel alike methods into a particular category (Bryan et al. 2013), but this assemblage into self-defined groups may lead to misapprehension. Moreover, a set of predictors influencing the famers' decision was also anticipated to be diverse for different adaptations. Hence, a binary logit model appears as the most relevant technique for the study of farmers' adaptation decisions.

The binary logit model provides the facility to overcome many restrictive assumptions of linear regression by design; i.e., linearity, normality, and equal variances are not assumed, nor it is assumed that the error term variance is normally distributed.

Marginal effects

It was necessary to discuss the magnitude of the effect, but coefficients did not provide any information about the magnitude of the effect; hence, there was a need to quantify the impact. For this purpose, marginal effects were estimated for each effect separately. The marginal effects measure the expected change in probability of a particular choice with a unit change in an explanatory variable (Long 1997; Greene 2000). Marginal effect explains the effect of a unit change in explanatory variable on the probability of a dichotomous outcome.

$$Y_{ij} = Pr\ (Yij = 1).\left(1 - Pr\left(Y_{ij} = 1\right)\right)\ \beta_k \qquad (2)$$

Results and discussion

Perceived adaptation choices and adaptations undertaken

Growers' responses or adaptation practices to perceived changes in local climate were explored. Their responses were captured at two stages; firstly, perceived changes in local farming under changing climate were enquired, while secondly, they were enquired about the adaptations undertaken. It is undoubted that farmers behave differently in different regions due to different socio-economic factors and environmental conditions. In the case of present study, although adaptation strategies were the same, the impacts were different in different regions.

Figure 2 highlighted both perceived adaptations and adaptations undertaken. Most of the farmers' perceived changes in local farming, but a very few of them adapted to perceived changes in farming due to several constraints, although farmers perceived changes in cropping pattern (77%), cropping activities (94%), input applications (89%), soil conservation (92%), water conservation (90%), and diversification of income. Only about 29% farmers adapted in cropping pattern, while about 52%, 50%, 42%, 44%, and 30% of farmers adapted in cropping activities, input applications, soil conservation, water conservation, and diversification of income respectively. The findings in Fig. 2 highlighted the differentials in perceived adaptation choices and adaptations undertaken. The differentials in perceived and adapted strategies are the outcome of some constraints or problems the farmers had to face. The need of a comprehensive adaptation strategy can only be achieved by identifying the constraints in adaptation process.

Constraints in adapting to climate change

Farmers who perceived adaptations in farming but could not adapt highlight some constraints that are described in Table 1. Results indicated the lack of knowledge about appropriate adaptations, lack of irrigation resources, and lack of information about climate change as the major constraints in study area. This shows that the farmers' biggest obstacles were information and knowledge based that can be solved by enhancing institutional support and capacity and improved extension services.

Results of binary logit models and marginal effects

The impact of various factors that influence farmers' decision while undertaking various adaptation measures under climate change has been quantified in this section. For this purpose, binary logit models were applied to different adaptation measures. The coefficients of exogenous variables in logistic regression only explain the direction; therefore, marginal effects for all adaptation measures were also estimated to have a closer look at how unit change in explanatory variables affected the

