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Alternate Modes of Irrigation and Farmer Returns Under Conjunctive Water Management in Pakistan

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Abstract

The paper describes a study of canal and supplemental ground water used by 544 farmers for wheat growing in the Rechna Doab catchment of Pakistan. The main objective was to assess the on-farm financial gains through alternate modes of irrigation and comparing them with conjunctive water use. For econometric analysis, a linear relationship between the wheat production and different determinant variables was assumed.

The results highlighted the problem of increased use of tubewell water in the saline groundwater zones that had resulted in the deterioration of the groundwater quality and led to the problem of permanent upconing of saline groundwater. Conjunctive water management increased the farm income by about Rs. 1000 and 5000 per hectare compared to only using the canal and tubewell water, respectively The results of financial analysis show that the net gains were 30 percent higher on the farms using conjunctive water management as compared to the farms using only tubewell irrigation.

Introduction

Conjunctive water management refers to the use of multiple water resources (surface water and groundwater in this case) within a basin such that adequate water of acceptable quality is made available at the farm, in a timely manner for irrigation. The international literature is filled with the studies on conjunctive water management and its impact on crop productivity and related issues [Gangwar and Toorn (1987); Bredehoeft and Young (1983); Gorelick (1988); Lingen (1988); O'Mara (1988); Shah (1988); Brewer and Sharma (2000); Datta and Dayal (2000); Raju and Brewer (2000) and Chaudhary (2003)].

In Pakistan, the literature review shows that all of the previous studies conducted in the arena of water management reported the management problems leading to the inefficiencies in irrigation application and reduction in crop productivity, [Kijne and Velde (1991), Mustafa (1991), Siddiq (1994) and Prathaper *et al.* (1994)]. Few of the studies took into consideration the impact of waterlogging and salinity on productivity at farm level [Prathaper *et al.* (1997), Meyer *et al.* (1996), O'Connell and Khan (1999), and Sakkhati and Chawala (2002)]. None of these studies have taken into consideration the alternate modes of irrigation and farmer returns under conjunctive water management in Pakistan. This paper focuses on these issues and presents results from the Rechna Doab.

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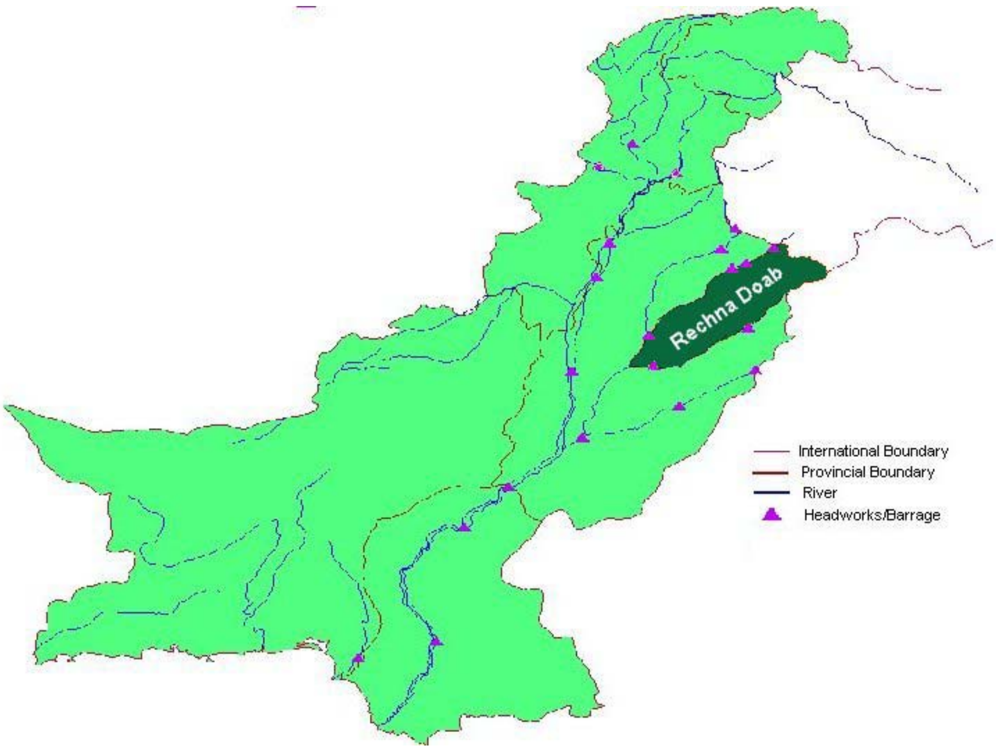
The Rechna Doab (area between Ravi and Chenab rivers) has a gross area of 2.98 million hectare (Mha), of which 2.319 Mha is the Gross Command Area (Figure 1). In the Rechna Doab, three types of irrigation sources are commonly used on farms i.e. canal irrigation, tubewell irrigation and the combination of both. Irrigated agriculture started in the Rechna Doab in 1892 via the Lower Chenab Canal. The designed cropping intensity of the irrigation system was pitched low, in the order of 60-70 percent at the start, but now the cropping intensity is more than 120 percent, indicating the increased water demand. This demand is being met through more than 180,000 tubewells in the fresh groundwater areas of the Rechna Doab.

