Climate Risk Management 32 (2021) 100288

Contents lists available at ScienceDirect

Climate Risk Management

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

# Farmers' perceptions and role of institutional arrangements in climate change adaptation: Insights from rainfed Pakistan

Nasir Mahmood [a,b,c,*], Muhammad Arshad [d,a], Yasir Mehmood [e], Muhammad Faisal Shahzad [f], Harald Kächele [a,g]

[a] Research Area 2 "Land Use and Governance", Working Group: Sustainable Land Use in Developing Countries, Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Street 84, 15374 Müncheberg, Germany
[b] Department of Economics & Agricultural Economics, PMAS-Arid Agriculture University, Rawalpindi, Pakistan
[c] Department of Agricultural Economics, Humboldt University of Berlin, Unter den Linden 6, 10099 Berlin, Germany
[d] National University of Sciences & Technology (NUST), School of Social Sciences and Humanities (S3H), House No. 448, Street 11, Sector F-10/2, Islamabad 44000, Pakistan
[e] Department of Social & Behavioral Sciences, National University of Medical Sciences, Rawalpindi, Pakistan
[f] Pakhtunkhwa Economic Policy Research Institute (PEPRI), Abdul Wali Khan University, Mardan (AWKUM), Pakistan
[g] Eberswalde University for Sustainable Development, Schickler Str.5, 16225 Eberswalde, Germany

ARTICLE INFO

*Keywords:*
Risk perceptions
Adaptation planning
Climate risk management trainings
Digital advisory services
Rainfed
Pakistan

ABSTRACT

Rainfed farmers are among the most vulnerable farming communities to climate change in Pakistan because of the heavy reliance of crop farming on rain and of farmers' livelihoods on crop farming. The best and most timely responses against climate change are suitable adaptation measures. Accurately perceiving the risks associated with climate change is an essential factor for planning and then implementing adaptations. Using farm household-level data of 400 rainfed farmers collected through a well-designed and field-tested questionnaire, this study examines the association between various adaptation stages (climate risk perceptions, adaptation planning, and implementation of adaptation) and their determinants using a multivariate probit (MVP) model. The findings indicate that farmers' perceptions of climatic changes are in line with historical climatic data. Climate risk management (CRM) trainings and digital agriculture extension and communication (DAEC) services (indicators of formal institutional arrangements) show a highly significant impact on all adaptation stages. Input market distance, farmer cooperative meetings (an indicator of informal institutional arrangement), off-farm income, education, and number of male family members are among the other key determinants. A highly significant association between various adaptation stages indicates that accurate climate risk perceptions lead to planning and implementation of adaptations. When risk perceptions are underestimated or lacking, then adaptations do not occur. The results further indicate that the timely availability of reliable information on advanced agricultural inputs, weather parameters, crop farming advisory services, and market information could help rainfed farmers devise sound adaptations to minimize risks associated with climate change. The study recommends the provision of CRM trainings and DAEC services to provide a better understanding and promote sound adaptation planning through the adaptive capacity enhancement of rainfed farming communities for sustainable production and livelihood security.

* Corresponding author at: Research Area 2 "Land Use and Governance", Working Group: Sustainable Land Use in Developing Countries, Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Street 84, 15374 Müncheberg, Germany.
*E-mail address:* nasir.mahmood@zalf.de (N. Mahmood).

https://doi.org/10.1016/j.crm.2021.100288
Received 26 October 2020; Received in revised form 2 February 2021; Accepted 15 February 2021
Available online 20 February 2021

## 1. Introduction

Climate change is affecting the globe in various ways, including rising temperatures, droughts, heatwaves, melting snow, rising sea levels, and flooding. The impacts are more severe in developing regions of the world, including Asian and African countries. However, certain developed regions might benefit from the rise in temperatures, including Russia, Canada, and Scandinavia. The situation could be reversed if the temperature continues to rise in these regions, which would lead to other climatic extremes, including floods and droughts. (Wade and Jennings, 2015). The negative impacts of climatic changes are more observable in natural and human systems (IPCC, 2014), which means that the climate change phenomenon is truly global in nature and requires strong attention from scientists and policymakers to address this problem through a proactive policy agenda.

Agriculture in general and crop farming in particular are among the leading business sectors that are directly influenced by natural phenomena; thus, these sectors are prone to risk (Mahmood et al., 2020a). Despite significant technological advancements, suitable weather conditions are still essential for improving agricultural production (Jha, 2015). Among climatic factors, temperature and rainfall act as key factors for determining crop yields (Akhtar et al., 2019). Crop farming is under heavy threat due to the changing climatic conditions with varying intensities worldwide. However, in developing and low-income agrarian economies, changing climatic conditions strongly impact crop farming, thus causing a reduction in crop yields. Climate change is also impacting rural livelihoods in the developing world and further increasing the vulnerability of farming communities (Abid et al., 2019). Although farmers have been using recommended input levels and crop management strategies under changing climates, seasonal temperatures and heat stress adversely impact crop yields, especially wheat yield, which is more sensitive to heat (Arshad et al., 2017a).

South Asian countries are among the most vulnerable to climate change due to their heavy dependency on the agricultural sector and meagre adaptive capacity. The agriculture sector alone offers livelihood opportunities to 70% of the total population, employs 60% of the workers, and contributes 22% to the gross domestic product (GDP) of the South Asian region (Wang et al., 2018). The region is frequently experiencing floods, droughts, heatwaves, and fluctuating precipitation patterns, especially in recent decades, and these changes have impacted the food and livelihood securities of regional people (Lobell et al., 2012). By the end of the 21st century, a temperature increase of 3.4 °C was projected in the Indus Delta, which mainly covers Pakistan and a few Indian territories (Rasul et al., 2012). Moreover, the GDP of South Asian economies is predicted to decrease 1.8% by 2050 and 8.8% by 2100 if sound adaptation strategies are not implemented (Ahmed and Suphachalasai, 2014). Adaptation practices in agriculture include specific activities that are purely designed to decrease vulnerability and increase the resilience of agricultural systems (Vogel and Meyer, 2018). Moreover, the impact of climate change varies according to the adaptive capability of a system (Vermeulen et al., 2013). An accurate understanding of climate change challenge and feasible adaptive measures are needed to maintain sustainability in agriculture through efficient policy design.

Pakistan is one of the top ten most vulnerable countries and has already been adversely affected by climate change (Kreft et al., 2017). The country has an agro-based economy, with the agriculture sector accounting for 19.3% of its GDP (GOP, 2019) and the majority of the rural population depending on the success of the agriculture sector for their livelihoods. Pakistan has been facing the severe impacts of climate change in the form of floods, droughts, heatwaves, and erratic rainfalls. A handful of studies have investigated the possible impacts of climate change on various crops in different agroecological territories of Pakistan (Arshad et al., 2017a, 2018; Ahmad and Afzal, 2020). Although previous studies have identified several adaptation strategies in response to climate change to minimize the harmful impacts on agriculture (Arshad et al., 2017b; Fahad and Wang, 2018; Khan et al., 2020; Shahzad and Abdulai, 2020a), most of these studies have been conducted either in mixed agroecological zones across the country or within at provincial-level agroecological zones. In addition, all previous studies have reported the need for more research on the identification of area-specific adaptation strategies. However, few impact assessment studies have solely focused on the most important region of the country, the rainfed zone (Mahmood et al., 2019, 2020b). Hence, the present study focuses on rainfed agriculture, which is substantially influenced by climate-related risks.

The success of crop farming in rainfed areas relies on ideal temperature levels and sufficient rain due to the lack of proper irrigation facilities, which means that quick and promising actions from rainfed farmers are needed to fight against climate change. Moreover, farmers' perceptions regarding the risks associated with climate change could help them implement appropriate actions in the form of adaptations (Jin et al., 2015; Niles and Mueller, 2016). Accurate perceptions about climate-related risks have a very strong and positive impact on the planning and final implementation of an adaptation strategy (Abid et al., 2019). Therefore, before devising adaptation strategies, an important prerequisite is the identification of factors that can possibly affect the adaptation process, starting from the accurate perceptions of farmers to the actual implementation of an adaptation. This is the first study to investigate the factors that can possibly affect the adaptation process in rainfed areas of Pakistan. The reason for the sole emphasis on rainfed areas is that the crop yield in a specific agroecological region is primarily influenced by local climatic conditions rather than global change (Jha, 2015). Furthermore, studies with a sole emphasis on rainfed areas of Pakistan are urgently needed for the following reasons: (1) rainfed farming communities mainly rely on crop farming for sustenance, (2) rainfed conditions make crop farming even more vulnerable to climatic extremes, (3) small size land holdings to fulfil their food requirements, (4) multiple cropping has a very limited scope due to the lack of supplemental irrigation, and (5) frequent drought spells occur due to insufficient and erratic rains. This study includes two novel policy variables: "Climate Risk Management (CRM) trainings and "Digital Agriculture Extension and Communication (DAEC) services". CRM trainings and DAEC services are indicators of institutional arrangements devised by state departments to enhance the adaptive capacity of rainfed farmers. We evaluated the influence of these variables on the adaptation process. The focus on the rainfed areas of Pakistan and investigation into the role of 'CRM trainings' and 'DAEC services' in the adaptation process make this study unique. The following research objectives are achieved: (1) farmers' perceptions about climatic changes are compared with historical metrological trends of temperature and precipitation, (2) the association between various stages of adaptation (i.e., climate risk perceptions, adaptation planning, and implementation of adaptation) are determined and (3) the impact of 'CRM trainings', 'DEAC services' and other explanatory variables on different stages of adaptation are investigated.