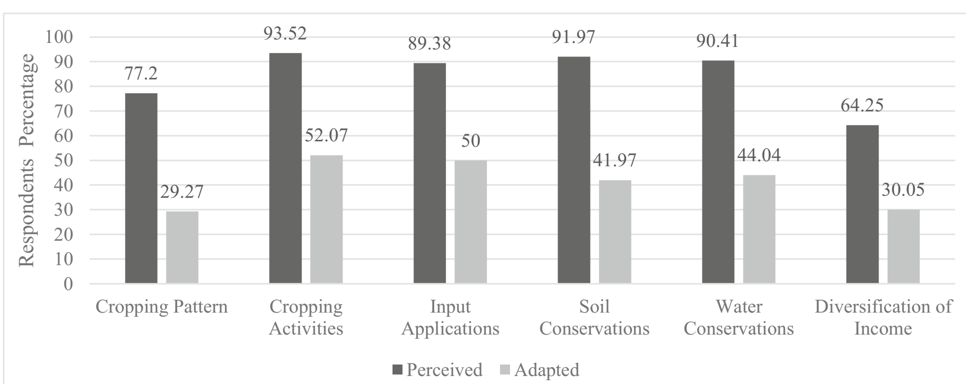

Fig. 2 Perceived adaptation choices and adaptations undertaken

Table 1 Constraints in adapting to climate change

Constraints		Degree of constraint			
		High	Medium	Low	No
Lack of knowledge about appropriate adaptations	Frequency	127	111	93	55
	Percentage	32.90	28.76	24.09	14.25
Lack of irrigation resources	Frequency	131	99	86	70
	Percentage	33.94	25.65	22.28	18.13
Lack of climate information	Frequency	123	84	107	72
	Percentage	31.87	21.76	27.72	18.65
Lack of market access	Frequency	57	80	111	138
	Percentage	14.77	20.73	28.76	35.75
Insecure property rights	Frequency	41	70	68	207
	Percentage	10.62	18.13	17.62	53.63

adaptation decisions. Akaike information criteria (AIC), Schwarz criteria (SC), and log likelihood are the usual criteria used in assessing model fitness, so all of the three were used, and the model fit summary is given the Appendix Table 4. The results of all binary logit models are presented in Table 2, while the results of marginal effects are presented in Table 3.

Age is always considered a sign of maturity and experience; hence, it is a vital element in the process of decision-making. Although Maddison (2007), Hassan and Nhemachena (2008), and Deressa et al. (2009) concluded that age had a positive link to adaptations, the coefficients of age were found mixed but negative with most of adaptation measures in study area, indicating that younger growers were more adaptive to CC than the older ones. The results of this study are supported by the findings of Muzamhindo et al. (2015) and Bryan et al. (2009). From Table 2, it is evident that age was significantly and negatively affecting the decision for planting different varieties and changing the irrigation applications, while it was positively and significantly affecting the decision of early sowing, private business, migration to urban area, mulching, and water efficient methods. Findings about marginal effects in Table 3 highlighted that a 1-year increase in age would decrease the probability of planting different varieties (− 0.48%), irrigations (− 0.95%) and water efficient methods (− 1.2%), private business (− 0.84%), and migration to urban area (− 0.33%), whereas a 1-year increase in age would increase the probability of adapting sowing time (1.14%) and mulching (0.86%).

It is argued that education is a prominent aspect in shaping understandings and consequently the decisions (Dolisca et al. 2006; Anley et al. 2007). It is also assumed that education leads to adaptation in agriculture (Maddison 2007) because it helps in accessing the advanced information on new and improved varieties and technologies that ultimately enhance the benefits of farmers through increased productivity. Like Abid et al. (2015), and Deressa et al. (2009), this study concluded that the coefficient of education was positively connected with most of the adaptations that confirm the pre-mentioned assumption that educated growers are more probable to adapt. Findings of marginal effects indicated that a 1-year increase in education would increase the likelihood of planting different crops (1.20%), sowing time (1.1%), mulching (1.26%), crops to livestock (1.59%), and farming to non-farming (1.37%).

Landholding represented the total amount of land cultivated by the respondents. It is considered a proxy for respondent's wealth indicating that growers with larger size of farm are expected to adapt more (Gebrehiwot and Van-der-Veen 2013; Amsalu and De-Graaff 2007). A positive coefficient of landholding represents a positive relation between landholding and probability of adaptation (Abid et al. 2015). Findings of this research exposed a positive and significant impact of landholding on likelihood of planting different crops, sowing time, irrigations, and water efficient methods and shifting from crops to livestock, while on other hand, it had negative coefficients for private business and migration to urban area. Results of marginal effects highlighted that a 1-acre increase in landholding would increase the probability of planting different crops (1.69%), sowing time (2.45%), irrigations (1.5%), water efficient methods (1.6%), and crops to livestock (2.31%), while on other hand, an increase in landholding probability of adaptation was found to decrease for private business (− 1.4%) and migration to urban area (− 0.7%).