Looking at the physiography of the Rechna Doab, we see that it consists of (a) Active flood plains, (b) Abandoned flood plains, (c) Bar Uplands and (d) Kirana Hills (longitudinal across the doab). Regarding the groundwater quality, Rechna Doab is divided into three distinct zones (i) Fresh Water Zone (TDS < 1000 ppm) 1.36 Mha. (ii) Mixing Zone (TDS 1000-3000 ppm) and (iii) Saline Zone (TDS > 3000 ppm) 0.198 Mha.

The soils are tertiary in nature and have recent alluvial deposits that consist of fine to very fine sand and silt. Soils are southwesterly sloped and the slope is 0.38 meter/kilometer (m/Km) and 0.29 m/Km in the upper part and the lower part, respectively. Surface salinity is found in patches covering more than 20 percent of the cultivated area in the Rechna Doab (1.17 Mha).

The meaning of conjunctive water management and its scope, practices and standards vary a great deal depending on the scarcity and quality of water in the Rechna Doab. This paper attempts to analyze the impact of alternate water management practices on wheat crop production in the Rechna Doab.

Figure 1. Hydrological Layout of Rechna Doab, Punjab, Pakistan



Objectives:

The specific objectives of the study are:

- To examine farmers' practices of irrigation and compare them with conjunctive water management in wheat cropping and access their perceptions about the groundwater quality in the Rechna Doab;
- To compare the net gross margins from wheat produced on farms under various irrigation management conditions; and
- To estimate the relationship between wheat yield and the factors affecting the productivity of wheat on sample farms under different water management conditions.

Methodology

Data Source

The study was conducted in the 26 irrigation subdivisions of the Rechna Doab. Primary and secondary data sets have been used to carry out the present analysis. The primary data set comprised survey data of 543 sample farms. The sample areas were identified through the use of spatial models. These sample sites were located in eight districts (Sialkot, Gujranwala, Sheikhupura, Hafizabad, Faisalabad, T.T. Singh, Jhang and part of the Kabirwala sub-district of the Khanewal District). The primary data were collected on a well-designed pre-tested questionnaire from farms (using canal supplies, groundwater, and combination of both for irrigation) located in 181 different sampling sites. The secondary data were collected from the Irrigation Department, Salinity Monitoring Organization (SMO) and Economic Survey of Pakistan (GOP 2002).

Specification of the Model

To estimate the empirical relationship between wheat production and different determinant variables, a multiplicative relationship was assumed and the econometric criteria suggested by Fuss, McFadden and Mundlak (1978), Madala (1988) and Ramunathan (1992) were used. Based on the adjusted R^2 values, a linear model was the best match to test the relationship between wheat yield input applications, irrigation intensity, quality of water, farm size, farmer's experience, formal education and the incidence of salinity, sodicity and waterlogging on the farm. The effects of different irrigation sources i.e. Canal, Tubewell and Conjunctive Use (use from C+T), was estimated by using Dummy variables in the equation. The dependent and independent variables, which are included in the models, are defined in the following:

The following variables are included in the model as defined below: -

$$Y_i = a + \sum_{j}^{18} B_j X_{ij} + e \qquad (1)$$

i = 1, 2, ...n farm households.

j = 1, 2, ...n determinant variables.

