The Pakistan Development Review
41 : 2 (Summer 2002) pp. 161–177

Potential for Blue-Gray Water Trade-offs for Irrigation in Small Towns of Pakistan: A Case Study of Farmers' Costs and Benefits in Haroonabad

MEHMOOD UL HASSAN and NAZIM ALI

The growing demand and the competition for fresh water in various sectors suggest that the irrigated agriculture will have to release freshwater for more important and valuable uses. This implies that other options would need to be identified to meet water demands for agriculture. Meeting irrigation requirements through non-conventional water sources is one of the options for agricultural uses. Gray water use for irrigation, a pervasive practice in urban and peri-urban areas of many developing countries, could be one of the solutions. The debate on wastewater irrigation from an environmental point of view is already on, focussing more on human and environmental "safety" aspects. The "value" aspect of the wastewater irrigation remains neglected, however. The irrigation users of untreated wastewater in many parts of the world had already traded off and revealed their preference for gray over blue water decades ago, when the water supply systems in towns and cities were set up. Why they would do it despite the high environmental and health risks associated with its use needs an answer. The paper documents the costs and benefits of wastewater irrigation from users' point of view, and assesses the potential for real blue water savings in a small town setting in the southern Punjab, Pakistan. The data presented in the paper suggest that wastewater irrigation does lead to blue water savings, and it is profitable for farmers. While its potential is not fully exploited, more focus on appropriate approaches to physical and institutional aspects of wastewater disposal planning and management could make wastewater irrigation more productive, profitable, and safe for individuals as well as for the society as a whole.

1. INTRODUCTION

As populations are growing, different sectors and uses are demanding a greater share of blue water. Irrigation of agricultural crops, the major consumer of blue water so far, is therefore under growing pressure from other sectors to release

Mehmood Ul Hassan and Nazim Ali are Water Institutions Specialist and Agricultural Economist, respectively, at the International Water Management Institute's regional office for Pakistan, Central Asia, and the Middle East.

Authors' Note: The authors wish to acknowledge the financial support from the IWMI, as well as the permission to publish this work. The authors also gratefully acknowledge the valuable comments from Wim Van-der-Hoek, from Liqa Raschid Sally of the IWMI's Water, Health, and Environment theme, and also those of an anonymous reviewer on earlier drafts of this paper. The opinions expressed in the paper are those of the authors and may not necessarily reflect those of the IWMI.

water for more valuable uses. There are only limited options for blue water savings in agriculture which seem viable. The most promising options are:

(a) producing "more crop per drop" to the extent that enough blue water is saved to satisfy more pressing demands first and agriculture uses the leftover blue water—this solution requires better water management in agriculture, and developments in genomics to develop crop varieties that consume much less water [Rijsberman (2001)];
(b) exploiting non-conventional water sources for agriculture, such as municipal and industrial effluent (gray[1] and black water, respectively) which are unsuitable for other uses.

While option (a) is already under rigorous research and discussion by the policy-makers, planners, and the research community, option (b), the subject matter of this paper, has received some attention but mostly from an environmental point of view. Most of the research questions have been aimed at finding out the conditions under which it is safe to irrigate with wastewater, its composition, and the guidelines and treatment mechanisms for making it safe for irrigation etc.

Wastewater irrigation is not a new practice. What is new, however, is the extent of this practice, which has become pervasive. In India, Pakistan, China, and Mexico, to cite a few examples, wastewater for irrigation originated and remains an unplanned activity. It has been practised for decades, even centuries, by poor farmers in urban and peri-urban areas. Untreated wastewater remains and will continue to remain a cheap and reliable source of water and nutrients in many developing countries in arid and semi-arid regions, as the municipalities have more urgent demands on their resources than treating wastewater.

While irrigation with untreated wastewater certainly has health and environmental risks, it may have important economic and environmental benefits for both farmers as well as the society. The societies may have benefits such as limiting pollution to localised areas rather than polluting rivers and other surface waters through untreated wastewater disposal, which in many instances might be the only viable option to dispose of gray and black water. The farmers using wastewater may be able to reduce the need for artificial fertilisers, and increase crop yields. They may also be able to "save" blue water for other users and uses by meeting their irrigation requirements from irrigation with wastewater. Farmers may have more reliable water supply from the wastewater than that supplied through poorly managed canal systems.

As a source of irrigation water, this gray and black water, thus, has the potential to release blue water for more pressing demands. However, the exploitation of this potential

[1]Usually, the term "gray water" is used for the effluent from washrooms, which does not have sewage in it. In developing countries, however, the sanitation systems of towns and cities lack separate systems for disposing different kinds of sewage water. In this paper, therefore, we use this term to denote effluent that does not have industrial pollutants.

to the fullest level depends on the efficiency with which it is used for irrigation. If the municipalities keep on discharging wastewater out of the disposal stations without considering who the users are, why they use it, and how these uses can be improved to achieve "more crop per drop"[2] in an environmentally favourable way, the potential may remain under-utilised. As a matter of fact, gray water irrigation requires much more planned and regulated use than blue water irrigation, due to its associated health and environmental hazards. Any efforts aimed at planning and regulating wastewater irrigation requires understanding the users' incentives for using gray/black water so that its use for irrigation is optimised in terms of societal costs and benefits. Thus, societies' and farmers' costs and benefits need to be understood.

