Farmers' adaptation to irrigation water reallocation:
The Lower Chenab Canal (LCC) irrigation system in Pakistan

Abstract: Pakistan is facing the challenge to cope with decreasing agricultural productivity due to poor water quality (salinity) along the irrigation canal systems. Reallocation of water use between the head, middle and tail reaches of the distributaries in the canal systems can improve the groundwater quality (minimize salinity) as well as maximize crop productivity. This study employed a discrete choice model for analysing the socioeconomic and technological factors that can influence the farmers' adaptation to reallocation of water use under an optimal water use scenario. Based on farm survey data collected during 2010 and 2012 cropping seasons at the Lower Chenab Canal (LCC) irrigation system in Pakistan, the following question was analysed; *Can installation of tube wells at the head reach of the system to extract more groundwater help address the problem of poor water quality at the tail reach?* It was found that farmers who have more resources (land holding), experienced (aged) and membership with farmer organisation recognised the need to have more water, available for redistribution, through more groundwater extraction at the head reach of the system. Further the respondents in the study area were also asked to rank the options available to the farmers that can potentially improve their adaptation for the optimal water use scenario (reallocation). The ranking of the options indicated that majority of the farmers think that the best solution to the problem of water scarcity and its quality lies in water reallocation.

Keywords: Farmers' adaptation, groundwater, Pakistan, PROBIT model, water allocation.

1. Introduction

Pakistan's economy is mainly depended on agriculture, which contributes for 21 % of the GDP and employs 44% of the labour force. Irrigated agriculture supplies more than 90% of agricultural production and around 61% of the rural population are directly or indirectly employed in agricultural sector (GOP 2018). Irrigated agricultural water use is around 151 km^3/year, which is above 95% of the total withdrawal of water (Kanwar 2010). Water is increasingly becoming scarce in the country and the frequent occurrence of drought poses a threat to the economy. The agricultural sector is highly dependent on irrigation and it faces the challenges of low crop yield and an increasing difference between demand and supply of agricultural production. This trend is worsened by inequality of water allocation among water users at head, middle and tail reaches of the irrigation system. The distribution of irrigation water poses inequality at different levels of the Lower Chenab Canal (LCC) irrigation system, i.e. along main canals, distributaries and within watercourses.

The farmers situated at the head reach of the irrigation system have access to sufficient water however the farmers situated at the middle and the tail reaches of the irrigation system do not get their share of water (Hussain 2005). The farmers situated at the tail reach of the system face insufficient water from the canal system as well as poor quality of groundwater (saline water) which reduces the crop yield and also causes land degradation (Qureshi *et al.* 2010). Conjunctive use of canal (surface) and groundwater is important in the areas where canal water supply is insufficient, and increasing groundwater use in these areas has significantly contributed to rising agricultural production in the last two decades. However, in some of these areas, groundwater use has been over-exploited and due to this trend, the groundwater tables are falling in these areas with a risk of saline water intrusion into fresh water aquifers which could make groundwater as unusable for irrigation.

Agricultural productivity in Pakistan is relatively low compared to other countries and it is limited by availability of sufficient water and its quality. The main sources of water for agriculture are rainfall (10-20%), cannel (surface) water (40%) and groundwater (40-50%). However, water scarcity is a major issue in Pakistan due to increased crop intensity which results in over extraction of groundwater, deepening of groundwater table and saline water intrusion. The issues confronted in relation to irrigation management are estimating net water availability, equitable distribution of water, and incentives/policy instruments for capacity building of the water sector and farmers. Groundwater management issues are both technical and legal, but they cannot be dealt without properly understanding the socioeconomics of farmers, their perspectives and the benefits involved. In Pakistan farmers have ownership of tube wells, however since groundwater is a common property resource, the Government can facilitate its management towards sustainable use.

