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RESEARCH ARTICLE

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Evaluating socio-economic and environmental factors influencing farm-level water scarcity in Punjab, Pakistan

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Abstract

Pakistan's economy is primarily dependent on agriculture, but it faces serious water challenges. This paper critically evaluates the water resources and socio-economic and environmental factors contributing to increased farm-level water scarcity in the Punjab region. The study involved conducting structured interviews with 370 farmers to gather data necessary for conducting a detailed sociotechnical factor analysis. From this, eight factors were identified that were found to directly impact farmer well-being including climate change (rise in temperature and erratic rainfall), poor socio-economic farmer conditions, issues linked to the *warabandi* (canal water distribution system), inadequate irrigation, reduced water availability, poor water course maintenance, and low adoption of efficient irrigation techniques. The Kruskal-Wallis test was then used to assess statistical differences between the respondents' demographic attributes and the identified factors. Demographic factors including age, education, land size, farming experience, and cultivated area showed significant mean differences with the eight factors. Young farmers with higher education levels were more likely to adopt high-efficiency irrigation systems to conserve water. The research also highlighted the importance of introducing crops with a lower water demand into the region and the need to proactively support agricultural extension services to encourage farmers to adopt more efficient irrigation systems to improve crop productivity and facilitate on-farm water conservation.

KEYWORDS
agriculture, climate change, drought, irrigation, water resources

Résumé

L'économie du Pakistan dépend principalement de l'agriculture, mais elle est confrontée à de graves problèmes d'eau. Cet article évalue de manière critique

[*] Évaluation des facteurs socio-économiques et environnementaux influençant la pénurie deau au niveau des exploitations au Pendjab, au Pakistan.

les ressources en eau, les facteurs socio-économiques et environnementaux contribuant à l'augmentation de la pénurie d'eau au niveau des exploitations dans la région du Pendjab. L'étude a consisté à mener des entretiens structurés avec 370 agriculteurs pour recueillir les données nécessaires à la réalisation d'une analyse factorielle sociotechnique détaillée. À partir de là, huit facteurs ont été identifiés qui ont un impact direct sur le bien-être des agriculteurs, notamment le changement climatique, les mauvaises conditions socio-économiques des agriculteurs, les problèmes liés au warabandi (système de distribution d'eau du canal), une irrigation inadéquate, une disponibilité réduite de l'eau, un mauvais entretien des cours d'eau. et faible adoption de techniques d'irrigation efficaces. Le test de Kruskal Wallis a ensuite été utilisé pour évaluer les différences statistiques entre les attributs démographiques du répondant et les facteurs identifiés. Des facteurs démographiques tels que l'âge, l'éducation, la taille des terres, l'expérience agricole et la superficie cultivée ont montré des différences moyennes significatives avec les huit facteurs. Les jeunes agriculteurs ayant un niveau d'éducation plus élevé étaient plus susceptibles d'adopter des systèmes d'irrigation à haut rendement pour économiser l'eau. La recherche a également mis en évidence l'importance d'introduire des cultures moins gourmandes en eau dans la région et la nécessité de soutenir de manière proactive les services de vulgarisation agricole pour encourager les agriculteurs à adopter des systèmes d'irrigation plus efficaces pour améliorer la productivité des cultures et faciliter la conservation de l'eau à la ferme.

MOTS CLÉS

agriculture, changement climatique, sécheresse, irrigation, ressources en eau

1 | INTRODUCTION

In Pakistan, agriculture contributes nearly a fifth (18.9%) to the country's gross domestic product and employs nearly half (42.3%) of the national labour force. However, an increasing population is exerting severe pressure on the need to increase agricultural productivity. Crop diversification, more efficient use of water, the promotion of high-value crops, enhancing the availability of agricultural credits, the provision of subsidized inputs, and support for technical advisory services are key priorities that have recently been identified to improve the agricultural sector. Awan and Mustafa (2013) reported that a 1% increase in water availability would increase agricultural growth by 0.93% in Pakistan. Conversely, agricultural production is known to be negatively impacted by any reductions in water availability. Reliable supplies of water for agriculture are essential therefore to support sustainable development. Agriculture is the largest consumer (> 90%) of water in Pakistan with timely supplies of water being critical for irrigation since 90% of food comes from irrigated production, with only 10% from dryland agriculture (Qureshi, 2011).

