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# Climate change perception, adaptation, and constraints in irrigated agriculture in Punjab and Sindh, Pakistan

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## Abstract

Pakistan's irrigated agriculture suffers from climate change due to its high exposure to climate extreme events and the low adaptation of its farming systems. Understanding the human aspects of adaptation decisions in a vulnerable climatic environment is integral for policymakers who want to enhance farmers' adaptive capacity. This study investigates how farmers perceive climate change and what adaptation strategies they consider. Furthermore, we assess the enabling and constraining factors influencing farmers' adaptation decisions. We conducted in-person interviews with 800 farmers across Pakistan's irrigated districts of the Punjab and Sindh provinces. We used a standardized questionnaire to gather primary cross-sectional data, which we analyzed with descriptive statistics. The results show that farmers in the Indus Plain have noticed changes in climate extremes along with longer summer and shorter winter seasons during the last ten years. Most farmers are aware of adaptation options and have already applied some measures. However, the dominant adaptation strategies differ between regions. The farmers in Punjab have primarily adopted crop and farm management practices, while farmers in Sindh have focused on implementing irrigation measures. In both provinces, farmers regarded rainwater harvesting as the least adopted strategy due to perceived lower effectiveness and practical challenges. The main constraints in the region are a lack of financial resources, water scarcity, and poor soil fertility. Farming decisions are primarily influenced by the availability of financial capital, and specific challenges such as variable rainfall patterns and rising temperatures. Our findings can help policymakers design better policy instruments that account for farmers' perceptions, motivations, and constraints and are thus more effective in promoting sustainable farming practices in Pakistan.

**Keywords** Climate change perception · Adaptation · Constraints · Irrigated agriculture · Indus plain · Pakistan

## 1 Introduction

Climate change presents a critical challenge to agriculture in Pakistan, a country heavily reliant on its agricultural sector, constituting 22.9% of its GDP and engaging 37.4% of its labor force as of 2022 (GoP 2023). Despite the dependence of agriculture on canal irrigation, Pakistan is notably vulnerable to climate change due to arid conditions in many parts (Abdullah et al. 2023; Adnan et al. 2017; Ahmed et al. 2019; Schilling et al. 2013; Ullah et al. 2022). This vulnerability is further aggravated by global climate change as Pakistan is the fifth most highly affected country from 1999 to 2018 (Eckstein et al. 2019). These circumstances highlight the urgency for research in climate change perception, adaptation, constraints, and factors of adaptation decisions, particularly in significant food-producing areas like irrigated plains of Punjab and Sindh provinces.

The agricultural sector in Pakistan is already facing severe challenges from rising temperatures, droughts, floods, and low crop yields (Abbas 2013; Ahmad et al. 2020; Ahmed & Schmitz 2011; Mohsin & Adnan 2023; Waseem et al. 2022). The climate of the regions is now confronting an even more significant threat from projected climatic variations (East-erling et al. 2000). These projections suggest an intensification of climate change effects on the country's rain-fed and irrigated agricultural systems. Specifically, Punjab and Sindh are the key wheat and rice production regions. These regions have witnessed declining crop yields and rising crop diseases due to climate extremes such as floods, droughts, and heat waves (Ishfaq et al. 2019). It is estimated that the crop yield can further decline in productivity under various climate scenarios (IPCC 2014), necessitating examining local adaptation measures to avoid these adverse effects.

Current research on climate change perception and adaptation to Pakistan's agriculture has provided substantial insights. However, it often lacks comprehensive coverage across diverse agroecological zones, especially the irrigated plains of Punjab and Sindh (Abid et al. 2015; Abid et al. 2019; Abid et al. 2016a, b; Ali & Rose 2021; Gorst et al. 2018; Salman et al. 2018; Sargani et al. 2022; Syed et al. 2022). Most of these studies cover smaller farming areas and sample sizes. This limitation restricts the applicability of findings and challenges the development of effective policies. Furthermore, a notable deficiency exists in understanding how local farmers perceive climate change and its direct impact on their livelihoods. The interaction between environmental drivers and farmers' decision-making processes in these areas remains underexplored. This study, which recognizes this gap, focuses on both Punjab and Sindh provinces, aiming to offer a more comprehensive view of climate change adaptation in the irrigated plains of the Indus. In light of the above context, this study explores the adaptation dynamics in irrigated zones, emphasizing the specific constraints and factors affecting the farmers' adaptation strategies.

Our research, aiming to address these issues, encompasses an extensive field survey in the Punjab and Sindh provinces. This approach allows a deeper understanding of these provinces' adaptation strategies across diverse environmental and socio-economic settings. The survey, with a significant sample size ( $n=800$ ), is designed to capture farmers' perceptions, adaptation, constraints, and factors of adaptation in the upper and lower irrigated plains of the Indus basin. We investigate the following three principal research questions:

1. How do farmers perceive climate change and its impacts on irrigated agriculture?
2. Which adaptation options do they know, and what is their adoption status in the study area?
3. What factors and constraints influence farmers' adaptation decisions?

These questions are essential for understanding the challenges of effective adaptation strategies in agricultural practices, particularly regarding farmers' perceptions and behaviors in Punjab and Sindh provinces.

## 2 MPPACC as a theoretical framework

Several studies have investigated the climate change perception of farmers and their adaptation actions using a variety of theoretical assumptions. Below are some of the most widely used theories for understanding perception-based adaptation actions. These theories are based on the understanding of the socio-cognitive processes of individuals. Some relevant theories are given below.

Ajzen (1985) proposed the Theory of Planned Behavior (TPB), which states that individual intention can explain individual behavior. Individuals' intentions depend on their attitudes, subjective norms, and perceived behavioral control. The TPB has its roots in the Theory of Reason Action (TRA), which states that an individual's intention to engage in a behavior is determined by their attitude toward the behavior and subjective norms (Fishbein & Ajzen 1977). TRA and TPB effectively explain how attitudes, subjective norms, and perceived behavior control intended behavior, but they overlook other intrapersonal factors and socio-environmental contexts. The Values Beliefs Norms Theory (VBN) focuses on how personal values, environmental beliefs, and moral norms drive pro-environmental behavior, underscoring the role of normative influences but neglecting socio-environmental contexts (Stern 2000). The Protection Motivation Theory (PMT) of Rogers (1983); and Rogers and Prentice-Dunn (2014) urges the role of threat appraisal and coping appraisal to motivate the intention to protect oneself against perceived threats without considering the influence of socio-environmental context (Floyd et al. 2000). Later, Grothmann and Patt (2005) proposed the Model of Private Proactive Adaptation to Climate Change (MPPACC), which modified the PMT's cognitive processes and supplemented socio-environmental factors into the model to address climate change risk and adaptation appraisal.

The PMMACC's focus on climate change as a risk, appraisal of adaptation, and inclusion of socio-ecological elements makes it an apt theoretical framework for the present study. This theory is suitable for analyzing farmer's climate change adaptation appraisal. The process model of MPPACC covers how farmers perceive climate change as a risk and their ability to adapt, which perfectly aligns with our study's focus. The model also addresses adaptation strategies known to the farmers and the extent of their implementation. The model also considers the role of external cognitive factors and constraints that challenge farmers' decision to adapt. All these aspects are the focus of the present study. Many studies employed the PMMACC to understand climate change perception, and adaptation in agriculture. We tabulate some of them below in Table 1

Table 1 summarizes that farmers' adaptation intention is significantly influenced by their self-efficacy and empirical adaptive capacity rather than merely cognitive perceptions of risk. Additionally, social and political capabilities, alongside awareness of effective measures, play a critical role in shaping adaptation behaviors, with a notable impact of social identity on climate risk perception and motivation.

**Table 1** Studies on the use of MPPACC as a theoretical framework

Author	Study area	Sample	Approach	Study's Insight
(Yang et al. 2024)	China	2230	Quantitative	Self-efficacy is a positive predictor of adaptive action
(Mitter et al. 2024)	India	20	Qualitative	Farmers have diverse adaptation intentions, including innovative and contractive measures
(Bagambilana and Rugumamu 2023)	Tanzania	328	Quantitative	The adaptation intention of farmers is largely explained by empirical adaptive capacity rather than cognitive factors
(Zobeidi et al. 2022)	Iran	250	Quantitative	Self-efficacy has a negative effect on adaptive behavior. Perceived susceptibility affects maladaptation and adaptive behavior
(Mitter et al. 2019)	Austria	29	Qualitative	Adaptation intentions are only formed if farmers are aware of effective adaptation measures
(Woods et al. 2017)	Denmark	1053	Quantitative	Farmers expressed limited concern about climate change impacts but show a moderate willingness to take adaptive actions in the future if they see benefits arising from climate change impacts
(Burnham and Ma 2017)	China	483	Quantitative	Self-efficacy predicts the intention to adapt, while merely perceiving climate change risks and impacts does not necessarily result in an adaptation intention
(Eakin et al. 2016)	USA	33	Quantitative	Linking capabilities like social and political capital motivates collective decisions of action
(Frank et al. 2011)	Mexico	318	Quantitative	Social identity shapes farmers' climate risk perception, motivation, and adaptation
(Kuruppu and Liverman 2011)	Kiribati	132	Quantitative	Self-efficacy is a driver of adaptation intention

### 3 Literature review

Climate change is a significant challenge to agriculture (Smith & Olesen 2010), and all around the world, people are asking to adapt to the current climate conditions (Howden et al. 2007). This urgency to adapt is equally pronounced worldwide, particularly in South Asia where a major glacial melt and monsoon changes pose serious challenges to agriculture (Mishra et al. 2020). So, this region is under natural and man-made constraints (Aryal et al. 2019). These constraining factors are more daunting for the smallholders due to their low adaptive capacity (Ozor et al. 2011). However, higher adaptive capacity positively influences adaptation practices (Masud et al. 2022; Mobeen et al. 2023). Several studies have reported that the effectiveness of adaptation decisions is linked to stronger climate change perception (Ahmad 2021; Elum & Snijder 2023; Ifeanyi-obi et al. 2023; Irham et al. 2022; Priyanto et al. 2021). The link between perception and adaptation is significant as it shapes the attitude and willingness to adapt as a consequence of climate change (Arbuckle et al. 2013; Zhang et al. 2022). Furthermore, the awareness of climatic changes among farmers influences the choice of their adaptive actions (Ifeanyi-obi et al. 2023). However, the decision-making of adaptive actions is not straightforward rather is constrained by several factors like limited resources, capabilities, technological awareness, and financial resources (Kabir et al. 2020; Phuong et al. 2017). These constraints deter farmers from adopting adaptive decision-making to respond effectively to climate change and further complicate the influence of decision-making factors (Tessema 2019). Consequently, the adaptation strategies of a farmer are not a simple process to understand; rather they are a complex interplay of perception, adaptive capacity, and local constraints to their decisions.

