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Climate-Induced Water Variability and Smallholder Farmers' Perceptions of Irrigation Access in South Punjab, Pakistan

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ABSTRACT

Climate-induced water variability poses a significant challenge to smallholder farmers in South Punjab, Pakistan, affecting their access to irrigation, crop productivity, and rural livelihoods. This study examined farmers' perceptions of irrigation access in relation to changes in water availability, reliability, and distribution, alongside socio-economic and institutional factors influencing these perceptions. A cross-sectional survey of 300 farmers from Multan, Muzaffargarh, and Dera Ghazi Khan revealed that water availability had declined (Mean = 4.35, SD = 0.82), irrigation supply was unreliable (Mean = 4.20, SD = 0.89), and distribution was inequitable (Mean = 4.12, SD = 0.91). Factors such as small landholding (<5 acres, mean = 4.31, $\chi^2 = 18.52$, p = 0.001), low household income (<50,000 PKR, mean = 4.28, $\chi^2 = 15.36$, p = 0.002), limited education, and lack of participation in WUA were significantly associated with perceived water challenges. Adaptive strategies included reliance on private tube wells (66%), crop diversification (58%), adoption of water-saving irrigation techniques (55%), and engagement with governance mechanisms (45%). Binary logistic regression indicated that landholding size, income, education, access to extension services (Exp(B) = 1.81, p = 0.002), WUA participation, and climate awareness significantly increased the likelihood of adaptation (Exp(B) = 1.81, p = 0.002), while greater distance to irrigation sources reduced it (Exp (B) = 0.67, p = 0.005). The study underscores the need for integrated policies that enhance irrigation infrastructure, promote equitable water distribution, and provide institutional support to build resilience among smallholder farmers, thereby counteracting irrigation shortages.

***Keywords*:** Climate variability, irrigation access, smallholder farmers, adaptive strategies, and water governance

INTRODUCTION

The agricultural sector in Pakistan has approximately 19% share in national GDP. It encompasses nearly 38% of labor force (Pakistan Economic Survey, 2024). Water has remained a fundamental means of maintaining agricultural production and rural lifestyles, where agriculture is the primary economic driver. The Indus Basin Irrigation System (IBIS), consisting of rivers and canals, is the largest irrigation system in the world and it assists Millions of farmers in the country. However, the variability caused by climate change in water availability has led to uncertain and unequal access to irrigation, especially in semi-arid regions like South Punjab (Ali & Shah, 2024). The effects of such variability are far-reaching to agricultural sustainability, rural livelihoods and poverty alleviation.

South Punjab has an agrarian economy and is mainly dependent on the canal water and groundwater as the source of irrigation for smallholder farmers. Among the recurring challenges in the area are also the changing levels of the river, falling groundwater, and altered rainfall distribution patterns, all of which are exacerbated by the impact of climate change (Ali, 2023). An increase in temperature and a variation in the regimes of precipitation have caused the conditions of water scarcity and water overabundance that have disrupted the pattern of crop production and reduced the predictability of irrigation systems (Hussain et al., 2021). In addition, inadequate infrastructure, uneven water distribution, and poor institutional management are other factors that make farmers susceptible to water stress, implying that most smallholders may fail to effectively adapt to such developments. Understanding how farmers perceive the availability of irrigation in the context of water variability due to climate change is highly crucial for the development of sustainable water management policies. The farmers also have perceptions that influence their decisions regarding the crop choices, irrigation, and adaptive strategies (Aryal et al., 2021). According to past research studies, physical water availability is not the only variable that facilitates the development of the perspectives of water scarcity, but social, institutional and economic variables like land tenure, access to extension services, and water governance at the community level also contribute (Assan et al., 2020; Awuku et al., 2023). The perceptions of smallholders in South Punjab provide a reasonable explanation of the localities of the irrigation management in an area where smallholders are typically excluded and limited resources may be the primary challenge.