## 2. Conceptual framework

Rainfed cropping is threatened by climate change due to its heavy reliance on sufficient rainfall and ideal temperatures, which in turn means that food and livelihood security of farm households is directly dependent on climatic factors. Promising solutions to minimizing the risks associated with climate change include suitable adaptation strategies. The adaptation process can be defined as a linear process that consists of three stages, where one stage leads to another. The first stage is "accurate climate risk perceptions", the second stage represents "adaptation planning", and the last stage involves the final "implementation of an adaptation". Poor perceptions of climate risks by farmers may lead to maladaptation and can negatively impact food and livelihood security (Abid et al., 2019). Therefore, the first stage is further classified into "accurate climate risk perceptions" and "underestimated climate risk perceptions", with the base category of "no climate risk perceptions". Accurate climate risk perceptions indicate coherence between farmers' risk perceptions and historical climatic trends (i.e., temperature and rainfall), and underestimated climate risk perceptions indicate inconsistency between these two. Farmers whose perception of temperature fluctuations is consistent with historical climatic trends but not consistent with rainfall changes and farmers whose perception of rainfall changes is consistent with historical climatic trends but not consistent with temperature fluctuations both have "underestimated climate risk perceptions". The risks associated with climate change are mainly the risks induced by increasing temperatures (e.g., heat stress, drought conditions, and heat waves) and fluctuating rains (e.g., excessive rains, insufficient or absence of rains and flash floods caused by heavy rains). The prerequisite for planning and then implementing sound adaptations is the accurate perception of the climate risks by farmers (Mahmood et al., 2020a). As shown in Fig. 1, accurate climate risk perceptions may lead farmers to plan and implement adaptation, while underestimated climate risk perceptions may lead to no adaptation at all. Similarly, farmers who plan to adapt are more likely to implement adaptation to minimize the risks associated with climate change, whereas farmers with no planning are unlikely to implement any adaptation.

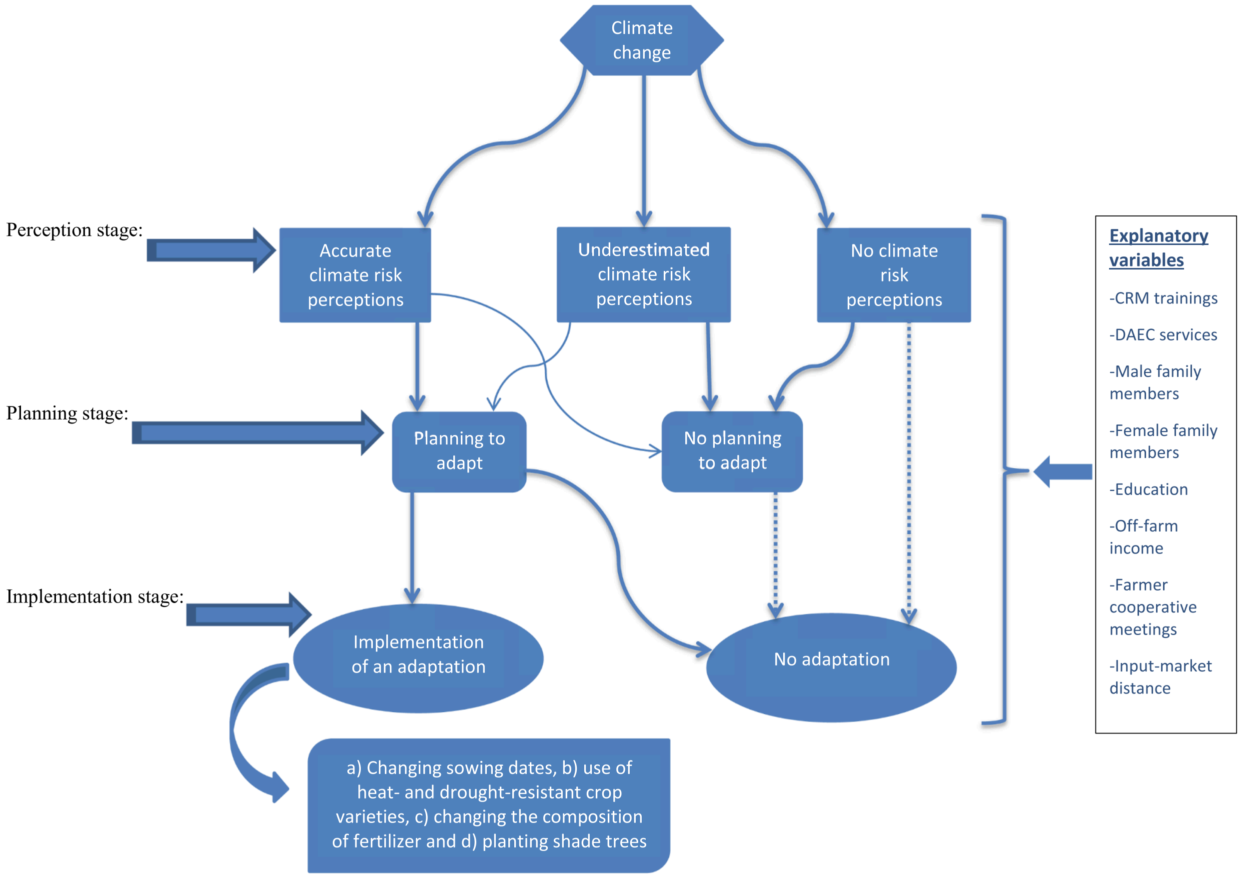



**Fig. 1.** Conceptual framework showing the various adaptation stages with the strength of association between these stages. The diagram shows a unidirectional causal relationship between adaptation stages in which one stage leads to another. The bold arrows show a stronger association between respective adaptation stages, while thin arrows show weaker connectivity. The dotted arrows show a pathway towards no adaptation against risks induced by climate change. The potential factors that can influence the adaptation process are on the right side of the diagram.

For the adaptation process, accurate climate risk perceptions are considered to lead to adaptation planning while underestimated and no climate risk perceptions are considered to lead to poor adaptation planning. Furthermore, sound adaptation planning leads to the actual implementation of adaptation and no adaptation planning leads to no adaptation for minimizing the risks associated with climate change, which means that we have four binary variables out of the three stages of the adaptation process, i.e., accurate climate risk perceptions, underestimated climate risk perceptions, adaptation planning, and adaptation implementation. To inspect the factors that may affect the adaptation stages, a multivariate probit (MVP) model was used in this study. The factors are shown on the right side of Fig. 1 under “explanatory variables”. A detailed description of the dependent and independent variables is presented in Table 1.

The explanatory variables in this study are CRM trainings, DAEC services, male and female family members, education, off-farm income, farmer cooperative meetings, and input-market distance. As rainfed farming relies on sufficient rains and good soil moisture conditions, CRM trainings are usually designed in view of the specific crop farm requirements in rainfed areas. The CRM trainings cover the following aspects: (1) special trainings with emphasis on using heat-tolerant and drought-resistant crop varieties for enhancing yield (in a situation of low rainfall and less soil moisture) instead of using traditional varieties and (2) trainings through practical demonstration of various tillage and field management practices to reduce the risks induced by climate change. Tillage practices include (i) zero-tillage to cultivate a particular crop, which is performed for optimal use of soil moisture; (ii) deep tillage in the absence of a crop in the field, which is performed so that soil absorbs as much rain water as possible for subsequent availability for crop, (iii) ploughing the fields in the absence of crop in the opposite direction of rainwater flow, which is performed to retain the water for a maximum time in small ridges to ensure maximum absorption by the soil, and (iv) frequent use of organic manure and mulching, which is performed to improve the retention of soil moisture and, (3) trainings to enable the farmers to consider the possibility of constructing field pounds to harvest rainwater and use it later for irrigation purposes. Two local research institutes named Barani (i.e., rainfed) Agriculture Research Institute, Chakwal, Pakistan, and Agency for Barani Area Development (ABAD), Rawalpindi, Pakistan, have been rigorously working in very close connection with local farmers in addition to local agriculture extension department. CRM trainings are usually offered in various rainfed territories during the time of harvesting one crop and before the cultivation of the second crop to ensure maximum participation of local farmers.

Another important variable modelled in this study is ‘Digital Agriculture Extension and Communication (DAEC) services’. Through a special mobile application designed with the help of a telecommunication company and local agriculture department, rainfed farmers receive notifications and news alerts regarding information on crop farming and weather in the national language. Farmers can also call an agricultural helpline during official hours to obtain assistance related to crop farming. The DAEC services mainly cover (1) meteorological information on temperature, rainfall and daily readings of storms and their forecast values for 7 to 15 days, (2) news alerts for farmers regarding how they can best utilize weather-related information to protect crops against climate risks, e.g., changing the application time of various agricultural inputs, including shifting the date of sowing or harvesting if there is a forecast of rain or wind storms, (3) a two-way communication service via phone calls between farmers and agricultural experts to obtain information regarding the use of particular inputs (such as pesticide and fertilizer) and updates on new production technology of a particular crop, and (4) various pamphlets provided via mobile phones that contain information on recommended seed varieties of different crops being cultivated in rainfed regions, time of sowing, available subsidies for various inputs, and market prices of various commodities, including grain crops, vegetables, and fruits.