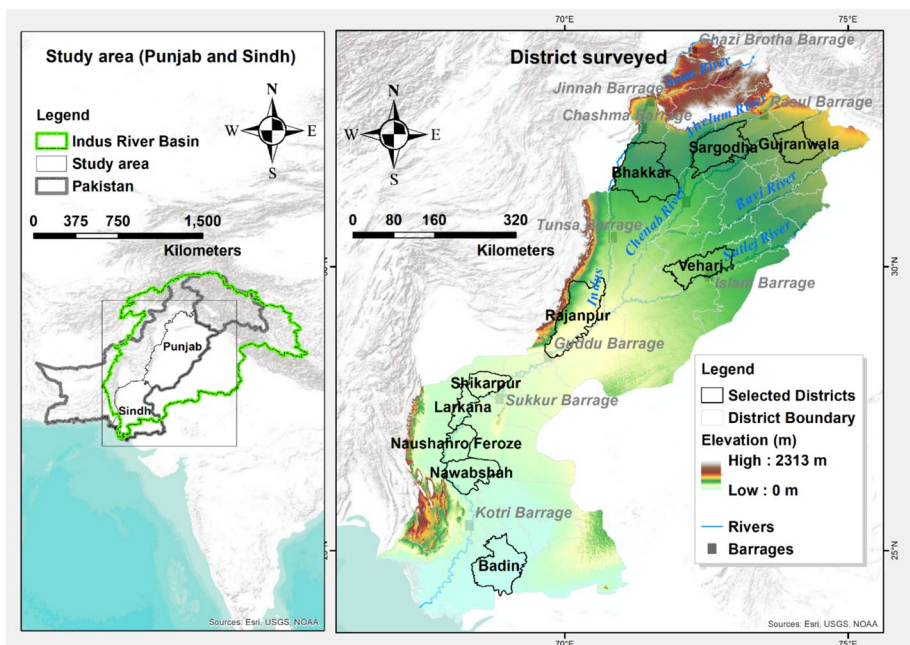
In Pakistan, the climate change perception and adaptation is well researched. The previous studies report diverse findings ranging from the negative impacts of changing temperature and climate change to some yield-increasing case studies. The perception of climate change and its effects are well recognized among the farming community, compelling them to adapt. The number of citations in a paper is a crucial metric for judging the influence and quality of research (Waltman 2016). The semantic scholar compiles extensive data based on these citations (Lwoga et al. 2017). Here we mention 10 highly cited ( $\geq 100$  citations) papers published after 2015 on climate change perception and adaptation in Pakistan's agriculture. Ali et al. (2017) studied the effects of climate on Pakistan's agriculture, highlighting the vulnerability of wheat production to climate change which has gotten more than 319 citations so far. They also investigated the vulnerability of farmers in Punjab to climate risks which are further aggravated by socioeconomic constraints, cited 187 times. Fahad and Wang (2018) explored the adaptive actions of farmers to climate variability through diversification strategies, despite systemic hindrances such as labor shortages and insecure land tenure. Their study has been cited 260 times, highlighting its significance in the field. The anticipated decline in cotton yield due to climate variability, as projected by Rahman et al. (2018), and the impacts of carbon emissions on various sectors, as investigated by Rehman et al. (2021), are notable contributions with 161 and 154 citations each. The alignment of farmers' perceptions with observed climatic trends, as discussed by Abid et al. (2018), and the demographic determinants of adaptive practices, as investigated by Khan et al. (2020), are critical insights from works cited 131 and 122 times, respectively. Abbas et al. (2017) addressed the accelerated phenology of maize, highlighted adaptive sowing practices as mitigation, was cited 114 times. Hussain et al. (2019) concluded the discourse by assessing climate change's broad impacts on Pakistan's agriculture and

economy. Their study was cited 107 times. This body of work collectively underscores the intricate dynamics of climate change impacts and adaptive behaviors within Pakistan's agricultural sector. Despite this extensive body of literature, there is a gap in the literature regarding the distinction between adaptation practices in irrigated agriculture from rain-fed agriculture (Torre et al. 2021) which is a vast area in Pakistan. The adaptation dynamics of irrigated and rainfed agriculture differ (Gopalakrishnan et al. 2019; Rockström, 2003).

## 4 Data and methods

### 4.1 Research design

We applied a quantitative research approach and developed a questionnaire to collect the data through face-to-face interviews with farmers from December 2021 to April 2022. We included small farmers with landholding up to 16 acres (Hussain & Thapa 2012) in the irrigated plains of Punjab and Sindh, Pakistan. We employed a sampling frame of 800 farmers from 10 districts covering 39 Tehsils/Talukas (district's subunits) with 80 samples from each district. Figure 1 illustrates the geographic location of our survey. Moreover, our survey excluded farmers with landholdings situated beyond the canal command areas within the districts studied.



**Fig. 1** Digital Elevation Model (DEM) of the study area



## 4.2 Description of the study area

The Indus Basin Irrigation System (IBIS) covers a total area of 16.85 million hectares (Mha). It consists of the Indus River and its tributaries; Kabul, Jhelum, Chenab, Ravi, Beas, and Sutlej (shown in Fig. 1). For irrigation control, the IBIS comprises three significant reservoirs, 12 inter-river link canals, and 44 main canals (Hasan et al. 2021; Steenberg et al. 2015). The region has the world's most extensive irrigation system, where almost 80% of the cultivated area is irrigated (Muhammad et al. 2016), producing 90% of the country's harvests (Zhu et al. 2013).

Our study focused on the irrigated regions within the Punjab and Sindh provinces, encompassing all the major rivers (excluding the Kabul River), every link canal, and a total of 39 main canals. Out of 16.85 Mha, 7.8 Mha of Punjab is irrigated with the help of 25 canals, two reservoirs, and seven barrages, while 5.3 million hectares of Sindh are irrigated with the help of three barrages and 14 canals. We selected this study area for two reasons; first, it contributes considerably to the country's agricultural output and is vulnerable to climatic change. The area shares borders with neighboring India from the east and the Khyber Pakhtunkhwa (KPK) and Baluchistan provinces from the west. It is approximately 40% of the total area of Pakistan, where 74% of the country's total population lives.

The soil of these plains comprises alluvium deposits accumulated by the river actions of the Indus River and its associated tributaries in the geological past. This soil property makes the area fertile for agricultural purposes. Pakistan is among the world's top ten producers of cotton, sugarcane, wheat, mango, dates, and Kinnow (citrus). Major crops (rice, cotton, wheat, and sugarcane) alone contribute 4.9% of Pakistan's economy (AARI 2024; FAO 2023). However, water resources in the region are highly stressed, whether judged by per capita water availability or by the ratio of withdrawals to runoff (Archer et al. 2010). The mean average temperature in Punjab ranges from  $-2^{\circ}$  to  $45^{\circ}$  C, and exceptionally reaches  $50^{\circ}$  C in summer and drops down to  $-8^{\circ}$  C in winter. In Sindh, temperatures rise above  $46^{\circ}$  C from May to August and drop to  $2^{\circ}$  C in winter. The interior of lower Sindh experienced up to  $53.5^{\circ}$  C in 2010, the fourth-highest reading ever recorded in Asia (Abbas et al. 2018; Huber & Gullede 2011). Recent calculations in 2021 estimate a decreasing precipitation trend all around Pakistan with  $-1.11$  mm/year (Ali et al. 2021). Most of the regions in Punjab province receive moderate to high rainfall ranging from  $\sim 275$  to  $830$  mm/year, while Sindh province receives  $\sim 150$  to  $180$  mm/year. The amount of rain declines if we approach from north to south.

The elevation of the Indus plains varies from 300 m in northern Punjab to 75 m near the southern border of Punjab, down to the Arabian Sea. In the plains, the slope fall rate is 0.3 m per 1.6 km (Khan 2016). The lower Indus Plain is part of Sindh province, the second largest province in population. Figure 1 shows the Digital Elevation Map of the area where we conducted our fieldwork. The area of both provinces is mainly agricultural, which is under stress due to the region's lack of rain and desertification trends.

## 4.3 Population and sampling

Small farmers (with landholdings  $\leq 16$  acres) cultivating irrigated areas of Punjab and Sindh were the population under study. In Pakistan, 80% of farmers own 28% of cultivable land. There are 7.4 million smallholders in Pakistan who hold less than 12 acres of land (5 hectares) (ASF 2021; GoP 2010; Khan 2022). We chose small farmers because they are



important to Pakistan's agriculture for several reasons. Firstly, most of them live in rural areas and make their living through agriculture. Secondly, small landholdings are so common throughout the country. Therefore, they are so important for a country's food security. Thirdly, small farmers are often the ones most affected by economic shocks and natural disasters because they don't have the money or credit that commercial farmers do. Therefore, small farmers are important for promoting sustainable farming practices because they depend more on natural resources and have more at stake in keeping them around for future generations. These small farmers are distributed in the entire IBIS of Punjab and Sindh province, which have 66 (36 + 30) districts. We used a multistage spatial cluster sampling strategy to select the respondents from these districts. Table 1 contains the distribution of our interviewees in our selected locations.

In the first stage, we chose an equal number of districts from both provinces. We selected five districts from Punjab and five from Sindh based on the physiographic and irrigation control of the provinces. We used the Punjab and Sindh physiographic and irrigation maps to select districts. Punjab plains are divided into four interfluves, while Sindh has relatively uniform physiography. In Punjab, Terbel and Mangal reservoirs provide water for irrigation. In Sindh, Guddu, Sukkur, and Kotri Barrage irrigate its agricultural land.

In Punjab, we randomly selected at least one district from each interfluve. We selected Bhakkar from Sagar doab, Vehari from Bari doab, Sargodha from Chaj doab, Gujranwala from Rachna doab, and Rajanpur from the lowermost part of Punjab. Terbel reservoir controls the irrigation of Bhakkar, Vehari, and Rajanpur, while Mangal controls the irrigation of the Sargodha district.

Sindh province has not had much physiographic heterogeneity in its irrigated areas. Therefore, in Sindh, we selected districts based on irrigation-controlling structures. We selected Shikarpur from the Guddu barrage, Badin from the Kotri barrage, and Larkana, Naushahro Feroze, and Shaheed Benazirabad from the Sukkur barrage.

In stage two, we covered all Tehsils and Talukas (Sub-unit of the district) in every district and visited a total of 39 Tehsils. In stage three, we randomly selected mauzas (the smallest revenue-collecting unit in Pakistan) based on the best spatial coverage of the Tehsil. In the last stage, we selected farmland and the respondents for the interview based on our convenient road connectivity to reach any farmer. Overall, 800 and precisely 80 farmers from each district were interviewed. We interviewed a minimum of 10 and a maximum of 35 farmers from each Tehsil, but our target for each district was 80 interviews. The number of Tehsils in each district is different, and the number of interviews in each Tehsil is varied. Table 1 shows the valid samples in every district and tehsils which we included in the study.

#### 4.4 Development of questionnaire and data collection

Similar to previous studies (Bhalerao et al. 2022, 2021), we developed a standardized questionnaire comprising 51 questions to study our research question. We divided perception into 16 questions, adaptation into 18 questions, constraints into eight questions, and decision-making variables into nine statements.