Despite the importance of this issue, little research has been conducted to determine the influence of climate variability on the perceptions of smallholder farmers in the South Punjab with respect to irrigation access. Most of the available literature has focused on either the technical aspects of irrigation systems or the overall effects of climate change, without taking into account the subjective aspects of farmers (Ali et al., 2025b). The gap in this paper is that it addresses the perception of smallholder farmers regarding changes in water availability, reliability, and distribution, as well as their perceptions of agricultural practices and adaptability strategies.

The findings of the given research will assist in concentrating on the overall understanding of the interdependence between the variability of water, determined by the climate conditions and the availability of irrigation at the farmer level. Knowledge is necessary to inform evidence-based policies that will enhance water governance, climate resilience, and the livelihoods of vulnerable farming communities in South Punjab. Lastly, another critical agenda to improve access to irrigation in the context of climate change should also be applied as a measure to ensure food security and sustainable rural development in Pakistan. The research objectives are to examine the perception of smallholder farmers on the availability, reliability, and distribution of irrigation water, to determine the socio-economic and institutional variables that influence the perceptions of farmers regarding irrigation water and to determine the adaptation strategies farmers have embraced in response to induced water variability.

MATERIALS AND METHODS

Research design

The article employed a quantitative and cross-sectional study design that incorporated the cross-sectional survey study to examine the relationship between the water variability due to climate, and the perceptions of irrigation access to the South Punjab smallholder farmers in Pakistan. The quantitative approach was selected because it can be measuring objectives statistically and generalize findings (Creswell, 2014). Data collection used a structured questionnaire, and secondary sources on climate and irrigation practices were used to assess farmers' perceptions and identify long-term trends in water availability.

Study population and sampling

The study was undertaken in the three districts of South Punjab, namely Multan, Muzaffargarh and Dera Ghazi Khan, which were selectively sampled based on the criterion of agricultural significance, dependence on the Indus Basin Irrigation System (IBIS) and prone to climatic variations such as floods, droughts and patchy rainfall. The small-scale farmers face the challenge of irrigation that can be looked into holistically because the districts represent different agro- ecological areas. The targeted farmers were the smallholders; these are farmers who own less than 12.5 acres of land. A multi-stage sampling method was used to achieve representative coverage. In the first stage, the three districts were selected purposely. The second stage involved the selection of two tehsils in each district randomly. The third stage involved the selection of two or three villages in each tehsil, randomly, depending on the availability of irrigation facilities as well as the number of farmers. In the fourth stage, respondents in each village were selected through systematic random sampling with the assistance of lists provided by the local agricultural extension offices. The sample of a finite population was calculated in the following formula: Yamane (1967):

$$n = \frac{N}{1 + N(e)^2}$$

Where:

- n = sample size
- N = total population of smallholder farmers in the selected districts
- e = margin of error (0.05)

Based on population estimates, a total of 300 farmers were selected, with 100 respondents each from Multan, Muzaffargarh, and Dera Ghazi Khan. This sample size was considered adequate for statistical analysis and ensured precision in the estimates while maintaining feasibility in data collection.

Data collection

A structured questionnaire was designed to collect data systematically, ensuring alignment with the study objectives. The questionnaire was pre-tested with 30 farmers outside the main study sample to identify ambiguities, assess timing, and improve clarity. The final version incorporated feedback to ensure comprehensiveness and relevance.

Data analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 28. Both descriptive and inferential statistics were applied. Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize socio-economic profiles and farmers' responses. Reliability analysis was conducted using Cronbach's alpha, which measures the internal consistency of Likert-scale items. The reliability coefficient was calculated using the formula:

$$\alpha = \frac{K}{K\text{-}1}\,(1\text{-}\,\frac{\sum_{i=1}^{k}\sigma_i^2}{\sigma_T^2})$$

Where:

- α = Cronbach's alpha
- k = number of items
- σ_i^2 = variance of each item
- σ_T^2 = total variance of the scale

A value of 0.70 or higher was considered acceptable, indicating that the questionnaire was reliable for data collection.