An economic modelling approach for different water use scenarios have been developed to address the problem of inequality in water use and the impact of salinity on crop yield (such as wheat) along the head, middle and tail reaches (locations/distributaries) of the LCC irrigation system in Pakistan. A multistage stratified random sampling method was conducted to collect data from 256 farm households during 2010-2011 and 2012-2013 cropping sessions, respectively in the LCC irrigation system. The models were estimated by regression analyses for the effect of water quality on crop yield under different water use scenarios. For each scenario, the canal and groundwater use were defined as the percentages of total water use. The base scenario for instance included 60:40, 50:50, and 30:70 percentages of the canal and groundwater use at the head, middle and tail reaches, respectively. The optimal water use scenario implies that more groundwater should be used at the head reach (distributary) of the canal system (30:70) while more canal water should be used at the tail reach (distributary) of the canal system (70:30). The economic modelling approach and the alternative water use scenarios developed have been presented at the ICDA2019 conference (Culas, 2019) as well as reported in Culas and Baig (2020).

Following the economic modelling approach, a discrete choice (PROBIT) model was analysed for the farmers' adaptation behaviour towards the optimal water use scenarios developed for the reallocation of water use. The PROBIT model was setup for the following question (dependent variable); *Can installation of tube wells at the head reach of the system to extract more groundwater help address the problem of poor water quality at the tail reach?*

The results are discussed in relation to various socioeconomic and technological factors (explanatory variables) that can improve the current water use pattern and for the farmers' adaptation behaviour towards more equitable and sustainable water use practices.

2. Data and methodology

The study area is in Punjab province, Pakistan and situated in the Lower Chenab Canal (LCC) irrigation system (Figure 1).

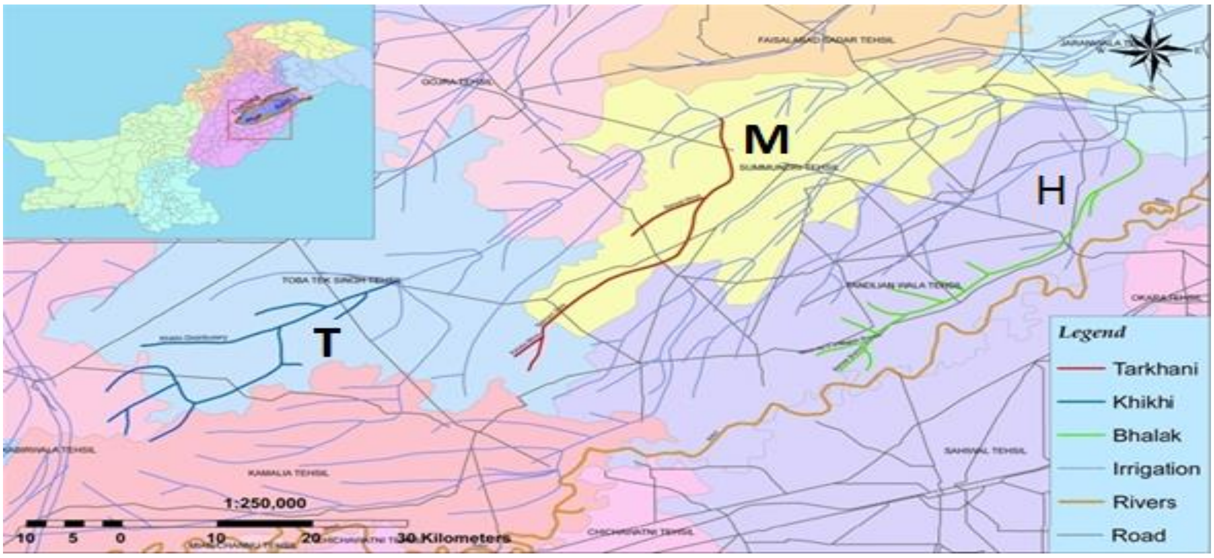

Figure 1. Location of the selected distributaries in the LCC East irrigation system

A baseline socioeconomic survey of irrigators along the head, middle, and tail reach of the LCC East irrigation system was conducted during 2010-11 and 2012-13 cropping sessions, respectively, as part of an ACIAR funded project (Culas *et al*. 2015). Three distributaries of the LCC East irrigation system, namely, Bhalak, Tarkhani, and Khikhi have been selected for the head, middle and tail reaches, respectively**.**