We subdivided the perception part into the following categories: Perception about climatic indicators (CI), Perception about soil (SO), Perception about climatic hazards (CH), Perception about farming (FA), and Perception about water (WA). We categorized adaptation into three categories; Crop management (CM), Farm management (FM), and Irrigation management (IM). We adapted these categories from the adaptation paradigm

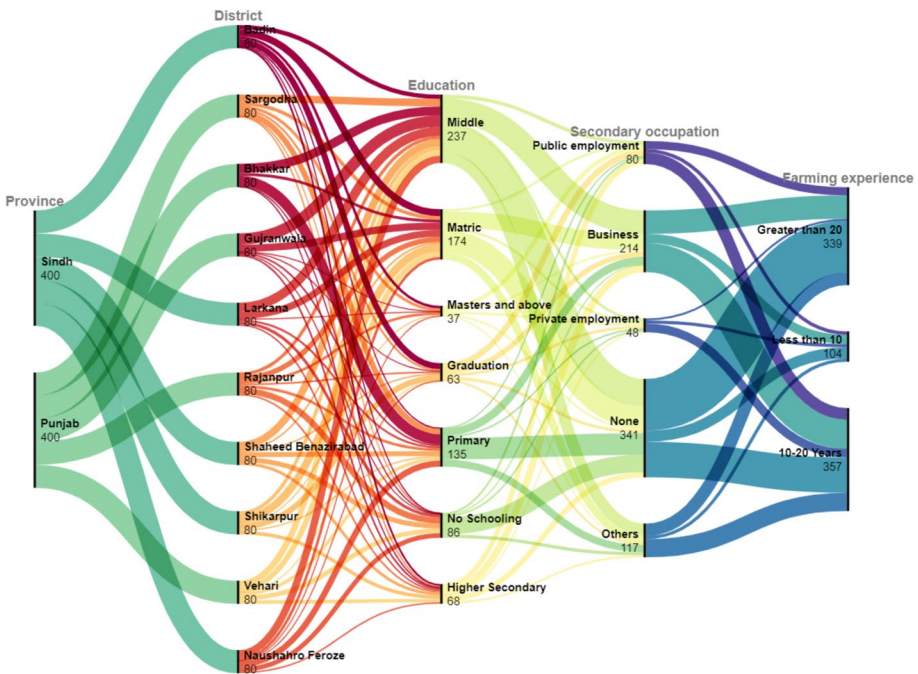
model of farmers (Zobeidi et al. 2022). We grouped the constraints section into Human constraints (HCO) and Natural constraints (NCO), while factors of decision-making are classified as Climatic Factors (CF) and Non-climatic Factors (NF).

We then asked the respondents to rate each of these items on a five-point Likert scale ranging from strongly disagree to strongly agree. The scale contains a neutral option in the middle of disagreement and agreement. The Likert scale is a psychometric response scale in which respondents indicate their level of agreement with a statement ranging from strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5) (Robinson 2014). In addition to survey data, we used smartphone GPS applications to gather coordinates of the farmland to provide a more accurate spatial representation of our inquiries.

At the start of the questionnaire, we added a section of basic socio-demographic information about our respondents. Figure 2 shows our respondents' education, farming experience, and secondary occupation.

Before field visits, we provided off-field and in-field training to the enumerators. We briefed them regarding the objective of our study and data collection methods. We conducted five online interviews with farmers in the Gujranwala district to pre-test the questionnaire. We paraphrased the questions statements and added measurement units of area and distance with the open-ended questions based on the pre-test results.

We were able to collect 913 questionnaires in total. However, out of 913 questionnaires, we rejected 113 because of their multiple quality issues, such as double entries (27), incomplete (19), respondents' misconduct (44), and legibility issues (23). In the end, we were left with 800 questionnaires for our analysis.



**Fig. 2** Socio-demographic traits of respondents

### 4.5 Data analysis

We used the Statistical Package for the Social Sciences (IBM SPSS Statistics; Version 28.0.1.1) for data tabulation and coding. We employed the Likert package in RStudio for the Likert plots and analysis and ArcGIS 10.8 to map the Digital Elevation Model (DEM) and the spatial distribution of adaptation in our study area. DEM Shuttle Radar Topography Mission (SRTM) was applied with a spatial resolution of 3 arcsecs (~90 m) as input, derived from C-band images obtained during 11–22 February 2000 flown over the study area. The DEM dataset was downloaded from USGS Earth Explorer using the link: <https://earthexplorer.usgs.gov/>. We used an open-source online platform, i.e., <https://app.rawgraphs.io/>, for alluvial visualization (Fig. 2) of the socio-demographic information of our respondents.

To explore the respondents’ perceptions of climate change, we prepared the Likert scale data into SPSS. We imported this data into RStudio for the Likert plot, which ranked respondents’ perceptions from low to high (Fig. 3). A similar method was used to plot the adaptation (Fig. 4) on a five-point scale. To investigate the adaptation level, we recorded the data from a five-point scale of adaptation to a four-point scale ranging from no adaptation to low, medium, and high (see Figs. 5 and 6). We summarized the score of all items in the crop, farm, and irrigation management and plotted results (Fig. 7) to understand the trends in different adaptation categories. To explore the spatial variation of adaptation in the study area, we calculated the mean for the adaptation levels of every Tehsil and mapped it (Fig. 8). We separated the number of adaptors

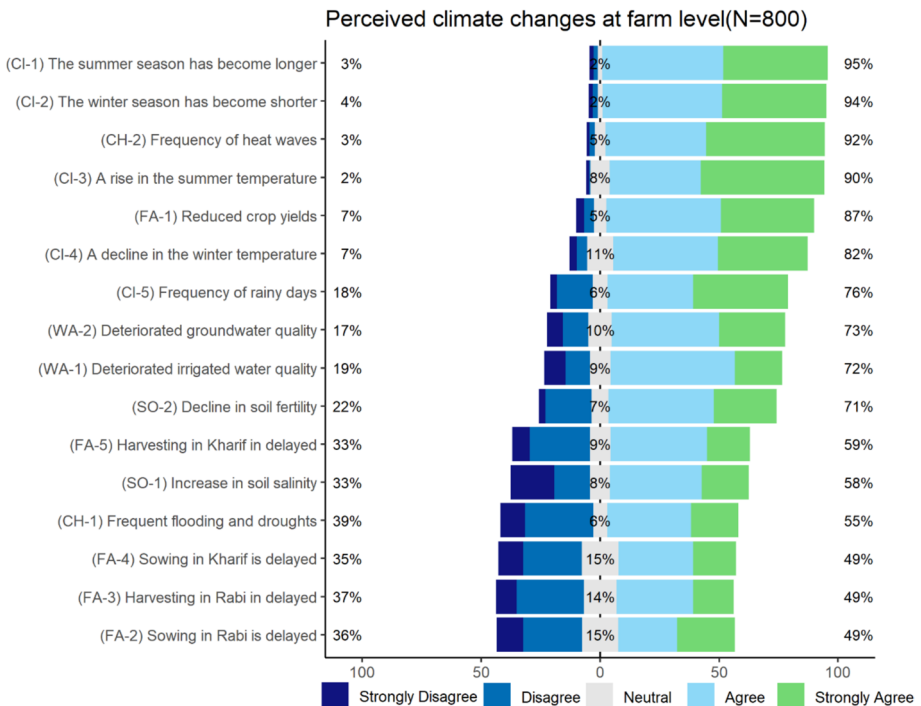
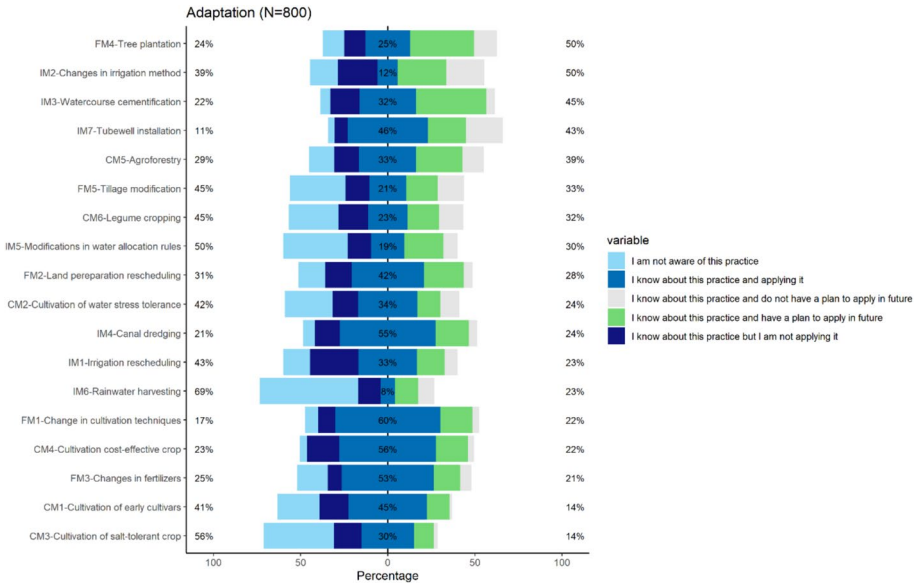
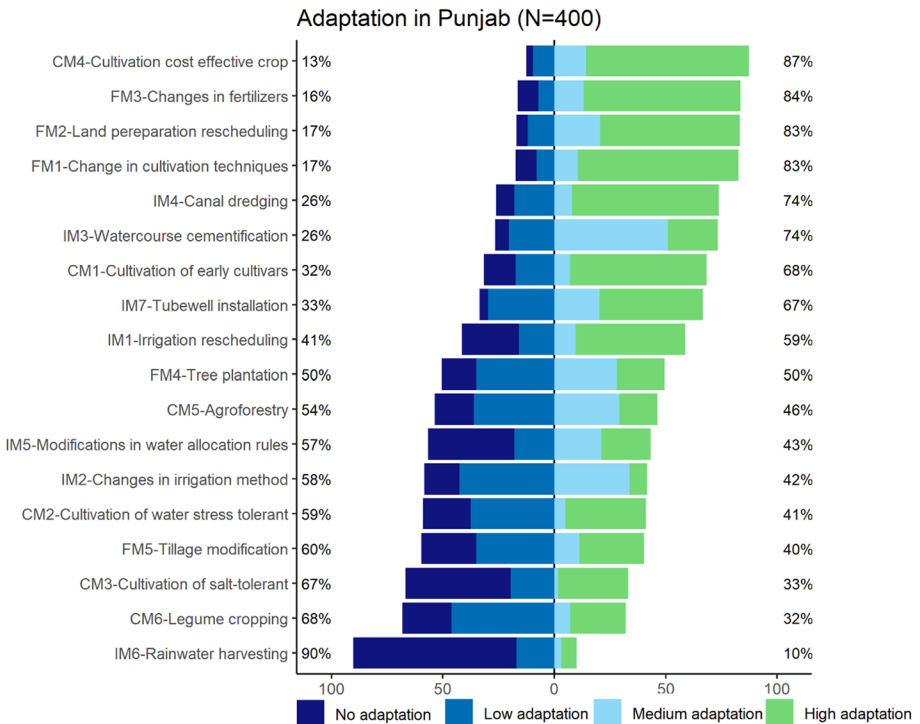