For inferential analysis, the Chi-square test (χ^2) was employed to examine associations between categorical variables such as education level, irrigation source, and perception of water adequacy. The formula for the Chi-square test is:

$$X^2 = \sum \frac{(O\text{-}E)^2}{E}$$

Where:

O = observed frequency,

E = expected frequency.

This test helped determine whether there were significant relationships between socio-economic factors and perceptions of irrigation access.

To identify the most influential factors affecting farmers' perceptions and adaptation decisions, binary logistic analysis was applied. The dependent variable in this model was irrigation access (coded as 1 = adequate access, 0 = inadequate access). Independent variables included socio-economic characteristics, institutional support, and climate perception indicators. The logistic regression model was expressed as:

$$\text{Ln}\,(\frac{P}{1\text{ - }P}) = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \ldots + \beta kXk$$

Where:

- P = probability of adequate irrigation access
- $\text{Ln}\,(\frac{P}{(1\text{ - }P)})$ = natural log of the odds of adequate access
- β0 = constant term
- β1, β2…, βk = regression coefficients for predictor variables
- X1, X2…, Xk = independent variables (e.g., education, farm size, income, access to extension services)

The significance of predictors was assessed using Wald statistics and odds ratios, with a 95% confidence interval.

Validity and reliability

Several measures were undertaken in order to ascertain the validity and reliability of findings. Expert validity involved the review of the content by the agricultural extension officers and irrigation specialists. The pilot testing ensured that questions were coherent and culturally relevant. Triangulation was done through comparison of primary data with secondary data on climate and irrigation records. Throughout the research process, ethical concerns were monitored. All participants gave their informed consent and were assured of anonymity and confidentiality. The participants decided that they could not be withdrawn at any point since they were made aware of this right and data was treated with utmost security.

RESULTS AND DISCUSSION

This section introduces and discusses the results of the research on the analysis of the problem of climate-induced water variability and how access to irrigation impacts the perception of South Punjab, smallholder farmers in Pakistan. The findings are structured under the four objectives of the study and commenced by analyzing the water variability caused due to climatic factors using the perception of the farmers. This is then preceded by a discussion of how the small holder farmers perceive access to irrigation, the socio-economic and institutional factors that affect the perceptions of the farmers and the adaptation mechanisms farmers have adopted to address the challenges presented by water.

Farmers' Perceptions of Irrigation Access

Table 1 shows how the smallholder farmers of South Punjab perceive their access to irrigation, especially concentrating on the water availability, reliability and distribution in the last five years. A structured questionnaire was used to collect the data from 300 respondents on the basis of five-point Likert scale, where 1 is strongly disagree and 5 strongly agree. The table shows the average of the scores, standard deviations and categorization of each indicator to find out the most pressing issues that farmers in the study area have.

Table 1: Smallholder Farmers' Perceptions of Irrigation Access in Relation to Water Availability, Reliability, and Distribution (n = 300)

Perception Indicator	Mean	SD	Rank
Water availability for irrigation has decreased over the past five years	4.35	0.82	1
Irrigation water supply is unreliable during peak cropping seasons	4.20	0.89	2
Distribution of irrigation water across farms is inequitable	4.12	0.91	3
Delays in water delivery negatively affect crop productivity	3.96	0.95	4
Conflicts among farmers over irrigation access have increased	3.88	0.97	5
Dependence on groundwater has increased due to declining surface water availability	3.74	1.01	6
Current irrigation management practices are effective in meeting farm-level requirements	2.95	1.02	7