Table 1 presents the optimal water use scenario designed for the redistribution of water allocation following the economic modelling approach reported in Culas and Baig (2020). The optimal scenario suggests that when water use can be reallocated in terms of the percentages given for the canal and groundwater, the impact of salinity on the crop yield can be minimized or avoided. The base scenario included 60:40, 50:50, and 30:70 percentages of the canal and groundwater use at the head, middle and tail reaches (distributaries), respectively. Whereas the optimal water use scenario implies that more groundwater should be used at the head distributary (30:70) and more canal water should be used at the tail distributary (70:30).

Table 1. Optimal water use scenarios (base scenarios are given in brackets) (%)

Scenario 3			
	Bhalak	Tarkhani	Khikhi
Canal (surface) water	30 (60)	40 (50)	70 (30)
Groundwater	70 (40)	60 (50)	30 (70)
Total water use	100 (100)	100 (100)	100 (100)

Source: Culas and Baig (2020)

Following the economic modelling approach and the optimal water use scenarios developed, as reported in Culas and Baig (2020), a discrete choice (PROBIT) model was empirically analysed for the farmers' adaptation behaviour. The PROBIT model is a type of regression where the dependent variable can take two values (1 = Yes, 0 = No).

The purpose of this model is to estimate the probability that an observation with particular characteristics will fall into a specific category (choice); moreover, an estimated probability greater than half is treated as classifying an observation into a predicted category. The PROBIT model is a type of binary classification and based on the cumulative normal probability function defined as:

$$P_{1/i} = F(\alpha + \beta X_i) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\alpha+\beta X_i} e^{-u^2/2} du \qquad (1)$$

Where:

$P_{1/i}$ = probability a certain practice/technology will be adopted by the i^{th} individual,

F = cumulative normal probability function,

U = standard normal deviate with mean zero and variance of one,

β = vector of unknown parameters, and

X_i = vector of independent variables.

Equation 1 states that $P_{1/i}$ is the area under the standard normal curve between -∞ and ($\alpha + \beta X_i$). The greater the value of ($\alpha + \beta X_i$), the more likely is the chance that the i^{th} individual will adopt the practice/technology. The PROBIT model (linear model) can be derived by applying the inverse F^{-1} of the cumulative normal probability function of equation 1. The left-hand side of equation 2 increases in value from -∞ to +∞ as $P_{1/i}$ increases from 0 to 1.

$$F^{-1}(P_{1/i}) = (\alpha + \beta X_i) \qquad (2)$$

PROBIT models have been employed in a number of studies where the dependent variable is dichotomous in nature. For example, Bhandari and Pandey (2006) used PROBIT model to study the adoption of shallow tube wells in Nepal Terai; Khair *et al.* (2012) analysed PROBOT models to study the socioeconomic characters of farmers and groundwater markets in Balochistan, Pakistan.

3. Empirical model and the results

The empirical model analysed is detailed below. Farmers' response was recorded in terms of a binary response variable taking the value of '1' and '0' as dependent variable. The model contains a list of explanatory variables where some of them are qualitative variables constructed in shape of dummy variables while the others are quantitative variables.

Dependent variable (1 = Yes, 0 = No)

Can installation of tube wells at the head reach of the system to extract more groundwater help address the problem of poor water quality at the tail reach? This would make extra surface water available for the tail reach of the system. This option was put in front of the respondents and they were asked to show their willingness for this option. The response of the farmers was analysed by using discrete choice model thus enabling the water savings. The respondent was given a value of '1' if the above option (in relation to the optimal water use scenario) was acceptable to him while he was given a value of '0' if the base scenario (current pattern of) water use was acceptable to him.

Qualitative explanatory variables

DWCL: This dummy variable was based on the location (water course) of the farm with respect to head, middle or tail region of each distributary. Therefore, if the respective water course of the farming household was located at the tail region of the distributary, the respondent was given a value of '0' while it was given a value of '1' otherwise (i.e. respective water course is located at the head or middle region of the distributary).