The years of farming experience have a positive relation with most of adaptations in agriculture (Abid et al. 2015). Further, farming experience improves the perceptions about potential benefits and hence adaptation decisions (Hassan and Nhemachena 2008). It is clear from outcomes that likelihood of adapting to CC positively and significantly influenced the decisions of adapting water efficient methods, planting different varieties, and migration. Marginal effects also indicated that a 1-year increase in farming experience enhances the probability of planting different varieties (1.63%), migration (0.61%), and water efficient methods (0.71%).

Table 2 Results of binary logit models for adaptations to climate change

Parameter	Planting different crops	Planting different varieties	Sowing time	Irrigations	Mulching	Water efficient methods	Crops to livestock	Farming to non-farming	Private business	Migration to urban area
Intercept	− 1.068 (0.076)*	− 1.0218 (0.109)*	− 3.2866 (0.000)***	− 0.3545 (0.598)	− 1.9150 (0.001)***	−3.0626 (0.000)***	− 1.9503 (0.002)***	− 2.0109 (0.010)***	− 1.9512 (0.013)***	− 2.7437 (0.003)***
Age	0.0049 (0.643)	− 0.0210 (0.083)*	0.0470 (0.000)***	− 0.0382 (0.002)***	0.0239 (0.017)***	− 0.0461 (0.0001)***	0.0153 (0.161)	− 0.0039 (0.772)	− 0.1036 (0.0001)***	− 0.0358 (0.039)**
Education	0.0369 (0.089)*	0.0059 (0.795)	0.0581 (0.020)**	0.0039 (0.874)	0.0345 (0.097)*	0.0265 (0.275)	0.0599 (0.013)***	0.0858 (0.006)***	0.0568 (0.179)	0.0171 (0.581)
Landholding	0.0689 (0.003)***	0.0268 (0.187)	0.1065 (0.000)***	0.0460 (0.009)***	0.0026 (0.867)	0.0520 (0.006)***	0.0969 (0.000)***	− 0.0168 (0.418)	− 0.1240 (0.008)***	− 0.0494 (0.074)*
Farming experience	0.0010 (0.920)	0.0558 (0.000)***	0.0167 (0.129)	0.0179 (0.137)	0.0141 (0.152)	0.0259 (0.022)**	− 0.0072 (0.505)	− 0.0020 (0.879)	− 0.0086 (0.703)	0.0541 (0.002)***
Access to climate information	0.0953 (0.654)	0.0832 (0.702)	− 0.1208 (0.617)	− 0.0289 (0.902)	− 0.0953 (0.636)	− 0.2399 (0.286)	− 0.3755 (0.104)*	− 0.0341 (0.892)	0.3728 (0.295)	0.1411 (0.642)
Access to credit	0.0998 (0.660)	0.6411 (0.005)***	0.5544 (0.026)**	0.5957 (0.017)***	0.4201 (0.057)**	1.0513 (0.000)***	0.2260 (0.343)	0.8519 (0.001)***	1.0289 (0.001)***	0.7635 (0.005)***
Access to extension services	0.5476 (0.009)***	0.1353 (0.518)	1.0428 (0.000)***	0.6404 (0.002)***	0.4392 (0.018)***	0.3575 (0.104)*	− 0.6861 (0.005)***	− 0.3294 (0.217)	0.6625 (0.076)*	0.2811 (0.309)
Soil quality	0.0359 (0.796)	0.0185 (0.898)	0.2702 (0.080)*	0.2556 (0.087)*	0.1514 (0.259)	0.3041 (0.047)**	0.1284 (0.379)	0.0520 (0.774)	0.3599 (0.134)	0.2645 (0.214)
Rajan Pur	− 0.0594 (0.776)	− 0.0864 (0.687)	1.0735 (0.000)***	0.7758 (0.003)***	0.0160 (0.934)	− 2.1081 (0.000)***	0.4081 (0.080)*	0.5157 (0.055)**	6.2093 (0.000)***	1.3765 (0.002)***
Jhang	0.0979 (0.615)	0.1219 (0.545)	0.7998 (0.002)***	1.9627 (0.0001)***	0.3786 (0.038)**	− 1.0173 (0.000)***	0.6263 (0.003)***	0.4302 (0.088)*	6.5404 (0.000)***	0.9961 (0.022)**

Values in parenthesis are *p* values. *, **, and *** represent 10%, 5%, and 1% levels of significance respectively