The aim of this study was to contribute to improving water productivity and conserving the environment through an analysis of wastewater irrigation practices so as to help the policy-makers and water managers with informed policy and decision-making. The specific objective was to understand farmers' costs and benefits of wastewater irrigation and quantify the resulting water savings of blue water. The central hypothesis was that wastewater irrigation not only has the potential to save blue water but also gives farmers an opportunity to grow high value cash crops, which they might not be able to grow using the much scarce blue water.

The following have specifically been compared for wastewater and canal water farming:

(a) land use and cropping patterns;
(b) types and costs of inputs;
(c) water availability and use;
(d) differences in rental value of land;
(e) water and land productivity and profitability;
(f) volumes of water used, and potential for blue water savings.

The work reported here was a component of a larger study that assessed the economic, health, and environmental costs and benefits of wastewater irrigation. The second section describes the setting and the third section entails the methodology followed. Sections 4 and 5 respectively present the results of the study with regard to costs and benefits and water savings. Section 6 concludes the paper.

2. SITE CHARACTERISATION AND METHODOLOGY

2.1. Site Characteristics

The study was carried out in Haroonabad town of Bahawalnagar district in the southern Punjab. Haroonabad, located at the edge of the Cholistan Desert, has a population of approximately 63,000. Rainfall is mainly limited to the monsoon

[2]The research at the IWMI suggests that since water is scarcer than land in many parts of the world, the countries should focus more on enhancing water productivity. The emphasis so far has been on increasing land productivity.

periods of July and August and is quite scanty, averaging 160 mm. a year. Groundwater is brackish and therefore water supply to the town is dependent on irrigation water from nearby Hakra-4/R Distributary Canal.

While the main population lives in the central parts of the town, recent decades have witnessed new colonies emerging as satellites around the town. Different colonies have different disposal stations for wastewater. Several sites in and around Haroonabad were irrigated with raw sewage sometimes combined with canal water. Some of these sites have only recently been irrigated with wastewater, while others, including the main site, from where the current study uses data, had been irrigated with wastewater for the past thirty-five years.

The main disposal scheme has two pumps operating for 12 hours. The effluent was mainly used to irrigate an area of 120 ha. There are two smaller schemes that irrigate an additional area of 25 ha. The total discharge from these stations approximated 4600 $m.^3$ of raw sewage a day.

2.2. Data Requirements, Sampling, and Data Collection

For finding out the differences in the aforementioned variables, data on crops, inputs, outputs, prices, irrigation water application, and farmer's opinion about the sufficiency of irrigation water were required. The methodology used for data collection was surveys for recording input use, outputs, type of crops, land use, and cropping patterns and the prices paid or received by the farmers. Informal interviews and focus group discussions with farmers were helpful in obtaining information about changes over time in cropping patterns, contracts about wastewater, overall situation of area and the reasons for growing specific crops in wastewater area. Besides, these interviews helped in understanding the water distribution system followed by the farmers.

In order to compare the costs and benefits of wastewater irrigation to those of the alternative sources of irrigation, comparative data sets were required. In total, some 45 farmers[3] used wastewater at the main wastewater site; all of them grew vegetables but only 22 maintained some record about their production and expenses. Only those farmers were selected who were willing to cooperate in sharing and maintaining the record of their production and expenses.

The control sample comprised only those canal-irrigating farmers who represented similar agricultural and marketing setting, and comprised only a fraction of the total canal farmers.[4] As vegetables were the main crop for wastewater

[3]The term farmer is used here for actual tillers of the land, who were the sharecroppers and were cultivating almost entire land on the wastewater site. The land-owners and lessees did not participate in farm operations, though some of them participated in decision-making for crop choice and input use.

[4]Hakra 4-R, a 60 kilometre-long distributary canal, supplies water to some 4700 farms located across its entire length.

farmers, canal farmers growing vegetables were specifically targeted as the control group. Additionally, the canal irrigation farms from within a radius of 5 kilometres of the centre of the town were selected to represent similar marketing opportunities available to the farmers. There were only 24 canal-irrigating farmers around the town of Haroonabad who grew vegetables. Out of those only 20 farmers were selected based on willingness and ability to share data about their incomes and production consistently. Due to these limitations 20 farmers were selected from each of the wastewater and canal water farmers.

All of the 20 farmers in wastewater area used wastewater as the only source of irrigation, while in canal irrigated area the source of irrigation was canal and occasionally the private tubewells.