We modelled the male and female family members to separately assess their impact on the adaptation process. The farmers’ education level indicates their ability to read and write in the national language. The variable of off-farm income illustrates whether a farmer has a source of income other than farming. Farmer cooperative meetings refer to farmers’ participation in local cooperative gatherings at a common place to discuss farming issues, exchange information about field management practices, and present market-related information. Last, input-market distance means the distance (in kilometres) between the farm and the local input market, which also indicates farmers’ access to the input market.

**Table 1**
Description of the variables used in the multivariate probit (MVP) model.

| Variable name | Variable description |
|---|---|
| ***Dependent variables*** (*binary;$AS_{ij}$*) | |
| Accurate climate risk perceptions ($AS_{i1}$) | Takes a value of 1 if the farmer accurately perceives climate risks and 0 otherwise |
| Underestimated climate risk perceptions ($AS_{i2}$) | Takes a value of 1 if the farmer underestimates the risks induced by climate change and 0 otherwise |
| Adaptation planning ($AS_{i3}$) | Takes a value of 1 if the farmer plans to adapt and 0 otherwise |
| Implementation of an adaptation ($AS_{i4}$) | Takes a value of 1 if the farmer implements an adaptation and 0 otherwise |
| ***Independent variables*** | |
| Climate Risk Management (CRM) training | Takes a value of 1 if the farmer participated in CRM training and 0 otherwise |
| Digital Agriculture Extension and Communication (DAEC) services | Takes a value of 1 if the farmer has access to DAECS and 0 otherwise |
| Male family members | Number of male members in farmer’s family |
| Female family members | Number of female members in farmer’s family |
| Education | Takes a value of 1 if the farmer can read and write in national language and 0 otherwise |
| Off-farm income | Takes a value of 1 if the farmer has off-farm income and 0 otherwise |
| Farmer cooperative meetings | Takes a value of 1 if the farmer does cooperative meetings with other farmers and 0 otherwise |
| Input-market distance | Distance of the farm from input market in kilometres |

## 3. Materials and methods

### 3.1. Study area

Pakistan has diverse agro-climatic conditions, soil features, geographical location, socioeconomic characteristics of the farm households, and cropping systems. Based on these features, the country has been categorized into 12 different agroecological zones by the Pakistan Agricultural Research Council (Mahmood et al., 2019). The rainfed agroecological zone is one of them and is mainly distributed in two provinces: Punjab and Khyber Pakhtunkhwa (KPK). Fig. 2 shows the map of the study area (highlighted in green and blue colour) and surveyed districts (highlighted in green colour), which are Attock, Bannu, Chakwal and Gujrat.

The primary reason for selecting the rainfed agroecological zone is the region's extreme vulnerability to climate risks. The rainfed zone of Pakistan is characterized by hot summers and cold winters, and it has an average annual temperature of 23 °C (Baig et al., 2013); moreover, 60–70% of the rainfall occurs from June to August each year with monsoon rains. Approximately one-third of rainfed farmers cultivate only wheat crop due to low moisture conditions. Other crops cultivated in the rainfed zone include chickpea, groundnut, millet, mung bean, and mustard (Mahmood et al., 2019).

### 3.2. Primary data collection and sampling procedure

This study uses cross-sectional farm-level data collected in 2017 through a field survey using a well-structured questionnaire. The questionnaire was designed after a thorough literature review of climate-related studies in general and previous climate-related research work performed in Pakistan in particular. The survey mainly collected information on the farmers' socioeconomic features, institutional parameters, farm management practices, adaptation measures, and livelihood sources. Furthermore, detailed information was collected on the adaptation process starting from farmers' perceptions of the risks induced by climate change to the final

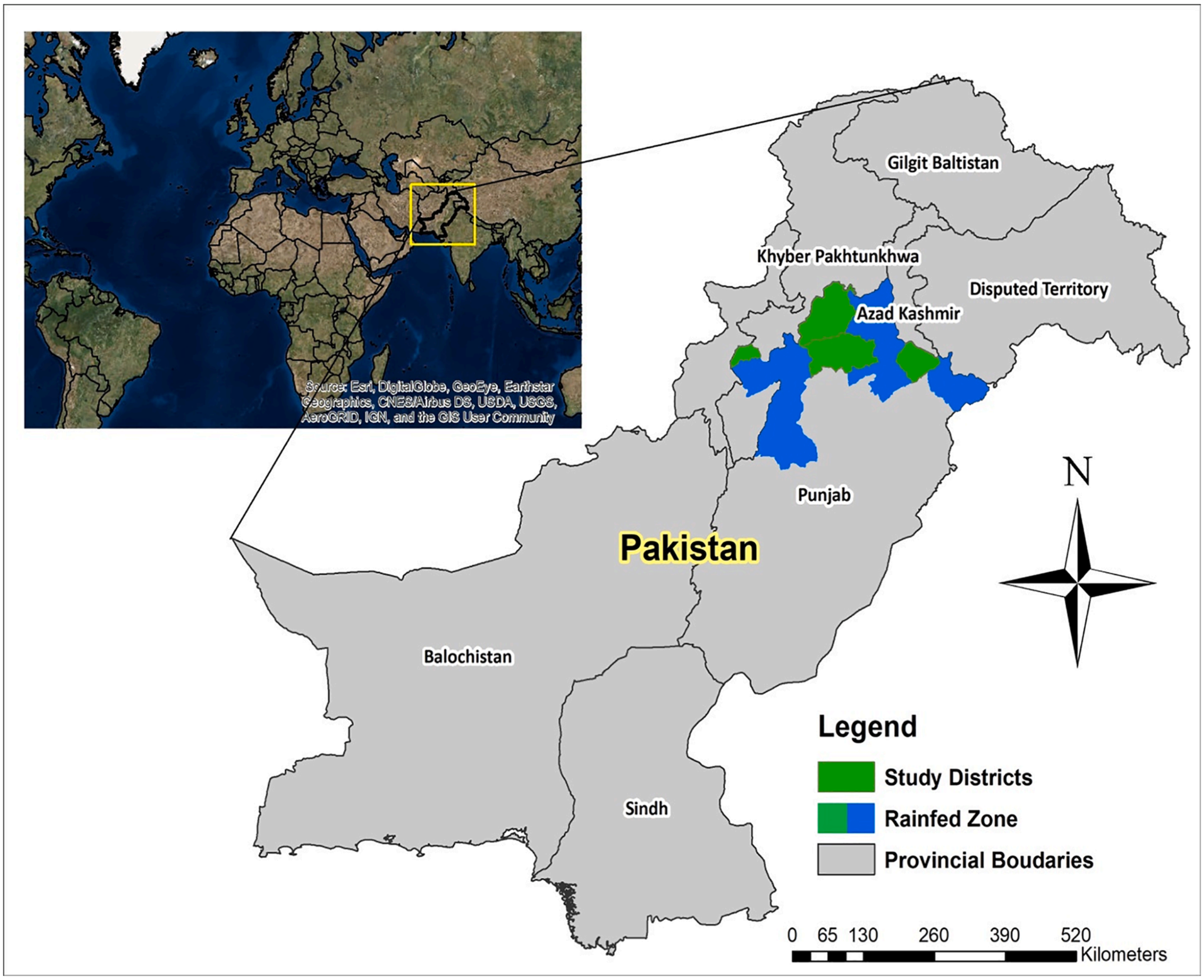



**Fig. 2.** Map of the study area.

implementation of an adaptation. The questionnaire was pretested by surveying 15 farmers from each randomly selected rainfed district, which was performed by a well-trained team of enumerators for the inclusion of required and relevant information and the exclusion of irrelevant questions. The enumerators were agriculture graduates from the agriculture university located in the rainfed zone, and they have rigorous experience with field surveys on climate change and agriculture-linked studies. The enumerators were trained for 5 days on the subject before the initiation of the final field survey. The questionnaire was further improved based on detailed discussions with local agriculture officers. The final data collection was performed by the same team employing a simple random sampling technique. Before the start of the interviews, farmers were appropriately briefed about the purpose and type of information being collected. The final interviews were conducted on farmers' full willingness to provide the requested information. The simple random sampling technique consisted of the following steps:

1. Selection of the rainfed agroecological zone of Pakistan as the main study area;
2. Random selection of four *districts* (an administrative unit) from rainfed agroecological zone;
3. Selection of one *tehsil* (sub-administrative unit) from each randomly chosen *district;*
4. Selection of one *union council* (smallest administrative unit in the country) from each randomly chosen *tehsil;* and
5. Selection of 100 farmers at random for interviews from each randomly selected *union council*; making a total sample of 400 rainfed farmers.

### *3.3. Processing of secondary data on temperature and rainfall*

Secondary data of temperature and rainfall for four randomly selected rainfed districts were obtained from the Pakistan Meteorological Department (PMD) Islamabad for the last 38 years (1980 to 2017). The data were further processed for two separate seasons (winter or *Rabi* season and summer or *Kharif* season) to obtain a clear picture of the prevailing trends of temperature and rainfall. The rainfall was measured as total seasonal rainfall (mm), whereas temperature (°C) data were measured as seasonal averages. This exercise was performed because crop farming is more sensitive to total rainfall than its mean, and temperature means are frequently used to explain the phenomenon of climate change (Iqbal and Zahid, 2014). The winter or *Rabi* season is defined as the time period between November and April, whereas the summer or *Kharif* season is defined as the time period between May and October (NAMC, 2012; Abid et al., 2019).