Where:

Y_i = wheat yield per hectare

X_1 = Seed cost per hectare irrigated by canal + tubewell irrigation

X_2 = Dummy for seed cost per hectare irrigated by tubewell irrigation

X_3 = Dummy for seed cost per hectare irrigated by canal irrigation

X_4 = Fertilizer cost per hectare irrigated by canal + tubewell irrigation

X_5 = Dummy for fertilizer cost per hectare irrigated by tubewell irrigation

X_6 = Dummy for fertilizer cost per hectare irrigated by canal irrigation

X_7 = Irrigation per hectare by canal + tubewell irrigation (M^3/Ha)

X_8 = Dummy for irrigation per hectare by tubewell irrigation (M^3/Ha)

X_9 = Dummy for irrigation per hectare by canal irrigation (M^3/Ha)

X_{10} = Age of the farmers

X_{11} = Experience in farming

X_{12} = Formal education

X_{13} = Proportionate area under saline soils on the farm

X_{14} = Proportionate area under sodic soils on the farms

X_{15} = Proportionate area under waterlogged soils on the farm

X_{16} = Proportionate of culturable waste area on the farm

X_{17} = Tubewell water quality

X_{18} = Tubewell age

a = Constant

B = Estimated coefficients

e = Random error term

According to Equation 1, if the values of the coefficients (B_1- B_9) are positive it shows that investment on seed, fertilizer and irrigation would increase the production of wheat. The positive values of the coefficients (B_{10}- B_{12}) reflects that the age, experience in farming, formal education have a direct relationship with wheat production. Negative values of the coefficients (B_{13}- B_{16}) show that the incidence of salinity, sodicity, waterlogging and incidence of culturable waste area on a farm has negative impact on wheat productivity. The value and the sign of the coefficients (B_{17}-B_{18}) reflect the impact of tubewell water quality and its age on the wheat productivity.

Results and Discussion

In the Rechna Doab, the farmers exploit groundwater to supplement canal water supplies. The quality of the groundwater differs spatially. The literature shows that groundwater of good quality is found in the upper parts of the Doab and in a 24 to 48 Kilometer wide belt along the flood plains of the Chenab and Ravi rivers. Highly saline groundwater is found in the lower and central parts of the Doab.

The Upper Rechna contains fresh water of 500 parts per million (ppm), but in the central and lower portions, groundwater salinity concentration varies from 3,000 to 18,000 ppm. In the central and lower parts of the Doab, majority of the tubewells are pumping marginal to poor quality groundwater, especially at the tail ends of the canal irrigation system. Table 1 provides figures pertaining to the farmers' perception about the quality of irrigation water in the Rechna Doab.

Out of the 535 wheat-growing farms, about 47 percent farmers (majority of which is located in the Upper Rechna Doab) perceived the groundwater quality at their farms to be good while at about 38 percent of the sample farms located in the central and lower part of Rechna Doab, the farmers responded that the groundwater at their farm was saline and was not fit for irrigation.

About eight percent of the farmers were not aware of the groundwater quality because they either have just installed the tubewell on the farms or they had taken the land on lease for the first year. About seven percent of the farmers believed that they had the marginal quality groundwater, which they were using by mixing canal water for irrigation purposes.

Table 1. Farmer's perceptions about the quality of irrigation water in the Rechna Doab

Farm Size	Good	Saline	Marginal	Not Known	All Categories
Small	39	24	1	6	70
Medium	79	80	11	31	201
Large	135	97	24	8	264
Total	253	201	36	45	535
	(47)	(38)	(7)	(8)	(100)

Note: The figures in parenthesis are percentages.

Out of total sample farms, about 93 percent farms were using groundwater through tubewells on their farms (Table 2). About 29 percent of farms were using tubewell water as the only source of irrigation supplies and about 59 percent of the total sample farms were using tubewell water to supplement their canal water supplies. It was observed that it was common in the whole sample farm area that the farmers have never had a laboratory test for their tubewell water quality. Thus, it is likely that they might be applying the poor quality tubewell water to their fields. This would result in problems of salinity or sodicity in their fields and increased area under secondary salinization.