Table 3 Results of marginal effects for adaptations to climate change

Parameter	Planting different crops	Planting different varieties	Sowing time	Irrigations	Mulching	Water efficient methods	Crops to livestock	Farming to non-farming	Private business	Migration to urban area
Intercept	0.1267	0.1319	− 0.3456	− 0.5888	− 0.2048	− 1.3983	− 0.1141	0.0003	0.5014	− 0.0403
Age	0.0021	− 0.0048	0.0114	− 0.0095	0.0086	− 0.0129	0.0044	− 0.0009	− 0.0084	− 0.0033
Education	0.0120	0.0013	0.0137	0.0032	0.0126	0.0085	0.0159	0.0137	0.0004	0.0013
Landholding	0.0169	0.0077	0.0245	0.0153	0.0010	0.0158	0.0231	− 0.0035	− 0.0143	− 0.0072
Farming experience	0.0007	0.0163	0.0042	0.0045	0.0052	0.0071	− 0.0021	− 0.0009	− 0.0006	0.0061
Access to climate information	0.0317	0.0194	− 0.0269	− 0.0145	− 0.0358	− 0.0927	− 0.0881	0.0028	0.0221	0.0080
Access to credit	0.0483	0.2371	0.1613	0.1820	0.1573	0.3011	0.0871	0.1946	0.2303	0.1495
Access to extension services	0.2435	0.0426	0.2267	0.1850	0.1626	0.0927	− 0.1585	− 0.0539	0.0768	0.0298
Soil quality	0.0110	− 0.0133	− 0.0568	− 0.0759	0.0566	− 0.0813	0.0253	0.0122	0.0357	0.0299
Rajan Pur	− 0.0030	− 0.0269	0.2315	0.1561	0.0082	− 0.6378	0.1142	0.1016	0.0986	0.1394
Jhang	0.0322	0.0335	0.1392	0.5565	0.1420	− 0.3373	0.1737	0.0846	0.1526	0.0676

It is expected that farmers who are more aware about changes in climate would adapt more (Hassan and Nhemachena 2008). Therefore, access to information on climatic indicators is considered a key determinant in shaping farmers decisions (Maddison 2007). Access to climatic information was observed insignificant for most of the adaptation methods proving the farmers' poor access. Access to climatic information had a negative coefficient for shifting from crops to livestock, while their marginal effects reduced the probability of adaptations (− 8.8%).

Easy access to the credit facilities is always a vital factor that increases espousal of new skills and technologies (Hassan and Nhemachena 2008; Tizale 2007; Kandlikar and Risbey 2000). It is also important while studying farmers' adaptation especially in developing world where higher poverty is a major reason behind lower adaptation capacity. To date, many studies concluded a positive relation between credit facilities and adaptation to CC (Abid et al. 2015; Deressa et al. 2009; Tizale 2007; Pattanayak et al. 2003). This study also confirmed a positive sign for a number of adaptations in study area for access to credit facilities. Findings of marginal effects highlighted a positive relation between access to credit services and planting different varieties (23.7%), sowing time (16.1%), irrigations (18.2%), mulching (15.73%), water efficient methods (30.1%), farming to non-farming (19.5%), private business (23.0%), and migration to urban area (14.9%).

The extension service is a good source of agricultural education and information about climate as well that ultimately influences the adaptation decisions. It is assumed that growers having extension facilities are more likely to adapt. Findings of many studies had concluded a positive relation between adaptations in agriculture and access to extension services (Tizale 2007; Bekele and Drake 2003). Access to extension services was observed to significantly and positively shaping farmers' decisions about planting different crops, sowing time, irrigations, mulching, water efficient methods, crops to livestock, and private business.

Marginal effects also showed that access to extension services would rise the adaptation probability for planting different crops (24.4%), sowing time (22.7%), irrigations (18.5%), mulching (16.3%), water efficient methods (9.3%), and private business (7.7%), while on other hand, access to extension services would reduce the probability of adapting shifting from crops to livestock (− 15.9%).

Soil quality had a positive coefficient for irrigations and water efficient methods, while findings of marginal effects confirmed that better quality of soil would increase the likelihood of adapting to irrigations (7.6%) and water efficient methods (8.1%).

