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Concerns of Groundwater Depletion and Irrigation Efficiency in Punjab Agriculture: A Micro-Level Study

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Abstract

The present study, conducted during 2005-06, in two districts, viz. Amritsar and Faridkot of Punjab, (former having pre-dominantly tubewell-irrigated area and the latter having canal + tubewell irrigation facilities) has assessed the extent of water depletion and has measured irrigation efficiency at the farm level. Due to profitability and availability of water at shallow depths during 1970s, paddy and wheat (two of the high water-consuming crops) replaced other crops like maize, groundnut and pulses in the entire state. The area under these two crops increased from 7.22 per cent to 32.92 per cent for paddy and from 37.12 per cent to 43.53 per cent for wheat, from TE 1965 to TE 2005. Consequently, the problem of groundwater depletion has become severe in the Amritsar district, with a fall of 77cm/annum in watertable. In the district of Faridkot, this fall has been of 33cm/annuum. The technical efficiency of irrigation on farms estimated through Data Envelopment Analysis, has indicated the mean irrigation efficiency of 57 per cent and 65 per cent in paddy production and 61 per cent and 68 per cent in wheat production, in tubewell-irrigated and canal+tubewell irrigated farms, respectively. It has clearly indicated that there is potential to improve irrigation efficiency by 39 per cent and 32 per cent, respectively in the sample farms. To sustain production system in the state, there is an urgent need to (i) do away with the rice-wheat cropping system in the regions where groundwater depletion is very severe, (ii) evolve regulation for use of groundwater and conjunctive use of surface water, and (iii) disseminate improved agronomic practices for increasing use-efficiency of water and other inputs.

Introduction

The state of Punjab, in common parlance known as 'Food Bowl' of the country, is the largest surplus state in terms of food grains. It has a total geographical area of 50.36 lakh hectares out of which almost 83 per cent is under cultivation with cropping intensity of 189 per cent (Govt. of Punjab, 2005). The agriculture in the state is highly intensive in terms of use of land, capital, energy, and all other agricultural inputs, including irrigation water. This is the reason that, with only 1.5 per cent of geographical area of the country, the state produced about 21 per cent of wheat, 12 per cent of rice and 11 per cent of cotton of their respective national production in 2004-05. But, this increase in agricultural production has been at the cost of unsustainable use of resources like land, water and chemical inputs, the externality of which is being faced now

Presently, a major concern of the state is the rapid decline of water-table. About 77 per cent area of the state is facing the problem of falling water-table (Hira *et al*., 2004). To meet the present level of crop production, the demand for water far exceeds its supply from different sources (Government of Punjab, 2005). The excess demand is met through over-exploitation of groundwater, due to which the

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groundwater table is successively going down. Therefore, an efficient use and management of agriculture resources, especially water, has become absolutely necessary to sustain intensive agriculture and income of farmers in the state by preserving the scarce natural resources. Keeping these facts in view, the study was undertaken in Punjab to measure the irrigation efficiency at the farm levels and also to assess the extent of water depletion with time and its consequences.

Data Collection

The three-stage stratified random sampling design was used to collect the primary data from 150 sample households of Punjab during the agricultural year 2005-06. Based on the irrigation systems, the districts of Amritsar (mainly tubewell irrigated) and Faridkod (canal dominated) were selected. From each selected district, two blocks — Verka and Jandiala Guru from Amritsar and Faridkot and Kotkapura from Faridkot — were selected randomly. A cluster of three villages was randomly selected from the blocks. Finally, 75 households from each cluster of 3 villages were randomly selected from each block. Thus, out of total 150 sample households, 75 farms were irrigated exclusively by tubewells in the district of Amritsar and the rest 75 farms from the district of Faridkot, which had both canal and tubewell irrigation. All the selected farm households were further classified into three farm-size groups, viz. small (up to 2 ha), medium (2-4 ha) and large (above 4 ha).

