Resource Use and Farm Productivity under Conjunctive Water Management in Pakistan

Waqar A. Jehangir,
Muhammad Ashfaq,
Evan Christen

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RESOURCE USE AND FARM PRODUCTIVITY UNDER CONJUNCTIVE WATER MANAGEMENT IN PAKISTAN

Waqar A. Jehangir[1], Muhammad Ashfaq[2] and Evan Christen[3]

ABSTRACT

The paper describes a study of canal and supplemental ground water used by 544 farmers for wheat crop in the Rechna Doab catchment of Pakistan. The main objective was to assess the on-farm financial gains through 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 tubewells water in the saline 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.

IMPORTANCE

Conjunctive water management refers to the use of multiple water resources (surface and ground water in this case) with in a basin such that adequate water of acceptable quality is made available at the farm, in timely manner for irrigation. In the Rechna Doab (area between Ravi and Chenab rivers), three types of irrigation sources are in common practices on the farms i.e. canal irrigation, tubewell irrigation and the combination of both in terms of conjunctive water use. Irrigated agriculture started in Rechna Doab in 1892 via lower Chenab Canal. The designed cropping intensity of the irrigation system was pitched low in the order of 60-70% at the start, but now cropping intensity is more than 120% indicating increased water demand. This demand is being supplemented through more than 180,000 tubewells in the fresh groundwater areas of the Rechna Doab. The Rechna Doab has a gross area of 2.98 Mha, from which 2.319 Mha is the Gross Command Area (Figure 1). 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 ground water quality Rechna Doab is divided in to 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 are having proportions of fine to very fine sand and silt. Soils are southwesterly sloped and the slope is 0,38 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 % of the cultivated area in 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

[1] Senior Agricultural Economist, International Water Management Institute, Lahore, Pakistan E-mail w.jehangir@cgiar.org
[2] Assistant Professor, University of Agriculture, Faisalabad, Pakistan
[3] Irrigation and Drainage Engineer, CSIRO (Land and Water) Griffith, NSW, Australia

Doab. This paper attempts to analyze the impact of conjunctive water management on wheat crop production in the Rechna Doab.

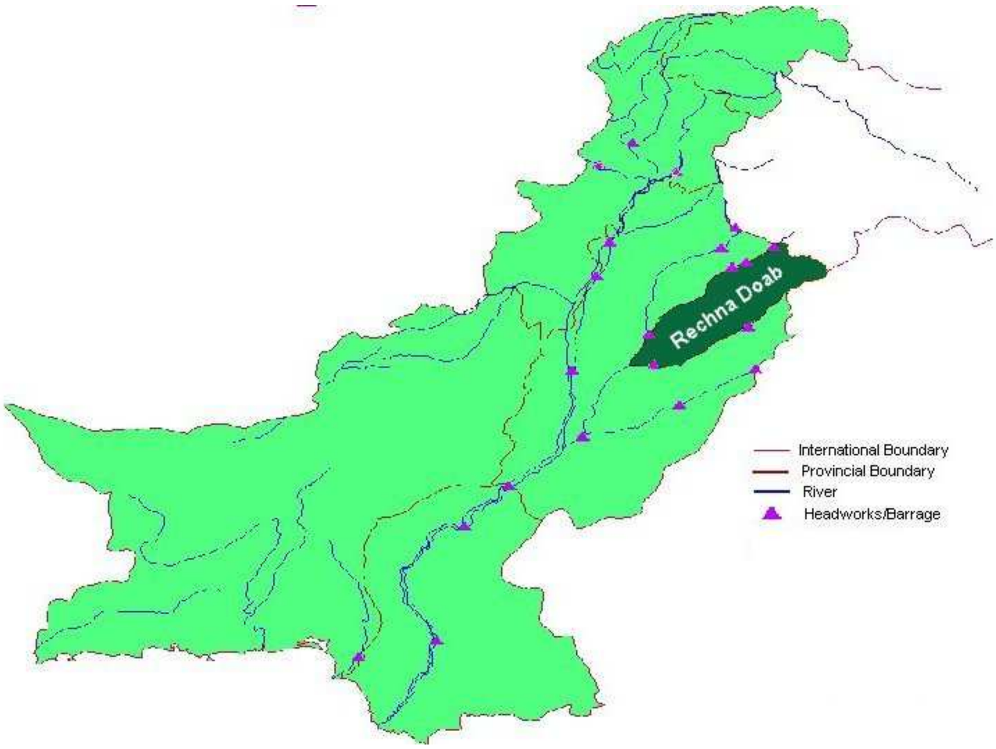

Figure 1. Hydrological Layout of Rechna Doab, Punjab, Pakistan

Objectives:

The specific objectives of the study are:

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

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 the 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 irrigation department, Salinity Monitoring Organization (SMO) and Economic Survey of Pakistan (GOP 2002).

Specification of the Model

To estimate the empirical relationship between the wheat production and different determinant variables a multiplicative relationship is assumed and the econometric criteria suggested by Fuss, McFadden and Mundlak (1978), Madala (1988) and Ramunathan (1992) are used. Based on the adjusted R^2 values, the 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 water (use from C+T) was estimated by using the 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 reflects that the investment on seed, fertilizer and irrigation will 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 the wheat production. The 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 the 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-kilometers 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 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, a majority of the tubewells is pumping marginal to poor quality groundwater, especially at the tail ends of the canal irrigation system. Tables 1 provide figures pertaining to the farmers' perception about the quality of irrigation water in Rechna Doab. Out of the 535 wheat-growing farms about 47 percent farms (253, majority of which is located in the Upper Rechna Doab) perceived the ground water quality at their farms to be good while at about 38 percent of the sample farms (201, located in the central and lower part of Rechna Doab), the farmers responded that the ground water at their farm is saline and is not fit for irrigation. About 8 percent of the farms (45) were not aware of the ground water quality whether it is good or bad due to the reasons that either they have just installed the tubewell on the farms very recently or the respondents took the land on lease for the first year and were unaware of the ground water quality but 7 percent of the farms (36) behold that they have the marginal quality ground water which they are using by mixing it with the canal water for irrigation purposes.