Fig. 3 Perception of climate change impacts



**Fig. 4** Implementation of adaptation strategies



**Fig. 5** Adaptation strategies and levels in Punjab

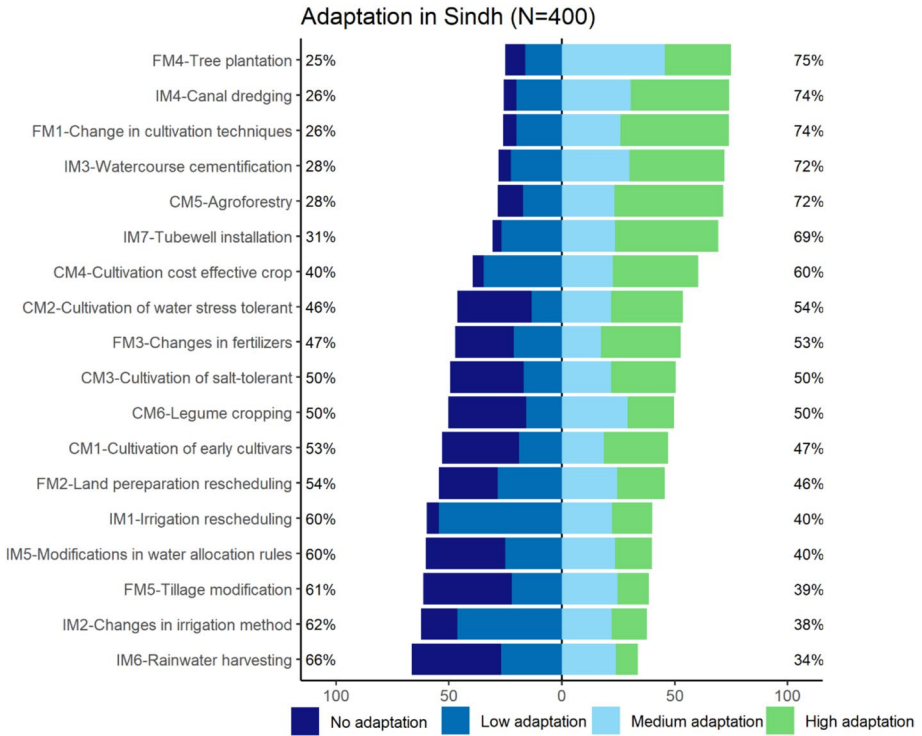
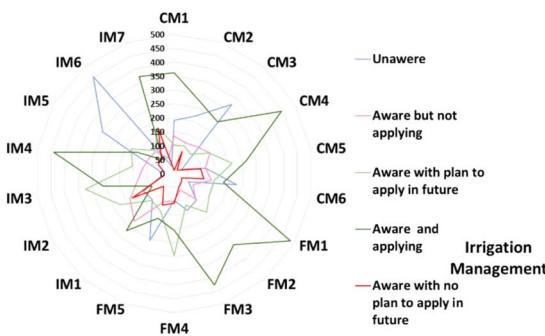


Fig. 6 Adaptation strategies and levels in Sindh

(a) Knowledge and implementation of adaptation



(b) Adaptation in Punjab and Sindh

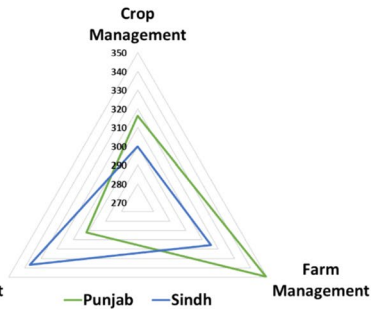
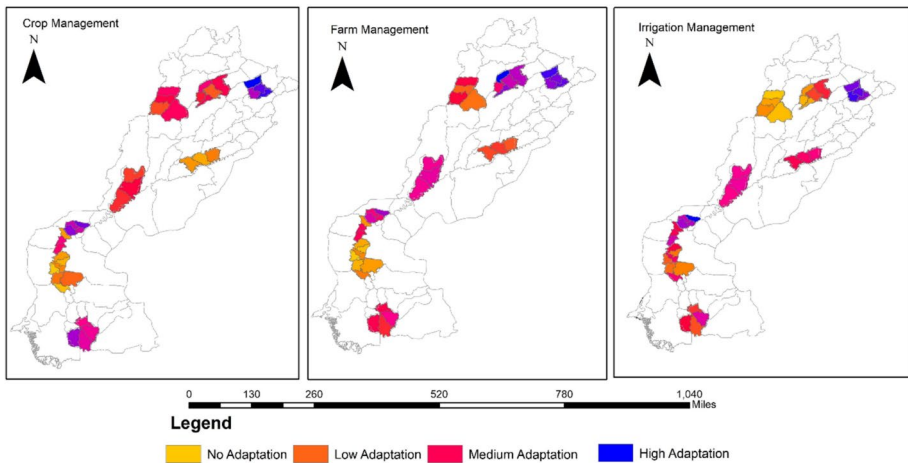


Fig. 7 a and b Provincial comparison of adaptation levels in different categories

and non-adaptors in crop, farm and irrigation management (see Table 2) in Punjab and Sindh province. To analyze constraints and factors of decision-making, we used the same ranked Likert plots using the Likert package in RStudio (Figs. 9 and 10).



**Fig. 8** Spatial distribution of adaptation strategies in Punjab and Sindh

## 5 Results

### 5.1 Socio-demographic profile of respondents

A significant observation from the socio-demographic profile of our respondents is (see Fig. 2) that the majority of farmers have education up to the middle level (237), while 86 still have no schooling. Regarding their farming experience, most of the farmers, 85%, have more than 10 years of experience in farming. There is a trend of their engagement in secondary occupations like small-scale business (214), public (80), and private (48) employment but a substantial number of farmers (341) do not have a secondary occupation, underscoring their dependence on agriculture.

### 5.2 Farmer's perception of climate change and its impact

More than 94% of farmers perceive the lengthened summer (CI-1) and shortened winter (CI-2) (Fig. 3). About 65% of the farmers noticed an increase in the summer temperature, while 26% believed the winter temperature increased. 76% of respondents agreed that the frequency of rainy days (CI-5) has increased, as 76% of our respondents agreed with our statement.

Regarding the perception of climate change impacts on soil (SO), 71% of farmers noticed a decline in soil fertility (SO-2), while 58% perceived salinity problems in the soil (SO-1) over the last ten years. Regarding Perception of Climatic Hazards (CH-), farmers believed heat waves (CH-2) to be the most common climatic hazard, with 92% agreeing. In comparison, 55% of farmers saw frequent flooding and drought (CH-1) as their region's most common climate extremes. Regarding the impacts of climate change on farming, 87% perceived low crop yields (FA-1) due to climate change over the last ten years. We also found perceived changes in the cropping calendar. 49% of farmers noticed delays in sowing during Rabi and Kharif (FA-2, FA-4) season. The same percentage of farmers (49%)

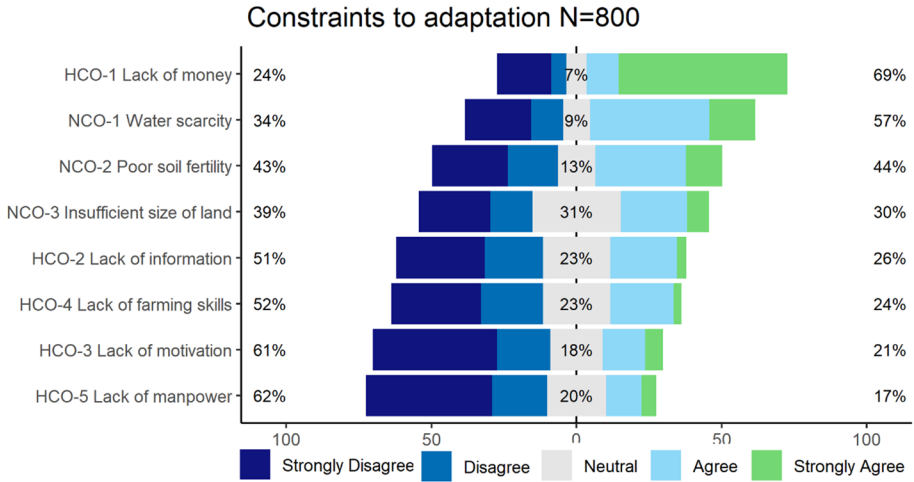
**Table 2** Valid Sample details from every Tehsil and Taluka

Province	Districts	Tehsils/Taluka	Valid Sample
Punjab	Sargodha	Sargodha	12
		Bhalwal	23
		Sahiwal	32
		Shahpur	13
	Bhakkar	Bhakkar	25
		Mankera	22
		Darya Khan	20
		Kallur Kot	13
		Gujranwala	07
	Gujranwala	Wazirabad	24
		Noshera	17
		Kamoke	32
		Rajanpur	29
		Jampur	26
	Rojhan	Rojhan	25
		Vehari	24
		Mailsi	35
	Burewala	Burewala	21
		Tando Bago	24
		Matli	17
	Sindh	Badin	Badin
Golarchi			14
Larkana			08
Rato Dero			22
Shaheed Benazirabad		Shahdad Kot	13
		Dokri	23
		Kambar Ali	14
Shikarpur		Nawabshah	33
		Daulat Pur	23
		Sakrand	24
Naushahro Feroze		Garhi Yasin	23
	Shikarpur	23	
	Khanpur	15	
	Lakhi	19	
Total	Naushahro Feroze	Naushahro Feroze	14
		Bhiria	28
		Kandiaro	26
		Moro	12
<b>Total</b>			<b>800</b>

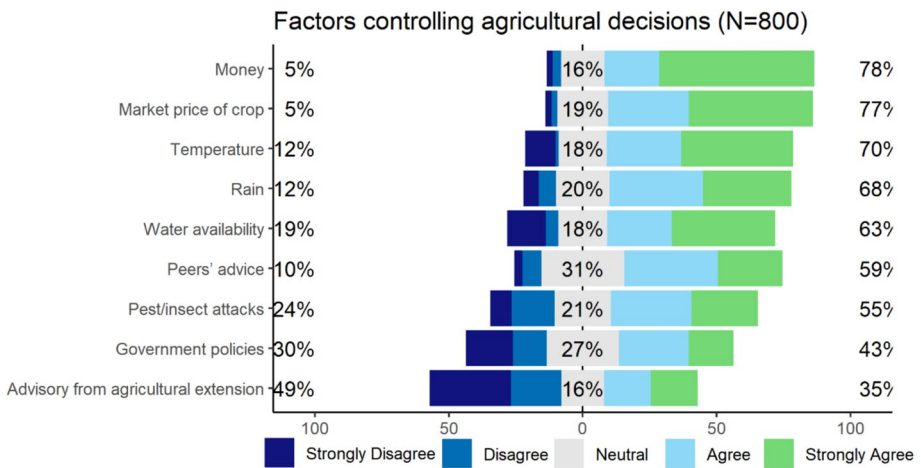
perceived that the harvesting in the Kharif season has also been delayed in the last ten years.

Interestingly, our results reveal that the vast majority of the farmers (more than 90%) perceived changes in the climatic indicators. However, only half of the respondents (49%)





**Fig. 9** Constraints to adaptation (HCOs are Human constraints; NCOs are Natural constraints)



**Fig. 10** Factors of farmer’s adaptation decision making

could translate these changes to their cropping calendar. Finally, regarding climate change’s effects on water quality, we found that 73% believed groundwater quality has deteriorated. In comparison, 72% of the respondents’ irrigation water quality has declined over the last ten years.

