GROWING SCARCITY OF THE WATER RESOURCE

By

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"And We send down water from the sky in fixed measures"
"O Children of Adam!... Eat and drink: But waste not by excess, for God loveth not the wasters."
Al-Qura'an

"Nearly one third of the world's population – about 2.7 Billion people – will experience severe water shortages within the next years."
Study by a Leading Global Water Organization

"Water scarcity is now the single greatest threat to human health, the environment & the global food supply."

"Within the next 25 years, there is great potential for more water conflict not just within countries but between them."
Director General, International Water Management Institute, Washington

"Pakistan is included in the list of 17 countries facing absolute water scarcity and will face serious shortfall of water around 2025."
Consultative Group on International Agricultural Resource, Washington

"Pakistan is currently close to using all of the surface and ground water that it has available, yet it is projected that over 30 % more water will be needed over the next 20 years to meet increased Agricultural, Domestic and Industrial demands."
The World Bank

Considering the above extracts and growth of population of Pakistan, which has arisen from 34 million in 1947 to 150 million in 2006, and it is estimated to increase to 221 million by 2025. This increase sounds alarm-bells for all of us, because it will enormously increase water requirements for food & fibre, industrial & domestic uses. The agricultural sector provides livelihood for 2/3rd of country's population living in rural areas, contributes 22 % to GDP, 60 % to exports and 45 % to employment of the labour force. In view of the increasing demand for water in the coming years there is a need to

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study the growing scarcity of water and potential of this precious resource.

Surface Water:

Inflows from the River Indus and its tributaries form the main source of the surface water. Under the Indus Water Treaty of 1960, the water rights of three eastern rivers i.e. Sutlej, Beas and Ravi were allowed to India. Pakistan is now dependant on three Western Rivers i.e. Indus (including Kabul), Jhelum and Chenab. The average annual inflows at rim stations during the post Tarbela (1976-2006) are 139.9 MAF. About 20 per cent of the annual river flows in Rabi and 80 per cent in Kharif seasons.

The original live storage capacity of 15.72 MAF of Mangla, Tarbela and Chashma dams on the Indus River System has declined by 3.795 MAF by 2007, and may further drop by 6 MAF by 2010 suggesting the need for new reservoirs. The completion of small / medium dams can increase the water availability by about 4.0 MAF. Nevertheless, the total availability of future development is 25 MAF after deducting miscellaneous uses on the Indus system.

It is estimated that the irrigation water availability at the field is 78 MAF out of 105 MAF of water diverted into the canal system. As such 27 MAF is lost in the secondary level irrigation system attributable to surface evaporation seepage from the unlined canals and the poorly maintained canal banks. Lining of canal distributaries and minors can reduce this colossal loss. The major loss of 49 MAF occurs at tertiary/watercourses level due to the poorly maintained water-courses, poor land-levelling and defective irrigation practices at the field level. This loss can be checked by renovation and lining of the watercourses and precision land-levelling. Pakistan has not managed its water resources with due care and is now becoming increasingly water stressed (current availability of 1100 cubic metres per capita which is fast approaching the water scarcity regime of under 1000 cubic metres per capita), compounded by overuse of water resulting in water-logging and salinity. The country's current storage capacity at 9 per cent of average annual flows is very low compared with the world average of 40 per cent. On average 35 MAF of water flows to the sea annually during flood season. In addition, extensive damages result due to flooding.

Without additional storage, the shortfall will increase by 12 percent over the next decade. Increasing storage capacity is thus an important part of the strategy. It is planned to increase storage capacity by 18 MAF (6 MAF for replacement of storage lost to silting / sedimentation and 12 MAF of new storage) in order to meet the projected requirements of 134 MF. The large storages will have to be complemented by a comprehensive programme of small dams, delay action dams, and other measures for recharging underground reservoirs.

Integrated water resource management, which aims at ensuring the most optimal use of water, is a major strategy for overcoming the looming water scarcity. While agriculture sector will remain the predominant user of water, the requirements for industry, municipal and human use will continue to increase. The strategy is to enhance efficiency for all uses of water, including re-cycling and re-use.

Thus the irrigation sub-sector envisages construction of new water reservoirs which are essentially required on long-term basis to supplement surface water resources. Moreover, construction of new canals, rehabilitation, remodelling and lining of the existing irrigation network on selective basis, and construction of small irrigation schemes like delay action dams, check dams, infiltration galleries and diversion weirs has been envisaged so as to provide additional irrigation water, on the one hand, and to mitigate water-logging in the affected areas on the other.