The table 1 findings depict that farmers believe that the supply of irrigation water has declined in the last five years, with the highest score of 4.35. This is how water shortage is generally perceived, and it is consistent with the study that revealed the reduction of surface water flows in the Indus Basin due to climate change, irregular precipitation, and increased water demand (Ayanwale, 2024; Azizi-Khalkheili et al., 2021). Research by Nyang'au et al. (2021) indicated that the change in rainfall pattern and an increase in temperatures have influenced river waters and consequently, low water levels to sustain agriculture in South Punjab. The second position, with a mean of 4.20, reveal the element of uncertainty of the irrigation water during the most crucial seasons in the agricultural industry, such as the wheat and cotton cultivation season. This uncertainty disrupts the farm's activities, as it affects the sowing and harvesting processes. Ojha et al. (2023) also reported the same conclusions and found that an unreliable canal schedule is one of the factors contributing to low yields and farmer discontent. In addition, irrigation water attitude is unfairly distributed, had an average score of 4.12 (third lowest), showing the concerns of farmers in the unfairness in irrigation water distribution. The upstream users or wealthy landowners tend to gain at the expense of smallholders (Boora et al, 2024). These differences in distributions are known to be the reason for conflicts between farmers, which consequently lead to a mediocre score of 3.88 (location five). As the studies by Castillo et al. (2021) and Dadzie (2023) indicated that tension among water users has been aggravated by the absence of transparency and weak institutional governance over irrigation water. Many farmers agreed with the statement that they now relied more on groundwater for irrigation due to the declining availability of surface water, with 3.74 as the mean value. Although groundwater is a sustainable solution, unsustainable pumping has led to a decline in water levels and an increase in soil salinity, which in turn increases production costs and compromises the long-term sustainability of agricultural processes (Bakker et al., 2021). The results are not novel because, according to Balana et al. (2020), groundwater levels in Punjab have steadily declined over the years and most intensive farming areas, such as Multan and Muzaffargarh, have been affected. The lowest mean score of 2.95 was recorded regarding the statement that existing irrigation management methods are working, which expressed the maximum level of discontentment amongst the farmers. This suggests that the existing management systems are not meeting the needs at the farm level due to lack of proper maintenance, inadequate infrastructure and lack of participation of farmers in water governance. Similar problems were observed by Dasmani (2020), who indicated that there was a need to transform the institutions to be more efficient and more accountable in the allocation of irrigation water.

Based on the results, the issue of climate change has made the problem of water management in South Punjab more challenging. The reduction in water supply is not only a problem that farmers have to contend with; there are also the issues of inconsistency in the supply and inequality in distribution that push the farmers into the unsustainable use of groundwater. These findings highlight the need for policies that aim to optimize irrigation timing, promote equitable water allocation, and enhance groundwater management, as well as the role of farmers in the decision-making process. These interventions are essential in both increasing the resilience of the smallholders and ensuring sustainable growth of agricultural systems of South Punjab (Enwerem et al., 2022; Dadzie, 2023).

Factors influencing the perceptions of the farmers and the availability of irrigation water.

Table 2 presents the results of the analysis that was conducted to identify the socioeconomic and institutional factors that influence the perception of the farmers and their availability of irrigation water in South Punjab, Pakistan. The sampling was done on 300 smallholder farmers and analysis was done on the data collected through descriptive and inferential statistics. The table refers to landholding size, household income, education level, access to extension services, and membership in water governance groups as some of the important variables that are identified to be associated with the perceptions of farmers on the five-point Likert scale (1 strongly disagree, 5 strongly agree).

The results reveal that the size of landholding is one of the most important variables that have a significant impact on the irrigation water perceptions ($\chi^2 = 18.52$, $p = 0.001$), which means that farmers' perception about irrigation water i.e. its availability, sufficiency, and equitable distribution is dependent on the farmers' landholdings. Small landholders with less than 5 acres showed the highest perception score (Mean = 4.31). On the other hand, farmers who had a larger land scale (>10 acres) had lower scores on perception (Mean = 3.42), indicating that they are less concerned about irrigation water. Large landowners usually had access to canal irrigation and alternatives such as tubewells due to more personal resources or more social and political leverage. These results align with previous research conducted by Hatch et al. (2022) and Higginbottom et al. (2021), which have indicated that smallholders are disproportionately impacted by water scarcity due to their limited resources and lack of power over irrigation schemes. The irrigation perception was also significantly and strongly associated with household income ($\chi^2 = 15.36$, $p = 0.002$). Low-income farmers (earning less than 50,000 PKR a month) had more difficulties with irrigation water (Mean = 4.28), as they often lack the budget to own tubewells, or even avail themselves of alternative options. Comparatively, the perception scores of high-income farmers (>100,000 PKR per month) were lower (Mean = 3.40), which means that they have a higher adaptive capacity and access to alternative water sources. This connection is what upholds the results of Eshete et al. (2020), who claim that income is a crucial aspect of whether a farmer can respond to water variability caused by climate change.