### 5.3 Adaptation measures and their implementation

Our results show that most farmers (60%) have adapted to changes in their cultivation techniques (see Fig. 4). They started using hybrid seeds and shifting to a crop variety that a farmer could harvest early. Due to the recent hike in inflation in Pakistan, farmers have

shifted to cost-effective crops (56%). The farmers prioritized cheaper seeds rather than their higher productivity. More than half of the farmers (53%) changed their fertilizers. However, the underlying reason for fertilizer change was inflation or the marketing of fertilizer and pesticide companies.

As the study area was the irrigated region of Pakistan, rainwater harvesting is not even known to most farmers. Few farmers are just aware of the practice but are not applying it. Cultivating salt-tolerant crops has been introduced by some agriculture research institutes, especially in the Punjab region. However, most people (56%) are unaware of them, and some are aware but unable to implement them on their farms. Regarding Irrigation-related management (IM), canal dredging (IM4) is the most widely implemented adaptation practice (55%). Tube well installation has been adapted by 46%, while almost half of them cannot install it due to its high economic cost. In some areas, local modification of irrigation rules (IM5) is in practice (19%), but most farmers are unaware of it. Only 25% are applying plantation on the farm (FM4).

#### 5.4 Adaptation level in Punjab and Sindh

Figures 5 and 6 compare the adaptation levels in both provinces (Punjab  $N=400$  and Sindh  $N=400$ ) in our study area. To represent the degree of adaptation, we categorized adaptation into no adaptation, low, medium, and high adaptation levels in crop, farm, and irrigation management adaptation practices.

In Punjab, the overwhelming majority (87%) practice cost-effective cropping (CM4), 84% tried different fertilizers (FM3), and 83% adapted changes in the scheduling of their farmland preparation (FM2). Regarding the least practiced adaptations, only 10% adapted to rainwater harvesting (IM6), 32% adapted through legume cropping (CM6), and 33% sifting to salt-tolerant cropping (CM3).

Farmers in Punjab adapted early cultivars (68%). The agriculture of Punjab is more market-oriented than that of Sindh because 87% of the farmers in Punjab adapted to cultivate cost-effective crops, while this percentage is 60% in Sindh (see Fig. 6).

In Sindh, 75% adapted with on-farm tree plantation (FM4) due to intense heat waves during recent times, 74% applied canal dredging (IM4), and 74% adapted through changes in cultivation techniques (FM1). On the other hand, only 34% apply rainwater harvesting (IM6), and 38% change their irrigation methods (IM2). In addition, almost 40% are employing tillage and water allocation rules. Table 2 shows our field survey data on individual adaptation practices by farmers in the Punjab and Sindh provinces. We show here the adaptors and non-adaptors in crop, farm, and irrigation management in both provinces. In Sindh, tree plantation (75%) and agroforestry (72%) are better adapted than in Punjab (50% and 46%, respectively). It is because of the heat waves and hotter summer in the region where the temperature touches 52 to 53 C Table 3.

Figures 7 a and b compare adaption in the provinces of Punjab and Sindh. Farmers in Punjab switched to farm management strategies rather than irrigation. Adaptive crop management practices are also more common in Punjab than in Sindh. In irrigation management, however, farmers in Sindh (337) adapted better than those in Punjab (302). Table 2 and Fig. 7 a show our findings from individual adaptation measures.

The map below (Fig. 8) shows the spatial distribution of adaptation actions within our study units. In our study area, we plot the computed adaptation score of crop management, farm management, and irrigation management for 39 spatial units (Tehsils and Talukas).

**Table 3** On-farm adaptation in Punjab and Sindh, Pakistan

Adaptation		Punjab ( <i>n</i> = 400)		Sindh ( <i>n</i> = 400)	
	Code	Adaptors	Non-Adaptors	Adaptors	Non-Adaptors
Crop Management	CM1	343	57	264	136
	CM2	314	86	268	132
	CM3	210	190	269	131
	CM4	389	11	381	19
	CM5	330	70	355	45
	CM6	312	88	262	138
	Avg	316	84	300	100
Farm Management	FM1	363	37	377	23
	FM2	381	19	296	104
	FM3	364	36	296	104
	FM4	338	62	365	35
	FM5	301	99	243	157
	Avg	349	51	315	85
Irrigation Management	IM1	298	102	379	21
	IM2	337	63	336	64
	IM3	376	24	379	21
	IM4	367	33	378	22
	IM5	244	156	259	141
	IM6	105	295	242	158
	IM7	386	14	385	15
	Avg	302	98	337	63

In crop management, the northernmost (Gujranwala) and the southernmost (Badin) districts have the highest adaptation, while the southern Punjab region (Vehari and Rajanpur) has very low or no adaptation. In Farm management, the two northern districts in Punjab province (Gujranwala and Sargodha) showed the highest adaptation score. District Vehari in Punjab is again found low in adapting strategies at the farm. Interestingly irrigation management is the highest in Gujranwala and medium in Rajanpur. District Bhakkar (half desert) was the lowest in adapting irrigation-related adaptation strategies. There is no clear trend in the lower Indus plains (Sindh), whereas it shows a mix-up of all possible adaptation scores (low to high).

## 5.5 Constraints and factors in adaptation

Despite having enough realization regarding climate change in our study area, many farmers did not make significant adjustments to their farming. We identified and ranked some constraints preventing farmers from adopting different climate change mitigation strategies. We found that a lack of financial resources (cited by 69% of respondents) was the most significant barrier to adaptation.

We found that water scarcity (57%) and poor soil fertility (44%) are second and third if we rank the constraints to adaptation. Figure 9 expresses the constraints faced by the farmers in our study area. A previous study found inadequate irrigation supplies and knowledge about appropriate adaptation options were significant roadblocks to the adaptation process (Ali & Rose 2021). (Shah et al. 2022) recently reported financial constraints (28%), lack of knowledge and information (25%), and inadequate farm resources (23%) in the northwestern province of Pakistan.

We see factors as variables that influence farmers' decisions. Figure 10 shows the ranking of agricultural decision-controlling factors in our study area. We found that financial liquidity and crop price sensitivity are the critical factors that control farmers' farming decisions in our study area with their significance quantified at 78% and 77%, respectively. Interestingly, climatic factors (temperature 70%, rain 68%, water availability 63%, and pest attacks 55%) are secondary if we compare them with money-related factors. According to Bryan Bryan et al. (2013), wealth, access to extension services, credit, and knowledge of the local climate are all factors that affect farmers' decisions to adapt in South Africa and Ethiopia.

## 6 Discussion

This study was aimed to highlight farmers' perceptions of climate change, their adaptation strategies, and the constraints they face and factors that shape their decision making in the irrigated plains of Punjab and Sindh, Pakistan. Our findings confirm that climate change is a key challenge in the region shaping perception and adaptation decisions, as evidenced by the significant impacts on crop yields and water quality reported by farmers in both provinces.

Climate change is a daunting challenge for a fragile farming system in Pakistan (Syed et al. 2022). Rising temperatures and shifts in precipitation patterns in the Indus Plains are reported (Mobeen et al. 2017). According to our survey results, farmers in Punjab and Sindh provinces perceive changing seasonal patterns, which aligns with Bhatti et al. (2019). According to Abbas (2013), rising heat waves and more rainy days are severe challenges for agricultural practices in Pakistan. Several studies (Abid et al. 2019; Arshad et al. 2017) have yielded similar outcomes in the last five years. In situ meteorological observations from 1981–2010 also reported extended summers by 4.19 nights and 0.92 days per decade (Abbas 2013).

Most farmers are well aware of climate change and believe it is one reason for their low crop yield. In addition, most respondents believe climate change is responsible for deteriorated irrigated water and groundwater quality in the last ten years. Shah et al. (2019) also reported the perceived decline in irrigated water quality and groundwater table.

Climate changes and subsequent regional perception shifts influenced agricultural practice in all respects. Especially the effects of climate change on agricultural output in Punjab province have been the subject of extensive research (Bashir & Mobeen 2018), which reported a decline in productivity due to climate change. Scientific literature highlights that climate change is fueling existing problems and creating new ones, such as changes in rainfall and temperature, which are pushing farmers to change their cultivation practices for better results. Scheffran et al. (2012) investigated this nexus of defining the role of climate change, which was later reported on by Froese and Schilling (2019); Ide et al. (2016).

Adaptation to climate change is a complex process requiring a sound understanding of how farmers perceive and interpret climatic changes locally (Abbas et al. 2022). According to our survey, the awareness of adaptation strategies varies from place to place. Farmers in Sindh are less likely to be aware of improved crop varieties and cultivation methods, which is not the case in Punjab. Therefore, the farmers in Punjab have strongly adopted to salt-tolerant and water-stress-tolerant crop varieties. Farmers in Punjab are also adapted to cultivating early cultivars, especially in upper Punjab. Another contrast is that the agriculture of Sindh is less market-oriented than that of Punjab because 87% of the farmers in Punjab adapted to cultivate cost-effective crops, while this percentage is 60 in Sindh. Tree plantation (75%) and agroforestry (72%) are more adapted in Sindh, while in Punjab, the percentage is 50 and 46, respectively. The underlying cause of this disparity could be heat waves and a hotter summer in the region where temperatures reach 52 to 53 °C.

Lack of knowledge regarding adaptation measures is a significant cause of low adaptation rates in rural areas. We found that many farmers in the Indus Plain were unaware of many useful adaptation measures. For example, farmers do not know enough about using salt-tolerant crop varieties, legume cropping, tillage modification, local modification of irrigation rules, and rainwater harvesting. The agriculture extension department should address the lack of awareness by launching an awareness campaign in rural areas.

Many farmers knew the possible adaptation practice but could not apply it despite their positive adaptation intention. For example, cultivation of high revenue-producing crops, irrigation rescheduling, watercourse certification, and new tub well installation are those measures that are well known to most farmers. They want to adopt these measures but cannot do it due to insufficient resources. Therefore, we recommend that governmental financial institutions and banks dispense interest-free loans and subsidies.

An appropriate adaptation strategy needs a clear understanding of farmers' perception of climatic patterns and the drivers and constraints to adaptation (Esham & Garforth 2013). However, despite realizing enough about climate change in our study area, many farmers did not significantly adjust their farming.

Surprisingly, there were a large number of farmers who were well aware of some helpful adaptation practices but were not ready to implement them. We can attribute this adaptation delay to perceived constraints and decision-making factors. Nevertheless, we need to explore this further from the behavioral study viewpoint. In our results, we found that some farmers were not ready to adapt even though they were pretty sure about the benefit of some adaptation measures. For example, 42% farmers avoided installing new tube wells to address water shortage due to their high cost. However, they did not apply even the low-cost measures, i.e., Changing irrigation methods (43.5%) and local modification of irrigation rules (16.25%). The reason behind this behavior is worth exploring for future research regarding climate change adaptation in Pakistan's agriculture sector. Some studies dealt with this behavior as cognitive dissonance of the people (Oswald & Bright 2022).

