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Assessing Barriers in Adaptation of Water Management Innovations under Rotational Canal Water Distribution System

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Abstract: This study assessed problems associated with irrigation water provisions and the potential barriers to the adaptation of the interventions (soil moisture sensors, on-farm water storage facilities and the drip method) under rotational canal water distribution in Punjab, Pakistan. Three groups of stakeholders were individually surveyed during September–December 2020: (i) 72 farmers, (ii) 15 officials, and (iii) 14 academicians. We used descriptive statistical analysis, cross-tabulation and the Fisher test to explore the pattern of responses across the groups. The main problems in the canal water distribution system were expressed by the farmers as limited water allocation, while academicians were concerned mostly with inflexibility and officials indicated discussion among neighbors. According to the farmers' responses, the conventional depth/interval of irrigation is flooding the field with water and observing the plants, indicating over-irrigation behavior. Moreover, the most important barriers in the adaptation of the interventions that were highly rated by the three groups were low awareness, lack of training and financial resources. Additionally, farmers' education revealed a statistically significant influence on awareness of soil moisture sensors and water storage facilities, while large farm holders showed a positive relationship to conducting a joint experiment with scientists and farmers' associations on part of their land to improve water use efficiency.

Keywords: rotational water distribution; water management interventions; adoption; obstacles

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1. Introduction

Irrigated agriculture in Pakistan falls under the Indus Basin Irrigation System (IBIS) and inflows from the Indus River's tributaries (the Indus, Jhelum, Sutlej, Chenab, Ravi and Kabul), which fee into a large and complex system of canals that deliver surface water to irrigated fields [1]. Public authorities have regulated the surface water distribution in the IBIS following the Warabandi principle for over a century now. The Warabandi term is taken from two words, 'Wara' and 'bandi'. The meaning of wara is 'turn' and bandi means 'fixation'. Together, these terms reflect the rotation of water distribution according to a rigid schedule [2,3].

Under the Warabandi principle, canal water is distributed to all fields in each watercourse. The distribution is characterized by a rigid cycle of considering once a week a particular time period in a pre-planned schedule determining the day, hour and duration of water delivery with an amount proportional to the area of agricultural land owned by farmers [3]. To maintain an equitable distribution of surface water, the canal water allocation is kept low to cope with water scarcity by efficiently irrigating as much land as possible [2].

The irrigation sector of Pakistan faces problems attributed to the surface water distribution system and environmental changes that have accelerated water scarcity conditions in the area. Despite being relatively simple to manage and regulate by institutions, use of the Warabandi system remains a challenge for the present and future increasingly variable water demand in the agricultural sector. It is, for example, a rigid supply-based water distribution mode that does not match crops' water demand stages and does not take into account soil properties or environmental changes. Furthermore, it fails to account for canal conveyance losses, resulting in decreased water allocation for downstream canal users [2–5].

In addition to water distribution problems, a rise in cropping intensity of ~125% has been recorded, and the IBIS was designed considering a cropping intensity ~75% [4]. Moreover, the prediction for 2025 shows that the country might record an ~28% shortage in canal water associated with the reservoir siltation. Increasing demand for water consumption in several sectors (domestic use, ecology, industry, agriculture) and due to the influence of climate change may further enhance irrigation water scarcity in the country [1,6]. Additionally, old irrigation infrastructure and ineffective operation and maintenance of irrigation canals in IBIS have resulted in low conveyance efficiency [7], causing limited, unequal and inconsistent surface water supply, particularly to tail-end farmers. Moreover, inefficient on-farm water practices are further aggravating the supply–demand imbalance that has led to the unrestricted extraction of groundwater using fuel energy and that could cause sustainability problems in the region (deteriorating groundwater quality and salinization) [1,7–9].

A number of studies have addressed the on-farm water management issues and proposed interventions to the limited canal water allocation problems in the Warabandi-guided irrigation scheme. A study suggested introducing low water demanding crops and the adoption of an efficient irrigation system [10]. Similarly, another study showed field layout improvements enabling the lowering of irrigation depths, thereby enhancing field application efficiency [5]. In addition, the application of laser grade profile and the furrow irrigation method were supported [11], and using the drip irrigation technique and bed planting method were also proposed [12,13]. However, they lack the consideration of barriers and obstacles in implementing these measures. However, other studies assessed the potential barriers to the adaptation of several climate-smart agricultural practices for boosting the productivity of water and non-water agricultural inputs [10,14–18]. Hence, the options for technical interventions are available; therefore, a major task which remains to be addressed is determining how these interventions could be clustered and implemented, which is basically the intention of this study with a focus on selected interventions forming a package.

This study focuses on the implementation of a water management intervention package that includes soil moisture sensors, on-farm water storage facilities and drip technology. The performance of on-farm water storage has been assessed in India under the Warabandi conditions, indicating that on-farm water ponds have facilitated the implementation of sprinkler techniques and the pond-based sprinkler systems that have resulted in improved water use efficiency, cropping yield and net benefits [19]. Similarly, a study recommended on-farm water storage for canal water management in Pakistan that enables the storage of potential surplus water under rigid rotations [20]. Moreover, it provides an enabling environment for efficient irrigation systems, such as drip, which requires frequent irrigation of rather small amounts to unfold the full potential of that technique. Therefore, drip, as an advanced irrigation method, was highly recommended for improving water use efficiency in the water stress conditions of Pakistan [12]. Furthermore, sensor-based soil moisture monitoring supports farmers regarding when and how much water to irrigate, which has resulted in a substantial saving of irrigation water in other regions of the world [21–23]. The combination of an on-farm water pond, provision of irrigation scheduling and a drip technique have achieved higher water productivity at the farm level for cotton crop given the framing conditions of the Warabandi in Punjab, Pakistan [24].

Therefore, this study distinctively considered the evaluation of obstacles hindering the introduction of irrigation scheduling as a package of water management interventions for the farmers' farms under the rigid and erratic canal water supply. Thus, the main stakeholders (farmers, officials and academicians) were involved and surveyed to reveal the integrated perspectives on the hurdles that require support to advance the understanding of the feasibility process for adopting the measures by farmers.

The study aims to assess the problems associated with the irrigation water provisions and the potential barriers to the adaptation of water management interventions on farmers' farms under the framing conditions of the Warabandi principle. This research attempts to support making the implementations more targeted by considering the requirements and views of the water users (farmers), water suppliers (officials of irrigation administration) and academicians.

2. Material and Methods

2.1. Study Site Description

The survey was carried out in the Mungi distributary canal command area, which is one of the distributaries of the Lower Chenab Canal in Punjab, Pakistan (Figure 1). It is situated within 30°33′ and 31°2′ N and 72°08′ to 72°48′ E, at an altitude of 184 m. The gross command area of the Mungi canal is ~20,290 ha.