Table 2: Socio-Economic and Institutional Factors Influencing Farmers' Perceptions of Irrigation Access (n = 300)

Variable	Category	Frequency (f)	Percentage (%)	Mean Perception Score (1-5)	Chi-Square (χ^2)	p-value
Landholding Size (Acres)	Small (<5 acres)	128	42.7	4.31	18.52	0.001 **
	Medium (5-10 acres)	102	34.0	3.89		
	Large (>10 acres)	70	23.3	3.42		
Monthly Household Income (PKR)	Low (<50,000)	146	48.7	4.28	15.36	0.002 **
	Medium (50,000-100,000)	94	31.3	3.85		
	High (>100,000)	60	20.0	3.40		
Education Level	Illiterate	82	27.3	4.10	12.27	0.007 **
	Primary	76	25.3	3.89		
	Secondary	68	22.7	3.61		
	Higher (Intermediate & Above)	74	24.7	3.39		
Access to Extension Services	Yes	104	34.7	3.62	10.48	0.014 *
	No	196	65.3	4.20		
Water Governance Participation	Participates in water user groups	72	24.0	3.55	14.80	0.003 **
	No participation	228	76.0	4.23		

Significance levels:
- p<0.05 (*significant)
- ** p<0.01 (**highly significant)

Another determinant was education, which had a strong correlation with the perception of farmers ($\chi^2 = 12.27$, $p = 0.007$). Illiterate farmers raised the most serious questions regarding the availability of irrigation (Mean = 4.10), while more educated farmers are less concerned and are not worried about irrigation water shortage (Mean = 3.39). Fahad et al. (2020) also stated similar observations and stressed the importance of education in improving the capacity of farmers to make better decisions and adapt to changing circumstances presented by water scarcity. The influence of institutional factors was also very significant in water governance mechanisms ($\chi^2 = 14.80$, $p = 0.003$).

Whereas, farmers' participation in water user associations (WUAs) or other local governance bodies was found to have lower scores in irrigation water perception (Mean = 3.55) than the non-participating farmers (Mean = 4.23). This implies that participation in the WUAs enhances the aspect of transparency and accountability in terms of the distribution of irrigation systems, which leads to a more justifiable access to water and satisfaction among farmers. These results are consistent with the studies of Hasan et al. (2024) and Li et al. (2025), who emphasized the necessity of the involvement of farmers in governance mechanisms for improving water management in Pakistan.

On the same note, the availability of extension services also had a significant impact on the perceptions of irrigation ($\chi^2 = 10.48$, $p = 0.014$). The farmers who had frequent interaction with extension officers had lower scores for irrigation water perceptions (Mean = 3.62), which means that advisory services enable the farmers to embrace more desirable irrigation practices in addition to being able to overcome water scarcity and water distribution difficulties. Conversely, farmers lacking the extension support felt that there were greater challenges (Mean = 4.20), which shows that there is a loophole in terms of institutional outreach and service delivery. This observation supports the importance of the enhancement of agricultural extension systems, which is highlighted by Makone et al. (2021).

Findings indicate that socio-economic status, as well as institutional engagement, are significant in defining farmers' perceptions of access to irrigation in South Punjab. The most vulnerable groups are smallholders, low-income households, and illiterate farmers. Their concerns can be addressed to some extent through their involvement in governance structures as well as providing them with relevant and timely extension services. The findings have revealed the need to implement specific policy measures in order to deal with socio-economic imbalances, facilitate farmer education and improve institutional processes to create equitable and sustainable allocation of irrigation water in response to climate-related variability.