Groundwater:

It caters for more than 45% of crop water and permits greater demand-based timely irrigation of crops in and outside the Indus Basin. It has been estimated that the total groundwater potential is 45 MAF and currently 38 MAF is being exploited. Other estimates are that a sustainable potential is not exceeding 25 MAF.

Similar studies showed that out of 7,00,000 tube-wells currently installed in the country, nearly 70 percent pump out slightly to highly brackish water. Use of well-established sulphurous acid generator technology has great potential to make this brackish water useable for crop production on gypsiferous soils, while the use of gypsum technology for making it useable on non-gypsiferous soils. The low and medium salinity water can be conjunctively used with the canal water by the ratio of 1:1 and 5:1 depending on the level of salinity and sodicity. If canal water is not available then the aforementioned technologies can also be used in such areas. Again, the well established saline agriculture can be followed by using the non-useable saline water, especially in our 10.0 million hectares of sandy deserts Sandy desert soils provide excellent strata for quick percolation of water through sand. The salt tolerant plants growing on sandy soils are well aerated as sand affords more space between its particles. The chlorides of sodium and magnesium, the components of harmful saline water are easily washed down to deeper layers of sandy soils without affecting the selective root system of plants. The harmful sodium ions are not absorbed on sand participles unlike their easy absorption on the surface of clay particles. Use of chemical components further improves the prospects of saline agriculture as is being successfully followed in several countries of the world including India, Australia, and the US.

The massive expansion of private-sector tube-well irrigation in Pakistan has had its serious environmental consequences; 11 per cent of the 22 million hectares of arable land has been declared as ‘disaster area’ because of severe water-logging and salinity (water table only 0 – 5 feet), while another 20 per cent is under stress (water tables 5 – 10 feet below the surface). The reforms would involve changing the institutional and legal environment in which water is owned, supplied and used, with the objective to improve water use efficiency.

Groundwater exploitation in fresh groundwater areas will remain with the private sector. However Government will formulate and implement a comprehensive groundwater regulatory and monitoring framework. This framework will be periodically reviewed and updated in the light of data collected and experience gained. In the private sector, development of fractional tubewells (having capacity less than 1 cfs) in fresh groundwater zones can be promoted whereas in the public sector, tubewells having capacity less than 2.5 cfs will be installed in saline groundwater in order to check the intrusion of saline aquifer into the fresh ones and to control water table in these regions. The Government intends to adopt a policy of not mobilizing the deepwater salts until it is absolutely essential for the reclamation of agricultural lands and a proper disposal outlet is available for the safe disposal of highly saline effluent. Use of groundwater management tools such as development of salt movement models, satellite technology, etc. needs to be promoted.

Rain Water:

In Pakistan average rainfall is 400 mm, which provide a good potential of rain water harvesting. Around 10 mm of rain equals to 1000 litres of water per hectare. Rain water harvesting provides water for regions where other sources are, too distant. The modern rain-water harvesting technologies are now followed in several countries of the world, most of which are getting their rain-fed crop yields nearly equal to irrigated yields. Of the various rain water harvesting techniques roof-top water harvesting from residential, commercial and industrial buildings is being successfully followed in several countries of the world to meet the declining groundwater availability for domestic and industrial purposes. This system has been made mandatory in many Indian cities. The annual requirements of the Indian President's Palace are met from its roof-top rain water harvesting and the Indian government had earmarked sizeable budget in their Ninth Five-Year Plan for this purpose.

In Pakistan, roof-top harvesting needs to be introduced as cities like Karachi, Lahore, Rawalpindi, and Islamabad are facing serious water shortages. Similarly, sewage water could be collected, treated and recycled to meet agriculture requirements as is being successfully done in other countries such as England, China etc. Again there is unlimited potential of using sea water along our 1050 km long coast for domestic, industrial and agricultural purposes after desalinization.