## 4. Statistical analysis

In the adaptation process, accurate perception of climate change by the target group is a prerequisite (Mahmood et al., 2020a). Therefore, we compared the farmers' perceptions with the observed trends of temperature and rainfall, which were determined using meteorological data. For this purpose, we first asked the farmers about their observations regarding climatic parameters, including temperature and rainfall, and extreme climatic events (floods, droughts, and heat waves). Then, we plotted the trends of temperature and rainfall for both seasons (Rabi and Kharif) using the meteorological data from 1980 to 2017 and compared these trends with the farmers' perceptions. The comparison of farmers' perceptions of climatic trends is further explained with descriptive statistics. All the farmers resided in the study area for at least 15 years and had a minimum age of 30 years, which means that they have a sound understanding of their changing local climate and hence present better perceptions based on their farming experience in the study area.

Recently, multinomial logit (MNL) models and multivariate probit (MVP) models have been widely used when the variable of interest (dependent variable) has multiple responses. The multinomial logit (MNL) model is among the best options when all the responses of a dependent variable are self-determining and their occurrence is exclusively independent of each other (Alauddin and Sarker, 2014; Zhai et al., 2018; Mahmood et al., 2020a). However, the multivariate probit (MVP) model is among the most suitable options when the responses of dependent variables are mutually interdependent and correlated (Abid et al., 2019; Nkuba et al., 2020; Aryal et al., 2020). The potential existence of concurrent correlation among the adaptation stages (dependent variables) and tested correlation among the disturbances led to the use of the multivariate probit (MVP) model. Hence, a multivariate probit model (MVP) is used to examine the factors that can potentially affect the adaptation stages, including 1) accurate climate risk perceptions, 2) underestimated climate risk perceptions, 3) adaptation planning, and 4) adaptation implementation as elaborated in the conceptual framework. Taking into account the likelihood of simultaneous correlation among the dependent variables, the general form of the MVP model can be written as follows:

$$AS_{ij} = \beta_j x_{ij} + \varepsilon_{ij} \tag{1}$$

where $AS_{ij}(j = 1\ldots, m)$ symbolizes the adaptation stages ($j$), which are four ($m = 4$) in the present case for the $i$th farmer ($i = 1\ldots, n$); $x_{ij}$ is a $1 \times k$ factor of exogenous variables that affect the adaptation stages; $\beta_j$ depicts a $k \times 1$ vector of unknown parameters to be estimated; and $\varepsilon_{ij}$ is the unobserved error term. In this specification, each $AS_j$ is a binary variable, and thus Eq. (1) is actually a system of '$m$' equations ($m = 4$ in this case; shows the four adaptation stages) to be estimated:

$$AS^*_{i1} = \alpha_1 + \beta_1 x_{i1} + \varepsilon_{i1} \tag{2a}$$

$$AS^*_{i2} = \alpha_2 + \beta_2 x_{i2} + \varepsilon_{i2} \tag{2b}$$

$$AS_{i3}^{*} = \alpha_3 + \beta_3 x_{i3} + \varepsilon_{i3} \quad (2c)$$

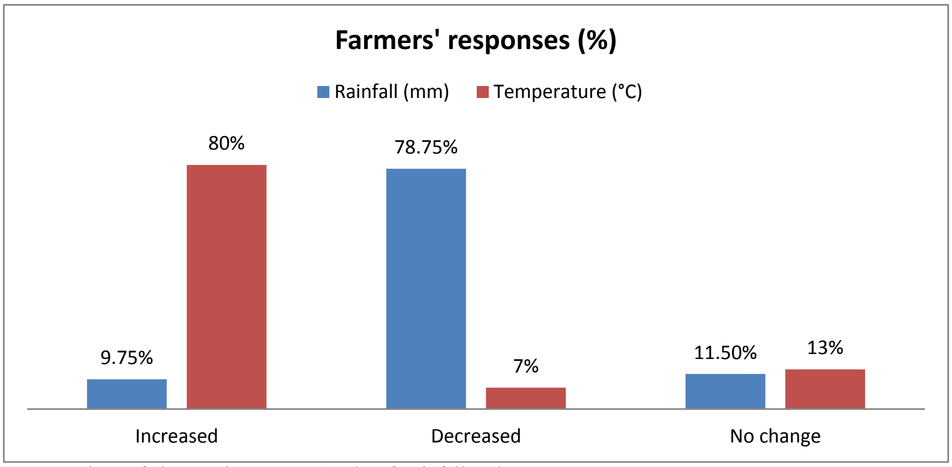
$$AS_{i4}^{*} = \alpha_4 + \beta_4 x_{i4} + \varepsilon_{i4} \quad (2d)$$

where $AS_{i1}^{*}$,$AS_{i2}^{*}$, $AS_{i3}^{*}$ and $AS_{i4}^{*}$ are the four latent variables underlying each of the adaptation stages, such as $AS_{i1}^{*} = 1$ if $AS_{ij}^{*}$gt and 0 otherwise. The first two equations (2a & 2b) represent accurate climate risk perceptions and underestimated climate risk perceptions, while no climate risk perceptions have been used as a base. Eqs. (2c) and (2d) represent the adaptation planning and adaptation implementation, respectively. $\alpha_j$ is the intercept showing the projected value when all independent variables are equal to zero. The adaptation against climate change to minimize the associated risks is a chain process in which one stage correlates with the other. Thus, a hypothesis that the adaptation stages were not correlated was made, and then it was tested by applying the likelihood ratio test (LR-Test) and Wald $\chi 2$ test. Based on the assumption of multivariate normality, the unknown parameters in Eq. (1) are estimated by maximizing the simulated likelihood (SML). The simulated likelihood (SML) utilizes the Geweke–Hajivassiliour–Keane (GHK) simulator to evaluate the multivariate normal distribution.

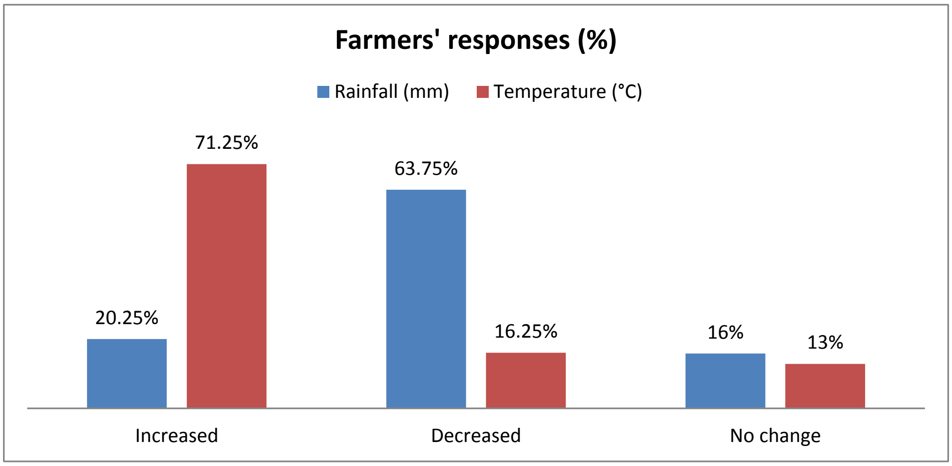
## 5. Results and discussion

### 5.1. Perceptions and recorded metrological readings of seasonal temperature and rainfall

An accurate perception of the risks induced by climate change can lead to better adaptation planning and ultimately to the implementation of an adaptation against climate change by farming communities. Therefore, an assessment of how farmers perceive climate change is an essential factor for the development of efficacious adaptation policies by relevant government departments. The statistics presented in Fig. 3(a & b) illustrate that farmers perceived a rise in both summer and winter temperatures over the period of




a. Perceptions of changes in summer ( *Kharif*) rainfall and temperature




b. Perceptions of changes in winter ( *Rabi*) rainfall and temperature

**Fig. 3.** (a & b). Rainfed farmers' perceptions of changes in seasonal (i.e., summer and winter) temperature and rainfall over the period 1980–2017.

the last two decades in the study area. The perception of a rise in temperature in summer is higher than the perception of a rise in winter temperature. Specifically, 80% of rainfed farmers perceived an increase in summer temperature compared to 71.25% of farmers who perceived a rise in winter temperature. Conversely, only 7% and 16.25% of rainfed farmers perceived a decline in summer and winter temperatures, respectively, while 13% perceived no change (Fig. 3). Regarding rainfall, farmers perceived a decline in both summer and winter rainfall. The perception of declining summer rainfall (78.75%) is relatively higher than the perception of declining winter rainfall. Furthermore, 20.25% of farmers perceived an increase in winter rainfall and only 9.75% perceived an increase in summer rainfall, while 16% and 11.50% of farmers perceived no change in winter and summer rainfall, respectively.

We plotted and analysed the historical trends of seasonal temperature and rainfall for the period of 1980 to 2017 (Fig. 4). The summer and winter temperatures showed an increasing trend over time, which is in accordance with the farmers' perceptions of both summer and winter temperatures. Similarly, we plotted the historical records of seasonal rainfall, which showed a downward trend and is consistent with the farmers' perceptions of a decline in rainfall for both summer and winter seasons. Our findings also coincide with previous studies (Gbetibouo, 2009; Zampaligré et al., 2014; Abid et al., 2019). The coherence between farmers' perceptions of seasonal temperature and rainfall and historical trends of both parameters shows that rainfed farming communities appear to be very vigilant about changes in the local weather conditions.