Pakistan has an extensive irrigation system on which almost the entire agricultural sector is dependent; this is often referred to as the Indus Basin Irrigation System (IBIS) and is reported to have the largest irrigation command globally. The IBIS covers almost 65% of Pakistan, with 20% in China and Kashmir, 7% in Azad Kashmir, and 8% in Afghanistan (Burki and Laporte, 1984). In Pakistan, it is located in the mountainous areas north and west to the Indus and Kacchi Plains and the desert of the Sindh and Balochistan. The Indus, Jhelum, Kabul, and Chenab Rivers flow from the Indus Basin with Pakistan having rights on these four river systems to acquire water for irrigation. The total catchment area of the Indus River system is 590,629.2 km^2 (367,000 miles^2) From this, an annual withdrawal of 57.5 million hectare-feet (MHF) (142 million acre-feet, MAF) comes from this basin (Shehzad *et al.*, 2016), with 42.59 MHF (105 MAF) diverted for irrigated agriculture. The IBIS is 2,900 km long, has a drainage area of 966,000 km^2, and comprises three main types of canals including perennial, non-perennial, and inundation. Snow and glacial melt and rainfall in the region are the main sources of water for the IBIS. Other than the IBIS, most of the rivers in Pakistan are ephemeral and only flow during the rainy season. Therefore, these rivers do not contribute to the water needs of the IBIS inside the basin (Qureshi, 2011). Pakistan relies on both natural and stored water resources. Natural resources include rainfall, rivers, ponds, lakes, glaciers, and storage within the IBIS. The monsoon and western depression (a weather system, which originates over the Mediterranean Sea) are two major sources of rainfall. Pakistan receives about 70% of annual monsoon rainfall between July and September. The entire Indus Plain receives an average rainfall of 212 and 53 mm in the *kharif* (summer) and *rabi* (winter) cropping seasons, respectively (Ahmed *et al*., 2007).

In Pakistan, over-irrigation is responsible for wasting a significant volume of water, which has resulted in problems linked to nutrient leaching and soil erosion (Kaleem, 2004). In 1951, per capita water availability was reported to be 5,600 m^3; now it is currently less than 1,000 m^3 (Awan and Mustafa, 2013; Lohano and Marri, 2020). A changing climate coupled with a rising population and mismanagement of water resources are the main reasons of fluctuations in water availability (Shehzad *et al*., 2016). Better management of water resources as well as improved farmer education regarding the importance of water and its conservation is thus urgently needed. While numerous studies in Pakistan have evaluated water resource availability and water conservation for agriculture, much fewer studies have specifically evaluated the factors with on-farm impact that contribute to agricultural water scarcity. The aim of this study was therefore to critically analyse these environmental and socio-economic aspects that are contributing to increased water scarcity at farm level using principal component analysis (PCA) techniques which are part of the broader domain of factor analysis.

2 | METHODOLOGY

The research was targeted at the Punjab region which was selected through purposive sampling on the basis of having the largest provincial population and a high dependence on water to support irrigated cultivation (Figure 1). The Punjab has an area of 20.5 million hectares (50.9 million acres), of which 54% is cultivated. This extensive area requires a substantial amount of irrigation (Alam *et al*., 2000). The study was conducted within Faisalabad District, which was selected through the lottery method of sample selection. The Punjab Province comprises 36 districts—tickets bearing each district name were prepared. One ticket was chosen; this was Faisalabad. This lottery method gave each district an equal chance of selection and has been used in previous studies (Thakur, 2003). Faisalabad is known for its agricultural potential and the Lower Chenab Canal (LCC), which is the main source of irrigation used for supplying 80% of cultivated land in the district. The most common method in the study area is surface or flood irrigation. The soils in the region are mainly loamy with a significant proportion of silt (Ahmad and Rasul, 2008). The major crops in the study area are wheat, sugarcane, corn, and fodder.