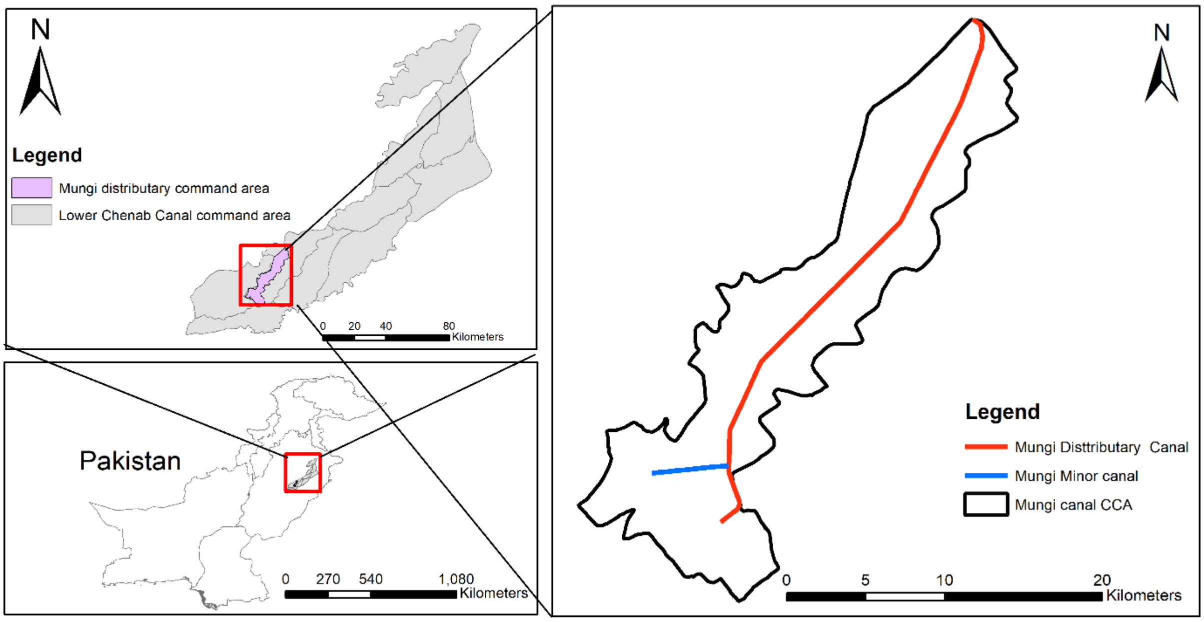


Figure 1. Position of the study region.

2.2. Survey Structure

We designed surveys with a semi-structured, multiple-choice, rated and open-ended format. During the months of September–December 2020, we surveyed three different groups of stakeholders: (i) 72 farmers were randomly selected in the command area of the Mungi distributary canal, (ii) 15 government officials, and (iii) 14 academicians. The sample represents demographic attributes of a cross-section of farmers with differing schooling years, farm location along the Mungi distributary canal, farm size, land ownership and years of experience, whereas officials and academicians were selected based on their background related to irrigation water management.

The sample size was limited due to an ongoing wave of the COVID-19 infection in the study area in 2020. The survey was conducted individually and face to face, taking into account the COVID-19 safety measures, with the assistance of a local language translator.

The survey questionnaires (Supplementary Materials) were broadly focused on the challenges of Warabandi water distribution faced by farmers in the fields/farms, the proposed water management interventions and the barriers to implementing these measures.

The interventions led to a more flexible irrigation strategy within the farms, taking into account the framing condition of the Warabandi in larger-scale water allocation.

Water management interventions were selected as water storage facilities, usage of soil moisture sensors and a combination of an on-farm water pond, soil moisture sensors and the drip technology. These interventions function as adaptation measures on farmers' farms to deal with the challenges associated with the unreliable and limited canal water supply versus a rising and increasingly variable water demand [20,22–24].

The literature permitted the identification of a set of potential barriers that may affect the implementation of selected interventions. They are summarized as follows: low awareness, lack of financial resources, maintenance and operation, and lack of training [15,17]. The survey tried to quantify the relative importance of these barriers based on stakeholders' opinions (farmers, scientists and officials).

2.3. Method of Analysis

We applied descriptive statistical analysis, frequency tables, cross-tabulation and the Fisher test in order to compare and explore the impact and pattern of responses across three groups [25–31].

A cross-tabulation is a joint frequency distribution of incidents considering two or more categorical variables [31]. The Fisher exact test can be used to assess whether the variables are statistically independent or whether they are associated by using the joint frequency distribution [26]. It also compares the actual and expected data distribution within categories. If there is an association between variables, then other indicators of the relationship could be applied to explore the degree to which the values of one variable predict or differ from those of the other variable. We set a significance threshold of $p = 0.05$ [32]. The more significant the finding is, the smaller the p-value is. We explored whether a statistically significant relationship between independent variables (farmers' education, experience, land ownership, farm size and field location) and the categorical variables exists or not [26,30]. The null hypothesis (N_0) was that there is no relationship between independent and categorical variables [27]. Stata statistical software was used for data analysis [33].

For rating questionnaires, participants from the three groups were asked to rate the strength of each potential barrier from 0 to 5 for the adaptation of a water management intervention. A rating of "0 " indicates the barrier that does not affect the adaptation of the measure and a rating of "5 " shows the strongest effect of the barrier on implementation of the relevant intervention. We categorized the strongest effect of barriers from 3 to 5, while 1 to 3 indicated a moderate effect, and 0 to 1 showed a low effect. Spider graph presents the aggregated average rating as the perception of each group on strength of the effect of potential barriers identified for implementation of each measure. Categorization permitted us to visualize the responses in a spider graph and compare the most or least important aspects agreed by all the groups [29].

3. Results

3.1. Descriptive Statistics

Table 1 shows the demographic characteristics of the farmers. More than half (52%) of the farmers had a secondary school education, with an average of ~8 years of schooling, while 18% had no formal education. The respondents showed an average farming experience of ~12 years, and the average farm size was ~4 hectares (10 acres), which is in line with the study that reported approximately 90% of Pakistan's farmers are small-scale, with landholdings of less than 5 hectares [17]. Moreover, the majority of the farmers (~75%) were landowners, while the farms' distribution over the Mungi distributary canal was scattered over the head, mid and tail as 25, 40 and 34%, respectively.

Table 1. Heterogeneous attributions of the farmers (total participants = 72).

Farmers' Characteristics	Indicators	Frequency	Percentage	Average	Standard Deviation
Farmers education	No formal education	13	18.06	8.29	4.50
	Primary school	7	9.72		
	Secondary school	38	52.78		
	College	10	13.89		
	University	4	5.56		
Farmers experience	1–12 years	37	51.39	12.62	4.45
	>12 years	35	48.61		
Farm size	1–4 ha	39	54.17	10.45	8.28
	>4 ha	33	45.83		
Land ownership	Tenant	18	25		
	Land owner	54	75		
Field location along Mungi canal	Head	18	25		
	Middle	29	40.28		
	Tail	25	34.72		

On the question of environmental changes in the Mungi area over the past two decades, considering multiple choice options, over 50% of the farmers reported a decrease in canal water allocation. The dropping of the groundwater table, deterioration in its quality and increasing land and soil salinity in the area have been observed by the farmers and were reflected in their responses as 43, 28 and 37%, respectively (Figure 2). Despite the efforts of the institutions in improving the performance of the irrigation infrastructure in recent years, the decrease in the canal water allocation is attributed to old water infrastructure and poor operation and maintenance resulting in high conveyance losses [7], while increasing intensification and the introduction of new and water-demanding crops (e.g., sugarcane) have led to a higher demand (which is aggravating canal supply and demand gaps). Moreover, these factors could be associated with the impact of climate changes, the sedimentation of the reservoirs and sharpening competition for water use (agriculture, industry, domestic use and environment) [1]. The deteriorating groundwater quality is attributed to the percolation of irrigation water loaded with fertilizers and agricultural substances into aquifers [34].