Following Arshad et al. (2018) and Mahmood et al. (2020a), we also calculated the seasonal anomalies for both temperature and rainfall to compare the study period's (2017) temperature and rainfall records with historical records (1980–2016). The temperature anomaly is calculated as the difference between the study period's mean temperature and historical mean. The temperature anomaly is positive and indicates an increase in temperature, which also validates the coherence between farmers' perceptions and meteorological trends of temperature. Similarly, the rainfall anomaly is calculated as the difference between the study period's total rainfall and the average total rainfall over the period from 1980 to 2016. The rainfall anomaly is negative and shows a decline in total rainfall, which also validates the coherence between farmers' perceptions and meteorological trends of rainfall (Fig. 5).

### 5.2. Climate risk perceptions and adaptation implementation

The coefficients of correlation among the stages of adaptation estimated with the multivariate probit (MVP) model clearly reveal a connection between the adaptation stages (Table 2). The positive and highly significant correlation coefficient between accurate climate risk perceptions and adaptation planning (rho31) implies that farmers with accurate climate risk perceptions are more likely to plan an adaptation. Furthermore, a positive and highly significant correlation coefficient between accurate climate risk perceptions

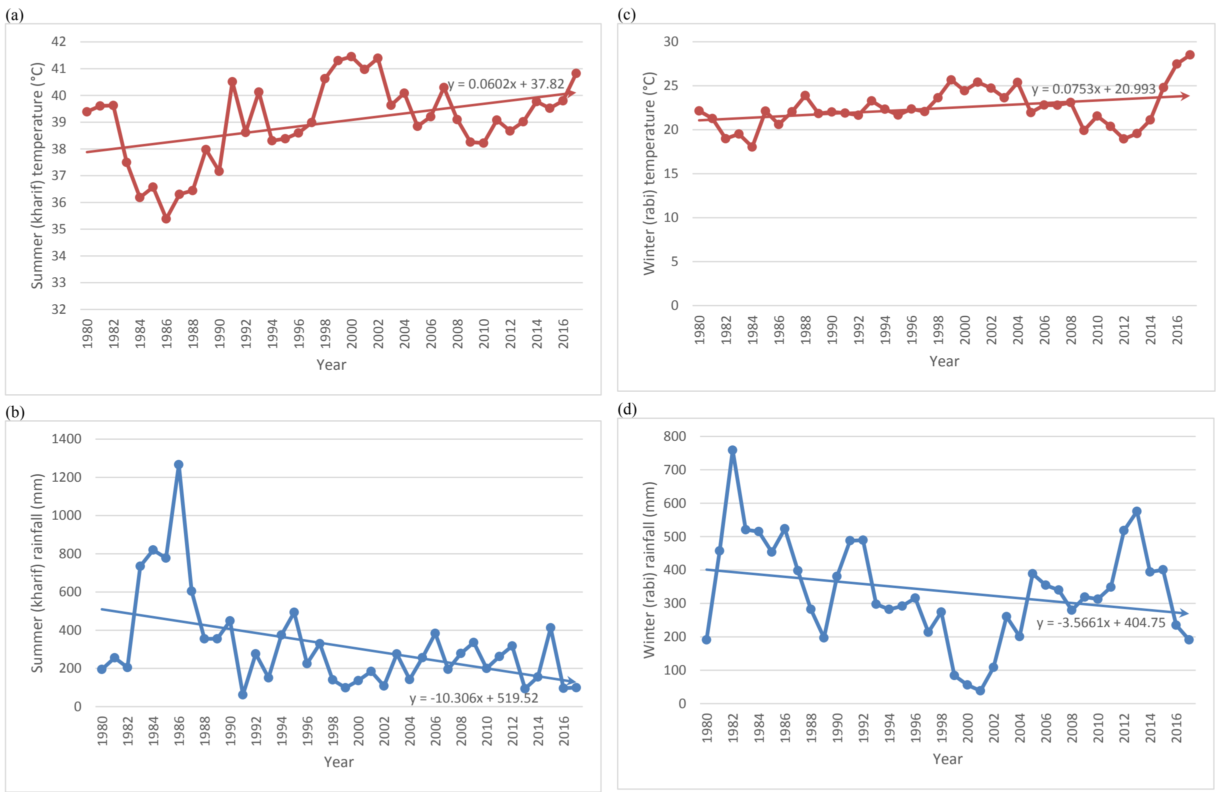



**Fig. 4.** (a–d). Observed trends in seasonal (i.e., summer and winter) temperature and rainfall in rainfed areas of Pakistan over the period 1980–2017.

and adaptation implementation (rho41) indicates that farmers with accurate climate risk perceptions are more inclined to adapt to minimize the risks associated with climate change. On the other hand, a negative and highly significant coefficient of correlation between underestimated climate risk perceptions and adaptation implementation (rho42) confirms that farmers with underestimated climate risk perceptions are less likely to implement an adaptation. Moreover, a positive and significant correlation coefficient between adaptation planning and implementation of adaptation (rho43) shows that farmers with positive planning (intention to adopt) are more likely to adapt to minimize the risks associated with climate change. The likelihood ratio (LR) test and Wald $\chi^2$ tests also endorse the use of the MVP model by rejecting the null hypothesis of conjoint nullity of $\rho_{kj}$ (see Table 2).

The results of the MVP model are presented in Table 3. The explanatory variables affect the adaptation stages differently with varying strengths.

The variable 'CRM trainings' takes a value of '1′ if the farmer has participated in CRM trainings at least once in a cropping season (means at least two times per year) and '0′ otherwise. The effect of CRM trainings is statistically significant for the accurate climate risk perceptions stage. The positive and highly significant value shows that the precision of climate risk perceptions increases with farmers' participation in CRM trainings. Similarly, a negative and significant coefficient of CRM trainings for underestimated climate risk perceptions reveals that farmers with no participation in CRM trainings underestimate the risks associated with climate change. More interestingly, the variable CRM trainings also showed a very strong and positive impact on farmers' planning to adapt and subsequently implement an adaptation measure, which means that CRM trainings play an essential role in the adaptation process starting from farmers' climate risk perceptions until the final adaptation implementation. A recent study conducted in Cambodia highlighted the importance of special trainings for the adoption of climate risk management strategies (Bairagi et al., 2020). The study reported that adequate access to better information via special trainings increased the adoption of three different climate-resilient strategies, which means that an adequate and timely provision of special trainings could facilitate the minimization of risks associated with climate change, especially crop yield losses. Mulwa et al., 2017 and Aryal et al., 2018 also reported a positive and highly significant impact of agricultural trainings on farmers' likelihood of adopting climate-smart agricultural practices. Furthermore, Zakaria et al., 2020 strongly recommended the inclusion of farmer trainings on climate-smart agricultural practices (CSAPs) towards suitable adaptations. Such special agricultural trainings present learning pathways for farming communities about the latest technologies and are also essential for raising awareness about up-to-date field management practices (De Janvry et al., 2017), which will ultimately help farmers build resilience against the risks associated with climate change (Lipper et al., 2018). A recent study reported a positive and highly significant impact of climate-resilient crop farm trainings on the implementation of an adaptation measure in Pakistan (Mahmood et al., 2020a). The study highlighted the strong association of special trainings with adaptation, although it does not discern its specific impacts on other adaptation stages.

The variable 'DAEC services' takes a value of '1′ if a farmer has the availability of general and agromet advisory services on his mobile phone through a locally operated telecommunication network and a value of '0′ otherwise. The variable 'DAEC services'

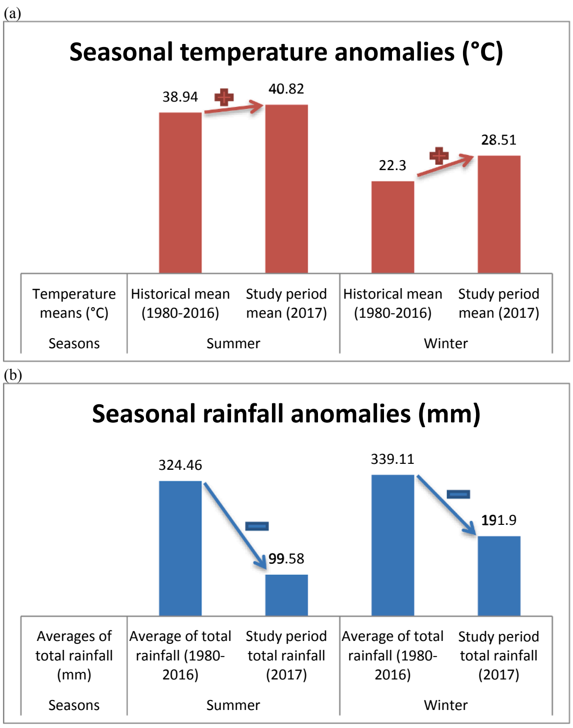



**Fig. 5.** (a & b). Temperature and rainfall anomalies for summer and winter seasons calculated based on a comparison between the study period (2017) and historical (1980–2016) meteorological data.