DWCT: The dummy variable DWCT was based on the response of the respondent with respect to the use of water conservation technologies. Farmers having deepest water table and marginal quality of water are more likely to adopt water-smart practices for groundwater management (Hussain *et al*. 2017; Zulfiqar and Thapa 2018; Imran *et al*. 2019). Respondents were given multiple options to choose between them. Respondents who were using these technologies or ready to use these technologies were given the value '1' while rest of the respondents were given value '0'.

DACM: This is a quantitative variable developed from an index based on the ranking of the information sources (media) used by respondents. If respondent scored three or more, he was assigned a value '1' indicating access to the media while respondents scoring less than three were assigned a value '0' indicating no access to the media. In India and Pakistan, a positive and significant relationship between access to information and farm income was reported by many researchers (Birthal *et al*. 2015; Aryal *et al*. 2018; Sapkota *et al*. 2018; Abid *et al*. 2015; Culas *et al.* 2015).

DFO: Farmer organizations were introduced in the area to take care of the operation and maintenance of the irrigation channels (from distributary to canal onward) in different irrigation circles in Punjab. These organizations were meant to make farmers responsible for handling the water related issues and can serve as a good proxy for the level of social responsibility and interaction among the farmers (Culas *et al.* 2015; Aryal *et al.* 2018). Therefore, if the farmer was a member of the farmer organization, he was assigned a value of '1' while a value of '0' was assigned otherwise. This variable served as a proxy for farmers' social mobility and influence in the area.

DCREDT: The dummy for access to credit was also used in the analysis as a proxy for the access to the resources and social status of the respondents. It is generally thought in Pakistan that more resourceful and powerful class has more access to the credit sources as compared to the poor and low-income groups (Culas *et al.* 2015; Aryal *et al*. 2018). The binary response variable was developed on the basis of respondent's access to the formal credit sources. Respondents having access to these sources were assigned a value of '1' while the remaining were assigned a value of '0'.

DTRC: Wealth and assets play an important role in determining the impact of technology on resource use and management practices. To determine the wealth status of the respondents, a proxy variable was developed based on the ownership of tractor. Wealthier farmers are supposed to own a tractor so the owners of the tractors were assigned a value of '1' while the poor farmers for non-ownership of the tractor were assigned a value of '0'.

Quantitative explanatory variables

Apart from the qualitative variables that have been explained above, the quantitative variables included in the analysis are explained below.

AGE: Age of the farmer is an important socioeconomic variable which has been widely used in the economic analysis to capture the social status of the respondent (Culas *et al*. 2015; Hussain *et al*. 2017; Abbas *et al*. 2017; Aryal *et al*. 2018). Many researchers have already explained the role of the age in decision making process and ability of the respondent to adapt to the changes. Age of farmer (in years) is used as a proxy for the experience of the farmer.

NSYEAR: Education has widely been accepted as a pivotal factor in influencing the adaptation, decision making and management skills of the respondent (Abbas *et al*. 2017; Aryal *et al*. 2018). Number of schooling years of the respondents was included in the analysis as a proxy for education.

FSZE: Family size is another important social indicator that has been included in the analysis. The impact of family size on behaviour and adaptation pattern has already been reported in literature (Mponela *et al.* 2016, Nkomoki *et al*. 2018; Kharti-Chhetri *et al*. 2016; Imran *et al.* 2018). Number of the dependent family member of the respondents has been included in the analysis to capture its impact on the dependent variable.

LANDHOLDING: The other important variable that was included in the analysis was the size of operational land holding of the respondent. Tiwari *et al.* (1999) determined that landholding is an important variable that affect the farming patterns and adaptation practices. In present analysis, operational agricultural landholding (in acres) of the respondent was included in the analysis.

The descriptive statistics of the quantitative variables are given in Table 2.