In reference to the respondents of Q1 (problems in canal water distribution) in Figure 3, the farmers stressed the limited canal water allotment in the Warabandi system as a major problem at 74% of the respondents, while rigid rotation and discussion with neighbors were rated as 23 and 3%, respectively. On other hand, considering Q2 (if more water is allocated) in Figure 3, the increase in the Warabandi allocation could enable farmers to grow high-water-demanding crops, reflected by the farmers with 73% of the respondents. It implies that the increase in the allowance could change the cultivation behavior of the farmers to water-demanding crops, which does not lead to water saving and it might result in more pumping of groundwater to fulfil the demand of the crops.

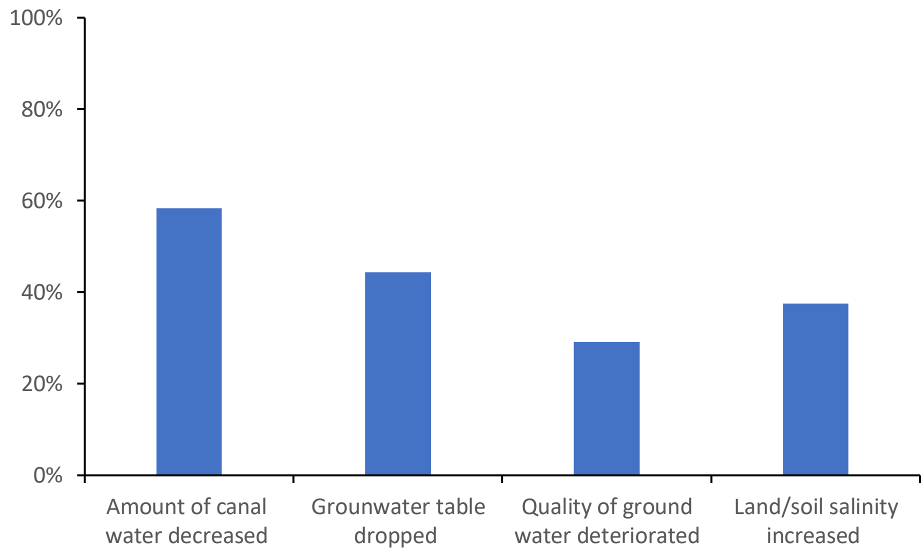


Figure 2. Response of the farmers to environmental changes in the Mungi area.

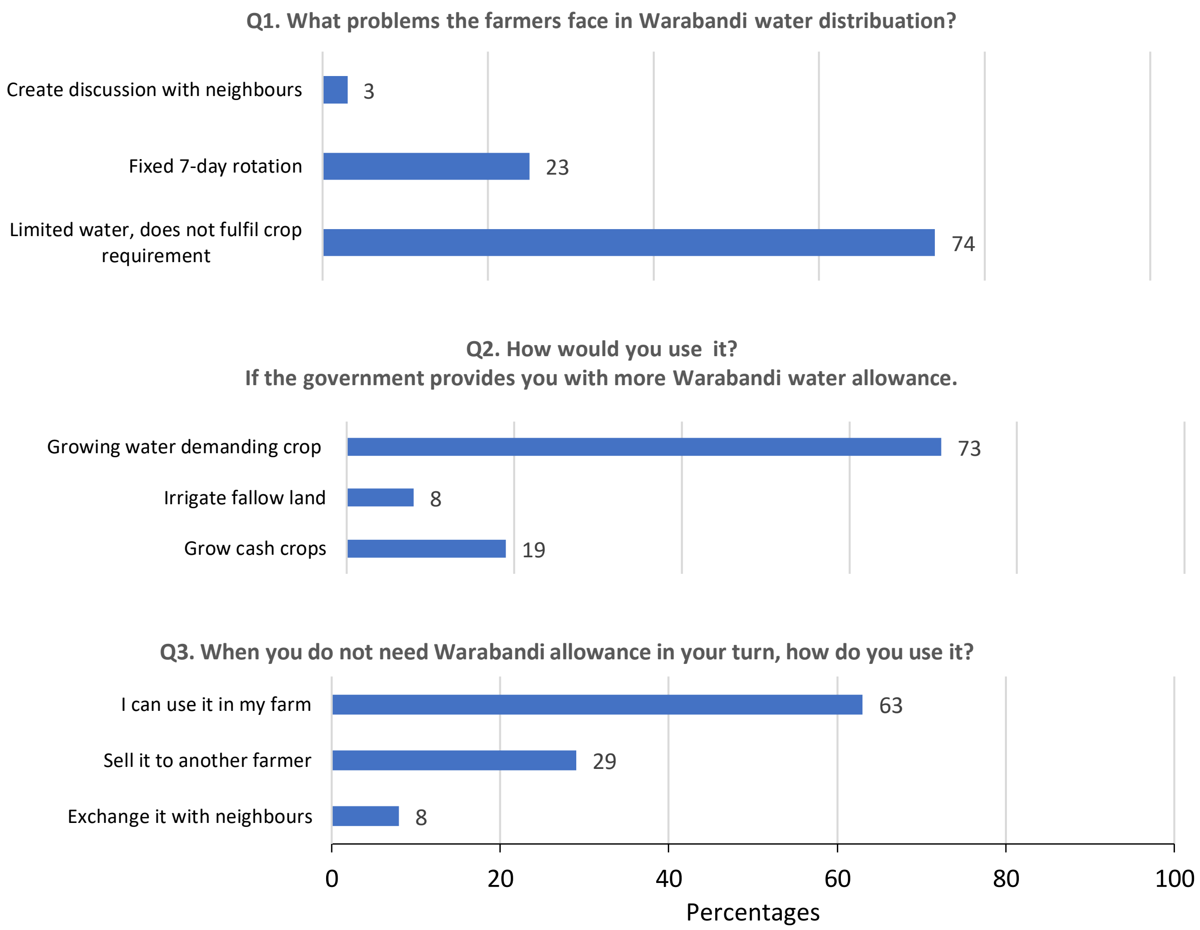


Figure 3. Percentage of 'Yes' responses related to Warabandi questionnaires.

Furthermore, for the past several decades, farmers have practiced irrigation scheduling under the fixed rotation of the Warabandi and have adapted to 7-day irrigation intervals for their common crops such as cotton, maize and wheat. Therefore, for the question of whether the farmer wants a change in the 7-days rotation, around 67% of respondents conveyed 'No'. Consequently, farmers choose alternative options for the using canal water allocation when it is not needed in their turns (Figure 3, Q3). The responses indicate that over 60% of the respondents use the canal water allowance in any case because they own big farms, while around 30% of the farmers sell it to another farmer, and less than 10% exchange it with neighbors (Figure 3, Q3).

The problems in the Warabandi principle were reflected by the three groups as depicted in Figure 4. Most of the farmers (~70%) expressed the limited canal water allowance as the main problem, while ~50% of academicians were concerned about inflexibility and ~60% of officials responded that creating discussion among farmers during the distribution of water under the rule of the Warabandi is the main problem. It implies a silo approach, which resulted in focusing on tackling existing problems in the canal water distribution system from each group's perspective, without collaborating with other groups in an integrative way in order to observe and solve the issue.