The main constraints to adaptation in the study area are lack of money, water scarcity, poor soil fertility, and small landholdings. The fact is in line with the findings of a study (Ali et al. 2020) in different agro-ecological units of Punjab province, which also identified that lack of money, high cost of farm inputs, and lack of knowledge about appropriate adaptations are the most critical constraints in adaptation practices. In another study (Bhalerao et al. 2022) in mountainous regions in India, most farmers (68.1%) indicated that the high cost of agricultural inputs is the most significant constraint, which slows down the adaptation process. Financial resource is a universal factor as it is equally influential all around the globe. Even in the developed world, Australia's major adaptation constraint was high production costs and debt (Brown et al.

2016). These constraints work as a deterrent factor in the adaptation process. On the other hand, larger farmer landholding size, capital, farming experience, farmer education level, soil fertility, water availability, and access to the latest information can positively affect the adaptation process. The lower value of any of these factors limits the farmer's capability to adapt or act.

We found an evident spatial variation in adaptation levels across the study area. This contrast may be due to farmers' heterogeneous capabilities and constraints across the region. In our findings, the magnitude of constraints is also different in different areas. Lack of financial resources is our study area's most widespread constraint on adaptation. To address this constraint, the government of Pakistan introduced many subsidies and financial loan schemes through banks. However, most farmers were reluctant to use bank credit financing due to high-interest rates and cumbersome documentary procedures. Simplifying this loan procurement procedure through banks can help farmers to deal with their problems (Saqib et al. 2016). However, the literature reports that such loans are not used to address agricultural challenges. Instead, they are used for non-farm expenditures like farmers' leisure activities and purchasing household items of daily use (Shabir et al. 2020).

According to our findings, poor soil fertility is another critical constraint in the Indus Plain. Low soil fertility is also a limiting factor that deters farmers from adopting new crop varieties. The studies have reported multiple soil nutrient deficiencies in the intensive cropping regions, especially cotton-wheat cropping areas of Sindh (Bux et al. 2022). The soil fertility loss was significantly improved when sustainable soil management and fertilizer treatment were applied in the affected regions of Punjab (Qazi & Khan 2021). Smaller landholdings are another constraint in adapting new adaptation measures. Saqib et al. (2016) reported that smaller landholdings in Sindh were a significant factor in low credit access to the farmers.

Various factors influence farmers' decisions, and there are multiple ways of grouping these factors (Chilonda & Van Huylenbroeck 2001). We grouped these factors into climatic and non-climatic factors. The farmers rated climatic factors significantly, but financial resources from the non-climatic factor group were found to be the most influential factor influencing their decisions. We also found that the role of government agricultural advisory and government policies significantly influences the decision of farmers. Peer advice is rated more important than advisory services in the region. This is typical of underdeveloped social structures where informal social capital is trusted more than formal, which was studied by Escandon-Barbosa et al. (2019).

The above discussion highlights some important underlying dimensions shaping the perception and adaptation decisions of the farmers. First, the differential adaptation responses between Punjab and Sindh indicate a broader socio-economic and cultural landscape influencing farmers' decisions beyond purely climatic factors. This disparity suggests further study of some localized solutions, sensitive to the socio-economic and cultural context of each province. Secondly, the role of financial constraints in shaping adaptation decisions reveals the deeper problem with resource accessibility among the farming community. The focus on economic constraints and the prioritization of cost-effective crops over higher productivity options reflect a survival strategy rather than optimal agricultural practice. This hints at the untapped potential for significant yield improvements through intervention. Furthermore, the high awareness about climate change impact as well as the gap in implementations of adaptation options indicate a knowledge transfer bottleneck. This situation highlights the need for a localized agricultural extension program to disseminate adaptation options.

## 7 Conclusion

The farmers in the Indus Plains have a significant perception of frequent heat waves, an extended summer, and a contracted winter. However, half of them can translate this seasonal change into changes in their cropping calendar. They strongly perceive the decline in crop yields in the last ten years because of climate change. Farmers in our study area report a loss of soil fertility and a decline in irrigated water quality. Most farmers are aware of the majority of adaptation options and have already adopted the measures. In Punjab, the farmers adapted more to crop and farm management; in Sindh, the farmers adapted to irrigation-related arrangements. It indicates that the water problem is more pronounced in the lower riparian region than in the upper riparian region, suggesting a critical need for policies that facilitate effective adaptation strategies, especially in resource-limited settings.

Future research can explore this variation of adaptation strategies in the Indus Plains. Rainwater harvesting is unknown to most of the farmers in the region. Recognizing the economic constraints highlighted by our findings, we advocate for targeted interventions such as promoting rainwater harvesting to cope with water challenges, using solar energy for tube wells to deal with energy crises, and integrating credit financing to mitigate financial challenges. Targeted subsidies for strategically important crops or regions most affected by climate change could enhance farmers' financial capacity, similar to the current cotton subsidies in the south Punjab region, ensuring sustainability and economic viability..

The use of organic fertilizers (manure use) should be promoted as they incur a meager cost, offering a cost-effective method to improve soil fertility. We identified knowledge gaps about some important adaptation options. For example, there is a lack of knowledge about new irrigation methods, legume cropping, and new crop varieties. An information campaign with the help of the agriculture extension department can be helpful to close these gaps. We also revealed that some farmers are not ready to adapt despite knowing the benefits of adaptation, and some have delayed their adaptation actions for the future. Exploring the reluctance to make adaptation decisions should be the subject of future research.

Constraints and factors, we believe, play moderating roles in the adaptation process. Lack of financial assets, limited water availability, poor soil fertility, inadequate land size, and a lack of information related to adaptation measures were significant constraints at the farm level. We also discovered that money and the market were important factors in Pakistani farmers' decisions, underscoring the necessity for targeted educational programs and financial support mechanisms. The farmers perceive the role of natural factors (temperature, rainfall, and water availability) as less important than the availability of financial resources. To address the lack of financial resources, timely payment for the crop from the mill owners, credit financing from banks, and subsidies on electricity can show good results.

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**Data availability** This paper is based on primary data, which can be provided upon request to the first author.

## Declarations

**Conflicts of interest** The authors declare that they have no conflict of interest.

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## References

- AARI (2024) World Food and Agriculture Statistical Yearbook 2023. Ayub Agricultural Research Institute Retrieved 2024/03/05 from [https://aari.punjab.gov.pk/pak\\_ranking](https://aari.punjab.gov.pk/pak_ranking)
- Abbas F (2013) Analysis of a historical (1981–2010) temperature record of the punjab province of Pakistan. *Earth Interact* 17(15):1–23. <https://doi.org/10.1175/2013ei000528.1>
- Abbas G, Ahmad S, Ahmad A, Nasim W, Fatima Z, Hussain S, Rehman MH, Khan MA, Hasanuzzaman M, Fahad S, Boote K, Hoogenboom G (2017) Quantification the impacts of climate change and crop management on phenology of maize-based cropping system in Punjab, Pakistan. *Agric for Meteorol* 247:42–55. <https://doi.org/10.1016/J.AGRFORMET.2017.07.012>
- Abbas F, Rehman I, Adrees M, Ibrahim M, Saleem F, Ali S, Rizwan M, Salik MR (2018) Prevailing trends of climatic extremes across Indus-Delta of Sindh-Pakistan. *Theoret Appl Climatol* 131(3):1101–1117. <https://doi.org/10.1007/s00704-016-2028-y>
- Abbas Q, Han JQ, Bakhsh K, Ullah R, Kousar R, Adeel A, Akhtar A (2022) Adaptation to climate change risks among dairy farmers in Punjab Pakistan. *Land Use Policy* 119:106184. <https://doi.org/10.1016/j.lusepol.2022.106184>
- Abdullah SMF, Ahmed SI, Husain E, Hasan F, Ahmed S (2023) Drought Assessment of a Data-Scarced Watershed – Quetta Valley, Pakistan. *Jordan J Civil Eng.* <https://doi.org/10.14525/jjce.v17i2.11>
- Abid M, Scheffran J, Schneider UA, Ashfaq M (2015) Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province Pakistan. *Earth Syst Dynam* 6(1):225–243. <https://doi.org/10.5194/esd-6-225-2015>
- Abid M, Schilling J, Scheffran J, Zulfiqar F (2016a) Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan. *Sci Total Environ* 547:447–460. <https://doi.org/10.1016/j.scitotenv.2015.11.125>
- Abid M, Schneider U, Scheffran J (2016b) Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. *J Rural Stud* 47:254–266. <https://doi.org/10.1016/J.JRURSTUD.2016.08.005>
- Abid M, Scheffran J, Schneider U, Elahi E (2018) Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environ Manage* 63:110–123. <https://doi.org/10.1007/s00267-018-1113-7>
- Abid M, Scheffran J, Schneider UA, Elahi E (2019) Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environ Manage* 63(1):110–123. <https://doi.org/10.1007/s00267-018-1113-7>
- Adnan S, Ullah K, Gao S, Khosa AH, Wang Z (2017) Shifting of agro-climatic zones, their drought vulnerability, and precipitation and temperature trends in Pakistan. *Int J Climatol.* <https://doi.org/10.1002/joc.5019>
- Ahmad S, Tariq M, Hussain T, Abbas Q, Elham H, Haider I, Li X (2020) Does Chinese FDI, Climate Change, and CO2 Emissions Stimulate Agricultural Productivity? An Empirical Evidence from Pakistan. *Sustainability*, 12(18), 7485. <https://www.mdpi.com/2071-1050/12/18/7485>
- Ahmad MM (2021) Indigenous farmers' perception of climate change and the use of local knowledge to adapt to climate variability: a case study of Vietnam. *J Int Dev.* <https://doi.org/10.1002/jid.3573>
- Ahmed K, Shahid S, Wang X, Nawaz N, Khan N (2019) Evaluation of gridded precipitation datasets over arid regions of Pakistan. *Water.* <https://doi.org/10.3390/w11020210>