Growers from different agro-ecological zones have unalike adaptations to CC because of different environmental and socio-economic settings, so farmers living in district Rajan Pur had positive and significant coefficients for a number of adaptation approaches to climate change. It had a negative coefficient only for water efficient methods. Findings about marginal effects highlighted that if a respondent belong to district Rajan Pur, the likelihood of adapting to climate change would increase for sowing time (23.2%), irrigations (15.6%), water efficient methods (− 63.7%), shifting from crops to livestock (11.4%), farming to non-farming (10.1%), private business (9.8%), and migration to urban area (13.9%)

Almost similar findings have been observed for the farmers from district Jhang (the irrigated mixed crop zone), with positive and significant coefficients for most of the adaptations. If the respondent belongs to the irrigated mixed zone, then the likelihood of adaptation would increase for sowing time (13.9%), irrigations (55.6%), mulching (14.2%), flood defense infrastructure (8.9%), water efficient methods(− 33.7%), shifting from crops to livestock (17.4%), farming to non-farming (8.4%), private business (15.2%), and migration to urban area (6.8%).

Conclusions

This study assessed the perception-based responses to climate change, adaptation strategies, determinants of adaptation behavior, and constraints in adaptation process. Perception leads adaptation to CC; therefore, it is recommended to integrate indigenous knowledge with scientific research while articulating climate change policy. Farmers perceive climate change and hence categorize different adaptation strategies accordingly. Age, education, farming experience, landholding, access to climate information, access to credit facilities, and access to extension services influence the adaptation behavior significantly. Enhanced institutional support and capacity and by strengthening the outreach of extension department can play an important role in enhancing the adaptation capacity of the farmers. Lack of money, lack of climate information, and lack of knowledge about appropriate adaptations are key constraints in the adaptation process that can be tackled through a better climate change policy based on local perceptions and knowledge with explicit emphasis on climate information dissemination and better credit facilities because both are closely linked to farmers' welfare. It is therefore suggested that higher investment in farmers' education with an improved institutional set-up will support the adaptations to changing the climate and ultimately enhance the farmers' well-being that is further linked to the economic development in the country.

Areas for future research

While studying the impact of factors influencing climate change, this study does not consider intra-regional variations that typically occur, but it provides details on inter-regional variations. Therefore, this approach offers the possibility to improve modeling in the future. Spatial econometric model or spatial autoregressive models (recently many advances have been made in these models) can be used as a way to put forward in understanding how the impacts of factors influencing CC can vary over space.

The logit model was used to identify factors influencing adaptations to CC. As farmers frequently adopt more than one adaptation strategies simultaneously in the study area, so count data model is an alternative approach for this kind of situation that can be employed in the future in order to get new insights about the factors influencing adaptation to CC.

This research is done in three different agro-ecological zones in Punjab, Pakistan; in the future, this research can be extended to other agro-ecological zones in Pakistan that will help in the formulation of more consistent policies in the light of indigenous knowledge and perceptions.

Authors' contributions MFA collected, analyzed, and interpreted the data, whereas SR assisted in literature review and write up.

Data availability The datasets generated and/or analyzed during the current study are not publicly available because primary data was collected for this study by interviewing farmers.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Appendix 1

Table 4 Model fit summary for binary logit models

Adaptation strategies	Log likelihood	AIC	SC
Planting different crops	− 221.89	446.55	490.06
Planting different varieties	− 203.84	429.69	473.20
Sowing time	− 163.80	349.59	393.11
Irrigations	− 175.50	372.99	416.50
Mulching	− 246.09	514.18	557.69
Water efficient methods	− 183.33	388.66	432.18
Crops to livestock	− 187.58	397.17	440.68
Farming to non-farming	− 127.73	277.46	320.97
Private business	− 68.15	158.30	201.81
Migration to urban area	− 103.98	229.95	273.47

Table 5 Summary of variables

Factors	Unit	Mean	Standard deviation
Age	Years	44.05	10.92
Education	Years	5.70	4.39
Farming experience	Years	22.01	10.83
Family size	Nos.	6.01	1.88
Total cultivated area	Acre	7.28	8.36

1 hectare = 2.47 acres (source: author's estimations)

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