Pre-designed questionnaires were pre-tested and were used to interview farmers and collect information about farm sizes, operational holdings, tenurial status, sources of irrigation, reasons for growing vegetables, and perceptions about availability and sufficiency of irrigation water. Another questionnaire was used to record panel data on area under different crops, agricultural operations, inputs used for different crops, cost of inputs, farming practices, yield of crops, and prices received, etc. The recall period was limited to only one week, and the enumerator used to visit each farmer to record the information for the previous week. Data about vegetable prices collected from farmers were frequently reconciled with those of the market committee.

A major problem in data collection was the data about vegetable production. Farmers did not weigh their vegetable produce and only remembered the number of baskets they transported to the market. To convert the baskets into weights, the baskets were weighed for different vegetables and average weights per basket were arrived at. To calculate total production, the number of baskets was multiplied with the average weight of the basket.

The volume of water was measured with cut-throat flume for crops for different sowing methods for one irrigation, and then the volumes of water per irrigation were multiplied with the number of irrigations to estimate the total applied water to that crop. The data were collected for one year, from April 2000 to March 2001.

The data thus obtained for the wastewater and canal-water farms were processed and the two-sample *t*-test was used to compare means of different variables. The results are summarised in Section 4.

3. WASTEWATER IRRIGATION SETTING IN HAROONABAD

Like all other municipalities, the Municipal Committee (MC) of the town is responsible for, *inter alia*, provision of the water supply and sanitation/disposal services to its citizens. The municipality has employed Sanitary Inspectors who have a crew of sewerage workers, sweepers, and pump operators with them to manage the tasks. The municipality's responsibilities end at the disposal station, from where the farmers take over the management of wastewater. Over the years, the farmers have evolved mechanisms of informally cooperating with each other and have converted an old irrigation channel into wastewater channel, thus revealing their preference for wastewater over fresh canal water supplies to their farms. All wastewater-irrigating farmers had water rights for fresh canal water, but they either sold their canal water somewhere upstream or they used it to irrigate their own areas located upstream.

The wastewater was not available to all farmers who were interested to have access to it because of lack of conveyance infrastructure. The farmers whose lands were not directly connected to the wastewater channel had no access to the wastewater. Such farmers could not connect themselves to wastewater channel until all the adjoining farmers agreed to let the water channel pass through their respective lands. Were the interested farmers able to connect their land to the wastewater, the area being irrigated with the existing wastewater facilities could possibly be more than doubled. The earlier experiences in collective action at tertiary level of the irrigation system in Pakistan suggest that it is extremely hard for farmers to cooperate, even with considerable facilitation from state [See for instance Mirza and Merry (1975); Merry (1986); Malik, *et al.* (1996)] in building new infrastructure and sharing it, unless the channel is a state property.[5]

In the case of Haroonabad wastewater channel, the main channel was the tail end of an old irrigation channel. To extend this channel to other farms was impossible unless all farmers agreed to it through a series of social mobilisation processes. There was no institutional arrangement for organising farmers to promote formal collective action for wastewater irrigation, which could deal with water distribution issues on an environmentally sustainable basis.

Landownership was found as a symbol of prestige in the area. However, working in wastewater was seen as an inferior occupation. Therefore, the richer landowners did not engage in direct farm operations, especially when wastewater was the source of irrigation. The landowners had rather preferred to lease out their land. The lessees had purchased the lease rights of parcels of land for a few years. The lessees tended to operate larger consolidated holdings by arranging leases with more landowners. Since wastewater farming in the area was intensive vegetable cultivation, it required more labour inputs during land preparation, seed sowing, inter-culture, and picking. Since fodder market was limited due to small size of the town, only vegetables were grown in the wastewater-irrigated area. Therefore, there was a general tendency among the lessees to share out small parcels of 1-2 ha. to the tenants with larger families, who could provide family labour for farm operations.

[5]Most of the tertiary irrigation channels of the canal network are state channels (*Sarkari Khal*) in the Punjab Province, to which farmers connect their private channels to irrigate. Due to this very reason, a number of water-related disputes in irrigation communities relate to the route of the channel, diversion points from where farmers get water, and water allocations.

The water rights were automatically transferred with land, but day-to-day distribution of water among various tenants took place with their mutual cooperation and understanding.

The municipality auctioned use rights of wastewater to the highest bidder regardless of the ownership of land. Farmers saw a value in the availability of wastewater for irrigation, and therefore had been buying the wastewater as a single group to keep the water prices low. The land rents in the area had been quite high compared to similar lands without wastewater in the area. The average land rent for wastewater-irrigated lands (52,000 rupees[6] /ha.) was around 3.5 times higher than that of the canal-irrigated lands.