The LCC contains the Rakh Branch, Jhang Branch (Upper), Jhang Branch (Lower), Gogera Branch, and Bhowana Branch Canals. Through purposive sampling the Rakh branch canal was selected on the basis of having the largest irrigated area comprising 32 distributaries

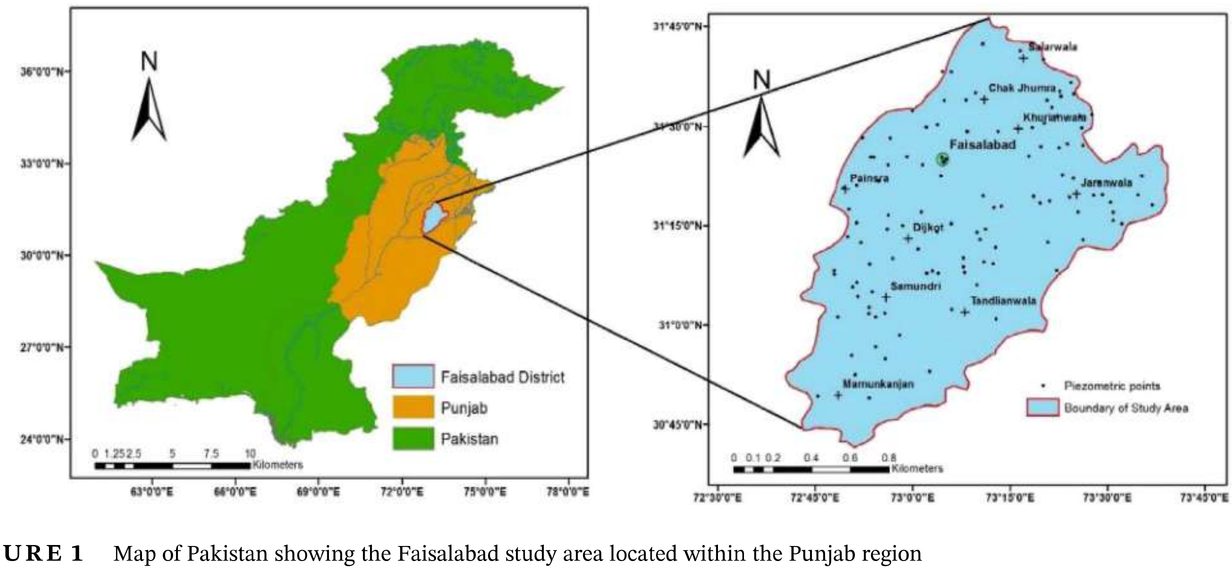

FIGURE 1 Map of Pakistan showing the Faisalabad study area located within the Punjab region

and 346 outlets. There were reported to be 32,667 farmers who received direct benefits from the canal water (Asghar, 2014). From the 32 distributaries, the Butti, Dijkot, Lakhuana, and Taror were purposively selected as compared to the other distributaries these have a larger number of beneficiary farmers. Using surveysystem.com, a sample of 370 farmers was selected from the total farmer population (32,667). A proportionate sampling technique was adopted for each distributary, resulting in 60 farmers selected from Butti, 178 from Dijkot, 76 from Lakhuana, and 53 from the Taror distributary. An equal number of farmers were selected from the head, middle, and tailwater sections of the distribution canal. An interview schedule was then designed to collect data from the respondents, drawing on previous research. Potential factors linked to water scarcity were identified and incorporated into the research instrument through a review of literature, and a variety of questions were defined using different options including the Likert scale, open-ended and closed-ended questions, and funnel and inverted funnel questions. Using a range of different types of questions can help collecting meaningful and result-oriented data (Ponto, 2015). The interview schedule was pretested with 40 farmers to check the reliability of the research instrument. Minor revisions were made to the interview schedule. The reliability of the interview schedule was assessed using the Cronbach Alpha technique; a value of 0.85 for the data from the 40 respondents confirmed that the research tool was reliable. Quantitative data from 370 respondents were then collected through face-to-face interviews to ensure the reliability of the data. Data collection was undertaken over a period of 8 months in 2019. Data were analysed using the Statistical Package for Social Sciences (SPSS); in addition, descriptive analysis techniques were used to assess the relationships between the demographic attributes of the respondents with the newly extracted factors.

PCA was then used to identify the factors influencing farm-level water scarcity. PCA is a multivariate statistical technique that is widely used to identify critical components in a study. The method is guided by central data or its differences and particularly used to explore forms of concurrent variation (Wang *et al*., 2014). PCA was used to reduce the larger data sets, engaging many interrelated variables into smaller data sets which are easy to handle unrelated variables. The outcome variables maintain the existing variability of the original data sets intact. These variables are grouped linearly, and the eigenvector values denoted coefficients. Each variable backs total variance of the original values. Each variable contributes to the total explained variance of the original variables. One main advantage is that PCA can uniquely identify key variables from overlapping variables by reducing the large set of factors included in the interview schedule (Chua, 2009).