**Table 2**
Results of the multivariate probit (MVP) model showing correlations among adaptation stages.

| Adaptation stages against climate risks | Coefficient | Standard error |
|---|---|---|
| rho21 = Underestimated climate risk perceptions and accurate climate risk perceptions | −0.2595 | 0.2158 |
| rho31 = Adaptation planning and accurate climate risk perceptions | 0.4760** | 0.1321 |
| rho32 = Adaptation planning and underestimated climate risk perceptions | 0.1232 | 0.0929 |
| rho41 = Implementation of an adaptation and accurate climate risk perceptions | 0.7752*** | 0.0691 |
| rho42 = Implementation of an adaptation and underestimated climate risk perceptions | −0.6705*** | 0.0861 |
| rho43 = Implementation of an adaptation and adaptation planning | 0.5153** | 0.1017 |
| Log likelihood value | −586.62 | |
| Wald $\chi^2$ (32) | 153.54 | |
| LR (likelihood ratio) test of $\rho_{kj}$ ($H_o = \rho_{kj} = 0$) | 97.61*** | |
| Total observations | 400 | |

***, ** and * indicate significance at the 1%, 5% and 10% p-levels, respectively.

**Table 3**
Results of the multivariate probit (MVB) model with the parameter estimates of factors affecting the various adaptation stages in rainfed farming systems of Pakistan.

| Variables | Climate risk perceptions | | Adaptation planning | Implementation of an adaptation |
|---|---|---|---|---|
| | Accurate climate risk perceptions | Underestimated climate risk perceptions | | |
| CRM trainings | 0.6501** | −0.5042** | 0.3139* | 1.3535*** |
| | (0.329) | (0.204) | (0.175) | (0.267) |
| DAEC services | 0.7353*** | −0.9146*** | 0.6488*** | 0.9251*** |
| | (0.218) | (0.235) | (0.182) | (0.160) |
| Male family members | 0.0777 | −0.0438 | 0.0623** | 0.1195** |
| | (0.087) | (0.074) | (0.021) | (0.053) |
| Female family members | 0.0350 | 0.0318 | −0.0548 | −0.1549 |
| | (0.079) | (0.065) | (0.055) | (0.089) |
| Education | −0.0909 | 0.0272 | 0.1324** | 0.3846** |
| | (0.256) | (0.182) | (0.051) | (0.180) |
| Off-farm income | −0.0252 | −0.2464 | −0.2192* | −0.3112* |
| | (0.229) | (0.199) | (0.119) | (0.169) |
| Farmer cooperative meetings | 1.1680** | −0.2062 | 0.5695** | 0.6770*** |
| | (0.460) | (0.207) | (0.198) | (0.196) |
| Input-market distance | −0.0374* | 0.0254* | −0.0224* | −0.0248* |
| | (0.021) | (0.013) | (0.013) | (0.015) |
| Constant | 0.7975* | 2.1179*** | 1.1614*** | −0.3031 |
| | (0.426) | (0.412) | (0.328) | (0.306) |

***, ** and * indicate the significance at the 1%, 5% and 10% p-levels, respectively, and figures in parentheses show the standard errors.

showed a statistically significant association with all adaptation stages. It has a positive and highly significant impact on farmers' accurate perceptions of climate-related risks, whereas DAEC services reveal a negative and highly significant impact on underestimated climate risk perceptions, which implies that farmers having access to DAEC services accurately perceive climate risks while those having no access to DAEC services underestimate these risks. Furthermore, the variable showed a positive and highly significant impact on farmers' planning and final implementation of adaptation. It can be inferred that farmers with access to DAEC services are more likely to plan and implement adaptations. A recent and relevant study also highlighted the importance and role of information and communication technologies, mobile communication in particular, for better access to agriculture-related information that helps farmers adopt climate-smart farming practices (Westermann et al., 2018). Although several studies (Ouedraogo et al., 2018; Diouf et al., 2019; Partey et al., 2020) have reported the positive influence of climate information services (CIS) on farmers' awareness and adaptation behaviour under climate change, the majority of these studies emphasize the provision of face-to-face advisory services. Previous studies have focused less on the provision of advisory services via mobile communication and have only covered one component of climate information while ignoring others. As reported by Bryan et al. (2013), precise and appropriate access to market information enables farmers to design better adaptation plans to minimize climate-related risks. Similarly, easy access to accurate climate information enables farmers to fine-tune their sowing timings, daily field management practices, input application timings, and harvesting timings based on daily weather readings and forecasts (Mertz et al., 2009; Deressa et al., 2011). A recent study (Abid et al., 2019) conducted in Punjab Province of Pakistan highlighted the significant role of climate information, marketing information, and extension services separately in the adaptation process against climate change. Every component has a considerable impact on each adaptation stage. Abid et al. (2019) reported that although access to general extension services is positively related to the adaptation stage, the variable showed no impact on farmers' perceptions about climate risks and adaptation planning to minimize risk. Based on empirical findings, our study strongly recommends the provision of climate-based services alongside general extension services. We modelled a novel variable (DAEC services) that covered and examined the effects of all essential advisory services under one topic that is available to farmers via mobile phones. In a developing country context, it is a natural instinct of farmers to avoid the services for which they must expend time and effort. However, easy access to all the required services with one call via mobile phone could help farmers to better understand climate risks, devise more appropriate plans and implement adaptation measure because this variable showed a highly significant impact on all adaptation stages in our analysis. Mobile communication is one of the best, most cost-effective, and rather universal methods of disseminating agromet-information, especially for farming communities located far from central areas. Moreover, mobile applications are considered the best-suited platform for information dissemination between farming communities and suppliers of agricultural advisory services (Siraj, 2010).

Instead of using family size as mostly done in previous studies, we used 'male family members' and 'female family members' as two separate variables to analyse gender disaggregated effects. The variable 'male family members' in a farm household showed a positive and significant effect on adaptation planning and implementation. The variable 'female family members' did not appear to affect any adaptation stage, which means that farmers with more male family members are more likely to plan an adaptation against climate change and finally execute an adaptation to minimize the risks associated with climate change, which is totally in accordance with the fact that crop farming in rainfed areas and in Pakistan is generally headed by male family members (Mahmood et al., 2019). All the farmers in the selected sample were males who had complete control over farming matters and other farm-related decisions, which appeared to be the main reason that the variable 'male family members' showed a positive and highly significant impact on adaptation planning and the final implementation of an adaptation. Male family members are usually well aware of ongoing activities and therefore have a greater ability to adapt to climate change (Abdul-Razak and Kruse, 2017). Furthermore, male members are more active and productive in performing various field management practices and implementing adaptation strategies compared to female family members (Palacios-López and López, 2015). However, the variable 'male family members' does not show any effect on farmers' accurate climate risk perceptions and underestimated climate risk perceptions.

Farmer education is defined as '1′ if the farmer can read and write in the national language and '0′ otherwise. The logic of modelling this variable in a different way is that most of the information labelled on agronomic inputs and information dissemination from agriculture extension department is in the national language, i.e., Urdu. The variable showed a positive and significant impact on adaptation planning and implementation, which means that an educated farmer is more likely to plan and implement an adaptation to reduce the risks induced by climate change. Farmer education plays a pivotal role in understanding the risks associated with climate change, effective planning and finally adaptation. Similar results were reported by Aryal et al. (2018), who strongly emphasized that farmers' education can play a central role in changing their behaviour and devising suitable adaptation strategies against climatic risks. Education can also enable farmers to be more aware of future risks and trigger their focus towards climate-smart agriculture under climate change (Aryal et al., 2020). However, farmer education did not significantly affect accurate climate risk perceptions or underestimated climate risk perceptions stages, which is because rainfed farmers are well aware of the climatic changes and the possible risks associated with these changes. Farmers are keen observers of climatic changes based on their observations and past experiences (Mahmood et al., 2020b).

The variable 'off-farm income' also showed interesting results. The variable takes a value '1′ if a farmer has off-farm income and '0′ otherwise. The variable showed a statistically negative and significant impact on the stages of adaptation planning and implementation of adaptation, which implies that farmers who rely entirely upon farm earnings for their sustenance are more likely to plan and adapt than those having off-farm earnings. These results are consistent with the findings of Diiro (2013), who reported that farmers without off-farm income utilize all the available family labour intensively to perform various farm management practices and adopt adaptation strategies to obtain the maximum yield of a particular crop. In contrast, off-farm activities reduce family labour available to agricultural activities (lost labour effect). Conversely, some studies have reported a positive impact of off-farm income on adaptation to climate change due to the income effect (Fernandez-Cornejo and Mishra, 2007; Ojo et al., 2019). Our results are in line with Shahzad and Abdulai (2020b), who argue that the lost labour effect dominates the income effect and negatively influences the adoption process. However, off-farm income did not show any effect on the accurate climate risk perceptions and underestimated climate risk perceptions stages of adaptation.

The variable 'farmer cooperative meetings' takes a value of '1′ if farmers have frequently participated in meetings with fellow farmers at a common gathering place (which is normally done at a farmhouse, known as *Dera* in local language) and '0′ otherwise. The variable is statistically significant in all adaptation stages except the stage with underestimated climate risk perceptions. The accuracy of climate risk perceptions increases for farmers who participated in cooperative meetings. Although the variable did not affect the underestimated climate risk perceptions stage, the negative sign can be interpreted as farmers with no participation in cooperative meetings underestimating the risks associated with climate change. Farmers' participation in cooperative meetings also shows a positive and significant impact on adaptation planning and implementation, which implies that farmers' participation in these meetings increases their likelihood of planning and implementing adaptation. These results support the findings of a study conducted in the Punjab province of Pakistan (Abid et al., 2019). A highly positive and significant impact of this variable on adaptation stages reveals that such informal meetings may help farmers who do not have any direct contact with agricultural experts and even have limited knowledge about up-to-date farming practices. Informal interactions may also enable farmers to obtain assistance and guidance from fellow farmers. These findings are also supported by various studies (Huq and Reid, 2007; Van Aalst et al., 2008; Aryal et al., 2018), which have reported a positive and significant impact of farmers' meetings on their understanding and capability to minimize the risks associated with climate change.