The farmers shared water and its costs in proportion to the size of their land. They had devised a weekly irrigation roster specifying duration of irrigation for each farmer depending on the size of the landholding, nature of the soil, and topography. This schedule was modified in an annual meeting, when farmers met and agreed on their water and cost sharing arrangements for the forthcoming year and devised a strategy for bidding for water. Since they used to submit a single bid to the municipality, they operated as a monopolistic buyer. More recently, the farmers have refused to buy wastewater by not quoting a price for the bid at all. As the municipality had to dispose of the wastewater anyway, the farmers did not want to spend any money on buying wastewater, like the farmers in the nearby towns who did not pay for wastewater at all.

4. RESULTS AND DISCUSSION

4.1. Benefits of Wastewater Irrigation to Farmers

4.1.1. *Availability of Adequate, Reliable, and Cheap Water for Irrigation*

While a large majority (80 percent) of the wastewater-irrigating farmers considered water availability as sufficient to raise crops they had planted, the opposite was true for the canal-irrigating farmers. More than two-thirds of canal irrigators (70 percent) felt that the water supply remained insufficient. This was further confirmed by evaluating the actual water use during the period. The wastewater irrigators on average applied 1516 cubic meters of water/ha. as compared to the canal irrigators, who used 942 cubic meters/ha. (Annex 1). The cost of irrigation water, which includes the cost of water, and water tax on crop, was much higher for the canal irrigators than that of the wastewater irrigators (Annex 1). The canal water farmers had to purchase expensive groundwater to fulfil crop water requirements. The differences in the volume of water applied and the cost of water were significant for the two sets of farmers.

[6]Mid-year exchange rate for the year 2000 was 1 US$ = 56 rupees.

One of the main reasons for growing vegetables according to the perceptions of the farmers in the wastewater area was the availability of reliable supplies of water. The canal water farmers had fixed weekly irrigation turns, which limited flexible use of water. They could only irrigate when they had their own irrigation turn. Besides, canal was operated on a rotation basis and sometimes the farmers faced a severe shortage due to canal closure. Cheema, *et al.* (1997) reported that along the Hakra 4-R Distributary canal, 40 percent of the farmers missed 10 or more weekly irrigation turns in a year. The summer season was especially difficult for canal farmers as the crops wilted quickly if the canal was closed. The farmers could not use much of groundwater for supplementing canal supplies because it was expensive as well as was brackish. The wastewater supply ran continuously throughout the year, and farmers not only had their own irrigation turns but could also exchange turns with each other to make water availability more responsive to crop water requirements.

4.1.2. *Intensive Land Use*

High-value short duration crops such as vegetables and fodder were grown intensively in wastewater site. The comparison of cropping intensities revealed that the cropping intensity at the wastewater farms was much higher as compared to that of canal-irrigated farms. For canal-irrigating farmers, water supplies were rather fixed and availability of additional water was only possible through purchase of groundwater, which was expensive and of poor quality. Therefore, the canal water farmers tended to grow crops that were less sensitive to water stress. Crops like cotton and wheat span over longer periods, leaving no time to cultivate a third crop. However, vegetable crops were grown in a small area within sugarcane or cotton fields to increase utilisation of land and as a risk-aversion strategy against crop failure.

Table 2 shows that cropping intensity in wastewater and canal water farms was 264 percent and 184 percent, respectively. Due to reliability of wastewater, farmers could grow high-value crops like vegetables, which are sensitive to water stress. Of the canal-irrigated farms, vegetables covered only 18 percent area while in wastewater farms vegetables covered 83 percent of the cropped area.

Table 1

Farmers' Perceptions about Sufficiency of Irrigation Water

	Canal Water Farmers		Wastewater Farmers	
Categories	No.	%	No.	%
Water was not Sufficient for Crops Grown	14	70	4	20
Water was Sufficient for the Crops Grown	6	30	16	80
Total	20	100	20	100

Pearson's Chi-Square Value 10.1 Significant at 99 percent.

Table 2

Cropping Pattern and Cropping Intensities of Sample Farms during 2000-2001

	Canal Water Area		Wastewater Area	
Crops	Ha.	%	Ha.	%
Cotton	50	33	–	–
Wheat	49	32	–	–
Sugarcane	9	6		
Fodder	14	9	10	17
Vegetables	28	18	48	83
Others	3	2	–	–
Farm Area Total	84	100	22	100
Gross Cropped Area (Cropping Intensity %)	154 (184)	–	58 (264)	–

Note: The cropping intensity is calculated as a ratio of gross cropped area to total farm area.

4.1.3. *Higher Family Employment for Tenants*

Wastewater farmers in Haroonabad mainly grew vegetables, which required more frequent and intensive labour inputs than cotton and wheat. Since the actual tillers were the tenants who were required to contribute half of the inputs and full labour, they preferred to utilise their own family members rather than rely on the hired labour.[7] Annex 1 reveals that none of the wastewater farms used hired labour. The canal water farms used on average 37 man-days of hired labour per year per ha. The family labour input was almost three times higher on wastewater farms than on the canal water-irrigated farms. The canal-irrigating farmers could not plant much area under vegetables due to erratic water supplies, and did not need frequent labour. This difference was also statistically significant.