- Ahmed M, Schmitz M (2011) Economic assessment of the impact of climate change on the agriculture of Pakistan. *Bus Econ Horizons*, 4. <https://doi.org/10.15208/beh.2011.1>
- Ajzen I (1985) From intentions to actions: a theory of planned behavior. [https://doi.org/10.1007/978-3-642-69746-3\\_2](https://doi.org/10.1007/978-3-642-69746-3_2)
- Ali MF, Rose S (2021) Farmers' perception and adaptations to climate change: findings from three agro-ecological zones of Punjab Pakistan. *Environ Sci Pollut Res* 28(12):14844–14853. <https://doi.org/10.1007/s11356-020-11472-x>
- Ali MF, Ashfaq M, Hassan S, Ullah R (2020) Assessing indigenous knowledge through farmers' perception and adaptation to climate change in Pakistan. *Polish J Environ Stud* 29(1):525–532. <https://doi.org/10.15244/pjoes/85194>
- Ali G, Sajjad M, Kanwal S, Xiao T, Khalid S, Shoaib F, Gul HN (2021) Spatial–temporal characterization of rainfall in Pakistan during the past half-century (1961–2020). *Sci Rep* 11(1):6935. <https://doi.org/10.1038/s41598-021-86412-x>
- Ali S, Liu Y, Liu Y, Ishaq M, Shah T, Abdullah, Ilyas A, Din I U (2017) Climate change and its impact on the yield of major food crops: evidence from Pakistan. *Foods* 6. <https://doi.org/10.3390/foods6060039>
- Arbuckle JG, Morton LW, Hobbs J (2013) Farmer beliefs and concerns about climate change and attitudes toward adaptation and mitigation: evidence from Iowa. *Climatic Change*. <https://doi.org/10.1007/s10584-013-0700-0>
- Archer DR, Forsythe N, Fowler HJ, Shah SM (2010) Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. *Hydrol Earth Syst Sci* 14(8):1669–1680. <https://doi.org/10.5194/hess-14-1669-2010>
- Arshad M, Kächele H, Krupnik TJ, Amjath-Babu TS, Aravindakshan S, Abbas A, Mehmood Y, Müller K (2017) Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. *Int J Sust Dev World* 24(6):532–544. <https://doi.org/10.1080/13504509.2016.1254689>
- Aryal JP, Sapkota TB, Khurana R, Khatri-Chhetri A, Rahut DB, Jat ML (2019) Climate change and agriculture in south asia: adaptation options in smallholder production systems. *Environ Dev Sustain*. <https://doi.org/10.1007/s10668-019-00414-4>
- ASF. (2021). *IFAD – organizing smalholder farmers in Pakistan*. Agribusiness Support Fund (ASF). Retrieved 02 March from <https://agribusiness.org.pk/news-and-events/ifad-organizing-smallholder-farmers-in-pakistan/>
- Bagambilana FR, Rugumamu WM (2023) Determinants of farmers' adaptation intent and adoption of adaptation strategies to climate change and variability in Mwanza District, Tanzania. *Tanzania. Environ Manag* 72(4):785–804. <https://doi.org/10.1007/s00267-023-01792-2>
- Bashir S, Mobeen M (2018) Exploring impact of temperature and rainfall on citrus reticulata blanco in tehsil bhalwal, district sargodha Pakistan. *Indian J Agric Res* 52(5):505–511
- Bhalerao AK, Rasche L, Schneider UA (2021) Preparing for a better future: Delphi forecasts on competency development to enhance climate-resilient farming in Northeastern India. *Int J Sust Dev World* 28(3):255–266. <https://doi.org/10.1080/13504509.2020.1765043>
- Bhalerao AK, Rasche L, Scheffran J, Schneider UA (2022) Sustainable agriculture in Northeastern India: how do tribal farmers perceive and respond to climate change? *Int J Sust Dev World* 29(4):291–302. <https://doi.org/10.1080/13504509.2021.1986750>
- Bhatti MT, Ahmad W, Shah MA, Khattak MS (2019) Climate change evidence and community level autonomous adaptation measures in a canal irrigated agriculture system of Pakistan. *Climate Dev* 11(3):203–211. <https://doi.org/10.1080/17565529.2018.1442803>
- Brown PR, Bridle KL, Crimp SJ (2016) Assessing the capacity of Australian broadacre mixed farmers to adapt to climate change: Identifying constraints and opportunities. *Agric Syst* 146:129–141. <https://doi.org/10.1016/j.agsy.2016.05.002>
- 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. <https://doi.org/10.1016/j.jenvman.2012.10.036>
- Burnham M, Ma Z (2017) Climate change adaptation: factors influencing Chinese smallholder farmers' perceived self-efficacy and adaptation intent. *Reg Environ Change*. <https://doi.org/10.1007/S10113-016-0975-6>
- Bux RK, Haider SI, Batool M, Solangi AR, Shah Z, Karimi-Maleh H, Sen F (2022) Assessment of heavy metal contamination and its sources in urban soils of district Hyderabad, Pakistan using GIS and multivariate analysis. *Int J Environ Sci Technol* 19(8):7901–7913. <https://doi.org/10.1007/s13762-021-03691-7>
- Chilonda P, Van Huylbroeck G (2001) A conceptual framework for the economic analysis of factors influencing decision-making of small-scale farmers in animal health management. *Revue Sci Et Technique-Office Int des Épizooties* 20(3):687–700

- Eakin H, York AM, Aggarwal R, Waters S, Welch J, Rubiños C, Smith-Heisters S, Bausch C, Anderies JM (2016) Cognitive and institutional influences on farmers' adaptive capacity: insights into barriers and opportunities for transformative change in Central Arizona. <https://doi.org/10.1007/S10113-015-0789-Y>
- Easterling DR, Evans JL, Groisman PY, Karl TR, Kunkel KE, Ambenje P (2000) Observed variability and trends in extreme climate events: a brief review. *Bull Am Meteor Soc* 81(3):417–426. [https://doi.org/10.1175/1520-0477\(2000\)081%3c0417:OVATIE%3e2.3.CO;2](https://doi.org/10.1175/1520-0477(2000)081%3c0417:OVATIE%3e2.3.CO;2)
- Eckstein D, Künzel V, Schäfer L, Wignes M (2019) Global climate risk index 2020: Who suffers most from extreme weather events? weather-related loss events in 2018 and 1999 to 2018 Bonn: Germanwatch e.V. <https://www.germanwatch.org/en/crisis>
- Elum ZA, Snijder M (2023) Climate change perception and adaptation among farmers in coastal communities of bayelsa state, nigeria: a photovoice study. *Int J Climate Change Strateg Manage*. <https://doi.org/10.1108/ijccsm-07-2022-0100>
- Escandon-Barbosa D, Urbano-Pulido D, Hurtado-Ayala A (2019) Exploring the relationship between formal and informal institutions, social capital, and entrepreneurial activity in developing and developed countries. *Sustainability*, 11(2), 550. <https://www.mdpi.com/2071-1050/11/2/550>
- Esham M, Garforth C (2013) Agricultural adaptation to climate change: insights from a farming community in Sri Lanka. *Mitigation and Adaptation Strategies for Global Change*, 18(5), 535–549. <Go to ISI>://WOS:000318416600002
- Fahad S, Wang J (2018) Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. *Land Use Policy*. <https://doi.org/10.1016/J.LANDUSEPOL.2018.08.018>
- FAO (2023) World food and agriculture statistical yearbook 2023. Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/cc8166en/cc8166en.pdf>
- Fishbein M, Ajzen I (1977) Belief, attitude, intention, and behavior: an introduction to theory and research. <https://doi.org/10.2307/2065853>
- Floyd DL, Prentice-Dunn S, Rogers R (2000) A meta-analysis of research on protection motivation theory. <https://doi.org/10.1111/J.1559-1816.2000.TB02323.X>
- Frank E, Eakin H, López-Carr D (2011) Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas, Mexico. *Glob Environ Change*. <https://doi.org/10.1016/J.GLOENVCHA.2010.11.001>
- Froese R, Schilling J (2019) The nexus of climate change, land use, and conflicts. *Curr Climate Change Rep* 5(1):24–35. <https://doi.org/10.1007/s40641-019-00122-1>
- GoP (2010) Agriculture Census 2010. Lahore, Pakistan: Government of Pakistan (GoP), Statistics Division, Agriculture Census Organization, Pakistan Retrieved from [https://www.pbs.gov.pk/sites/default/files/agriculture/publications/agricultural\\_census2010/WRITE-UP%20AGRI.%20CENSUS%202010.pdf](https://www.pbs.gov.pk/sites/default/files/agriculture/publications/agricultural_census2010/WRITE-UP%20AGRI.%20CENSUS%202010.pdf)
- GoP (2023) Pakistan Economic Survey. Islamabad, Pakistan: Economic Adviser's Wing, Finance Division
- Gopalakrishnan T, Hasan K, Haque ATMS, Jayasinghe SL, Kumar L (2019) Sustainability of coastal agriculture under climate change. *sustainability*. <https://doi.org/10.3390/su11247200>
- Gorst A, Dehlavi A, Groom B (2018) Crop productivity and adaptation to climate change in Pakistan. *Environ Dev Econ* 23(6):679–701. <https://doi.org/10.1017/S1355770X18000232>
- Grothmann T, Patt A (2005) Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environ Change*. <https://doi.org/10.1016/j.gloenvcha.2005.01.002>
- Hasan Fu, Fatima B, Ashraf M (2021) Challenges to irrigated crop zones of punjab and sindh provinces in the wake of climate variability. *Int J Environ Sci Natural Resour*, 27. <https://doi.org/10.19080/IJESNR.2021.27.556207>
- Howden M, Soussana JF, Tubiello FN, Chhetri N, Dunlop M, Meinke H (2007) Adapting agriculture to climate change. *proceedings of the national academy of sciences*. <https://doi.org/10.1073/pnas.0701890104>
- Huber DG, Gullede J (2011) Extreme weather and climate change: Understanding the link and managing the risk. Center for Climate and Energy Solutions. <https://www.c2es.org/document/extreme-weather-and-climate-change-understanding-the-link-and-managing-the-risk/>
- Hussain M, Butt AR, Uzma F, Ahmed R, Irshad S, Rehman A, Yousaf B (2019) A comprehensive review of climate change impacts, adaptation, and mitigation on environmental and natural calamities in Pakistan. *Environ Monit Assess*, 192. <https://doi.org/10.1007/s10661-019-7956-4>
- Hussain A, Thapa GB (2012) Smallholders' access to agricultural credit in Pakistan. *Food Secur* 4(1):73–85. <https://doi.org/10.1007/s12571-012-0167-2>
- Ide T, Link M, Scheffran J, Schilling J (2016) The Climate-Conflict Nexus: Pathways, Regional Links, and Case Studies. In: Hans Günter B, Oswald Spring Ú, Grin J, Scheffran J (eds) *Handbook on sustainability transition and sustainable peace*, vol 10. (Hexagon Series on Human and Environmental Security and Peace). Springer