The secondary data on crop production, irrigation aspects, land utilization pattern, etc. were compiled from various issues of *Statistical Abstract of Punjab* and publications of Centre for Monitoring Indian Economy (CMIE). The data on the groundwater depletion were collected from various published sources of Central Ground Water Board (Northern Region), namely different issues of *Groundwater Statistics*, *Groundwater Yearbook*, etc. Research bulletins published by the Department of Soils, Punjab Agricultural University Ludhiana, were also used for the study. In 1995, the district of Faridkot was sub-divided and two districts, namely Moga and Muktsar; hence data presented after the division of Faridkot includes those of Moga and Muktsar districts to maintain the symmetry of the study over the years.

Methodology

Nature of Irrigation Accessibility and Groundwater Depletion

The accessibility of irrigation was analyzed based on the data collected from the farmers and its effect on cropping pattern was studied by tabular analysis. The depletion of the groundwater resources was analyzed based on the collected primary and secondary data.

Technical Efficiency

The data envelopment analysis (computer) program (DEAP) version 2.1 was used for the analysis of technical efficiency of irrigation water (Charnes *et.al.*, 1978). DEA is a multi-factor productivity analysis model for measuring the relative efficiencies of a homogenous set of decision-making units (DMUs).

Suppose data are available on K inputs and M outputs in each of N firms or DMUs. Input and output vectors are represented by x_{it} and y_{it}, respectively, for the i^{th} firm in t^{th} time period. The data for all firms may be denoted by K×NT input matrix, X and M×NT output matrix, Y. The purpose of DEA is to construct a non-parametric envelopment frontier over the data points such that all observed points lie on or below the production frontier. The best way to introduce DEA is via the ratio form. For each DMU, a measure of the ratio of all outputs is obtained over all inputs, such as $u'y_i/v'x_i$ where u is an M×1 vector of output weights and v is a K×1 vector of input weights. To select the optimal weights, the mathematical programming problem is specified as:

$$\max_{u,v} \quad (u'y_i/v'x_i),$$
$$\text{st} \quad u'y_i/v'x_i \leq 1, \qquad j = 1,2,\ldots\ldots,N$$
$$u,v \geq 0. \qquad \ldots(1)$$

This involves finding of values for u and v, such that the efficiency measure of the i-th DMU is maximized, subject to the constraint that all efficiency measures must be less than or equal to one. One problem with this particular ratio formulation is that it has an infinite number of solutions. To avoid this, one can impose the constraint $v'x_i=1$, which provides:

$$\max_{m,v} \; (\mu' y_i),$$
$$\text{st} \quad \nu' x_i = 1$$
$$\mu' y_j - \nu' x_j \;\; 0, \qquad j = 1,2,\ldots\ldots,N$$
$$\mu, \nu \geq 0, \qquad \ldots(2)$$

where, the notation change from μ and v to m and ν reflects the transformation. This form is known as the multiplier form of the linear programming problem. Using the duality in linear programming, one can derive an equivalent envelopment form of this problem:

$$\min_{\theta,\lambda} \theta,$$
$$\text{st} \quad -y_i + Y\lambda \geq 0,$$
$$\theta x_i - X\lambda \geq 0,$$
$$\lambda \geq 0, \qquad \ldots(3)$$

where, θ is a scalar and λ is a N×1 vector of constants. This envelopment form involves fewer constraints than the multiplier form (K+M< N+1), and hence is generally preferred. The value of θ will be the efficiency score for the i-th DMU. It will satisfy θ ≤ 1, with a value of 1 indicating a point on the frontier and hence a technically efficient DMU, according to Farrell (1957) definition. Note that the linear programming must be solved N-times, once for each DMU in the sample. A value of q is obtained for each DMU.

Results and Discussion

Distribution of Sample Farms across Farm-size and Irrigation System

The selected farm households from the districts of Amritsar and Faridkot were distributed across different farm-size groups and have been given alongwith their average operational holding in Table 1. A perusal of Table 1 revealed that in both the districts, number of large farms was maximum, followed by medium and small farms.

The average size of landholding ranged from 1.28 ha for small farmers to 2.53 ha for medium and 7.02 ha for large farmers in the district of Amritsar, whereas it was 1.03 ha for small, 3.25 ha for medium and 7.70 ha for large farms in the Faridkot district. There was 100 per cent irrigation in the sample farms, the source of irrigation being tubewells in Amritsar and canal and tubewell in Faridkot

Table 1. Distribution of sample farms according to different irrigation systems (Number of farms)

Size of farm	Tubewell (Amritsar)	Canal+Tubewell (Faridkot)
Small (up to 2 ha)	21	15
	(1.28)	(1.03)
Medium (2-4 ha)	23	16
	(2.53)	(3.25)
Large (above 4 ha)	31	44
	(7.02)	(7.70)
Total/ Overall	75	75
	(4.04)	(5.42)

Note: Figures within the parentheses indicate average operational holding (in ha) among the related farm-size groups.