The tenants at the wastewater farms used almost eight man-months per ha. of family labour. Working with family labour saved the wastewater farmers roughly 50 percent of the gross margin of a canal-irrigated farm annually.[8] The availability of the entire family employment on the same farm was considered a valuable opportunity available to the wastewater farmers. The family members had not to move farther to find casual jobs somewhere else and females, males, and children of the family could work together and feel safe and close to each other. The children below 15, who were involved mostly at the vegetable picking stage, formed around one-fourth and one-third of the total labour input at the canal and wastewater farms respectively.

[7]The poor sharecropping families are cash-short and prefer to use unpaid family labour, as they cannot afford to pay hired labour.

[8]Less use of family labour on canal-irrigated farms can be attributed to the fact that major labour inputs are not required on a day-to-day basis—rather in certain periods of the crop cycle, where professional casual labour is available at cheap rates and family labour is not enough for such operations (e.g., ploughing, irrigation, harvesting, cotton picking, etc.)

Though the use of family labour cannot directly be attributed to wastewater farming, the difference in the crop choice is certainly due to wastewater. Canal irrigators could only grow crops that are more drought-resistant because of poor water supply from canal. Likewise, the wastewater farmers were unable to grow anything other than certain vegetable crops. Therefore, wastewater farmers in small towns with similar soil and water conditions would face similar situations and would tend to use wastewater to grow vegetables, and employ more family labour.

4.1.4. *Savings on Artificial Fertilisers*

Due to the presence of nutrients in wastewater, the farmers may not necessarily need artificial fertilisers on wastewater farms. This seems true in case of the sample farms where the application of fertiliser was quite low in wastewater farms as compared to canal-water farms, which applied significantly lower doses of both nitrogenous and phosphatic fertilisers and no manure at all. Difference in the application of artificial fertiliser is shown in Table 3.

Table 3

Artificial Nutrients Applied in Sample Farms (Average Nutrient kg./ha.)

Sample Farms (No. of Sample Farms)	Nitrogen	Phosphorus
Canal Irrigation (n=20)	292.5	90.8
Wastewater Irrigation (n=20)	152.3	15.5
t-value	4.2	4.2

The canal water farmers used around 290 kg./ha. nutrient nitrogen whereas the wastewater farmers used only 152 kg./ha. Difference in the application of phosphorus was even greater. The difference in nutrient application between these two areas was statistically significant. Due to the difference in fertiliser application, costs of fertilisers were also significantly lower in wastewater farms (Annex 1). Only the canal water farmers manure their lands for adding organic matter.

4.1.5. *Higher Land Rents*

The value of wastewater is reflected in the land rents for wastewater farms, which on average were 3.5 times higher than those of the canal water farms. The difference was found statistically significant. Higher land rents for wastewater farms meant higher incomes for the landowners but relatively less net profit for lessees.

4.1.6. *Lower Cash Costs and Higher Value of Outputs*[9]

Ideally, the wastewater irrigated areas would have been compared with canal irrigated areas that had a similar cropping pattern. However, almost all wastewater farmers were growing vegetables that could not easily be grown by farmers who relied on canal water. Only cauliflower was an important crop that was grown by all the wastewater farmers and three canal water farmers. While the first part of this section compares the overall costs and outputs for both sites, the second part compares various variables for the cauliflower alone.

The wastewater farmers saved on the most important cash cost items, such as groundwater, fertilisers, and hired labour. This made their total costs slightly lower than those of the canal-irrigated farms. However, the difference of the total cash costs was statistically insignificant (Annex 1). The major advantage of the wastewater farms was in the higher production, and despite perishability of vegetables and price cycles, their gross value of product remained significantly higher (p=0.07) than the canal farms. The gross margins (gross value of product minus gross cash costs) of wastewater farmers were also significantly higher than those of the canal-water farmers, because vegetables brought higher returns to wastewater farmers.

While the land productivity of wastewater was significantly higher at the wastewater farms, the water productivity in the two cases was not significantly different. This might be due to the fact that the wastewater farmers had to over-irrigate, especially during the rainy season, when they could not refuse water. This indicates opportunities for further water savings at the wastewater farms, which use almost 60 percent more water per unit of land as compared to the canal irrigators.

The only comparable common crop for the canal and wastewater farms, the cauliflower,[10] occupied major parts of the wastewater farms, but only three canal-irrigating farmers in the sample grew it during the year 2000. The reason for the smaller number of canal farmers opting for cauliflower was that they could not compete with the wastewater farmers in the market, who got higher yields, and were able to bring their crop to the market earlier and reaped the highest prices.

A comparison of the cost of cauliflower production and the value of outputs is presented in Table 4. The machinery cost for cultivating cauliflower was higher in wastewater farms than in canal water area.

[9]Family labour is treated as a domestic resource and no opportunity cost is assigned as the farmers regard this as an employment opportunity for unemployed family labour, which has no alternative use.