Adaptive strategies

Table 3 is used to display the different adaptive mechanisms used by the South Punjab, Pakistan, smallholder farmers to deal with the water variability due to climate and irrigation problems. These strategies have been grouped into four key options as listed in the table: technological, agronomic, institutional, and livelihood diversification strategies, which show the various solutions used by the farmers in order to meet the rising water shortage and irregular availability of irrigation.

Table 3: Adaptive Strategies Adopted by Smallholder Farmers to Address Climate-Induced Water Variability (n = 300)

Category	Adaptive Strategy	Frequency	Percentage	Rank
Technological Adaptations	Use of tube wells or private boreholes	198	66.0	1
	Water-saving irrigation techniques (drip, sprinkler)	165	55.0	3
	Rainwater harvesting (ponds, tanks, bunds)	72	24.0	11
	Mobile-based weather and irrigation advisory apps	87	29.0	10
Agronomic Adaptations	Crop diversification (drought- and heat-tolerant crops)	174	58.0	2
	Adjusting cropping calendar (early/late sowing)	150	50.0	4
	Mulching and soil moisture conservation techniques	120	40.0	7
	Adoption of drought-resistant seed varieties	96	32.0	9
Institutional Strategies	Participation in Water User Associations (WUAs)	135	45.0	5
	Canal water rotation and scheduling adjustments	126	42.0	6
	Purchasing water from neighboring farmers	105	35.0	8
Livelihood Diversification	Migration to non-farm income sources (seasonal labor)	66	22.0	12
	Livelihood diversification (poultry, dairy, etc.)	54	18.0	13

The results in table 3 show that technological adaptations are the most common strategies used by farmers. The primary coping strategy, as described by most of the responses. About 66% of respondents revealed that they were using tube wells or small-bore holes to supplement the unreliable canal water supply. It implies that farmers are getting more and more dependent on groundwater as a source of irrigation, which is consistent with Mazhar et al. (2023) giving a warning of the unsustainable use of groundwater in the Indus Basin. The other technological interventions include application of water-saving irrigation techniques, such as drip systems and sprinklers, which farmers have adopted (55 percent). These systems may be effective in terms of enhancing water efficiency, but are usually not accessible to a few farmers because of the high initial investment cost and lack of expertise. Moreover, the farmers who use the rainwater harvesting systems, like the ponds and storage tanks, are only 24 percent of the total farmers due to financial constraints and inadequate institutional support. Further, 29 percent of farmers use mobile-based weather and irrigation advisory services, which indicates the critical role of digital technologies in agricultural decision-making, but a lower adoption. Adoptions aimed at agronomic adaptation are also prevalent, as they are affordable and easily accessible to smallholder farmers.

The second strategy adopted by farmers is the adjustments in agronomic practices. Most farmers cited crop diversification by adopting more drought and heat-tolerant crops such as millet, sorghum and sunflower as a means to reduce the use of water-intensive crops such as rice and sugarcane. The approach is helpful in mitigating the threat of climate change, as indicated by various studies such as Nikolaou et al. (2020), Hoogesteger et al. (2023) and Huang et al. (2024) highlighted crop diversification as a means of creating resilience in the farming system. Half of the farmers had changed their planting times (to better fit with rainfall and irrigation water) through either late or early planting. Further, 40% of respondents indicated the use of mulching and soil moisture conservation techniques to improve the health of the soil and reduce evaporation. Drought-resistant seed varieties were utilized relatively little (32%), which suggests the necessity to have more incentives to extend and provide easier access to the seeds. The collective action and improved governance institutional strategies were adopted moderately. Forty-five percent of the farmers indicated that they had attended Water User Association (WUAs), and 42 percent stated that they had changed canal water rotation and timing. Low participation of farmers in WUAs is most likely due to the problems of governance and the lack of transparency, as indicated by Kulugomba et al. (2025). A significant proportion of the farmers (35) said that they purchased tubewell water from neighbors, showing the emergence of the water market. Finally, the least common adopted strategy among farmers was livelihood diversification. Around one-fifth respondents indicated that they migrated seasonally to urban areas or engaged in non-farm employment as an alternative source of income. Similarly, 18 percent of the farmers had switched to other farming sources of livelihood, such as poultry and dairy farming.