Accessibility to Irrigation Water

The farms in Amritsar were irrigated by tubewells — personal or hired. However, almost all the farmers faced shortage of irrigation water during the crop seasons. Sharing of water among farmers was also very common. Many had to use diesel engine due to erratic power supply, which was a major problem affecting the timely application of irrigation. Due to persistent decline in the watertable, deepening of tubewells was a common recourse that required huge investment by farmers. Many farmers were of the opinion that canal water was required for irrigating the crops properly.

Contrary to it, the farms in Faridkot district were irrigated by tube wells as well as canal. The Sirhind Canal system has been serving the district for irrigation since long. The farmers had access to canal irrigation water once in a week at the rate of 20 minutes per acre (round the year or in a particular season), which was, however, not sufficient to irrigate water-intensive crops like paddy, so they had to depend on tubewells too.

On the basis of farmers' perception, the access to irrigation water on different farm-sizes, given in Table 2, revealed that the farmers had varying degree of accessibility to irrigation water. Though, they had

Table 2. Access to irrigation water for different farm-sizes

(per cent respondents)

Size of farms	Access of water to all the crops cultivated in a season			Access of water to all crops grown in a year		
	Poor	Good	Very good	Poor	Good	Very good
			Tubewell (Amritsar)			
Small	40	50	10	55	40	5
Medium	30	55	15	50	40	10
Large	30	60	10	40	50	10
Overall	33	56	12	47	44	9
			Canal+ Tubewell (Faridkot)			
Small	30	60	10	50	45	5
Medium	30	50	20	45	45	10
Large	20	60	20	35	55	10
Overall	24	58	18	40	51	9

enough access to irrigation water in their cultivated land, it varied across farms in the case of different crops in a year. The farmers faced difficulty in getting enough irrigation water in certain months, especially during July and August. During the *rabi* crop season too, they had difficulty in getting enough water for their crops. Erratic power supply and depletion of groundwater were the main reasons for the poor accessibility of irrigation water in Amritsar, whereas erratic power supply was the major concern in Faridkot, as given in Table 3. Many farmers complained about the poor management of canal irrigation, which was leading to contamination of water by sewage.

Cropping Pattern under Different Irrigation Systems

The crops grown by the farmers during both the crop seasons in both the districts are given in Table 4. In the Amritsar district (tubewell irrigation), paddy was the dominant crop across all farm-size groups. The cropping intensity was relatively lower among large farms as they faced difficulty in intensive cultivation and hence opted for less number of crops in a year. The choice of crops among different farm-sizes did not differ in general and most of the farmers relied heavily on the rice-wheat cropping system. In the Faridkot district (canal+ tubewell irrigation), besides paddy, cotton was the major crop, though, its share was small. Hence, there was no significant influence of irrigation systems on the cropping pattern in the two districts, though adequate availability of irrigation water enabled the farmers to grow water-intensive crops like paddy and wheat.

Depletion of Groundwater Resources in Punjab

Punjab agriculture is primarily based on intensive irrigation using surface as well as groundwater resources, since rainfall hardly meets 20 per cent of the irrigation requirements. Intensive agriculture has

Table 3. Farmers' perceptions on poor accessibility of irrigation water

(per cent of respondents)

Particulars	Tubewell (Amritsar)	Canal+ Tubewell (Faridkot)
Erratic power supply	95	90
Shortage of water in canal during crop season	-	80
Depletion of groundwater	80	45
High degree of losses during conveyance due to poor maintenance of canal	-	20
Smaller and fragmentation of landholdings	20	30

Table 4. Sources of irrigation and its influence on cropping pattern: 2005-06

(per cent of gross cropped area)