[10]Although gourds are also the common crop sown on both locations, yet the growing and harvesting seasons differ for wastewater and canal water. Due to the difference in seasons, these cannot be regarded as a comparable crop.

Table 4

Comparison of Cost and Income from Cauliflower Crop

Heads	WW (n=20)	CW (n=3)
Machinery Cost (Rs/ha.)	3354	2023
Cost of Seed (Rs/ha.)	4028	2916
Cost of Fertiliser (Rs/ha.)	2420	5008
Cost of Pesticides (Rs/ha.)	4387	4139
Cost of Irrigation Water(Rs/ha.)	231	235
Irrigation Water Applied (mm.)	806	520
Cost of Labour (Rs/ha.)	12649	11130
Cost of Transportation (Rs/ha.)	861	735
Miscellaneous Costs (Rs/ha.)	1809	1471
Yield (kgs./ha.)	13170	9720
Gross Income (Rs/ha.)	38109	29443
Gross Costs (Rs/ha.)	29740	27657
Gross Margins (Rs/ha.)	8369	1786
Land Productivity (kgs./ha.)	13170	9720
Water Productivity (kgs./m.^{3})	16.3	18.7

Note: The results could not be statistically compared because of the small number of canal farmers growing cauliflower in the sample.

Canal water farmers spent almost twice as much as the wastewater farmers on fertilisers. The costs of pesticides and irrigation were almost equal in both the sites.

Wastewater farmers applied more irrigation water as compared to canal water farmers, who had fixed weekly turns and limited volumes. The same was true of chemical fertilisers. Despite having enough nutrients in the wastewater, farmers still applied artificial fertilisers to maximise output. The wastewater farmers obtained 35 percent higher yield of cauliflower, and 370 percent higher gross margin per unit of land, as compared to those of the canal water farmers. However, the water productivity was not different.

2. Costs of Wastewater Irrigation to Farmers

4.2.1. *More Intense Land Preparation and Agricultural Operations*

For most vegetables sown in the wastewater farms, farmers needed to prepare furrows and beds. On the other hand, the canal water farmers generally planted wheat and cotton using a drill. Likewise, the vegetables needed weeding, inter-culture, and hoeing much more frequently. Similarly, picking vegetables was more labourious than harvesting wheat or sugarcane. This demanded additional machinery and labour inputs at the wastewater farms, because they planted more than 80 percent of area under vegetables. The average cost of agricultural operations per unit of land was much higher at the wastewater farms than that of the canal water farms (Annex 1), which was statistically significant.

4.2.2. *Higher Costs of Pest Control*

Since the wastewater was nutrient-rich, the crops got excessive vegetative growth as well, which attracted insects and pests. To control these pests, wastewater farmers frequently used pesticides and insecticides. The data showed a statistically significant difference in costs on insecticides in the wastewater farms as compared to the canal water farms (Annex 1).

4.2.3. *Limited Crop Choice and Price and Production Cycles*

The Haroonabad wastewater farmers had been irrigating their fields with wastewater for the past 35 years. By the study period, they had become much more experienced in the selection of crops suiting their soils, climate, and market conditions. The key informants stated that the wastewater farmers were unable to grow crops that were grown in canal-irrigated area. Wastewater farmers did not grow wheat and cotton, as these crops could not recover high land rent. Due to high nutrient content of wastewater, there was more vegetative growth affecting grain and boll formation, which reduced yields of wheat and cotton. They could not grow root crops and tubers because they had no clean water to wash these vegetables. Besides, some root crops like radish, carrot, and turnip became black due to chemicals depositions in the soil with continuous wastewater irrigation. Some crops showed more vegetative growth and fruit formation was affected. Some other vegetables like bottle gourd, okra, and beans had higher insect attack. Such crops rather survived well in canal-irrigated areas. Farmers, therefore, were left with a limited number of crops to grow, such as spinach, chillies, pumpkins, round gourds, eggplants, onions, tomatoes, cauliflower, and fodder. The marketable surplus of individual farmers in small towns was too small to export these vegetables to large city markets. As a result, the farmers tended to sell vegetables in the local market, where demand was rather limited and inelastic. Lack of storage facilities required farmers to sell their produce as soon as it was harvested due to the perishable nature of vegetables grown. All farmers growing similar crops and marketing the produce during the same period in a rather small market led to excess supply in the market during peak seasons and affected prices, and therefore the returns to the farmers.

In canal water area, wheat and cotton were the major crops. The government fixed the procurement prices of these crops before these crops were planted, so farmers had sufficient degree of surety that they could sell their produce at the procurement price. But in wastewater area prices were determined on the basis of daily supply and demand, and most of the produce brought to the market reaped relatively lower prices.