The growing trend of scarcity of the resource can be considerably overcome by;

- *Creation of awareness among end-users of water for the importance of conservation.*
- *Introduction of integrated and sustainable approach at the institutional level for meeting water shortages.*
- *Ground–water Regulatory Framework should be implemented as the level of the aquifer is dropping.*
- *By remodelling, renovation and lining of our canal irrigation system both at the secondary and tertiary levels, and laser land-levelling as it alone will save substantial quantum of water;*

- *Desalination of water is a promising prospect and it is quite common in the desert nations of the Middle East.*

- *Following the water resource conservation agriculture may further save irrigation water by 30 per cent;*

- *Changing to drip irrigation system may reduce water requirements by 40 per cent;*

- *Sprinkler irrigation on undulating lands may further save water;*

- *Encouraging crops with low water requirement will save water;*

- *There is potential of harvesting 13 MAF of rain water;*

- *Restricting groundwater off-take to 70 per cent of the annual recharge rate will check over-mining of groundwater and its exhaustion, especially in Balochistan where exhaustion has become a serious problem;*

- *Techniques may be developed for effective management of hill torrents as most of the hill torrent water is going waste;*

The projected future water resource development potential of 34 MAF is a questionable figure. The actual water resource development potential is far greater to meet the present scarcity situation which is mostly due to mismanagement and poor planning for utilizing the existing water resource potential.

WASTEWATER REUSE FOR CROP PRODUCTION; AN OPTION FOR SUSTAINABLE AGRICULTURE UNDER WATER SCARCE ENVIRONMENTS

By

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ABSTRACT

Pakistan is shifting from scenario of water abundance to water scarcity. The predicted per capita water availability in 2025 is 550 m^3, which was 5269 m^3 in 1951. On the other hand the population of the country is increasing rapidly. The country population which was 156 million in 2006 is estimated to be 221 million in the year 2025. That number of people will need almost double the water resources as compared to present. To meet the food requirements of such a big number of people intensive agriculture is needed, which is only possible with adequate and reliable water availability. There is a pressing need to search for unexploited water resources and to better manage the existing water supplies. Among various options for new water resources, the reuse of wastewater is one of the solutions to meet the water scarcity crisis.

The reuse of wastewater effluent for irrigation has many-fold benefits for farmers; one the availability of excessive amount of nutrient rich water; and two the prevention from environmental pollution caused by disposing wastewater off into drainage and irrigation networks. Wastewater irrigation also serves as a "natural" treatment method. Together with these benefits, wastewater irrigation also has some potential hazard such as health risks for the irrigators, groundwater and soil contamination by NO_3 leaching and heavy metals accumulation.

In this paper a review of the studies conducted by International Water Management Institute on wastewater reuse in agriculture sector has been presented. The studies were conducted on national level as well as in small towns like Haroonabad. These studies report that there are many benefits of wastewater irrigation along with some negative impacts on health and environment. By adopting some protective measures this important water source can be used to supplement the canal and groundwater supplies particularly in peri-urban irrigated areas for ensuring water reliability, improving crop yields and cropping intensities and diversifying the cropping patterns.

1. Introduction

Water is becoming a scarce resource rapidly in Pakistan and the country is shifting from the scenario of water abundance to water scarcity. This situation will be a major blow to the agricultural, industrial and urban water supplies in the near future. In 1951

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per capita water availability was 5269 m^3 per year which has fallen to 1100 m^3 and is estimated to be 550 m^3 in 2025 (Sufi, 2007). Besides this the existing storage facilities are being silted up rapidly and loosing their capacities gradually. On the other hand the population of the country is increasing rapidly. The country's population which was 156 million in 2006 is estimated to be 221 million in the year 2025 and such a bigh number of people will need almost double the water resources as compared to the present. This is a frightening situation under which the future food security and economic well being of the country will be at risk.

Now the nation has to ponder on better water management for future sustainability and to look for the alternative water resources to combat the imminent water scarcity crisis. A variety of options can be considered from river watershed management to farm level improved irrigation practices, inter and intra sector reallocation of water, planning agriculture and setting up industry as per water availability, construction of new water reservoirs including small and large dams, maintenance of existing irrigation and municipal water distribution networks and to harness the unused water resources or reuse of urban wastewater. All of these measures are important to consider, however in present day situation the reuse of wastewater is very important to consider as millions of cubic meters of wastewater is being produced from the urban areas, which is mostly dumped off unused into the nearby drains or rivers. A very small portion of wastewater is used for irrigation purposes, mostly unplanned.

Being rich in crop nutrients like Nitrogen (N), Phosphorus (P) and Potassium (K), wastewater has a lot of attraction for the farmers. Wastewater is a reliable source of irrigation water. It is of great importance in the peri-urban irrigated areas where groundwater is brackish and canal water supplies are limited to cultivate the cash crops like vegetables and fodder. Being an additional and reliable source of irrigation, wastewater ensures successful crop husbandry. Additionally, wastewater is usually rich in crop nutrients and saves the money needed for fertilizer application to crops. Resultantly it increases crop yields, diversify cropping pattern and enhances the cropping intensities in the wastewater irrigated areas. Thus it becomes a cheap and readily available source of irrigation water. In developing countries including the breadbaskets of China and India, approximately 80% of urban wastewater is used for irrigation (Cooper, 1991).