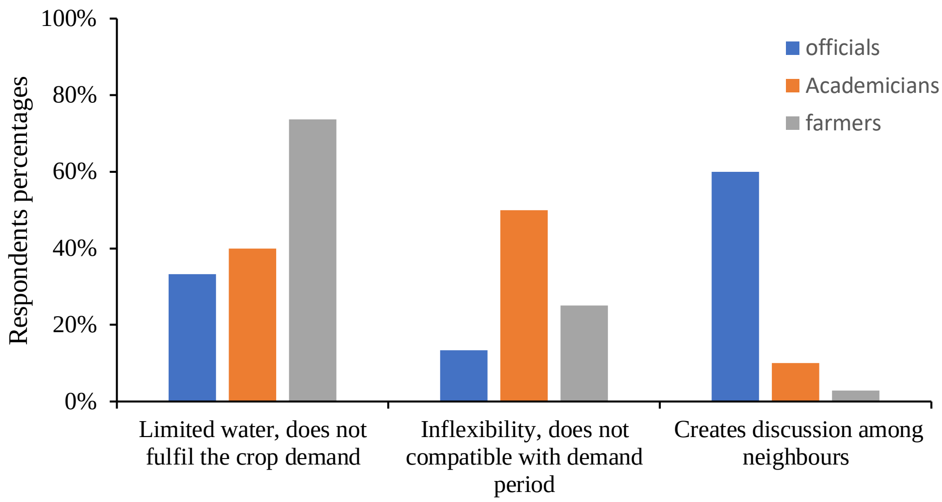


Figure 4. Responses from the farmers, academicians and officials on problems relevant to the Warabandi.

To understand the perception of the farmers' irrigation behavior, we narrowed down the questionnaires regarding the irrigating scheduling of cotton as a summer dominant and high-water-demanding crop in the Mungi area. According to Figure 5 (Q4, Q5 and Q6), around 90% of the farmers responded that the irrigation timing of cotton was decided based on observation of the plant, whereas, 85% responded that they fill the furrow depth with water and the irrigation interval usually takes place after 7 days (77% of the respondents). This indicates that conventional irrigation planning (time and depth) results in the over-irrigation behavior of the farmers. They do not consider the soil moisture content of the field and the time-dependent requirements of the crop. This implies the potential for intervention in irrigation scheduling to increase water use efficiency through performing joint experiments (farmers and scientists) and providing training options and facilities.

Farmers have limited understanding and low awareness of water management interventions, especially in the case of soil moisture sensors and on-farm water storage ponds, as evidenced by the 10 and 28% of 'Yes' responses in Figure 6. Furthermore, the institutions in Punjab provide farmers with a 60% subsidy for using drip technology [35]. Therefore, 68% of farmers acknowledged that they could afford the drip system with a 60% subsidy. The adoption of drip technology in Punjab is related to numerous elements such as farmer training on its operation and maintenance, water storage facilities, optimal integration with fertilizer application and the drip design taking into account soil features [24].

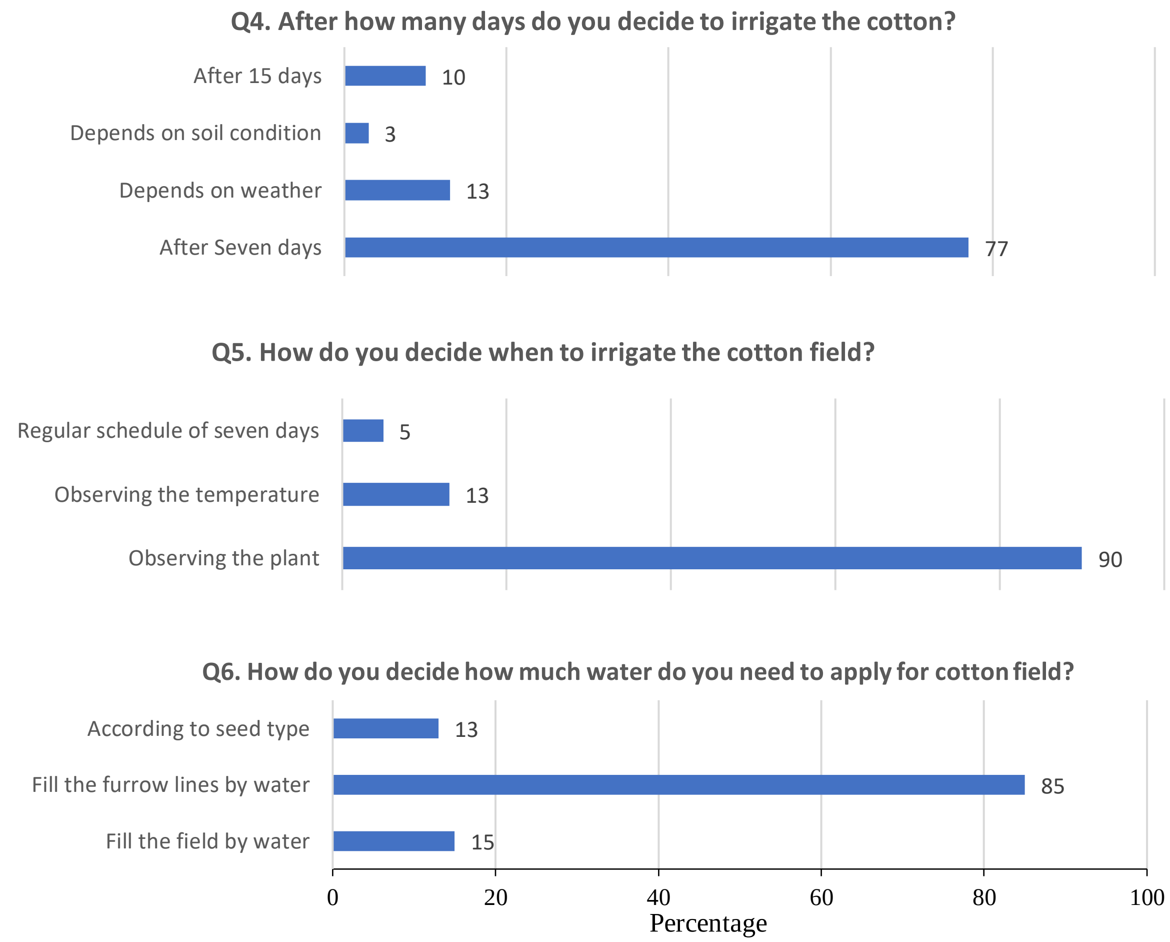


Figure 5. Percentage of 'Yes' responses relevant to cotton irrigation questions (It was open-ended question; 42 participants cultivated cotton crops and responded to the cotton-related questions).

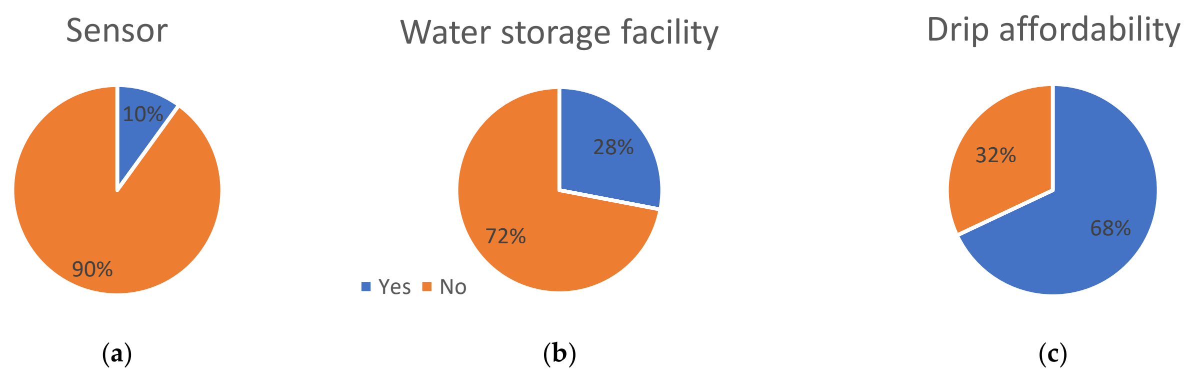


Figure 6. Respondent perceptions on (**a**) awareness about soil moisture sensors, (**b**) awareness about on-farm water storage facilities, and (**c**) affordability of the drip system by farmers receiving a 60% subsidy from the institutions.