A normality test was then applied to the data to examine the normal distribution of the factors and the Kruskal-Wallis test used to explore the significant mean differences between the demographic attributes of the respondents and the newly constructed factors. The Kruskal-Wallis test is a non-parametric test of the one-factor independent ANOVA used to explore significant means differences (Carver and Nash, 2006). In this study, age, education, land size, farming experience, and area under cultivation were the demographic attributes of the farmers that were tested against the factors.

3 | RESULTS

Field data were analysed using descriptive statistics, reliability analysis, PCA (factor analysis), normality tests, and the Kruskal-Wallis test. The key findings are briefly summarized below.

3.1 | Descriptive statistics

The demographic attributes of the respondents are given in Table 1. The mean farmer age was 46.5 years, but with a range between 24 and 70 years. Average schooling of respondents was approximately 7 years. Nearly a fifth (18.6%) of the respondents had no formal education. Maximum schooling was 12 years. Respondents showed an average experience of farming of 25.3 years (minimum and maximum experience of 2 and 50 years, respectively). The average landholding size was 3.4 ha (8.44 acres). About 3.2% of respondents were landless, while 96.8% possessed land. The maximum area for ownership was 81 ha (200 acres), but the average area under cultivation was 4 ha (9.81 acres) (minimum and maximum areas were 0.8 and 58.6 ha [2 and 145 acres], respectively).

3.2 | Reliability analysis

A Cronbach Alpha value of 0.723 was obtained for the 24 factors identified from the interview schedule and through a review of literature and pretesting the research instrument. Kröz *et al*. (2003) reported that the Cronbach Alpha value should range between 0.65 and 0.75, whereas Abu and Tasir (2001) reported it should exceed 0.60. The reliability analysis resulted in a value of > 0.65 for this study; this confirmed that the research instrument had a high reliability value.

TABLE 1 Demographic attributes of the respondents

Demographics	Mean+SD	Minimum	Maximum
Age (in years)	46.5 + 12.3	24	70
Education (in years)	7.03 + 3.77	0	12
Experience (in years)	25.3 + 12.8	2	50
Land owned (in acres)	8.4 + 15.5	0	200
Area under cultivation (in acres)	9.8 + 13.6	2	145

3.3 | Principal component analysis

Factor analysis was used on the data to identify the reasons likely to be contributing to water scarcity. The Bartlett test of sphericity and Kaiser-Meyer-Olkin measures of sampling adequacy were used to determine matrix factorability. Bartlett's test was significant ($p < .001$, $p = .00$), whereas the Kaiser-Meyer-Olkin measure was 0.791, which is higher than the standard value (0.60). Coakes and Ong (2011) reported that if Bartlett's test was significant, and the Kaiser-Meyer-Olkin value is > 0.60, then factorability is perceived to be implicit. Thus, it was considered appropriate to apply factor analysis to identify the factors contributing to farm-level water scarcity.

Table 2 shows the total variance at eight stages for the factors identified as contributing to water scarcity. Eight factors were extracted as their eigenvalues were > 1. These explained 70.2% of the variance and were (a) rise in temperature, (b) poor socio-economic condition of the farmer, (c) erratic rainfall, (d) warabandi, (e) unequal application of water in crops, (f) lower availability of water in canals, (g) uncleaned watercourses, and (h) non-adoption of high-efficiency irrigation.

Table 3 shows the rotated factor matrix for the interview schedule used for farmer data collection. Tabachnick and Fidell (2001) reported that variables with loadings equal to 0.45 were considered of average level, whereas variables with loadings of 0.32 were regarded as good. In this study, the variables all had factor loadings that were higher than 0.45. The Varimax Rotation Method followed by Kaiser Normalization was then applied to the data. The resulting matrix showed that factor 1 engaged eight other factors with factor loadings ranging from 0.56 to 0.84. The factors listed in factor 1 were f16, f21, f9, f5, f19, f4, f17, and f3. Factor 2 inducted four factors with factor loadings ranging from −0.54 to −0.83. The factors in factor 2 were f24, f1, f12, and f8. Factor 3 consisted of three factors and loadings ranged from 0.55 to 0.79. The factors in factor 3 were f18, f10, and f22. Factor 4 consisted of the three factors f6, f11, and f18 with factor loadings ranging from 0.76 to 0.78. F13, f20, and f14 belonged to factor 5, and the factor loadings ranged from 0.51 to 0.76. Factors 6, 7, and 8 each consisted of one factor, namely, f15, f23, and f2 respectively. Factor loading for factor 6 was 0.54 and 0.91 for factor 7, whereas it was 0.92 for factor 8.