There are also some negative impacts of wastewater irrigation on the environment and public health. It contains, sometimes, high amounts of nitrogen, excessive heavy metals, many pathogens, harmful bacteria and viruses. The high amounts of nitrogen in the wastewater and its heavy application can deteriorate the groundwater quality by excessive nitrogen leaching. The long term use of wastewater can cause build up of heavy metals in the soils which could cause toxic effects on the crop growth and also can be carcinogenic for human usage. The presence of pathogenic organisms in the wastewater cause a series of health problems to the farmers who are in contact with wastewater and to the consumers as well.

1.1 Problem statement

The current water policy ignores the proper reuse of the daily production of thousands of cubic meters of wastewater from the municipalities and industries in Pakistan. Water scarcity situations in Pakistan necessitate to bring under use any unexploited water source. It is not advisable to recommend straightforward the reuse of municipal or industrial wastewater for irrigation purposes without knowing exactly the benefits and hazards associated with it. There is a need of detailed studies that how this valuable water resource can be made useful for irrigation purpose keeping in view the environmental sustainability and the public health safety. There is research question that how the associated risks can be minimized by adopting some practical protective measures? The present paper focuses on such issues by synthesizing the findings of three research projects conducted by the International Water Management Institute (IWMI) in different areas of the Pakistan at different scales.

1.2 Objectives

The goal of this paper is to highlight the importance of wastewater reuse by throwing light on its positive and negative aspects by reviewing previous studies on this topic and thus the objectives of the paper have been set as the;

- Quantification of wastewater production and assessment of the quality of wastewater in order to judge its availability and suitability for irrigation purposes;
- Assessment of the impacts of wastewater irrigation on farmers health and environment
- Assessment of the net benefits and costs associated with wastewater reuse

2. Methods and Materials

This report is based on a review of results and findings of three different studies conducted by International Water Management Institute (IWMI) in Pakistan on wastewater reuse in agriculture sector. The studies were conducted as, in 2002-03, in which wastewater production and reuse was assessed at Pakistan level, the second study was conducted in Faisalabad in 2001-02, in which the same factor was considered, whereas the third study was a detailed study on wastewater in which many aspects of wastewater reuse were considered like the wastewater production and reuse, environmental and heal impacts of wastewater and the net incomes with wastewater irrigation.

3 Results

3.1 Nationwide wastewater survey (Source: Ensink et al, 2004)

A nationwide wastewater production and reuse survey was conducted from July 2002 to April 2003. All urban centers of Pakistan with a population over 10,000 were selected with the help of the provincial census reports of 1998, except Northern Areas and Azad Jammu and Kashmir. This selection led to a total number of 388 cities. These 388 cities were classified into four groups according to their population numbers (Table

1). All cities in group I and II were selected, while from groups III and IV,16 and 25 cities, respectively, were randomly selected. A total number of 60 cities were visited.

All of the selected cities, and in each city all identified direct wastewater-irrigated sites, were visited with a standard pre-tested questionnaire. This questionnaire dealt with issues related to water consumption, wastewater treatment, industrial activities and wastewater use and agronomic practices. During these visits, meetings were held with wastewater farmers (depending on the area irrigated 1 –15 farmers were interviewed), disposal pump operators, Water and Sanitation Authority (WASA) staff and municipality officials. Where possible, simple discharge measurements were taken in wastewater drains and trunk sewers.

Table 1. Classification of Pakistani cities by size and province.

Group	population range for groups*	No. of cities (selected cities)	Population
I	>1,000,000	7 (7)	21,490,000
II	250,001 –1,000,000	12 (12)	5,150,000
III	100,001 –250,000	32 (16)	4,795,000
IV	10,000 –100,000	337 (25)	10,690,000
Total		388 (60)	42,125,000

* The number of selected and visited cities per group is shown in brackets. (Source Ensink et al, 2004)

3.1.2 Wastewater production at national level and irrigated area

The total estimated area directly irrigated by wastewater was 32,500 hectares, with 19,250 households depending on direct wastewater use for their livelihoods. The number of cities with wastewater treatment plants was very low, with only 4 of the 7 cities with over a million inhabitants having treatment facilities. In the entire country it was estimated that only 2% of the 388 cities had wastewater treatment facilities. In those cities that did have wastewater treatment plants, the treatment capacity was limited: often less than 30% of the generated wastewater received treatment. The estimated total amount of direct wastewater used in agriculture was 2.4 MCM per day, while an additional 0.4 MCM per day of untreated wastewater was directly disposed off into the irrigation canals. This represented 31 and 5 percent, respectively of the total amount of wastewater that was produced per day. The remaining 64 percent was either disposed of in rivers or in the Arabian Sea.