- Ifeanyi-obi CC, Wigwe CC, Adesope OM, Obafemi AA (2023) Traditional perceptions of climate change phenomenon influencing adaptation decisions among women crop farmers in southern nigeria. *J Agric Ext*. <https://doi.org/10.4314/jae.v27i2.2>
- IPCC (2014) Climate change 2014: Impacts, adaptation, and vulnerability. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) 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. [https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-FrontMatterA\\_FINAL.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-FrontMatterA_FINAL.pdf)
- Irham I, Fachrista IA, Masyhuri M, Suryantini A (2022) Climate change adaptation strategies by indonesian vegetable farmers: comparative study of organic and conventional farmers. *Sci World Journal*. <https://doi.org/10.1155/2022/3590769>
- Ishfaq A, Asmat U, Rahman MHu, Burhan A, Syed Aftab W, Ashfaq A, Shakeel A (2019) Climate change impacts and adaptation strategies for agronomic crops. In H. Saddam (Ed.), *Climate change and agriculture* (pp. Ch. 4). IntechOpen. <https://doi.org/10.5772/intechopen.82697>
- Government of Pakistan (GoP), Islamabad, Retrieved from [https://www.finance.gov.pk/survey/chapters\\_23/Economic\\_Survey\\_2022\\_23.pdf](https://www.finance.gov.pk/survey/chapters_23/Economic_Survey_2022_23.pdf)
- Kabir MH, Azad MJ, Islam MN (2020) Exploring the determinants and constraints of smallholder vegetable farmers' adaptation capacity to climate change: A case of bogura district, bangladesh. *J Agric Crop Res*. [https://doi.org/10.33495/jacr\\_v8i9.20.159](https://doi.org/10.33495/jacr_v8i9.20.159)
- Khan NA, Gao Q, Abid M (2020) Public institutions' capacities regarding climate change adaptation and risk management support in agriculture: the case of Punjab Province Pakistan. *Sci Rep* 10(1):14111. <https://doi.org/10.1038/s41598-020-71011-z>
- Khan FK (2021) *Pakistan: Geography, economy, and people* (5th ed). Oxford University Press. <https://oup.com/pk/pakistan-geography-economy-and-people-fifth-edition-pctb.html>
- Khan D (2022) Smallholder agriculture — emergence of production clusters. *The Express Tribune*. <https://tribune.com.pk/story/2374250/smallholder-agriculture-emergence-of-production-clusters>
- Kuruppu N, Liverman D (2011) Mental preparation for climate adaptation: The role of cognition and culture in enhancing adaptive capacity of water management in Kiribati. *Glob Environ Change*. <https://doi.org/10.1016/J.GLOENVCHA.2010.12.002>
- Lwoga ET, Sangeda RZ, Sife AS (2017) online visibility of pharmacy research in tanzania: a scientometric study. *Int J Pharm Pharm Sci*. <https://doi.org/10.22159/ijpps.2017v9i9.19371>
- Masud MM, Akhtar R, Mamun AA, Uddin MS, Siyu L, Yang Q (2022) Modelling the sustainable agriculture management adaptation practices: using adaptive capacity as a mediator. *Front Environ Sci*. <https://doi.org/10.3389/fenvs.2022.963465>
- Mishra V, Bhatia U, Tiwari AD (2020) Bias-corrected climate projections for south asia from coupled model intercomparison project-6. *Sci Data*. <https://doi.org/10.1038/s41597-020-00681-1>
- Mitter H, Larcher M, Schönhart M, Stöttinger M, Schmid E (2019) Exploring farmers' climate change perceptions and adaptation intentions: empirical evidence from Austria. *Environ Manag* 63(6):804–821. <https://doi.org/10.1007/s00267-019-01158-7>
- Mitter H, Obermeier K, Schmid E (2024) Exploring smallholder farmers' climate change adaptation intentions in Tiruchirappalli District, South India. *Agric Human Values*. <https://doi.org/10.1007/s10460-023-10528-1>
- Mobeen M, Ahmed H, Ullah F, Riaz MO, Mustafa I, Khan MR, Hanif MU (2017) Impact of climate change on the precipitation pattern of district Sargodha, Pakistan. *Int J Climate Change Strateg Manage* 9(1):21–35. <https://doi.org/10.1108/IJCCSM-10-2015-0147>
- Mobeen M, Kabir KH, Schneider UA, Ahmed T, Scheffran J (2023) Sustainable livelihood capital and climate change adaptation in Pakistan's agriculture: Structural equation modeling analysis in the VIA-BLE framework. *Heliyon* 9(11):e20818. <https://doi.org/10.1016/j.heliyon.2023.e20818>
- Mohsin M, Adnan S (2023) Probabilistic modelling of interarrival time of drought for different operational drought indices used in Pakistan. *Int J Climatol* 43(14):6851–6865. <https://doi.org/10.1002/joc.8239>
- Muhammad A, Haider B, Ahmad Z (2016) IoT enabled analysis of irrigation rosters in the indus basin irrigation system. *Procedia Eng* 154:229–235. <https://doi.org/10.1016/j.proeng.2016.07.457>
- Oswald L, Bright J (2022) How do climate change skeptics engage with opposing views online? evidence from a major climate change skeptic forum on reddit. *Environ Commun* 16(6):805–821. <https://doi.org/10.1080/17524032.2022.2071314>
- Ozor N, Madukwe MC, Enete AA, Amaechina EC, Onokala PC (2011) Barriers to climate change adaptation among farming households of southern nigeria. *J Agric Ext*. <https://doi.org/10.4314/jae.v14i1.64079>

- Phuong LT, Biesbroek R, Sen LTH, Wals AEJ (2017) Understanding smallholder farmers' capacity to respond to climate change in a coastal community in central Vietnam. *Climate Dev*. <https://doi.org/10.1080/17565529.2017.1411240>
- Priyanto MW, Mulyo JH, Irham (2021) Comparison of awareness and perception of climate change between proklam and non-proklam farmers in sleman district. *E3s Web of Conferences*. <https://doi.org/10.1051/e3sconf/202123204007>
- Qazi MA, Khan NI (2021) Effect of site-specific integrated nutrient management on soil fertility under cotton-wheat cropping system of punjab Pakistan. *Polish J Environ Stud* 30(1):305–313. <https://doi.org/10.15244/pjoes/119093>
- Rahman MHu, Ahmad A, Wang X, Wajid A, Nasim W, Hussain M, Ahmad B, Ahmad I, Ali Z, Ishaque W, Awais M, Shelia V, Ahmad S, Fahd S, Alam M, Ullah H, Hoogenboom G (2018) Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. *Agric Forest Meteorol*, 94–113. <https://doi.org/10.1016/J.AGRFORMET.2018.02.008>
- Rehman A, Ma H, Ahmad M, Irfan M, Traoré OZ, Chandio A (2021) Towards environmental sustainability: devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan. *Ecol Indic*, 125. <https://doi.org/10.1016/J.ECOLIND.2021.107460>
- Robinson J (2014) Likert Scale. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 3620–3621). Springer Netherlands. [https://doi.org/10.1007/978-94-007-0753-5\\_1654](https://doi.org/10.1007/978-94-007-0753-5_1654)
- Rockström J (2003) Water for food and nature in drought-prone tropics: vapour shift in rain-fed agriculture. *Philos Trans Royal Soc B Biol Sci*. <https://doi.org/10.1098/rstb.2003.1400>
- Rogers RW, Prentice-Dunn S (2014) Protection motivation theory. <https://doi.org/10.4135/978148333222.N225>
- Rogers RW (1983) Cognitive and physiological processes in fear appeals and attitude change: A revised theory of protection motivation. *Social psychology: A source book*, pp 153–176
- Salman A, Husnain M, Jan I, Ashfaq M, Rashid M, Shakoor U (2018) Farmers' adaptation to climate change in pakistan: perceptions, options and constraints. *Sarhad J Agric* 34:963–972
- Saqib SE, Ahmad MM, Panezai S (2016) Landholding size and farmers' access to credit and its utilisation in Pakistan. *Dev Pract* 26(8):1060–1071. <https://doi.org/10.1080/09614524.2016.1227301>
- Sargani GR, Jiang Y, Chandio AA, Shen Y, Ding Z, Ali A (2022) Impacts of livelihood assets on adaptation strategies in response to climate change: evidence from Pakistan. *Environ Dev Sustain*. <https://doi.org/10.1007/s10668-022-02296-5>
- Scheffran J, Brzoska M, Kominek J, Link PM, Schilling J (2012) Climate change and violent conflict. *Science* 336(6083):869–871
- Schilling J, Vivekananda J, Khan MA, Pandey N (2013) Vulnerability to environmental risks and effects on community resilience in mid-west nepal and south-east pakistan. *Environ Natural Resour Res* 3(4). <https://doi.org/10.5539/enrr.v3n4p27>
- Shabir M, Amin K, Muhammad A, Ahmad J (2020) Impact of agricultural credit on cereal productivity: case study of district sargodha Punjab Pakistan. *Theor Econ Lett* 10(3):481–487
- Shah SIA, Zhou J, Shah AA (2019) Ecosystem-based adaptation (EbA) practices in smallholder agriculture; emerging evidence from rural Pakistan. *J Clean Prod* 218:673–684. <https://doi.org/10.1016/j.jclepro.2019.02.028>
- Shah AA, Khan NA, Gong Z, Ahmad I, Naqvi SAA, Ullah W, Karmaoui A (2022) Farmers' perspective towards climate change vulnerability, risk perceptions, and adaptation measures in Khyber Pakhtunkhwa, Pakistan. *Int J Environ Sci Technol*. <https://doi.org/10.1007/s13762-022-04077-z>
- Smith P, Olesen JE (2010) Synergies between the mitigation of, and adaptation to, climate change in agriculture. *J Agric Sci*. <https://doi.org/10.1017/s0021859610000341>
- Steenbergen F, Basharat M, Lashari B (2015) Key challenges and opportunities for conjunctive management of surface and groundwater in mega-irrigation systems. *Resources* 4:831–856. <https://doi.org/10.3390/resources4040831>
- Stern P (2000) New environmental theories: toward a coherent theory of environmentally significant behavior. <https://doi.org/10.1111/0022-4537.00175>
- Syed A, Raza T, Bhatti TT, Eash NS (2022) Climate impacts on the agricultural sector of Pakistan: risks and solutions. *Environ Challenges* 6:100433. <https://doi.org/10.1016/j.envc.2021.100433>
- Tessema AK (2019) Smallholder farmers' perception and adaptation strategies to climate change and variability in ankesha guagusa district of awi zone, North Western Ethiopia. <https://doi.org/10.7176/jrdm/58-02>
- Torre DMGd, Gao J, Macinnis-Ng C, Yan S (2021) Phenology-based delineation of irrigated and rain-fed paddy fields with sentinel-2 imagery in google earth engine. *Geo-Spatial Information Science*. <https://doi.org/10.1080/10095020.2021.1984183>

- Ullah S, Mehmood T, Ahmad T (2022) Green intellectual capital and green hrm enabling organizations go green: mediating role of green innovation. *Int J Innov Sci*. <https://doi.org/10.1108/ijis-12-2021-0222>
- Waltman L (2016) A review of the literature on citation impact indicators. *J Informetrics*. <https://doi.org/10.1016/j.joi.2016.02.007>
- Waseem M, Jaffry AH, Azam M, Ahmad I, Abbas A, Lee J-E (2022) Spatiotemporal analysis of drought and agriculture standardized residual yield series nexuses across punjab, Pakistan. *Water*, 14(3), 496. <https://www.mdpi.com/2073-4441/14/3/496>
- Woods BA, Nielsen HØ, Pedersen AB, Kristofersson D (2017) Farmers' perceptions of climate change and their likely responses in Danish agriculture. *Land Use Policy*. <https://doi.org/10.1016/J.LANDU.SEPOL.2017.04.007>
- Yang Y, Zhang Y, Zhu BX, Zhou J, Liu Y, Gao D, Sauer J (2024) ICT promotes smallholder farmers' perceived self-efficacy and adaptive action to climate change: empirical research on China's economically developed rural areas. *Clim Serv* 33:100431. <https://doi.org/10.1016/j.cliser.2023.100431>
- Zhang J, Tong Z, Ji Z, Gong Y, Sun Y (2022) Effects of climate change knowledge on adolescents' attitudes and willingness to participate in carbon neutrality education. *Int J Environ Res Public Health*. <https://doi.org/10.3390/ijerph191710655>
- Zhu T, Ringler C, Iqbal MM, Sulser TB, Goheer MA (2013) Climate change impacts and adaptation options for water and food in Pakistan: scenario analysis using an integrated global water and food projections model. *Water Int* 38(5):651–669. <https://doi.org/10.1080/02508060.2013.830682>
- Zobeidi T, Yaghoubi J, Yazdanpanah M (2022) Developing a paradigm model for the analysis of farmers' adaptation to water scarcity. *Environ Dev Sustain* 24(4):5400–5425. <https://doi.org/10.1007/s10668-021-01663-y>

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