From this analysis, eight new factors were highlighted (Table 4). Among these, rise in temperature received the highest variance (21.1), which meant 21.1% of its variance could be explained. The poor socio-economic condition of farmers was ranked second, showing a total variance of 12.5 followed by erratic rainfall (9.05). This confirmed that the determinants of climate change had a significant contribution to water scarcity since the rise in temperature and rainfall are often denoted as strong signals of climate change. Temperature rises will speed up melting of icecaps and glaciers, whereas erratic rainfall may cause droughts or floods which are damaging to farming communities. Warabandi, unequal application of

TABLE 2 Total variance of the newly constructed factors

Rotation sums of squared loadings			
Factors	**Total**	**Percentage of variance**	**Cumulative percentage**
1	5.07	21.1	21.1
2	2.99	12.5	33.6
3	2.17	9.06	42.7
4	1.84	7.66	50.3
5	1.38	5.74	56.1
6	1.22	5.07	61.1
7	1.14	4.74	65.9
8	1.02	4.25	70.1

TABLE 3 Factor matrix of the newly constructed factors

Rotated component matrix									
Subfactors		Extracted factors							
		1	2	3	4	5	6	7	8
f16	Humidity	0.84							
f21	Variation in rainfall time	0.79							
f9	Fog	0.79							
f5	Ground water level	−0.78							
f19	Change in cropping pattern	0.72							
f4	Effect on sowing time	0.68							
f17	Crop quality	0.67							
f3	Intensive farming	0.56							
f24	Substandard livelihood		−0.83						
f1	Conflicts		0.71						
f12	Water theft		0.63						
f8	Kacha Khala (unconstructed water channel)		−0.54						
f18	Germination problem			0.79					
f10	Epidemic diseases			0.73					
f22	Underground water quality			0.55					
f6	Uncleaned water courses				0.78				
f11	Flood irrigation				0.69				
f7	Monopoly by water distribution agencies				0.76				
f13	Industrialization					0.58			
f14	Unequal availability of water					0.51			
f20	Seepage and losses					0.84			
f15	Accumulation of mud/debris						0.54		
f23	Bad management of water courses							0.91	
f2	Poor adoptive capacity of farmer								0.92

water, less availability of canal water, uncleaned watercourses, and non-adoption of high-efficiency irrigation systems to conserve water were also extracted and considered strong determinants of water scarcity at farm level.

3.4 | Normality and Kruskal-Wallis tests

The eight factors contributing to water scarcity were then tested for normality (Table 5). Coakes and Ong (2011) confirmed that data are regarded as being normally distributed if the p value for the variable being tested is $> .05$. The normality test using the Kolmogorov–Smirnov method confirmed that the normality assumption for the eight factors did not meet the normality assumption as the p value was $< .05$. Since the factors did not meet the criteria for a normal distribution, a non-parametric Kruskal-Wallis test was used to test the mean differences between the socio-economic attributes and the factors influencing water scarcity. These attributes included age, education, experience, landholding size of respondents, and their area under cultivation. Five alternate hypotheses were tested:

- There is a significant mean difference between the age of the respondent and the factors contributing to water scarcity.
- There is a significant mean difference between the educational level of the respondent and the factors contributing to water scarcity.
- There is a significant mean difference between the experience of the respondent and the factors contributing to water scarcity.
- There is a significant mean difference between landholding size of the respondent and the factors contributing to water scarcity.