Finally, the variable 'input market distance' denotes the distance of the farm in kilometres from the input market. The variable showed a significant association with all adaptation stages. The negative and significant values show that an increase in distance from the input market decreases the accuracy of climate risk perceptions, while the positive and significant values show that underestimated climate risk perceptions increase with an increase in farm distance from the input market. Similarly, negative and significant values for adaptation planning and implementation of adaptation show that easy input market access increases the likelihood of planning and implementing adaptations. An easy approach to input markets actually enables farmers to obtain better information about new production technologies and adaptation strategies as well (Ullah et al., 2020a, 2020b), which ultimately facilitates farmers' accurate perceptions of the risks associated with climate change. Furthermore, input markets located in the vicinity empower farmers to purchase various inputs in a timely manner (e.g., seeds, fertilizer, and pesticides) and perform various crop management and adaptation strategies in a timely manner (Mahmood et al., 2019). Moreover, the negative and significant relationship of market distance with adaptation planning and implementation is consistent with the findings of previous studies (Jin et al., 2020; Menghistu et al., 2020; Mahmood et al., 2020a). Input markets located close to farms has a highly significant and positive impact on farmers' intention to implement adaptation measures. The present study has also identified the different adaptations that rainfed farming communities have been practising to minimize climate-induced risks. These adaptation strategies mainly include changing sowing dates, using heat- and drought-resistant crop varieties, changing the composition of fertilizer, and planting shade trees.

## 6. Conclusions

This study examined rainfed farmers' perceptions of the changing climate. The findings confirm that farmers' perceptions are consistent with historical meteorological trends of temperature and rainfall from 1980 to 2017. Furthermore, the study investigated the link between all stages of adaptation (climate risk perceptions, adaptation planning, and adaptation implementation) and the factors that can potentially affect these adaptation stages. Accurate perceptions of changing weather conditions are among the essential factors for devising suitable adaptation strategies at farm level. Rainfed farmers in Pakistan appear to have sufficient awareness about climatic changes and the associated risks, and they are keen observers of changing temperature, fluctuating rainfall patterns, drought conditions, and heat stress because, their farming and livelihoods are dependent on favourable weather conditions, as rain is the only source of crop irrigation. Rainfed farmers' perceptions of changes in temperature and rainfall are consistent with historical trends. These farmers perceived a rise in both summer and winter temperatures and a reduction in summer and winter rainfall. We used the MVP model to examine the link between three adaptation stages, and the findings confirm the chain association between all adaptation stages, where accurate climate risk perceptions lead to adaptation planning and ultimately to adaptation implementation. Conversely, a negative association between 'underestimated climate risk perceptions' and 'implementation of an adaptation' reveals that farmers with underestimated climate risk perceptions are unlikely to adapt to minimize the risks associated with climate change. The study also identified various factors that significantly affect various adaptation stages. Climate risk management (CRM) trainings, digital agriculture extension and communication (DAEC) services, farmer cooperative meetings, and input-market distance are among the important factors that strongly impact climate risk perceptions, adaptation planning, and the final implementation of various adaptation strategies at the farm level. Moreover, male family members in a farmer's family, farmer education, and off-farm income are the factors that influence the adaptation behaviour of rainfed farming communities. Educated farmers with more male family members show more concern about adaptation planning and the subsequent implementation of adaptation measures, while farmers with off-farm earnings are less interested in planning and implementing adaptations. The main adaptations to minimize the risks associated with climate change were changing sowing dates, using heat- and drought-resistant crop varieties, changing the composition of fertilizer, and planting shade trees.

The findings of this study have strong implications for agricultural policy formulation. The variables CRM trainings and DAEC services are highly significant among all stages of adaptation, which reveals their significant role starting from farmers' accurate climate risk perceptions until the implementation of adaptations to minimize the risks induced by climate change. Relevant authorities need to focus more on providing CRM trainings and DAEC services with additional parameters and should emphasize greater coverage in rainfed areas of Pakistan. One of the parameters could be policy advice for forming farmer cooperatives because such cooperatives had a significant impact on accurate risk perception, adaptation planning, and adaptation implementation. Farmer cooperatives serve as an information-exchange platform where one farmer can benefit from others' experience, which enables them to adopt the best agricultural practices to improve their yields and livelihoods. Furthermore, the provision of basic education on the national language and easy input market access can also have a triggering effect that increases the adaptive capacity of rainfed farmers because both variables significantly impact the adaptation planning and implementation stages. The input market provides a platform that enables farmers to have the latest information about various inputs and even adaptation practices from input dealers and fellow farmers. The aforementioned institutional arrangements from the authorities would increase the adaptive capacity of farmers, which would ultimately lead to an increase in farm production and improve the livelihoods of rainfed farming communities in Pakistan.

## Declaration of Competing Interest

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

## Acknowledgements

The first author acknowledges the financial support from the Punjab Higher Education Commission (PHEC), Pakistan (Ref. PHEC/HRD/FS/1-19/2016/). Muhammad Arshad was provided funding by the Alexander von Humboldt Foundation, Germany which is greatly acknowledged. We are also grateful to Fiat Panis, Germany, for providing funds to conduct field surveys for data collection. Furthermore, the authors would like to thank the Leibniz Centre for Agricultural Landscape Research (ZALF) for providing technical and administrative support. Muhammad Iqbal from the National Agriculture Information Centre, SUPARCO-Pakistan constructed a map of the study area which the authors are grateful for.