Crop	Small	Medium	Large	Overall
Tubewell (Amritsar)				
Paddy	49.19	47.41	49.5	48.77
Vegetables	0.00	1.11	0.20	0.42
Kharif other crops	0.79	1.85	0.50	1.00
Wheat	48.39	42.60	43.95	44.78
Vegetables	1.60	5.90	4.76	4.22
Rabi other crops	0.76	1.10	0.00	0.55
Gross cropped area	100.00 (2.46)	100.00 (4.85)	100.00 (12.60)	100.00 (7.38)
Cropping intensity (%)	192	192	179	187
Canal+ Tubewell (Faridkot)				
Paddy	42.66	45.25	49.80	47.40
Cotton	5.98	6.64	3.30	4.55
Kharif other crops	0.00	0.00	0.00	0.00
Wheat	48.46	46.22	45.81	46.43
Vegetables	0.00	0.00	0.91	0.53
Rabi other crops	2.99	3.73	0.91	1.93
Gross cropped area	100.00 (1.85)	100.00 (6.22)	100.00 (14.34)	100.00 (10.11)
Cropping intensity (%)	180	191	186	186

Note: Figures within the parentheses indicate gross cropped area in ha

led to a serious imbalance in the use and availability of groundwater resources. The total surface water availability at different head works is about 1.80 million hectare metre (Mha-m) per annum (Government of Punjab, 2005). Out of this, 0.35 Mha-m is lost during conveyance and only 1.45 Mha-m is available at the outlet that irrigates about 1.0 Mha land. The remaining 3.24 Mha land is irrigated using groundwater. The total sustainable availability of groundwater is 1.68 Mha-m per annum. The current crop production pattern dominated by paddy-wheat crop rotation requires 4.37 Mha-m of irrigation water per annum, against the total supply of 3.13 Mha-m per annum from both surface and annual recharge of groundwater resources, leading to a net deficit of 1.24 Mha-m (Government of Punjab, 2005). Consequently, the deficit is being met by over-exploitation of the groundwater reserves through tubewells.

The over-exploitation of groundwater has played havoc with the groundwater resources of the state. It has been found that out of 138 development blocks in the state, 84 blocks were marked as ‘dark’ (rate of exploitation: 85% of the rechargeable capacity), 16 blocks as ‘grey’ (rate of exploitation: 65-85%) and 38 blocks were ‘white’ (rate of exploitation: less than 65%) on the basis of groundwater availability and pumping (Groundwater Year Book, 2004).

Depletion of Groundwater in Selected Districts

The selected districts of Amritsar and Faridkot fall under the hydrological zones, namely Central and South-West Zone. The per cent area under different water depths in these hydrological zones of Punjab from 1973-2000 has been recorded in Table 5. The area under water-table above 10 m was only 3 per cent in 1973, which rose to 46 per cent in 1994 and further to 53 per cent in the year 2000. The per cent area under different watertable depths over the years showed that the rate of depletion was more pronounced in the Central than South-West zone. The per cent area where watertable has gone down more

Table 5. Area under different water depths in the Central and South West Zones in Punjab: 1973-2000

(per cent area)

Year	Central Zone (Amritsar)			South–West Zone (Faridkot)		
	<5m	5-10m	>10m	<5m	5-10m	>10m
1973	39	58	3	39	25	36
1990	9	66	25	39	49	12
1994	6	48	46	30	56	14
1996	6	69	25	45	47	8
1998	9	49	42	45	43	12
2000	6	41	53	41	50	9

Source: Hira and Khera (2000)

than 10 m had increased over the years in the recent past in the central zone of Punjab. This highlights the problem of over-exploitation of groundwater in the state.

In the South-West Zone, with fast development of canal network and better conjuctive use of surface and groundwater, the area with watertable below 10 m had decreased from 36 per cent in 1973 to 9 per cent in 2000. But, area under watertable depth of 5-10 m had almost doubled, from 25 per cent in 1973 to 50 per cent in 2000.