TABLE 4 Identified factors with their percentage variance

Factors	Name	Percentage of variance
Factor 1	Rise in temperature	21.1
Factor 2	Poor socio-economic condition of the farmer	12.5
Factor 3	Erratic rainfall	9.06
Factor 4	Warabandi (canal water distribution system)	7.66
Factor 5	Unequal application of water	5.74
Factor 6	Less canal water availability	5.07
Factor 7	Uncleaned water courses	4.74
Factor 8	Non-adoption of high-efficiency irrigation systems	4.25

TABLE 5 Normality test for the eight newly constructed factors

Tests of normality			
	Kolmogorov–Smirnov[a]		
	Statistic	Df	Sig.
Factor 1	.480	370	.000
Factor 2	.534	370	.000
Factor 3	.504	370	.000
Factor 4	.323	370	.000
Factor 5	.231	370	.000
Factor 6	.265	370	.000
Factor 7	.236	370	.000
Factor 8	.242	370	.000

[a]Lilliefors Significance Correction.

- There is a significant mean difference between the area under cultivation of the respondent and the factors contributing to water scarcity.

Hypothesis 1. Table 6 shows the significant mean differences between the age of the respondents and factors such as unequal application of water in crops ($p < .05$) and non-adoption of high-efficiency irrigation systems ($p < .05$). This implies that age had an association with balanced irrigation and adoption of high-efficiency irrigation techniques. For example, young individuals can be more receptive to conserving water and improving water use efficiency. With the unit increase in age, the decision-making ability of an individual decreases. In rural settings, more often older people think in stereotypic and more conventional ways.

Hypothesis 2. Table 7 shows that the experience of a respondent had a mean difference with a rise in temperature ($p < .05$), erratic rainfall ($p < .05$), unequal application of water in crops ($p < 0.05$), less availability of water in canal ($p < 0.05$), and non-adoption of high efficiency irrigation systems ($p < 0.05$). This difference implies that with increasing experience, respondents were more likely to observe increases in temperature and the erratic occurrence of rainfall. Similarly, farmer experience helps in recognizing to what extent balanced irrigation and adoption of high-efficiency irrigation techniques are important. In addition, respondents had experiences that were relevant to a rise in temperature including reporting on the melting of glaciers that were reducing the availability of their canal water over time.

TABLE 6 Relationship between newly extracted factors and age of the respondents

Factor		Chi-square	Asump sig.
1	**Rise in temperature**	**183**	**.21**
2	Poor socio-economic condition of the farmer	160	0.10
3	Erratic rainfall	161	0.82
4	Warabandi (canal water distribution system)	102	0.24
5	Unequal application of water in crops	116	0.00
6	Less canal water availability	115	0.13
7	Uncleaned water courses	106	0.67
8	Non-adoption of high efficiency irrigation system	142	0.00

TABLE 7 Relationship between newly extracted factors and experience of the respondents

Factor		Chi-square	Asump sig.
1	**Rise in temperature**	**152**	**0.03**
2	Poor socio-economic condition of the farmer	58.1	0.23
3	Erratic rainfall	132	0.00
4	Warabandi (canal water distribution system)	72.2	0.78
5	Unequal application of water in crops	86.8	0.00
6	Less canal water availability	74.8	0.00
7	Uncleaned water courses	95.2	0.41
8	Non-adoption of high-efficiency irrigation systems	85.0	0.00

Hypothesis 3. Table 8 shows that there was a significant mean difference in the educational level of the respondents with factors including the rise in temperature ($p < 0.05$), unequal irrigation ($p < 0.05$), and non-adoption of high-efficiency irrigation systems ($p < 0.05$). For the remaining factors, the mean differences were not significant.

Hypothesis 4. Table 9 shows a significant mean difference of landholding size with the rise in temperature ($p < 0.05$), warabandi ($p < 0.05$), unequal irrigation ($p < 0.05$), and less availability of canal water ($p < 0.05$). It is widely accepted that as the unit area of land increases, so too does the demand for irrigation, followed by the need for adoption of techniques to conserve water. Uneven distribution of canal water limits holders of larger land areas compared to farmers with smaller landholdings. Reduced availability of canal water created more problems for the larger farms although the availability of water impacted all farmers irrespective of land size and socio-economic status. The other factors showed no significant mean difference with the landholding size of the respondents.

Hypothesis 5. Table 10 shows a significant mean difference in the area under cultivation with the reduced availability of canal water ($p < 0.05$) and non-adoption of high-efficiency irrigation systems ($p < 0.05$). This implies that the timely availability of canal water is critical for irrigation, with reductions in crop health and yield reported to occur in response to this impact. In this context, the adoption of high-efficiency irrigation systems would help address these aspects relating to farm-level water scarcity.