We asked farmers if they would participate in a joint experiment at a small plot of their land with scientists and farmers' associations to improve water use efficiency, and more than 53% of the farmers responded 'Yes'. This could enable further research on farmers' farm considering actual field conditions that reflect the real challenges and impacts caused by the implementation of proposed water management interventions. Furthermore, it supports the surrounding farmers in being inspired by the result of the experiment and easily adopting the measures (farmer-to-farmer approach).

Regarding the most effective channels for approaching and providing guidance on water management to farmers in the Mungi distributary canal area, the private sector was most frequently mentioned (salespersons of the agricultural products), followed by the Agriculture Department and the Punjab Irrigation Department, with response rates of 46%, 32% and 24%, respectively.

3.2. Cross-Tabulation and Fisher Test

The results of the cross-tabulation and Fisher test are provided in Table 2. The findings revealed that the values of the Fisher test were greater than 0.05 as a significant interval for almost all the categorical variables. Therefore, we are unable to reject the null hypothesis and it implies that the incidence of all independent variables is not statistically significant with the categorical variable, which might be due to the limited sample size.

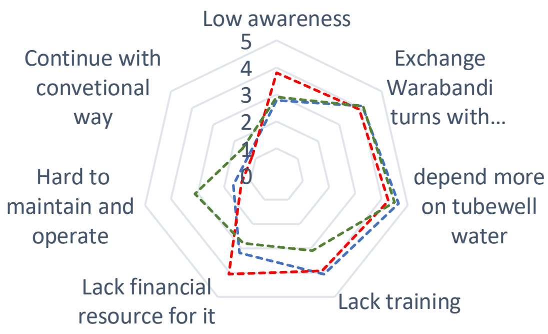
Table 2. Cross-tabulation results for the categorical variables versus independent variables related to farmers.

Farmers'	Fisher Test	Q.1: Is Drip a Good Cultivation Method for Cotton? (N = 42)	Q.2: Do You Want to Conduct an Experiment with Scientists at Your Field? (N = 72)	Q.3: Do You Want a Change in 7-day Rotation of Warabandi Principle? (N = 72)	Q.4: Have You Heard About Soil Moisture Sensors? (N = 72)	Q.5: Do You Have Discussion with Neighbors on Warabandi Water Allocation? (N = 72)	Q.6: Have You Heard about On-Farm Water Storage Ponds? (N = 72)
Education	*p*-value	0.377	0.63	0.52	0.000	0.713	0.001
Experience		0.142	0.233	0.619	1	1	1
Land ownership		0.669	0.417	0.094	0.181	0.495	0.362
Field location along the Mungi canal		0.136	0.912	0.071	0.408	1	0.200
Farm size		0.706	0.019	0.452	0.235	0.760	0.430

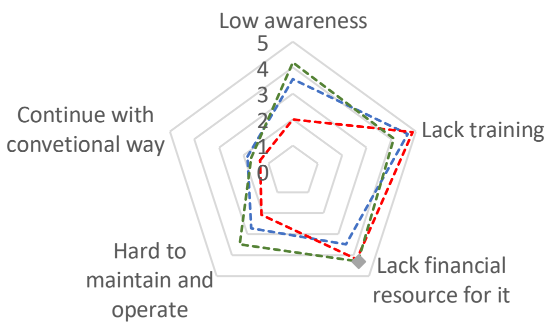
While the results also showed that the null hypothesis of no statistical association is rejected at the 5% level of significance, as reflected by p (a) = 0.000, p (b) = 0.001 and p (c) = 0.019. These figures correspond to farmers' education versus awareness of (a) soil moisture sensors and (b) water storage facilities and farm size in relation to (c) willingness of farmers to conduct a joint experiment at their plot of land together with scientists and farmers' associations, respectively. Thus, farmers with a university or a college degree had left their villages to travel to nearby cities to attend schools and learn about innovative agricultural products, such as soil moisture sensors and on-farm storage facilities. Farmers with larger amounts of agricultural land, on the other hand, agreed to provide a small portion of their land for experimentation, but small landholders who rely on their land for a living did not want to risk it.

3.3. Constraints in the Adoption of Water Management Interventions

The results in Figure 7a demonstrate that the farmers' reliance on tube-well water, exchange of Warabandi canal water with neighbors and lack of training were the strongest barriers to the adoption of an on-farm water storage at the farm level. They were rated between 3 and 5 by the three groups. While low awareness and lack of financial resources were moderate barriers according to farmers and academicians (rated between 1 and 3), officials perceived them as a strong hurdle. Furthermore, the barriers to operation and maintenance and using traditional methods were graded between 0 and 1, having a low effect. However, academicians rated operation and maintenance as a moderate obstacle. Therefore, creating an incentive for farmers to have a storage pond by increasing awareness and offering training on how to use canal water in a pond is critical. While farmers were not completely aware of the function of a pond, it creates an enabling environment for using higher irrigation technologies, such as drip and sprinkler, and storing the potential surplus water of the Mungi canal in October, November and December as well as during the shift from one season to another and on rainy days for later use [34,36].



(**a**)



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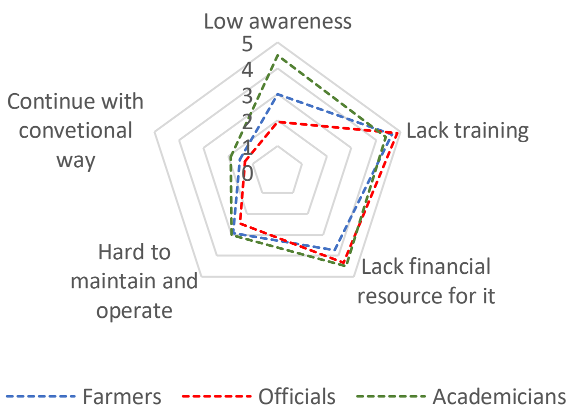

(**c**)

Figure 7. Perception comparison of three groups on barriers to ensuring the success of the adaptation process of (**a**) on-farm water storage facility (**b**) soil moisture sensors and (**c**) combination of a storage facility, soil moisture sensor and the drip method.

The adoption of soil moisture sensors could support farmers in estimating irrigation timing and amounts. According to the ratings of the three groups, the strongest barriers to adopting this technique are a lack of training and financial resources (Figure 7b). There was a large difference in academicians' and officials' recognizing the importance of low awareness and the operation and maintenance of soil moisture sensors because academicians rated them as having the strongest effect on adoption, whereas officials rated them as having a low impact. Practicing the conventional technique, on the other hand, was considered as a low impediment to sensor implementation by the three groups.

Figure 7c presents the insight of the groups on a combination of water management interventions (soil moisture sensors, storage ponds and drip). All stakeholders agreed that the strongest barriers to the implementation of these interventions were a lack of training and financial resources, whereas academicians also rated low awareness as the strongest obstacle. Moreover, the three groups reported operating and maintenance as having a moderate effect and practicing conventional methods as having a low effect on barriers to the application of these interventions.

The assessment of barriers revealed that all three groups, particularly farmers, rated conventional practices as having a low effect on the adoption of the interventions. It indicates that the incentive for change already exists in farmers and that they are willing to adopt the innovative strategies, but they require assistance in overcoming the obstacles. In addition to the identified obstacles, other hurdles may be influential, such as the farmers' socioeconomic status and the availability of each intervention. The findings support policymakers in developing appropriate strategies since the information advances the feasibility process of the measures.