The introduction of paddy in a big way was probably the most important reason for the declining watertable in the central region. Paddy being highly water-intensive crop requires 24-28 irrigations in its four-month production period. Also, over the years, it has replaced the low-water requiring traditional *kharif* crops, viz. maize, groundnut and pulses. Paddy and wheat together consume 66 per cent of the total irrigation water (Hira *et al*., 2004). Such a high intensity of irrigation cannot be met with the canal water even if it is available, where rainfall is scanty. Therefore, demand is met through pumping groundwater with electricity operated tube-wells. The government, through distorted price policy, supplied electricity to the agricultural sector at a flat rate or even free of cost for some years. It has led to unrestricted access to/use of electricity for irrigation purposes.

Depth of Watertable in Amritsar and Faridkot Districts

The depths of watertable in the districts of Amritsar and Faridkot during the past three years

Table 6. Average watertable depth in Amritsar and Faridkot districts: 2004-2006

(m)

Year	Amritsar	Faridkot
2004	10.91	6.59
2005	11.31	7.06
2006	11.49	7.06

Source: Based on personal communication with Additional Director (Research), Punjab Agricultural University, Ludhiana

have been given in Table 6. The watertable has declined in both the districts with time; consequently, water has to be pumped from lower depths that have higher energy requirements.

The data on watertable depths collected from the published sources of Central Ground Water Board (CGWB), have been presented in Table 7. The CGWB maintains national hydrograph stations at various locations. Groundwater levels are measured four-times in a year, during January, April/ May, August and November through a network of about 15000 observation wells located all over the country. The observations during 1983, 1993 and the latest published (January 2006/May 2005) were compared to estimate watertable depths.

The year 1983 was chosen because paddy had emerged as a major crop in Punjab agriculture during the 1980s. In the Amritsar district, a majority of the wells had the watertable depth of 5-10 m in 1983 during January as well as May months. None of the wells had a depth of more than 20m. But in 2006, the situation became alarming as wells with shallow

Table 7. Depletion of groundwater in Amritsar and Faridkot districts

(% of observation wells)

Watertable depth	January			May		
(metre)	1983	1993	2006	1983	1993	2005
			Amritsar			
0-2	0	0	0	0	0	0
2-5	26	12	0	26	11	0
5-10	63	71	20	66	81	27
10-20	11	17	60	8	8	55
>20	0	0	20	0	0	18
			Faridkot			
0-2	0	3	0	0	10	0
2-5	46	35	29	38	37	29
5-10	23	46	57	31	33	57
10-20	31	16	14	31	20	15
>20	0	0	0	0	0	0

Source: Reports published by Central Ground Water Board (Northern Region)

watertable (0-5 m) disappeared and only 20 per cent of the wells had watertable more than 20 m deep. The trend was similar for both the months, January and May. On the other hand, in the Faridkot district, a majority of the wells had watertable depth of 2-5 m in 1983. But later, a majority of wells had watertable of 5-10 m. However, over the years, the number of wells in 10-20 m category has declined. This shows that groundwater depletion was not pronounced in the Faridkot district and in fact, due to the spread of canal, there is problem of waterlogging in some pockets of the district. None of the wells had water depth of more than 20 m.

Average Water Depth in Sample Villages

The sample farmers in the two districts were asked about the depletion of groundwater over the past few years. Based on that, the average per annum fall in groundwater was recorded. The problem of groundwater depletion was more serious in the sample farms of Amritsar district, which were irrigated exclusively by tubewells, with a fall of 77 cm/annum. In the district of Faridkot, the fall was 33 cm/ annum. In the Amritsar district, tubewells being the only source of irrigation, their over-exploitation had led to the lowering of groundwater level. The farmers have to deepen their wells regularly due to the decline in watertable depth, as they receive canal water once in a week at the rate of 20 minutes per acre.

Technical Efficiency in Paddy and Wheat Production under Two Irrigation Systems

The input-output data on paddy and wheat production for the year 2005-06 collected from the sample farms were used to estimate the technical efficiency of the farms using DEA. The distribution of farms under the efficiency categories has been given in Table 8. The inputs were taken on per hectare basis and included human labour, seed quantity (kg), fertilizers (kg nutrients), plant protection chemicals (litres) and number of irrigations.

In the case of tubewell-irrigated farms, the minimum technical efficiency in paddy production was 55 per cent and the mean technical efficiency was 76 per cent, which indicated that on an average, the farms operated 24 per cent below the frontier output levels. The study implied that the paddy output of the "average farmer" could be increased by 18 per cent by adopting the technology followed by the "best practice" farmers under tubewell irrigation. The efficiency was higher in the case of the canal + tubewell irrigated farms with the mean technical efficiency of 80 per cent, which implied that there was injudicious use of inputs, and the output of paddy could be increased by 20 per cent in the area.