4 | DISCUSSION

Our research focused on determining the factors which are most likely to contribute to water scarcity in agriculture. Among the eight factors identified, a rise in temperature, poor socio-economic conditions of the farmers, erratic rainfall, the warabandi system, the non-uniform irrigation application, reduced availability of canal water, uncleaned water courses, and non-adoption of high-

TABLE 8 Relationship between newly extracted factors and education of the respondents

Factor		Chi-square	Asump sig.
1	**Rise in temperature**	**12.1**	**0.02**
2	Poor socio-economic condition of the farmer	50.3	0.95
3	Erratic rainfall	5.20	0.83
4	Warabandi (canal water distribution system)	31.0	0.10
5	Unequal application of water in crops	11.7	0.00
6	Less canal water availability	20.0	0.88
7	Uncleaned water courses	32.1	0.43
8	Non-adoption of high-efficiency irrigation systems	8.40	0.00

TABLE 9 Relationship between newly extracted factors and landholding size of respondents

Factor		Chi-square	Asump sig.
1	**Rise in temperature**	**70.3**	**.00**
2	Poor socio-economic condition of the farmer	93.0	0.13
3	Erratic rainfall	121	0.35
4	Warabandi (canal water distribution system)	76.6	0.01
5	Unequal application of water in crops	80.9	0.00
6	Less canal water availability	84.5	0.00
7	Uncleaned water courses	91.6	0.52
8	Nonadoption of high-efficiency irrigation systems	40.2	0.79

TABLE 10 Relationship between newly extracted factors and area under cultivation of the respondents

Factor		Chi-square	Asump sig.
1	**Rise in temperature**	**50.6**	**.20**
2	Poor socio-economic condition of the farmer	78.0	0.63
3	Erratic rainfall	109	0.15
4	Warabandi (canal water distribution system)	90.4	0.06
5	Unequal application of water in crops	74.9	0.11
6	Less canal water availability	77.2	0.00
7	Uncleaned water courses	79.1	0.27
8	Nonadoption of high-efficiency irrigation system	80.0	0.00

efficiency irrigation systems were all highlighted as being most important. The factors are anthropogenic, apart from temperature rise and erratic rainfall. According to Farooqi *et al.* (2005), rise in temperature in Pakistan could severely impact agricultural production. In Pakistan, temperature is predicted to increase by +0.9°C and +1.5°C by the 2020s and 2050s, respectively (Bae *et al.*, 2015). This would negatively impact water availability as glaciers, rainfall patterns, and extreme events including droughts and floods have all shown major shifts in their long-term underlying trends. The per capita annual availability of water may also reduce, as it already has reached < 1,000 m^3 (Hussain and Mumtaz, 2014). Our study supports the view that a rise in temperature is likely to affect the availability of water and crop production, leading to a reduction in income generation. Farmers who are already poor in the country would become poorer with the rise of temperature and fall of crop production.

The poor socio-economic conditions of the farmers studied were also shown to directly impact agricultural water scarcity in Pakistan. Socio-economic aspects including age, education, wealth, access to information, and gender do not have a direct relationship with water use per se, but do have a direct association with water conservation and its judicious use. Our findings are supported by those of Darkwah *et al.* (2019), who reported that farm size and access to credits had a significant relationship with farmer attitudes towards water conservation. In another study by Nkegbe and Shankar (2014), it was reported that the wealth of farmers, including their land area and access to information, strongly impacted their attitudes towards adopting water conservation measures. This implies that as the socio-economic position of farmers increases, this can lead to corresponding rises in the uptake of water conservation measures. In this study, if farmers were old, had lower levels of education, and were practicing small-scale farming, these factors collectively led towards a more likely contribution to water scarcity rather than towards water conservation.