3.1.3 Cultivated crops

Vegetables were the most commonly grown crop and were cultivated all year round in all cities. The vegetables cultivated included cauliflower, spinach, tomato, pumpkin, lady-finger, radish and potato. Other major wastewater crops were fodder (Sorghum), wheat, cotton, sugarcane and rice. The wastewater used was predominantly of domestic origin except in the cities of over a million population size, where it also included the industrial effluent. The survey results showed that only 8 (7 in group I and 1 in group II) of the total 60 cities surveyed had large-scale industry (tanneries, pharmaceutical or textile-related industry). Only one of these eight cities used the industrial wastewater for agriculture and this was because the farmers did not have access to any other water resource. In the other cities, farmers considered wastewater of industrial origin to be damaging to the crops.

3.2 Faisalabad case study

This study was conducted in 2001-02 in the Faisalabad city with the objective to assess the production and reuse of wastewater from the Faisalabad municipality. Various aspects of wastewater reuse were investigated but herein this report the wastewater production and reuse has been discussed.

3.2.1 Study Area

Faisalabad is a big industrial city located in center of the Punjab Province with a total population of two million. The total water supply to the city is 310,500 m^3/day (WASA, Faisalabad). The groundwater of Faisalabad is saline so the seepage water from Chenab Well Field near Channiot about 25 km from Faisalabad is supplied for domestic uses. The existing sewerage system of this city is divided into two distinct zones formed by the Rakh Branch canal and the railway line passing through the middle of the city. Each zone has independent sewage collection and disposal systems. Sewage from the existing collection systems is discharged untreated into Maduana drain and treated/untreated in Paharang Drain in the east and west respectively.

3.2.2 Methodology of field work

3.2.2.1 Reconnaissance and Walkthrough surveys

In order to find out the wastewater irrigation sites around the city and to estimate the areas irrigated with wastewater about four surveys were conducted. Every wastewater disposal station was visited and interviewed the local farmers and WASA staff detained at the disposal site as well. Among various sites of wastewater reuse, the Narwala Road site at Chakera village and the Channel 4 site around the wastewater channel 4 were the main sites on western and eastern sides respectively receiving wastewater for irrigation purposes.

3.2.2.2 Wastewater Measurements

For measuring the city’s total wastewater production, the whole sewage system was measured at the same time. There were about five points which pass whole of the city’s effluent, three on western side and two on eastern side. In first exercise the discharges were measured at the same time on one side and on the other at the same time the discharges were measured on the other side. First exercise was conducted in December

2001 and second was conducted in June 2002. The measurements were done with Large AA-Type and small pigmy current meters according to the size of the channel.

3.2.3 Results of field activities

3.2.3.1 Faisalabad City Wastewater Production

As mentioned earlier the city of Faisalabad has been divided into two zones, divided by Rakh Branch Canal and the Railway line passing through the center of the city. The two sides are the Eastern and Western sides of the city and the sewage generated at eastern side drains towards into Madhuanan Drain and western sides wastewater flow dumped into the Paharang Drain. Table 2 gives results of wastewater flows from the city.

Table 2: Faisalabad city's wastewater production

Date	Time	Western Side Flow (m^3/sec)	Eastern Side Flow (m^3/sec)	City Total (m^3/sec)
22-12-2001	10:00	2.73	1.97	4.70
27-06-2002	10:30	3.20	2.49	5.69
Average		2.97	2.23	5.19

In terms of volume per day the average daily wastewater production was about 0.454 MCM (million cubic meter) from which the average western side production was about 0.26 MCM and eastern side wastewater production is about 0.19 MCM. Western side wastewater is predominantly from household sources whereas eastern side wastewater is mostly from industrial sources.

3.2.3.2 Wastewater Irrigated Sites in Peri-urban Areas of Faisalabad

The major wastewater irrigated sites have been given in the Table 3. Besides these there are many small pockets around Faisalabad which are being irrigated with wastewater.