Table 1 Farmer's Perception 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 the percentages.

In spite of the fact that out of total sample farms about 93 percent (500) farms were using the ground water through tubewells on their farms (Table 2). About 29 percent of the farms were using the tubewell water as the sole source of irrigation supplies on their farms and about 59 percent of the total sample farms (317) were using the tubewells water to supplement their canal water supplies. It was observed that there was a common practice in the whole sample farm area that the farmers never got the laboratory test for their tubewell water quality, thus, it is likely that they might apply the bad quality tubewell water to their fields and end up having the problem of salinity or sodicity in to their fields and getting more area under secondary salinization.

Table 2. Farmers Mode of Irrigation in the Rechna Doab

Farm category	Canal	Pvt. Tubewell	Canal + Tubewell	Drain	Canal + Pub. 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 the percentages.

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. These tubewells at the middle and the tail ends of the LCC system 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 overexploitation of the fresh groundwater reservoir, salt imbalance-buildup of salinity/sodicity. This may result in an increase in unproductive lands, extra costs for groundwater quality improvement and salinized soils reclamation, and permanent up-coning of saline groundwater.

The resource use pattern of wheat crop 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 4 percent and 8 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. In case of the expenditure on land preparation, the Table 3 shows that it accounts for about 19 percent of the total cost of wheat production. The farms 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 reveals that aggregate resource use per hectare on wheat was about 10 and 9 percent lower on farms using the only canal or only tubewell irrigation, respectively as compared to farms using these both sources conjunctively. The wheat crop yields estimates show that it was 8 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, respectively.

Table 3. Input use and Output for Wheat under different Irrigation Practices in the Rechna Doab (Rs./Ha)

Inputs and Output	Source of Irrigation		
	Canal	Tubewell	Canal+ Tubewell
Seed	899	867	940
Fertilizer	2810	3004	3222
Labor	362	484	598
Land Prep.	2053	2117	2320
FYM	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

The Table 4 shows the results of the estimated regression equation relating the wheat production with the determinant variables. As stated earlier, several forms of regression equation were estimated and the best fit was selected for discussion. On the basis of the adjusted R^2 and the significance of the variables the linear function was selected for explaining the effect of investment on seed, fertilizer and irrigation inputs along with the other determinant variables on the wheat productivity under different irrigation practices in the Rechna Doab. The value of adjusted R2 was 0.61. The coefficient for X1, X3, X5, X6, X7, X13, X17 and X18 came out to be statistically significant and have the expected signs. The coefficient for X1 is positive and statistically significant at 99 percent level of confidence showing that the investment on better quality wheat seed on the farms practicing conjunctive water management will 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 will also increase the productivity of wheat on the farms under canal irrigation. How ever the dummy variable X3, for investment on seed under tubewell irrigation was non significant showing no impact on the productivity by investing more on the better quality seed on the farms using tubewells as a source of irrigation on the farms. The coefficient X4 for investment on fertilizer on the farms practicing conjunctive use of water is also statistically significant at 99 percent level of confidence and depicts that the investment on fertilizer will help in increasing the wheat yields on these farms. This might be due to more reliable and timely supply of tubewell water along with the better quality canal irrigation, which moderates the quality of tubewells water under 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 the wheat productivity. This may be due to shortage of canal-irrigation water on these farms, which result 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 on fertilizer may reduce the wheat productivity on the farms that are only using the 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 (COSEEDC+T)	0.0363***	0.013	2.72	0.01
X2 (COSEEDCA)	0.0274*	0.016	1.76	0.08
X3 (COSEEDTW)	0.0035	0.032	0.11	0.91
X4 (COFRTC+T)	0.0126***	0.004	3.05	0.01
X5 (COFRTCA)	-0.0123	0.009	-1.42	0.16
X6 (COFRTTW)	-0.0126***	0.005	-2.65	0.01
X7 (IRRIC+T)	0.244	0.301	0.81	0.42
X8 (IRRICA)	1.3900**	0.695	2.0	0.05
X9 (IRRITW)	-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 have the 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 the increase in the salinity and the age of the tubewell will reduce the wheat productivity in the Rechna Doab. This once again highlights the problem of increased use of tubewells water in the saline zones that may result in the deterioration of the groundwater quality and ends up in the permanent up-coning of saline groundwater. This problem needs to be addressed at the policy level by regulating the groundwater exploitation by some legal and institutional framework.

POLICY IMPLICATIONS

In this paper we presented the farmer's mode of irrigation on their farms and their perception about the quality of water in the Rechna Doab. 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 the saline and the marginal aquifers. These farmers are also facing the major threat of salinity on their farms. These farmers need to be educated about the conjunctive use of irrigation water to minimize the effect of salinity on these farms.

The above results are stark evidences of on-farm gains due to the conjunctive use of canal and tubewell water. These gains calls for more efficient use of conjunctive water use on the farms. Economic study on this technology also showed that potential farm benefits could be 30 percent higher in case of wheat crop provided judicious use of canal and tubewell irrigation is applied on the farms. The regression results show that the bad quality groundwater hampers the 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 the Rechna Doab, the government should put ban on the installation of new tubewells in the areas where the hazard of up-coning of brackish water is high.

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

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