Table 2. Descriptive statistics

	Minimum	Maximum	Mean	Std. Deviation
AGE	15	96	59.58	13.146
NSYEAR	0.00	16.00	4.8585	4.9660
FSZE	1.0	15.0	4.454	3.2531
Landholding (Acres)	0.00	2018.50	16.7377	141.1942
EAGRIC	-	-	40.340	17.711

Source: Survey data

The results for the PROBIT model are given in Table 3. The results are presented in relation to various socioeconomic factors that can potentially improve the current water use patterns and farmers' adaptation towards more equitable and sustainable water management practices in relation to the optimal water use scenario (reallocation) detailed above.

Table 3. Results of the PROBIT Model

Parameter Estimates [b]					
Parameter		Estimate	Std. Error	Z	Sig.
PROBIT [a]	DWCL	-.119	.087	-1.369	.171
	DWCT	.083	.063	1.312	.190
	DACM	-.663	.095	-6.971	.000
	DFO	.540	.072	7.467	.000
	DCREDT	-.278	.234	-1.190	.234
	DTRC	.062	.061	1.018	.309
	AGE	.005	.002	2.143	.032
	NSYEAR	-.003	.006	-.458	.647
	FSZE	-.026	.010	-2.667	.008
	Landholding	.001	.000	3.524	.000
	Intercept	-2.088	.192	-10.853	.000

a. PROBIT model: PROBIT(p) = Intercept + BX

b. Model is statistically significant at 0.1 level by Pearson Goodness-of-Fit Test

The implications of the results are that farmers recognise that the "equity" issue is there in relation to the current pattern of water user allocation among the distributaries (Razzaq *et al.* 2019), that the farmers who have more resources (land holding), experienced (aged) and membership with the farmer organisation recognised the need to have more water, available for redistribution, through more groundwater extraction from the distributary located at the head of the canal system (Culas *et al*. 2015). However, the farmers who have no access to media or information and large families (where the number of the dependent family member is above the average in the study area) seem to be concerned about extracting more groundwater from the distributary located at the head of the canal system.

4. Farmers' adaptation options (ranking)

The respondents in the study area were also asked to rank the alternative options (choices available) for improvement in the base scenario water use pattern if it was unacceptable to them. Six different options to improve the water distribution were offered to the respondents so that the equity issue in water use among the distributaries can be addressed. These options were ranging from less canal water use at the head distributary to water trading and pricing option.

Table 4 presents the ranking of the options offered to the farmers based on their opinion. The table is only showing the first ranked option by the respondents. The ranking shows that majority of the farmers think that the best solution to the problem of water scarcity and distribution in water use lies in water reallocation (Mekonnen *et al.* 2016).

Table 4. Ranking options offered to the farmers

Scenario Options	Bhalak		Tarkhani		Khikhi		Total	
	%	Rank	%	Rank	%	Rank	%	Rank
Less canal water at head (i.e. more groundwater use at head)	42	I	32	II	37	II	39	II
More conjunctive use for middle (50:50 canal and groundwater)	41	II	40	I	43	I	41	I

More canal water use for tail (i.e. less groundwater use at tail)	12	III	14	III	8	III	10	III
Changing the water rotation	2	IV	6	IV	4	IV	4	IV
Water trading	0	V	4	V	5	IV	4	IV
Economic incentives	2	IV	4	V	3	V	3	V

Source: Survey data

5. Conclusion

Pakistan is facing the challenge to cope with decreasing agricultural productivity due to poor water quality (salinity) along the irrigation canal systems. This study analysed a discrete choice (PROBIT) model to identify the variables that can influence the farmers' adaptation to reallocation of water use scenarios developed as reported in Culas and Baig (2020). It was found that farmers who have more resources (land holding), experienced (aged) and membership with farmer organisation recognised the need to have more water, available for redistribution, through more groundwater extraction from the distributary located at the head of the canal system. Further the ranking of the options available to the farmers made it clear that majority of the farmers were also not satisfied with the existing water use pattern (base scenarios) and they desired for improvement in the situation by adapting to alternative water use pattern as suggested by the optimal scenarios.

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