## References

Abdul-Razak, M., Kruse, S., 2017. The adaptive capacity of smallholder farmers to climate change in the Northern Region of Ghana. Clim. Risk Manage. 17, 104–122.
Abid, M., Scheffran, J., Schneider, U.A., Elahi, E., 2019. Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. Environ. Manage. 63 (1), 110–123.
Ahmad, D., Afzal, M., 2020. Climate change adaptation impact on cash crop productivity and income in Punjab province of Pakistan. Environ. Sci. Pollut. Res. 27 (24), 30767–30777.
Ahmed, M., Suphachalasai, S., 2014. Assessing the costs of climate change and adaptation in South Asia. Asian Development Bank.
Akhtar, K., Wang, W., Ren, G., Khan, A., Feng, Y., Yang, G., Wang, H., 2019. Integrated use of straw mulch with nitrogen fertilizer improves soil functionality and soybean production. Environ. Int. 132, 105092. https://doi.org/10.1016/j.envint.2019.105092.
Alauddin, M., Sarker, M.A.R., 2014. Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation. Ecol. Econ. 106, 204–213.
Arshad, M., Amjath-Babu, T.S., Aravindakshan, S., Krupnik, T.J., Toussaint, V., Kächele, H., Müller, K., 2018. Climatic variability and thermal stress in Pakistan's rice and wheat systems: a stochastic frontier and quantile regression analysis of economic efficiency. Ecol. Ind. 89, 496–506.
Arshad, M., Amjath-Babu, T.S., Krupnik, T.J., Aravindakshan, S., Abbas, A., Kächele, H., Müller, K., 2017a. Climate variability and yield risk in South Asia's rice–wheat systems: emerging evidence from Pakistan. Paddy Water Environ, 15 (2), 249–261.
Arshad, M., Kächele, H., Krupnik, T.J., Amjath-Babu, T.S., Aravindakshan, S., Abbas, A., Mehmood, Y., Müller, K., 2017b. Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. Int. J. Sustain. Dev. World Ecol. 24 (6), 532–544.
Aryal, J.P., Jat, M.L., Sapkota, T.B., Khatri-Chhetri, A., Kassie, M., Rahut, D.B., Maharjan, S., 2018. Adoption of multiple climate-smart agricultural practices in the Gangetic plains of Bihar, India. Int. J. Clim. Change Strategies Manage. 10 (3), 407–427.
Aryal, J.P., Sapkota, T.B., Rahut, D.B., Krupnik, T.J., Shahrin, S., Jat, M.L., Stirling, C.M., 2020. Major climate risks and adaptation strategies of smallholder farmers in coastal Bangladesh. Environ. Manage. 66 (1), 105–120.
Baig, M.B., Shahid, S.A., Straquadine, G.S., 2013. Making rainfed agriculture sustainable through environmental friendly technologies in Pakistan: a review. Int. Soil Water Conserv. Res. 1 (2), 36–52.
Bairagi, S., Mishra, A.K., Durand-Morat, A., 2020. Climate risk management strategies and food security: evidence from Cambodian rice farmers. Food Policy 95, 101935. https://doi.org/10.1016/j.foodpol.2020.101935.
Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., Herrero, M., 2013. Adapting agriculture to climate change in Kenya: Household strategies and determinants. J. Environ. Manage. 114, 26–35.
De Janvry, A., Macours, K., Sadoulet, E., 2017. Learning for adopting: technology adoption in developing country agriculture.
Deressa, T.T., Hassan, R.M., Ringler, C., 2011. Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. J. Agric. Sci. 149, 23–31.
Diiro, G.M., 2013. Impact of off-farm income on agricultural technology adoption intensity and productivity evidence from rural maize farmers in Uganda.
Diouf, N.S., Ouedraogo, I., Zougmoré, R.B., Ouedraogo, M., Partey, S.T., Gumucio, T., 2019. Factors influencing gendered access to climate information services for farming in Senegal. Gender Technol. Dev. 23 (2), 93–110.
Fahad, S., Wang, J., 2018. Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. Land Use Policy 79, 301–309.
Fernandez-Cornejo, J., Mishra, A.K., 2007. Off-farm income, production decisions, and farm economic performance.
Gbetibouo, G.A., 2009. Understanding farmers' perceptions and adaptations to climate change and variability: the case of the Limpopo Basin, South Africa (Vol. 849). Intl Food Policy Res Inst.
Government of Pakistan. Economic Survey., 2019. Finance Division, Economic Advisor's Wing, Islamabad, 2019.
Huq, S., Reid, H., 2007. Community-based adaptation: a vital approach to the threat climate change poses to the poor. London, UK, International Institute for Environment and Development.
IPCC, 2014. Climate change 2014: Impacts, adaptation, and vulnerability. Part a: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, p. 1048.
Iqbal, W., Zahid, M., 2014. Historical and future trends of summer mean air temperature over South Asia. Pakistan J. Meteorol. 10 (20).
Jha, P.K. (Ed.), 2015. Proceedings of International Conference on Biodiversity, Livelihood and Climate Change in the Himalayas. Central Department of Botany, Tribhuvan University.
Jin, J.J., Yiwei, G., Xiaomin, W., Nam, P.K., 2015. Farmers' risk preferences and their climate change adaptation strategies in the Yongqiao District, China. Land Use Policy 47, 365–372.
Jin, J., Kuang, F., Wan, X., He, R., Ning, J., 2020. Exploring the effects of sociocognitive factors on the adaptation behaviour of farmers in rural Southwest China. Clim. Dev. 1–9.
Khan, I., Lei, H., Shah, I.A., Ali, I., Khan, I., Muhammad, I., Huo, X., Javed, T., 2020. Farm households' risk perception, attitude and adaptation strategies in dealing with climate change: promise and perils from rural Pakistan. Land Use Policy 91, 104395. https://doi.org/10.1016/j.landusepol.2019.104395.
Kreft, S., Eckstein, D., Melchior, I., 2017. Global climate risk index. 2017. Who suffers most from extreme weather events? Global Climate Risk Index, 10.
Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., Branca, G., 2018. Climate smart agriculture. Nat. Resour. Manag. Policy 52, 2018.
Lobell, D.B., Sibley, A., Ivan Ortiz-Monasterio, J., 2012. Extreme heat effects on wheat senescence in India. Nat. Clim. Change 2 (3), 186–189.
Mahmood, N., Arshad, M., Kächele, H., Ma, H., Ullah, A., Müller, K., 2019. Wheat yield response to input and socioeconomic factors under changing climate: Evidence from rainfed environments of Pakistan. Sci. Total Environ. 688, 1275–1285.
Mahmood, N., Arshad, M., Kächele, H., Ullah, A., Müller, K., 2020a. Economic efficiency of rainfed wheat farmers under changing climate: evidence from Pakistan. Environ. Sci. Pollut. Res. 27 (27), 34453–34467.
Mahmood, N., Arshad, M., Kaechele, H., Shahzad, M.F., Ullah, A., Mueller, K., 2020b. Fatalism, climate resiliency training and farmers' adaptation responses: implications for sustainable rainfed-wheat production in Pakistan. Sustainability 12 (4), 1650.
Menghistu, H.T., Abraha, A.Z., Tesfay, G., Mawcha, G.T., 2020. Determinant factors of climate change adaptation by pastoral/agro-pastoral communities and smallholder farmers in sub-Saharan Africa. Int. J. Clim. Change Strategies Manage. 12 (3), 305–321.
Mertz, O., Mbow, C., Reenberg, A., Diouf, A., 2009. Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. Environ. Manag. 43, 804–816.
Mulwa, C., Marenya, P., Rahut, D.B., Kassie, M., 2017. Response to climate risks among smallholder farmers in Malawi: a multivariate probit assessment of the role of information, household demographics, and farm characteristics. Clim. Risk Manage. 16, 208–221.
NAMC, 2012. Monthly agromet bulletin for Pakistan. National Agromet Centre (NAMC), Pakistan Meteorological Department, Islamabad, Pakistan, p. 11.
Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Global Environ. Change 39, 133–142.
Nkuba, M.R., Chanda, R., Mmopelwa, G., Kato, E., Mangheni, M.N., Lesolle, D., 2020. Influence of Indigenous Knowledge and Scientific Climate Forecasts on Arable Farmers' Climate Adaptation Methods in the Rwenzori region, Western Uganda. Environ. Manag. 65 (4), 500–516.
Ojo, T.O., Baiyegunhi, L.J.S., Salami, A.O., 2019. Impact of credit demand on the productivity of rice farmers in South West Nigeria. J. Econ. Behav. Stud. 11 (1(J)), 166–180.
Ouedraogo, I., Diouf, N.S., Ouédraogo, M., Ndiaye, O., Zougmoré, R.B., 2018. Closing the gap between climate information producers and users: assessment of needs and uptake in Senegal. Climate 6 (1), 13.

Palacios-López, A., López, R., 2015. The gender gap in agricultural productivity: the role of market imperfections. J. Dev. Stud. 51 (9), 1175–1192.
Partey, S.T., Dakorah, A.D., Zougmoré, R.B., Ouédraogo, M., Nyasimi, M., Nikoi, G.K., Huyer, S., 2020. Gender and climate risk management: evidence of climate information use in Ghana. Clim. Change 158 (1), 61–75.
Rasul, G., Mahmood, A., Sadiq, A., Khan, S.I., 2012. Vulnerability of the Indus delta to climate change in Pakistan. Pakistan J. Meteorol. 8 (16).
Shahzad, M.F., Abdulai, A., 2020a. Adaptation to extreme weather conditions and farm performance in rural Pakistan. Agric. Syst. 180, 102772. https://doi.org/10.1016/j.agsy.2019.102772.
Shahzad, M.F., Abdulai, A., 2020b. The heterogeneous effects of adoption of climate-smart agriculture on household welfare in Pakistan. Appl. Econ. 52, 1–26.
Siraj, M., 2010. A model for ICT based services for agriculture extension in Pakistan. Pakistan, Rawalpindi https://assets.publishing.service.gov.uk/media/57a08acded915d3cfd000950/60818-extensionmodel-Pakistan.pdf.
Ullah, A., Arshad, M., Kächele, H., Khan, A., Mahmood, N., Müller, K., 2020a. Information asymmetry, input markets, adoption of innovations and agricultural land use in Khyber Pakhtunkhwa, Pakistan. Land Use Policy 90, 104261. https://doi.org/10.1016/j.landusepol.2019.104261.
Ullah, A., Arshad, M., Kächele, H., Zeb, A., Mahmood, N., Müller, K., 2020b. Socio-economic analysis of farmers facing asymmetric information in inputs markets: evidence from the rainfed zone of Pakistan. Technol. Soc. 63, 101405. https://doi.org/10.1016/j.techsoc.2020.101405.
van Aalst, M.K., Cannon, T., Burton, I., 2008. Community level adaptation to climate change: the potential role of participatory community risk assessment. Global Environ. Change 18 (1), 165–179.
Vermeulen, S.J., Challinor, A.J., Thornton, P.K., Campbell, B.M., Eriyagama, N., Vervoort, J.M., Kinyangi, J., Jarvis, A., Laderach, P., Ramirez-Villegas, J., Nicklin, K. J., Hawkins, E., Smith, D.R., 2013. Addressing uncertainty in adaptation planning for agriculture. Proc. Natl. Acad. Sci. 110 (21), 8357–8362.
Vogel, E., Meyer, R., 2018. Climate Change, Climate Extremes, and Global Food Production—Adaptation in the Agricultural Sector. In: Resilience. Elsevier, pp. 31–49.
Wade, K., Jennings, M., 2015. Climate change and the global economy: regional effects. Schroders. https://www. schroders. com/en/ch/asset-management/insights/economics/climate-change-and-the-global-economy-regional-effects (accessed on 20-04-2020).
Wang, Z., Li, J., Lai, C., Wang, R.Y., Chen, X., Lian, Y., 2018. Drying tendency dominating the global grain production area. Global Food Security 16, 138–149.
Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L., Campbell, B., 2018. Scaling up agricultural interventions: case studies of climate-smart agriculture. Agric. Syst. 165, 283–293.
Zakaria, A., Azumah, S. B., Appiah-Twumasi, M., Dagunga, G., 2020. Adoption of climate-smart agricultural practices among farm households in Trans-Volta Togoland, Ghana: the role of farmer participation in training programmes. Technol. Soc. 101338.
Zampaligré, N., Dossa, L.H., Schlecht, E., 2014. Climate change and variability: perception and adaptation strategies of pastoralists and agro-pastoralists across different zones of Burkina Faso. Reg. Environ. Change 14 (2), 769–783.
Zhai, S.-Y., Song, G.-X., Qin, Y.-C., Ye, X.-Y., Leipnik, M., 2018. Climate change and Chinese farmers: perceptions and determinants of adaptive strategies. J. Integr. Agric. 17 (4), 949–963.