The findings indicate that the strategies employed by farmers are varied, but there is an overutilization of individual and resource-intensive strategies, specifically groundwater extraction. The institutional and collective strategies are not applied to the fullest, which means that there are no governance and institutional enablement. These tendencies suggest that, in order to ensure the sustainable management of water resources, policies should focus on controlling water use from groundwater sources, providing more water-saving devices, and managing water use by the population. Additionally, the livelihood programs for vulnerable farmers should be diversified, and financial support should be provided to these farmers so that they have the best opportunity to mitigate the impact of climate change through water variability.

Binary logistic regression

Table 4: Binary Logistic Regression Results for Predictors of Farmers' Adoption of Adaptation Strategies (n = 300)

Independent Variables	B (Coefficient)	S.E.	Wald	Exp(B) (Odds Ratio)	p-value	Significance
Landholding Size (acres)	0.428	0.152	7.94	1.53	0.005	Significant
Household Income (PKR)	0.365	0.147	6.14	1.44	0.013	Significant
Education Level	0.321	0.138	5.39	1.38	0.020	Significant
Access to Extension Services	0.595	0.191	9.74	1.81	0.002	Highly Significant
Participation in Water User Associations (WUAs)	0.481	0.176	7.44	1.62	0.006	Significant
Climate Change Awareness	0.456	0.170	7.20	1.58	0.007	Significant
Distance to Irrigation Source (km)	-0.398	0.143	7.74	0.67	0.005	Negative Significant
Credit Access	0.341	0.150	5.16	1.41	0.023	*Significant*
Constant	-2.305	0.600	14.76	0.10	0.000	Significant

Table 4 explains the results of a binary logistic regression (BLR) model. The model used a number of independent variables, which included the socio-economic factors, institutional support and perception of climate, with the dependent variable being the uptake of the adaptation strategies by the farmers (1 = adopted, 0 = not adopted). The statistical significance of the model ($\chi^2 = 83.42$, $p < 0.001$) and Nagelkerke $R^2 = 0.47$ depicted that the predictors had explained 47 percent of the variance of the adaptation decisions of farmers. The overall accuracy of prediction was also high in the model, at 82.3%, which is an indicator that it is a robust and reliable model.

Table 5: Model Summary

Statistic	Value
-2 Log Likelihood	211.68
Cox & Snell R^2	0.35
Nagelkerke R^2	0.47
Model Chi-Square (χ^2)	83.42, $p < 0.001$
Overall Prediction Accuracy	82.3%

The findings indicated that adaptation was a powerful predictive socio-economic independent variable of landholding size, household income and education level. The likelihood of farmers with larger land areas using adaptation practices was 53% greater as compared to farmers with smaller land areas (p = 0.005), showing that resource availability had some impact in enhancing the adoption of practices to address climate change. Similarly, the likelihood of adoption increased significantly by 44% (p = 0.013) as household income increased, because better-off farmers would be able to afford water saving technologies, tubewells, and drought-resistant crops. Education as well became significant (p = 0.020), with every further level of education introducing odds of adaptation by 38 percent, highlighting the importance of knowledge and awareness in regard to adaptive behaviors. These data can be compared to previous studies conducted by Pangestu et al. (2025) and Usman et al. (2023), among others, which have found that the resources and education level of farmers are more likely to lead to the implementation of sustainable farming practices. The institutional factors also played a very critical role. Access to extension services (p = 0.002) was the most important predictor, with farmers receiving frequent extension support being 81% more likely to take adaptation measures. This emphasizes the instrumental value of advisory services in promoting climate-smart practices and providing technical advisory services on irrigation management. The other significant institutional condition was the participation in Water User Associations (WUAs) (p = 0.006), which increased the probability of adaptation by 62%. This means that mass action and community-based water management come in handy in ensuring a fair distribution of water and a collective resolution of issues between farmers. Further, access to credit was positively related to adaptation (p = 0.023) and farmers with access to credit had a 41% higher likelihood of investing in adaptive technology and improved water management practices.