5. WATER TRADE-OFFS AND POTENTIAL FOR BLUE WATER SAVING

According to the prevalent rules for canal water allocation in the area, each 1000 ha. of irrigated land was entitled to a canal discharge of 0.3 $m.^3$/sec. By this calculation, the 145 ha. under wastewater irrigation around Haroonabad were entitled to 0.04 $m.^3$/sec of canal water discharge or some 1.3 million $m.^3$ of water annually. However, due to water scarcity, only two-thirds of the allocated water was available to farmers located on the canal feeding this area.[11] So the actual supply of water can be assumed to be 0.8 million cubic meters annually. Using the net water productivity estimates of canal water from Annex 1, this water would be worth 29 million rupees. The wastewater farmers had released this water for other areas by using 0.22 million $m.^3$ of gray water during the year 2000-2001, and still generated an additional net value of 6.8 million rupees. Thus, each cubic meter of gray water used for irrigation not only released three to four times of the blue water for use elsewhere, it also generated an additional net monetary gain for the society as a whole, indicating an opportunity for additional private and social benefits.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

The paper proves that wastewater is a valuable resource for irrigation, and its use is profitable for the farmers and the society. The gray water farmers do better than the blue water farmers because (a) gray water is adequately and reliably available, and (b) it contains nutrients important to plant growth. However, wastewater is used rather inefficiently due to a number of physical, social, economic, and institutional constraints. There is a potential for increasing productivity of wastewater as well as its safe use by regulating its allocation and improving the mechanisms for conveyance and distribution, but the municipalities in Pakistan do not attend to these matters.

A community approach to wastewater disposal, management, and use seems more appropriate. When the municipalities plan sewage schemes, as a policy, they should be required to interact with all the farmers located in the vicinity of disposal stations, discuss and form appropriate formal community organisations, who will find out possibilities of providing wastewater to as much area as possible. In this way, a shared conveyance network can be made available to as many farmers as possible for use of wastewater, by starting with a bottom-up approach to wastewater management rather than following a top-down approach of urban planning.[12] Action

[11]Mirza and Hassan (2000) showed that against an allocated discharge of 6 cubic meters per second, the Hakra 4-R Distributary received an average daily discharge of 4 cubic meters per second during 1999-2000.

[12]The researchers found in interactions with farmers around the wastewater disposal station that many farmers wanted to have access to wastewater and were willing to share some of the costs if given access, indicating potential willingness to pay.

research around the area has already proved that if appropriate social organisation methodologies are followed, farmers show eagerness to engage in a dialogue for water resource sharing [Hamid and Hassan (2001); Memon and Hassan (2000); Wahid and Hassan (2000)]. The returns to such efforts are higher than the costs involved [Hassan, *et al*. (1999)]. Users' organisations share the natural resources more equitably under their own organisation than if controlled by the state [Hassan, *et al*. (2000)].

Farmers' contributions in cash and kind, advice on the route of the canal, and their local knowledge can be sought to minimise the financial and administrative costs of the projects. Involving users right from the start will also create a sense of ownership among farmers [Meinzen-Dick, *et al.* (1995)] and they will tend to protect the physical infrastructure, which usually falls into disrepair and decay if managed by the state. Besides, the municipalities can formulate the principles for water rights and water sharing in consultation with the prospective wastewater farmers. This will also give the municipalities the opportunities to recover parts of the operation and maintenance costs of the schemes, and attract possible investments, to carry out minimal pre-treatment of wastewater and promote sustainable use of wastewater for irrigation. Likewise, involving users right from the start in the wastewater management will provide opportunities for communities to be aware of the health hazards of wastewater use, management, and the crops grown with wastewater. Awareness campaigns would be easy to target, and enforcement of health and safety measures would also be easy. In the developing world, where institutions are usually weak or non-existent to enforce appropriate crop restrictions to minimise health risks to wastewater workers and consumers, a community approach to wastewater disposal, management, and use might provide those mechanisms. For example, the municipalities can sign service agreements with well-mobilised community organisations for the provision of wastewater to farmers' organisations, whereby rights and responsibilities of both parties can be defined. Instead of dealing with hundreds of individual wastewater farmers, the municipalities would only deal with the farmers' representative bodies, which in turn would impose crop restrictions (for example, growing fodder crops only to avoid health risks to consumers from vegetables).

This study was carried out in a small town with brackish groundwater and a limited market for high-value crops. It would, therefore, be interesting to study wastewater productivity and costs and benefits in an environment where a large number of farmers has access to a limited amount of wastewater, and where the market for wastewater-irrigated produce is not as closed as is the case in Haroonabad. Since wastewater allocation and distribution is largely controlled by the farmers alone, without any formal involvement of any government agency, the wastewater distribution strategies and the social organisation around it in different settings would be interesting to compare.