The warabandi (canal distribution system) and unequal application of water to crops were also identified as being two important factors likely to contribute to farm-level water scarcity. As above, the poor socio-economic status of farmers combined with poor access to information means farmers are unable to adequately irrigate their crops. It is worth mentioning that excessive or reduced irrigation both hamper impact on crop productivity. In order to meet the irrigation water requirements for their crops, farmers often use a combination of canal water and tube wells. In Pakistan, the warabandi systems are institutionalized, with a rotational distribution of irrigation allocations defined by fixed timings based on the area of land each farmer owns within the command area. The warabandis have previously been reported to be responsible for an overall shortage of irrigation water supply (Bandaragoda and ur Rehman, 1995), and the equity of water distribution depends on various factors, including conveyance losses (Iqbal and Ahmad, 2005). For example, Bhatti *et al.* (2017) reported high levels of efficiency in warabandis that had lined (78%) channels compared to unlined (50%) canals. A lack of canal maintenance also reduces water flows, and leads to increased seepage and evaporation losses, thus reducing the volumes available for farmers to abstract, particularly those that are situated at the downstream end of the warabandi.

Arshad *et al.* (2015) reported that water infrastructure in Pakistan is generally poorly designed and managed, resulting in significant water losses, especially during periods of irrigation. Naeem (1991) reported that one-third of the water in Pakistan is lost through conveyance. According to Anjum (1993) conveyance losses are 40% compared to other countries where losses range between 25% and 50%, particularly in unlined canals (Badar, 2000). Bhatti *et al.* (2017) studied 15 watercourses in the Khyber Pakhtunkhwa region and estimated losses to be between 25% and 45%. In contrast, Khan *et al.* (2009) reported a 27% increase in water delivery efficiency and 53% reduction in water losses in lined watercourses in the Khyber Pakhtunkhwa. Solangi *et al.* (2017) reported that water losses at field level in the Sindh region could be minimized through lining water courses. Reducing conveyance losses and increasing water availability for farmers are thus important factors in supporting increased agricultural productivity. Therefore, research institutions in Pakistan have proposed a range of techniques to combat water losses and increase water use efficiency. Farmers in Pakistan are also being provided with subsidies to strengthen their adaptive capacity. Among the different initiatives being proposed, the development of high efficiency systems, including drip and sprinkler irrigation, are being supported in response to persistent problems linked to water shortages in agriculture.

To increase water availability, numerous efforts such as pressurized irrigation systems have been made in Pakistan over the last five decades, but their success has been variable (Yasin *et al.*, 2001; Ashraf, 2012). The efficiency of drip irrigation was found to be double that of traditional surface irrigation (Latif *et al.*, 2016). In contrast, the non-adoption of more efficient irrigation systems and ongoing reliance on surface irrigation has contributed to increasing water scarcity. The efficiency of the existing traditional systems adopted by farmers in Pakistan is less than 40% (Latif *et al.*, 2016). This study also found that farmers had a greater inclination towards the traditional irrigation system and negligible interest in the adoption of high-efficiency irrigation systems.

In different parts of Pakistan, high-efficiency irrigation systems have shown positive impacts in the conservation of water, but adoption still remains very low and slow (Shah *et al.*, 2004). Socio-economic conditions of farmers and their low levels of affordability were found to be key obstacles to the adoption of high-efficiency irrigation systems. Farmer age, level of education, land area, and access to information also strongly influence the adoption of new technologies (Boz and Akbay, 2005; Mango *et al.*, 2017). This implies that in order to expedite wider water conservation through the adoption of high-efficiency irrigation systems at the farm level, it will be necessary to improve the socio-economic conditions of potential beneficiaries (famers). Clearly, the poor socio-economic position of farmers in this study was a major barrier and likely to exacerbate their water access and exploitation challenges.

5 | CONCLUSIONS

Eight factors were identified which are likely to contribute to increased water scarcity for agricultural irrigation in the Punjab region at the farm level. The Kruskal-Wallis test indicated that the socio-economic attributes, including farmer experience, education, age, landholding, and area under cultivation of the respondents, all had significant mean differences with the factors linked to water scarcity. The crops grown in the study area play a vital role in contributing to rural livelihoods and the national economy. By improving the socio-economic attributes of farmers, water use efficiency can be enhanced, and ultimately this would help reduce system-level water losses and improve the uptake of water conservation measures. This research has highlighted how water availability and water conservation are both critically important in helping to meet future irrigation demands in Pakistan, and our findings should inform policy development and the institutions responsible for promoting sustainable development. Further research is needed to address these water security issues to ensure irrigated agriculture can deliver the necessary levels of productivity required in Pakistan to meet growing national demands for food and to support increased foreign exchange earnings.

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