The impression one gets by examining these gross numbers is that the farmers are heavily dependent upon tubewell irrigation to bring more area under cultivation. The tubewells at the middle and the tail ends of the irrigation network are pumping poor quality groundwater which may be unfit for irrigation. The prevailing rate of installation and use of tubewell water may cause problems relating to the over-exploitation of fresh groundwater reservoir and salt imbalance buildup of salinity/sodicity. This may result in an increase in unproductive land, extra costs for groundwater quality improvement and salinized soil reclamation, and permanent up-coning of saline groundwater.

Table 2. Farmers' mode of irrigation in the Rechna Doab

Farm category	Canal	Private Tubewell	Canal + Tubewell	Drain	Canal + Public T/w	Drain+ Pvt. T/w	All Categories
Small	7	30	27	1	1	4	70
Medium	16	60	104	2	7	12	201
Large	8	63	169	1	9	14	264
Total	31	153	300	4	17	30	535
	(6)	(29)	(56)	(1)	(3)	(6)	(100)

Note: The figures in parenthesis are percentages.

The resource use pattern of wheat and output under different types of water management conditions is presented in Table 3. The expenditure on seed and fertilizer accounted for about 35 percent of the total cost for wheat production. The farms using only canal or tubewell water invested four percent and eight percent less on seed, respectively, to produce wheat as compared to the farmers using canal and tubewell water conjunctively. Similarly the farms in the first two categories invested 13 percent and 7 percent less on fertilizer, respectively to produce wheat as compared to the farmers using canal and tubewell water conjunctively. Table 3 shows that land preparation accounts for about 19 percent of the total cost of wheat production. The farmers using only canal or tubewell water invested 11 percent and 9 percent less on land preparation, respectively, to produce wheat as compared to the farmers using canal and tubewell water conjunctively. The table also reveals that aggregate resource use per hectare on wheat was about 10 and nine percent lower on farms using the only canal or only tubewell irrigation, respectively as compared the farms using both these sources conjunctively. The wheat crop yields estimates show that it was eight percent and 21 percent higher on the farms using conjunctive water management as compared to the farms using only canal irrigation or only tubewell irrigation, respectively. The estimates show that the net income was 30 percent higher on the farms using conjunctive water management as compared to the farms using only tubewell irrigation.

Table 3. Input use and output for wheat under different irrigation practices in the Rechna Doab (Rs./Ha)

Inputs and Outputs	Source of Irrigation Canal	Tubewell	Canal+ Tubewell
Seed	899	867	940
Fertilizer	2810	3004	3222
Labor	362	484	598
Land preparation	2053	2117	2320
Farm yard manure	655	438	592
Irrigation	309	510	610
Harvesting Threshing	3851	3579	3858
Total cost	10941	10999	12139
Yield (Kg/Ha)	3465	3337	3773
Gross income	26516	22672	28746
Net income	15575	11673	16607

Table 4 shows the results of the estimated regression equation relating wheat production with the determinant variables. A linear function was selected for explaining the effect of investment on seed, fertilizer and irrigation inputs along with the other determinant variables on wheat productivity under different irrigation practices in the Rechna Doab. The value of adjusted R^2 was 0.61.

The coefficient for X1, X3, X5, X6, X7, X13, X17 and X18 came out to be statistically significant and had the expected signs. The coefficient for X1 is positive and statistically significant at 99 percent level of confidence showing that the investment in better quality wheat seed on the farms practicing conjunctive water management would increase the productivity of the wheat crop. The coefficient for X2 is also significant at 90 percent level of confidence and reveals that the investment on better quality seed would also increase the productivity of wheat on the farms under canal irrigation.

However, the dummy variable X3 for investment on seed under tubewell irrigation was non significant showing no impact on the productivity by investing more on better quality seed on the farms using tubewells as a source of irrigation. The coefficient X4 for investment on fertilizer on farms practicing conjunctive use of water is also statistically significant at a 99 percent level of confidence and depicts that investment in fertilizer would help in increasing the wheat yields on these farms. This might be due to more reliability and timely supply of tubewell water along with the better quality canal water, which moderates the quality of tubewell water with the conjunctive water management practices.

Unlike X4 the coefficient for the dummy variable X5 depicts that fertilizer use on canal-irrigated farms was non-significant showing that the investment on fertilizer in the canal irrigated areas have no significant impact on wheat productivity. This may be due to shortage of canal water on these farms, which results in having no significant impact on wheat crop production. The coefficient for the dummy variable X6 is negative and statistically significant at 99 percent level of confidence. It shows that investment in fertilizer may reduce wheat productivity on the farms that are only using tubewell water for irrigation.