Annexure 1

Comparison of Inputs, Costs, and Value of Product on Wastewater and Canal Water Irrigated Farms

Description of Variable (Unit)	Canal Water-Irrigated Farms (n = 20)	Wastewater-Irrigated Farms (n = 20)	*t*-value
Average Cost of Land Preparation (Rs/ha.)	2897	4734	4.54**
Average Cost of Seed (Rs/ha.)	2903	5409	3.44**
Average Cost of Chemical Fertilisers (Rs/ha.)	5484	2621	5.19**
Average Cost of Farm Yard Manure (Rs/ha.)	1626	0	
Average Cost of Insecticides (Rs/ha.)	5378	7458	2.57**
Average Volume of Irrigation Applied ($m.^3$/ha.)	942	1516	4.22**
Average Annual Cost of Irrigation Water (Rs/ha.)	1141@	200	
Average Annual Water Charges (Rs/ha.)	385	678	
Average Cost of Irrigation Water (Rs/ha.)	1526	878	2.24**
Average Hired Labour Use (Mandays /ha.)	37	0	
Average Family Labour Use (Mandays/ha.)	86	221	6.51**
Average Cost of Hired Labour (Rs/ha.)	2940	0	
Average Total Cash Costs of Inputs (Rs/ha.)	22754	20901	0.85
Average Gross Value of Product (Rs/ha.)	57183	68118	1.89*
Average Net Value of Product (Rs/ha.)	34429	47217	2.50**
Gross Water Productivity (Rs/$m.^3$)	61	45	
Net Water Productivity (Rs/$m.^3$)	37	31	

Notes: @average cost of pumped groundwater used to supplement canal water.
* Significant at 90 percent confidence level.
** Significant at 95 percent confidence level.

REFERENCES

Cheema, M. A., Z. I. Mirza, M. U. Hassan, and D. J. Bandaragoda (1997) Socio-economic Baseline Survey for a Pilot Project on Water Users Organisations in the Hakra 4-R Distributary Command Area, Punjab. Pakistan National Programme, International Irrigation Management Institute, Pakistan, December. (Research Report No. R-37.)

Hamid, A., and M. U. Hassan (2001) Need for a Well-structured Social Organisation Methodology for Reforming Irrigation Management: Lessons from Hakra 4-R Distributary in Southern Punjab, Pakistan. Proceedings of the Drainage Seminar held on April 20-21, at Faisalabad Agricultural University, Faisalabad. National Drainage Programme.

Hassan, M. U., A. Hamid, K. Mahmood, and S. Mahmood (2000) Farmer Organisation's Potential for Reducing Waterlogging and Salinity Through Improved Equity and Reliability of Irrigation Water: Evidence from Hakra 4-R Distributary in Southern Punjab. Proceedings of the Drainage Seminar held on August 16-18, at Mehran University, Jamshoro. National Drainage Programme.

Hassan, M. U., Y. Memon, and A. Hamid (1999) Returns to Facilitating Farmers' Organisations for Distributary Maintenance: Empirical Results from a Pilot Project in Southern Punjab. *The Pakistan Development Review* 38:3, 253–268.

Malik, S. M., Waheed-uz-Zaman, and M. Kuper (1996) Farmers' Organised Behaviour in Irrigated Agriculture in Pakistan's Punjab: A Case Study of Six Watercourse Command Areas in Junejwala Minor, Lower Chenab Canal System. International Irrigation Management Institute. Colombo, Sri Lanka. (Working Paper No. 39.)

Meinzen-Dick, R., R. Reidinger, and A. Manzardo (1995) Participation in Irrigation. Participation Series. Environment Department, Washington, D. C., World Bank. (Paper No. 003).

Memon, Y., and M. U. Hassan (2000) Organising Farmers at Secondary Levels of the Canal System and Upscaling these Organisations to Entire River Basins in Pakistan. In W. O. Deason, *et al.* (ed.) *Proceedings 2000 US-ICID International Conference: Challengers Facing Irrigation and Drainage in the New Millennium*. Volume II. Colorado, USA.

Merry, D. J. (1986) Re-organising Irrigation: Local Level Management in the Punjab. In D. J. Merry and J. M. Wolf Irrigation Management in Pakistan: Four Papers. International Irrigation Management Institute. Colombo, Sri Lanka. (Research Paper No. 4.)

Mirza, A. H., and D. J. Merry (1975) Organisational Problems and their Consequences on Improved Watercourses in the Punjab. Colorado State University, Fort Collins, Colorado, USA. (Water Management Technical Report No. 55.)

Mirza, Z. I., and M. U. Hassan (2000) Impact of Rotational Irrigation Supplies on Agricultural Productivity and Environment: A Case Study from Eastern Sadiqia Canal Command in Pakistan's Punjab. International Water Management Institute Lahore. (Draft Research Report.)

Rijsberman, F. (2001) Genomics and Water Management?: Director General's Comment. Annual Report 2000-2001. International Water Management Institute, Colombo, Sri Lanka.

Wahid, M. A., and M. U. Hassan (2000) Union is Strength: Participatory Development Experiences of Hakra 4-R Distributary Farmers in Pakistan's Southern Punjab. *Canadian Journal of Development Studies*. Special Issue on Participatory Development.