In wheat production too, the technical efficiency was slightly higher in case of canal+tubewell-irrigated

Table 8. Technical efficiency of farms in paddy and wheat production under different sources of irrigation

(per cent of farmers)

Levels of technical efficiency (%)	Tubewell (Amritsar)	Canal+ Tubewell (Faridkot)
	Paddy	
Up to 60	3	3
60-80	62	49
Above 80	35	48
Mean	76	80
	Wheat	
Up to 60	0	1
60-80	65	43
Above 80	35	56
Mean	80	82

Table 9. Technical efficiency of irrigation in paddy and wheat production under different sources of irrigation

(per cent of farmers)

Levels of technical efficiency (%)	Tubewell (Amritsar)	Canal + Tubewell (Faridkot)
	Paddy	
Up to 40	5	4
40-60	29	12
60-80	43	49
Above 80	23	35
Mean	57	65
	Wheat	
Up to 40	5	9
40-60	25	11
60-80	47	40
Above 80	23	40
Mean	61	68

farms. The mean efficiency was 80 per cent and 82 per cent in tubewell and canal+tubewell irrigated farms, respectively. A majority of farms fell under 60-80 per cent efficiency category in the case of tubewell-irrigated farms and above 80 per cent in canal +tubewell-irrigated farms.

Irrigation Efficiency of the Sample Farms

The irrigation efficiency of sample farms estimated through DEA method has been given in Table 9. The difference between the actual and required number of irrigations for each sample farm gave a measure of inefficiency in irrigation. In the paddy production, the mean irrigation efficiency was 57 per cent in tubewell-irrigated farms and 65 per cent in canal+tubewell-irrigated farms. A majority of the farms were in the efficiency range of 60-80 per cent under both the systems.

In wheat production too, the canal+tubewell irrigated farms were technically more efficient in irrigating the crop when compared to their counterparts. A majority of the farms were in the 60-80 pr cent categories under both the systems of irrigation. The mean irrigation efficiencies were 61 per cent and 68 per cent in tubewell and canal + tubewell irrigated farms, respectively. It clearly indicates that there was sufficient potential to improve the irrigation efficiency by 39 per cent and 32 per cent, respectively in the sample farms for a judicious use of irrigation water.

Conclusions and Policy Suggestions

In Punjab, agricultural transformation has occurred at a very fast rate, but this has been at the cost of degradation of natural resources, as indicated by several indicators, especially, land, water and biodiversity in the recent past. Undoubtedly, this overstretched use of natural resources has been to meet the growing food demand in the country. At the farmers' level, the adoption of efficient water–use technologies can save lot of water in the state without adversely affecting the crop production and productivity. Therefore, efficient use and management of agriculture resources, especially water has become absolutely necessary to sustain intensive agriculture and income of farmers in the state. With rapidly depleting groundwater levels and an irratic rainfall pattern, water is vastly becoming a scarce resource at the national level and therefore, the policies for the production pattern in the state should take into consideration the long–term sustainability of the water resources. Keeping the above findings in view, following policy recommendations are made for sustainable crop production in the Punjab state:

- Continuation of rice-wheat cropping system may exaggerate the problem of groundwater depletion, and therefore change in cropping pattern in favour of low water-consuming crops needs to be encouraged by providing price and non-price incentives.
- Lack of regulation on water-use has led to over-exploitation of groundwater by the well-off farmers, depriving the poor resource-based farmers from accessibility of groundwater. Strict regulation for exploiting groundwater and conjunctive use of surface water need to be introduced at the earliest.
- Supply of free electricity to agriculture, particularly for irrigation purposes, has led to injudicious use of irrigation water. A proper price policy for electricity-use backed with proper information dissemination regarding optimum use of irrigation water needs to be introduced in the state.
- New crop production technology centered basically on HYV-fertilizer-irrigation use, be evolved. Emphasis should be given on evolving improved agronomic practices based on better water and other input efficiencies.

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