The most useful climate-related variables were climate change awareness (p = 0.007), at which farmers were more likely to implement adaptive actions (58 percent) by either changing their cropping schemes or investing in water-efficient irrigation systems. This highlights the importance of awareness creation programs and educating farmers in building climate resilience. Conversely, the distance to the irrigation source was the only variable that affected the adaptation negatively (p = 0.005). With each kilometer further away from the source of irrigation, the chances of decreasing the adaptation become 33 percent, in the sense that the more distant farmers suffer more expenditures, logistical inconveniences, and unpredictable water provision, which obstructs them in adapting to the water variability. These results are consistent with those of Ali (2023) and Ali et al. (2025).

Overall, the results prove the existence of a strong intervention of socio-economic status, institutional support, and climate awareness on adaptation behavior in farmers. The better educated farmers, larger landholding and access to the extension services have a greater likelihood of using the adaptive practices. These findings necessitate the development of specific policies and interventions to improve farmers' access to extension services, the growth of WUAs, the expansion of credit facilities, and the improvement of irrigation infrastructure. These interventions will help stimulate fair and sustainable water management, as well as increase the resilience of smallholder farmers to the mounting pressures of climate change in South Punjab.

Conclusion

The article identifies the drastic impacts of water variability as a result of the climatic conditions on the perceptions of the smallholders on the supply of irrigation in South Punjab in Pakistan. The findings have shown that farmers have been experiencing a high degradation in water supply, lack of reliability in water supply through canals and water distribution, which has intensified over the past five years due to irregular rainfall, unpredictable flow of rivers and loss of groundwater levels. The factors that proved to be significant in influencing the perceptions and adaptive behavior of the farmers included socio-economic and institutional dynamics, such as landholding size, household income, education level, and extension services, as well as membership in the Water User Association. Farmers with less income are more susceptible to water shortage, while wealthier and farmers can afford to deal with the situation through investing in alternative sources and influencing their socio-political influence in governance mechanisms. Tactics of alteration (such as use of individual tube wells, crop diversification, water-conserving irrigation systems, and involvement in governance systems) were highly embraced. The binary logistic regression confirmed that resource availability and institutional support have a significant influence on the adoption of adaptive practices, whereas physical constraints, such as distance to irrigation sources, have a lesser impact on adaptive capacity. Overall, it is noteworthy that the paper suggests that policy interventions aimed at enhancing irrigation infrastructure, promoting equitable water distribution, empowering farmers through education and extension facilities, and encouraging the sustainable use of groundwater should all be undertaken. The interventions are significant in strengthening climate resilience, safeguarding agricultural performance, and enhancing the livelihoods of South Punjab smallholder farmers.

Declarations

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Conflicts of Interest

Authors have no conflicts of interest.

Data Availability

Data will be available from the corresponding author upon request.

Ethics Statement

This work involved human data. The work was approved by the Institute of Agricultural Extension, Education, and Rural Development, University of Agriculture, Faisalabad, Pakistan.

Authors' Contribution

Habib-Ur-Rehman; Conceptualization, Data Curation, Methodology, Wiring Original draft, Muhammad Faheem Shahzad; Formal Data Analysis, Writing, Faisal Nadeem; Review and Editing, Data Analysis and Data Collection

Generative AI Statements

The authors confirm that no generative artificial intelligence-based tools were employed for content generation or interpretation. All intellectual content, interpretations, and conclusions are the sole responsibility of the authors.

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