4. Discussion

The development of agricultural policies necessitates understanding the perception of farmers and the socioeconomic factors affecting the implementation of the proposed adaptation measures [37]. The study's findings reveal that several obstacles influence the adaptation of water management interventions in the context of the Warabandi, with the strongest influences being low awareness and lack of both training and financial resources. All of these factors have been identified and reported in other studies as barriers to adopting climate-smart agriculture practices in Punjab [15,16,18]. According to a recent study [17], the main barriers to adopting sustainable land and water management measures (land laser leveling, bed planting and minimum tillage) in cotton cultivation were low awareness, financial and resource constraints, irrigation water shortages and the unavailability of the technological products.

In the current study, the farmers' education had a substantial influence on awareness of soil moisture sensors and storage ponds, whereas larger farm holders were more likely to be willing to conduct a joint experiment to improve water use efficiency. Similarly, the socioeconomic characteristics of the farmers influenced the application of the agricultural strategies documented in various studies. In a study [10], it was revealed that the demographic attributions of the farmers, such as land size, experience, and education, were significantly correlated with the adoption of high-efficiency irrigation techniques. In addition, another study in Punjab indicated that farmers' farming experience, education, land size, access to credit and belief in climate change all have a positive impact on the implementation of measures such as on-farm water storage, soil conservation techniques and efficient irrigation techniques [15]. Furthermore, the farmers' education, farm size and access to credit were all positively associated with the acceptance of adaptation measures (e.g., adjustments in sowing time, changing to a new crop and shifting to drought-tolerant crops) in all four provinces of Pakistan [14]. As a result, the farmers' socioeconomic characteristics collectively led to the adoption of the proposed techniques.

Farmers may continue to use traditional methods due to the accumulative influences of obstacles resulting from both farmers' characteristics and external hurdles [10]. For example, despite the fact that high-efficiency irrigation techniques (particularly drip) in Pakistan have shown a progressive impact in improving water use efficiency and were highly recommended for the country's water scarcity condition, adoption rates have remained quite low [12,38]. In addition to other issues, the limited access to and availability of agricultural services and tools were reported in Punjab [16,18].

The driving forces for the farmers to enhance the utilization of Warabandi canal water in the Mungi area include the poor quality of groundwater, which can have a negative impact on crop yield, the increasing salinization, the high cost of pumping groundwater using fuel energy and the high variability of environmental and climate change (erratic rainfall and rises in temperature) [18]. In addition, issues associated with the Warabandi could also influence farmers to adapt, for instance, the issues of limited and unreliable water supply [10]. Therefore, farmers are subject to change not only as a result of the pressures of environmental change but also in order to maintain farming activities and attain greater economic benefits.

The majority of farmers in Pakistan (more than 90 percent) are small growers with less than 5 ha of land, which is one of the main reasons for the low adoption rate of climate-smart agricultural methods [17], whereas offering subsidies has helped farmers, as in the case of the drip system and other farm machinery [35]. Thus, the institutions could provide subsidies for the recommended interventions (storage ponds, soil moisture sensors) while disseminating important information on these techniques through extension services, and the relevant organizations could raise farmers' awareness.

Furthermore, providing technical training has significantly assisted farmers in adopting the measures [17]. Therefore, we see the most promising point of the training that occurs at farmers' plots of land under real field conditions to be related to the applicability and impact of the proposed management practices. The entry point could be from large farmers' farms since they have indicated willingness to participate in the experiment in this study, while the surrounding small farmers would observe and benefit from joint experimentations.

Inefficient irrigation practices in the Mungi area have caused deteriorating groundwater quality by the percolation of irrigation water loaded with fertilizers and plant protective agents from the root zone of the crops. Thus, the trend of erratic canal water supply and low groundwater quality is reported to be from upstream to downstream of the Mungi canal [34,39]. For this reason, soil salinization has been observed due to irrigation of the fields by groundwater with higher salt content than the canal water in the Lower Chenab Canal command area, including the Mungi canal [39,40]. Additionally, the amount of CO_2 emissions into the atmosphere (due to the substantial abstraction of groundwater using fuel energy) contributes to global warming. In the future, the lack of adaptation to new irrigation strategies could further accelerate the negative environmental impacts within the study region, considering the pressure on Pakistan's water resources as a result of climate change, the increased water demand in various sectors and reservoir sedimentation [1,41,42]. These factors could lead to a decline in the groundwater table and degrade its quality, resulting in impact on aquifers as an important source of drinking water; the loss of agricultural land due to soil salinization; the imbalance in water consumption and demand in various sectors; and the maintaining of unsustainable resource management (water, fertilizers and agricultural inputs) [1,14,41,42].

The impact of inefficient irrigating practices on food security (supply–demand) in Pakistan is attributed to multiple interlinked drivers, especially climate change, water scarcity and population growth. The unreliability of canal water delivery and the high cost of groundwater abstraction using fuel energy have induced farmers to shift from high water-demanding crops, e.g., cotton, rice and wheat, to low water-consuming crops, such as vegetables, affecting the food market [43]. Moreover, the severity of the temperature in the summer months and changes in rainfall patterns and intensities have resulted in impacting crop yields [30]. On the other hand, the population growth rate of the country is above 2% per year, indicating an increase in food demand [43]. Therefore, innovative irrigation practices have a great potential to improve water and land productivities by producing more agricultural output for matching the food demand of a growing population, consuming fewer inputs and taking into account environmental sustainability [43,44]. For instance, in Pakistan, adopters of climate change adaptation strategies in the irrigation sector showed (8–13%) higher levels of food security than the non-adopters [14].

Over-irrigation leads to both an increase in input costs for the produced crops (high cost of fertilizers and fuel energy for pumping groundwater) as well as the pollution of aquifers due to percolated water leaching the fertilizers applied in the fields [40]. Moreover, improved on-farm water management practices could reduce the non-beneficial uses of water to crops, such as percolation and evaporation from the fields, and also maintain yields and contribute to resource management (water and fertilizer) [45]. For instance, obtaining similar cotton yields with lower applied water (i.e., under controlled deficit irrigating scenarios), in comparison with the current over-irrigation practices, has been reported in Pakistan, and under various agro-ecological conditions [46–48], because it is attributed to the curvilinear relationship between cotton yield and applied water [49].

The field application efficiency for the cotton irrigation methods in the Mungi area can be improved by upgrading the surface cultivation method from basin (38% efficiency) to the raised bed, ridge-bed and conventional furrow irrigation methods (the field application efficiency varied between 40 and 80%). Moreover, advanced irrigating technology, such as the drip system, has further improved the efficiency by over 90% [34]. In Punjab, cotton farming under the bed-planting system has been shown to save roughly 35% more water than traditional irrigation methods [13], while using drip technology in maize fields revealed a water saving of ~70% compared to the method of bed planting [50]. Therefore, this indicates potential water-saving options by raising field application efficiency through the use of advanced irrigation approaches.

Limitation of the Study

Adapting particular water management measures requires the consideration of essential aspects of this study. It includes a limited sample size of the participants (farmers and especially academicians and officials) and a lack of involvement of all the stakeholders in a focus group discussion, which was planned, yet could not be realized due to COVID-19 restrictions and precaution measures. Thus, a broader and in-depth survey of the participants could lead to a slight deviation from the results found in this study. For instance, a statistical conclusion from Table 2 necessitates more samples to test. Several studies in Pakistan have surveyed a higher number of farmers and showed a statistically significant association considering the adoption of climate-smart agriculture practices and farmers' experience, education and farm size [15,18,30]. Furthermore, the selection and distribution of the farmers were random in the Mungi command area. Therefore, the findings of this study could provide insight into the irrigation problems of farmers, which is an appropriate starting-point for further explorations.