Table 4.Regression results relating the wheat production with the determinant factors in the Rechna Doab

Independent Variables	**Coefficient**	**Std. Error**	**t-stat**	**Significance**
(Constant)	20.645	8.513	2.43	0.02
X1 (COSEED C+T)	0.0363***	0.013	2.72	0.01
X2 (COSEED CA)	0.0274*	0.016	1.76	0.08
X3 (COSEED TW)	0.0035	0.032	0.11	0.91
X4 (COFRT C+T)	0.0126***	0.004	3.05	0.01
X5 (COFRT CA)	-0.0123	0.009	-1.42	0.16
X6 (COFRT TW)	-0.0126***	0.005	-2.65	0.01
X7 (IRRI C+T)	0.244	0.301	0.81	0.42
X8 (IRRI CA)	1.3900**	0.695	2.0	0.05
X9 (IRRI TW)	-0.121	0.403	-0.3	0.77
X10 (AOR)	-0.0135	0.158	-0.09	0.93
X11 (EIF)	0.0278	0.149	0.19	0.85
X12 (FE)	0.788	0.625	1.26	0.21
X13 (SAL)	-0.3190**	0.145	-2.2	0.03
X14 (SOD)	-0.0937	0.31	-0.3	0.76
X15 (WLG)	2.062	4.396	0.47	0.64
X16 (RFCWA)	-0.0476	0.19	-0.25	0.8
X17 (WATERQLY)	-1.493**	0.722	-2.06	0.03
X18 (TWAGE)	-0.2050**	0.091	-2.25	0.03
Adjusted R^2	0.6145			

Notes: * = Significant at 90 percent level of confidence, ** = Significant at 95 percent level of confidence
*** = Significant at 99 percent level of confidence

This may be true on the farms located in the areas, which fall in the saline and brackish groundwater zones. Regarding the coefficients for X7, X8 and X9, only X8 is statistically significant at 95 percent level of confidence and has a positive value showing that canal irrigation use has a direct relationship with the wheat yield.

The coefficients for X13, X17 and X18 are negative and statistically significant at 95 percent level of confidence. These show that increase in salinity and the age of the tubewell would reduce wheat productivity. This once again highlights the problem of increased use of tubewell water in saline zones, which results in the deterioration of groundwater quality. This problem needs to be addressed at the policy level by regulating groundwater exploitation by some legal and institutional framework.

Policy Implications

In this paper, the farmer's mode of irrigation on their farms and their perception about the quality of water in the Rechna Doab is presented. The study shows that about 93 percent of the farms were using groundwater in the Rechna Doab. Among these users about 47 percent were exploiting saline and marginal aquifers. These farmers were also facing the major threat of salinity on their farms. They needed to be educated about the conjunctive use of irrigation water to minimize the effect of salinity on their farms.

The above results are stark evidence of on-farm gains due to the conjunctive use of canal and tubewell water. These gains call for more efficient conjunctive water use on farms. The economic study showed that potential farm benefits could be 30 percent higher in case of wheat provided judicious use of canal and tubewell irrigation were applied on the farms. The regression results show that low quality groundwater hampers wheat productivity on the farms. Besides appropriate government interventions, required to revert the process of land degradation due to the use of bad quality groundwater in the brackish areas of Rechna Doab, the government should put a ban on the installation of new tubewells in the areas where the hazard of up-coning of brackish water is high and must reallocate surface water to these areas.

In the past, government invested on large-scale drainage tubewell network to manage the salinity and waterlogging on the farms in the Rechna Doab. Currently, besides giving a subsidy on the new private tubewells the government is also encouraging communities to install community tubewells in the areas where the groundwater is of better quality. It is also necessary to formulate some legal framework to regulate tubewell operations in areas where the recharge problem exists. The existing institutions like the On Farm Water Management (OFWM) program and Punjab Groundwater Sector Development Program (PGSDP) may be strengthened to monitor aquifer depletion/recharge on a regular basis to ensure the sustainable supplies of groundwater in the fresh groundwater areas.

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