5. Conclusions

The current study investigated the factors hindering the adoption of water management measures (on-farm water storage facilities, soil moisture sensors and drip technology) that have the potential to significantly reduce the undersupply issue in the context of the Warabandi-guided irrigation scheme. According to the findings of this study, on-farm water management strategies should focus more on: (i) improving famers' awareness of intervention benefits, usage and impacts in order to persuade them to take a step toward implementing such measures; (ii) offering subsidies could increase the affordability of adaptation measures for farmers; and (iii) training could enable farmers to start using the measures. These obstacles are multi-institutional in scope and can be eliminated—or at least reduced—by the improvement of the services. It is vital to improve the farmers' socioeconomic situation, which is a long-term process, in order to increase their readiness to accept and implement the strategies. Farmers are inclined to adopt new measures as a result of increased water demand, erratic canal water supply and high variability in the environment and climate, which might severely affect their production. Close collaboration between farmers, scientific communities and administrative entities is essential in overcoming the constraints of the implementation of the measures. The development of water management adaptation strategies demands including and addressing farmers' perceptions of on-the-ground problems that could promote and sustain the application of the proposed techniques.

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References

1. Sarwar, A. Water management in the indus basin in Pakistan: Challenges and opportunities. *Indus. River Basin Water Secur. Sustain.* **2019**, *31*, 375–388. [CrossRef]
2. Ali, M.; Kumar, S.; Khoso, P.A. Institutional Analysis of Water Governance in Pakistan. *Glob. Leg. Stud. Rev.* **2018**, *3*, 10–20. [CrossRef]
3. Basharat, M. *Water Management in the Indus Basin in Pakistan: Challenges and Opportunities*; Elsevier Inc.: Amsterdam, The Netherlands, 2019; ISBN 9780128127827.
4. Ruigu, C. Soils under the Warabandi Water Management System. Master Thesis, Waterways Centre for Freshwater Management, University of Canterbury, Christchurch, New Zealand, 2016. [CrossRef]
5. Anwar, A.A.; Ahmad, W.; Bhatti, M.T.; Ul Haq, Z. The potential of precision surface irrigation in the Indus Basin Irrigation System. *Irrig. Sci.* **2016**, *34*, 379–396. [CrossRef]
6. Haddeland, I.; Heinke, J.; Biemans, H.; Eisner, S.; Flörke, M.; Hanasaki, N.; Konzmann, M.; Ludwig, F.; Masaki, Y.; Schewe, J.; et al. Global water resources affected by human interventions and climate change. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 3251–3256. [CrossRef]
7. Hussain, I.; Hussain, Z.; Sial, M.H.; Akram, W.; Farhan, M.F. Water Balance, Supply and Demand and Irrigation Efficiency of Indus Basin. *Water* **2011**, *49*, 13–38.
8. Young, W.J.; Arif, A.; Bhatti, T.; Borgomeo, E.; Davies, S.; Garthwaite, W.R., III; Gilmont, M.; Leb, C.; Lytton, L.; Makin, I.; et al. *Pakistan: Getting More from Water*; World Bank: Washington, DC, USA, 2019; p. 163.
9. Mekonnen, M.M.; Hoekstra, A.Y. Four billion people facing severe water scarcity. *Sci. Adv.* **2016**, *2*, e1500323. [CrossRef]
10. Khan, M.A.A.; Mahmood Ch, K.; Ashraf, I.; Siddiqui, M.T.; Knox, J.W. Evaluating socio-economic and environmental factors influencing farm-level water scarcity in Punjab, Pakistan. *Irrig. Drain.* **2021**, *70*, 797–808. [CrossRef]
11. Anwar, A.A.; Ahmad, W. Precision surface irrigation with conjunctive water use. *Sustain. Water Resour. Manag.* **2020**, *6*, 75. [CrossRef]
12. Latif, M.; Haider, S.S.; Rashid, M.U. Adoption of high efficiency irrigation systems to overcome scarcity of irrigation water in Pakistan. *Proc. Pakistan Acad. Sci. Part B* **2016**, *53*, 243–252.

13. Bakhsh, A.; Chauhdary, J.N.; Ahmad, N. Improving crop water productivity of major crops by adopting bed planting in rechna doab Pakistan. *Pakistan J. Agric. Sci.* **2018**, *55*, 965–972. [CrossRef]
14. Ali, A.; Erenstein, O. Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Clim. Risk Manag.* **2017**, *16*, 183–194. [CrossRef]
15. Shahid, R.; Shijie, L.; Shahid, S.; Altaf, M.A.; Shahid, H. Determinants of reactive adaptations to climate change in semi-arid region of Pakistan. *J. Arid Environ.* **2021**, *193*, 104580. [CrossRef]
16. Abid, M.; Scheffran, J.; Schneider, U.A.; Ashfaq, M. Farmers' perceptions of and adaptation strategies to climate change and their determinants: The case of Punjab province, Pakistan. *Earth Syst. Dyn.* **2015**, *6*, 225–243. [CrossRef]
17. Jamil, I.; Jun, W.; Mughal, B.; Wheed, J.; Hussain, H.; Waseem, M. Agricultural Innovation: A comparative analysis of economic benefits gained by farmers under climate resilient and conventional agricultural practices. *Land Use Policy* **2021**, *108*, 105581. [CrossRef]
18. Imran, M.A.; Ali, A.; Ashfaq, M.; Hassan, S.; Culas, R.; Ma, C. Impact of Climate Smart Agriculture (CSA) practices on cotton production and livelihood of farmers in Punjab, Pakistan. *Sustainability* **2018**, *10*, 2101. [CrossRef]
19. Amarasinghe, U.A.; Palanisami, K.; Singh, O.P. Improving canal irrigation performance with on-farm water storage: Evidence from the Indira Gandhi Nahar Pariyojana project in india. *Irrig. Drain.* **2012**, *61*, 427–435. [CrossRef]
20. Qureshi, A.S. Conjunctive Water Management in the Fixed Rotational Canal System: A Case Study from Punjab Pakistan. *Irrig. Drain. Syst. Eng.* **2014**, *3*, 2–7. [CrossRef]
21. Yu, L.; Gao, W.; Shamshiri, R.R.; Tao, S.; Ren, Y.; Zhang, Y.; Su, G. Review of research progress on soil moisture sensor technology. *Int. J. Agric. Biol. Eng.* **2021**, *14*, 32–42. [CrossRef]
22. Rivers, M.; Coles, N.; Zia, H.; Harris, N.R.; Yates, R. How could sensor networks help with agricultural water management issues? Optimizing irrigation scheduling through networked soil-moisture sensors. In Proceedings of the SAS 2015—2015 IEEE Sensors Applications Symposium, Zadar, Croatia, 13–15 April 2015. [CrossRef]
23. Munoth, P.; Goyal, R.; Tiwari, K. Sensor based irrigation system: A review. *Int. J. Engg. Res. Technol.* **2016**, *4*, 86–90.
24. Weber, F.-A.; Usman, M.; Tischbein, B.; Baggi, C.; Baumann, C.; Becker, R.; aus der Beek, T.; Berger, M.; Bolle, F.-W.; Bruess, U.; et al. InoCottonGRoW: Reducing the water footprint of the global cotton-textile industry towards the UN Sustainable Development Goals. In Proceedings of the GRoW—Mid-Term Conference: Global Analysis and Local Solutions for Sustainable Water Resources Management, Frankfurt am Main, Germany, 20–21 January 2019; pp. 32–35.
25. Singh, S. Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region, India. *Ecol. Indic.* **2020**, *116*, 106475. [CrossRef]
26. Friedlander, L.; Tal, A.; Lazarovitch, N. Technical considerations affecting adoption of drip irrigation in sub-Saharan Africa. *Agric. Water Manag.* **2013**, *126*, 125–132. [CrossRef]
27. Craddock, H.A.; Rjoub, Y.; Jones, K.; Lipchin, C.; Sapkota, A.R. Perceptions on the use of recycled water for produce irrigation and household tasks: A comparison between Israeli and Palestinian consumers. *J. Environ. Manag.* **2021**, *297*, 113234. [CrossRef]
28. Suri, M.R.; Dery, J.L.; Pérodin, J.; Brassill, N.; He, X.; Ammons, S.; Gerdes, M.E.; Rock, C.; Goldstein, R.E.R. U.S. farmers' opinions on the use of nontraditional water sources for agricultural activities. *Environ. Res.* **2019**, *172*, 345–357. [CrossRef]
29. Bengoechea, P.E.; Agr, I. Water Scarcity and Climate Change Impact and Vulnerability in Irrigated Agriculture in Mediterranean River Basins. Ph.D. Thesis, Departamento de Economía y Ciencias Sociales Agrarias Escuela Técnica Superior de Ingenieros Agrónomos, Universidad Politécnica de Madrid, Madrid, Spain, 2013.
30. Abid, M. Climate Change Impacts and Adaptation in the Agricultural Sector of Pakistan—Socioeconomic and Geographical Dimensions. Ph.D. Thesis, Fakultät für Mathematik Informatik und Naturwissenschaften im Fachbereich Geowissenschaften der Universität Hamburg, Hamburg, Germany, 2016; p. 190.
31. Ismail, S.; Ahmed, S. Water pollution and its sources, effects and managment: A case study of delhi. *Int. J. Curr. Adv. Res.* **2017**, *1*, 444.
32. De Veaux, R.D.; Velleman, P.F.; Bock, D.E.; Vukov, A.M.; Won, A.C. *Stats: Data and Models*; Pearson/Addison Wesley: Boston, MA, USA, 2008; ISBN 8424912993.
33. Alcon, F.; García-Bastida, P.A.; Soto-García, M.; Martínez-Alvarez, V.; Martin-Gorriz, B.; Baille, A. Explaining the performance of irrigation communities in a water-scarce region. *Irrig. Sci.* **2017**, *35*, 193–203. [CrossRef]
34. Sajid, I.; Tischbein, B.; Borgemeister, C.; Flörke, M. Performance Evaluation and Water Availability of Canal Irrigation Scheme in Punjab Pakistan. *Water* **2022**, *14*, 405. [CrossRef]
35. Rasul, G.; Ahmad, B. *Climate Change of Pakistan*; Asian Delopment Bank: Metro Manila, Philippines, 2019; ISBN 9789292577216.
36. Shabbir, A.; Arshad, M.; Bakhsh, A.; Usman, M.; Shakoor, A.; Ahmad, I.; Ahmad, A. Apparent and real water productivity for cotton-wheat zone of Punjab, Pakistan. *Pakistan J. Agric. Sci.* **2012**, *49*, 323–329.
37. Li, S.; Juhász-Horváth, L.; Harrison, P.A.; Pintér, L.; Rounsevell, M.D.A. Relating farmer's perceptions of climate change risk to adaptation behaviour in Hungary. *J. Environ. Manag.* **2017**, *185*, 21–30. [CrossRef]
38. Shah, M.A.A.; Anwar, A.A.; Bell, A.R.; ul Haq, Z. Equity in a tertiary canal of the Indus Basin Irrigation System (IBIS). *Agric. Water Manag.* **2016**, *178*, 201–214. [CrossRef]
39. Yongguang, H.; Buttar, N.A.; Shabbir, A.; Faheem, M.; Aleem, M. Precision management of groundwater abstraction on different spatial scales of lower Chenab canal system in Punjab, Pakistan. *IFAC-PapersOnLine* **2018**, *51*, 397–401. [CrossRef]

40. Waqas, M.M.; Shah, S.H.H.; Awan, U.K.; Arshad, M.; Ahmad, R. Impact of climate change on groundwater fluctuation, root zone salinity and water productivity of sugarcane: A case study in lower Chenab canal system of Pakistan. *Pakistan J. Agric. Sci.* **2019**, *56*, 443–450. [CrossRef]
41. Akhtar, F.; Nawaz, R.A.; Hafeez, M.; Awan, U.K.; Borgemeister, C.; Tischbein, B. Evaluation of GRACE derived groundwater storage changes in different agro-ecological zones of the Indus Basin. *J. Hydrol.* **2022**, *605*, 127369. [CrossRef]
42. Usman, M.; Liedl, R.; Zhang, F.; Zaman, M. *Groundwater Irrigated Agriculture Evolution in Central Punjab, Pakistan*; Springer: Cham, Switzerland, 2018; ISBN 9783319990767.
43. Asif, M. Climatic Change, Irrigation Water Crisis and Food Security in Pakistan. Master Thesis, Department of Earth Sciences, Uppsala University, Uppsala, Sweden, 2013; p. 39, No. 170, 30 ECTS/hp.
44. Ul Hasan, F.; Fatima, B.; Heaney-Mustafa, S. A critique of successful elements of existing on-farm irrigation water management initiatives in Pakistan. *Agric. Water Manag.* **2021**, *244*, 106598. [CrossRef]
45. Zhang, G.; Li, X. Estimate Cotton Water Consumption from Shallow Groundwater under Different Irrigation Schedules. *Agronomy* **2022**, *12*, 213. [CrossRef]
46. Aziz, M.; Rizvi, S.A.; Sultan, M.; Bazmi, M.S.A.; Shamshiri, R.R.; Ibrahim, S.M.; Imran, M.A. Simulating Cotton Growth and Productivity Using AquaCrop Model under Deficit Irrigation in a Semi-Arid Climate. *Agriculture* **2022**, *12*, 242. [CrossRef]
47. Himanshu, S.K.; Fan, Y.; Ale, S.; Bordovsky, J. Simulated efficient growth-stage-based deficit irrigation strategies for maximizing cotton yield, crop water productivity and net returns. *Agric. Water Manag.* **2021**, *250*, 106840. [CrossRef]
48. Witt, T.W.; Ulloa, M.; Schwartz, R.C.; Ritchie, G.L. Response to deficit irrigation of morphological, yield and fiber quality traits of upland (Gossypium hirsutum L.) and Pima (*G. barbadense* L.) cotton in the Texas High Plains. *Field Crop. Res.* **2020**, *249*, 107759. [CrossRef]
49. Yilmaz, E.; Gürbüz, T.; Dağdelen, N.; Wzorek, M. Impacts of different irrigation water levels on the yield, water use efficiency, and fiber quality properties of cotton (*Gossypium hirsutum* L.) irrigated by drip systems. *Euro-Mediterr. J. Environ. Integr.* **2021**, *6*, 53. [CrossRef]
50. Rizwan, M.; Bakhsh, A.; Li, X.; Anjum, L.; Jamal, K.; Hamid, S. Evaluation of the impact ofwater management technologies on water savings in the Lower Chenab Canal command area, Indus river Basin. *Water* **2018**, *10*, 681. [CrossRef]