Table 3: List of wastewater irrigated sites around the city

Site	WW Available (l/s)	WW Use (l/s)	Area irrigated (ha)	WW Type	Location	Crops Irrigated
Narwala Road	850	400	250	municipal	PS-3 Chakera	*Rabi* season cauliflower, spinach, wheat, s.cane, fodder. *Kharif* season fodder (maize, millet, sorghum), rice
Chohar Majra	40-50	70-80	75	municipal	PS-3 Chakera	-do-
Chak No. 279/RB	300	75	125	Industrial	Channel-3	
Sidhu Pura	70	70	50	Hospital waste	Allied Hospital WW	Wheat, fodder, rice
Islam pura	25	25	15	Municipal	Narwala Road	Like Narwala Road site
Gaoo Shala (marzi pura)	25	28	15	Municipal	Narwala Road	Like Narwala Road site
Satiana Road	1400	250	200	Industrial	Satiana Road	Wheat, Rice, s.cane, Fodder
Channel-4	1000	700	900	Industrial	Channel-4	Wheat, Rice, Spinach, Fodder (sorghum)

This survey shows that a total of 1630 hectares of peri-urban land was irrigated with wastewater, which was solely dependent upon wastewater. Vegetables, fodder (mostly sorghum) and wheat were the main crops there. Most of these sites get municipal wastewater, whereas the land around channel-4 and along the Satiana road get largely industrial wastewater.

3.3 Haroonabad case study (Source: van der Hook et al, 2002)

3.3.1 Study area

Haroonabad is a town with 63,000 inhabitants (GoP, 2001) located in the southern Punjab on the edge of the Cholistan Desert. There are no major industries in the town. The area has very limited natural water resources, and an extreme climate, with temperatures ranging from 2^{o} C in January to 48^{o} C in July, and with a average annual rainfall of 156 mm. As the groundwater is brackish the town depends on the Hakra-4/R irrigation canal for its supply of water. Shortly after the construction of a sewage disposal scheme in 1965, farmers started using untreated urban wastewater around the disposal station. At present there are three pumps with capacities ranging from 50 litters per second to 70 litters per second at different sites that supply wastewater to agricultural fields. The municipal committee of Haroonabad town is responsible for the provision of a supply of water and waste disposal services to its citizens.

The municipality auctions rights of wastewater use to the highest bidder. In 2000 it was Rs 140,000 for one year period. The municipality is not responsible for the conveyance of wastewater to farmers' fields, and therefore, only farmers whose lands are located in the vicinity of the disposal stations are able to irrigate their fields. Farmers converted an old irrigation channel into a wastewater channel. All wastewater-irrigating farmers have water turns for canal water, which they usually sell it somewhere upstream or use it to irrigate their own fields located upstream. An overview of wastewater reuse in the southern Punjab has been given in Table 4.

Table 4. Wastewater use in cities of the southern Punjab, Pakistan. (Source: Van der Hoek et, 2002)

City	Population (2000)	Wastewater-irrigated area (ha)	Crops grown with wastewater
Bahawalpur	408,000	600	Vegetables
Bahawalnagar	111,000	55	Vegetables and fodder
Burewala	152,000	500	Vegetables, wheat, cotton, and fodder
Vihari	94,000	160	Vegetables, wheat, cotton, and fodder
Arif Wala	74,000	300	Vegetables, rice, cotton, and fodder
Haroonabad	63,000	150	Vegetables, cotton, and fodder
Khairpur	27,000	25	Vegetables and fodder
Fort Abbas	35,000	100	Vegetables
Minchinabad	26,000	12	Rice

3.3.2 Methodology of field work

There were three different wastewater irrigation sites all around the city, two small and one large site, which has been reported as main wastewater irrigation site. In this report only the results of main wastewater irrigation site are presented. This site comprised of 115 hectares, receiving wastewater for last 35 years. A control site was also selected that was only irrigated with regular canal water from Hakra-4/R and had never received wastewater. Daily discharge data was collected from the wastewater pumping station from January to September 2000.

The environmental impacts of wastewater irrigation were also determined. The groundwater, and soils were checked for heavy metals and microbiological contamination at these wastewater irrigated and canal water irrigated site. The groundwater was sampled for nitrates and the soil samples were collected for the determination of heavy metals accumulation. The wastewater and canal water itself was sampled several times for detailed water quality sampling. A health survey was done to estimate the prevalence of intestinal parasitic infections in the residential areas in wastewater and canal water irrigated areas and all the households located in the settlements were selected who were involved in agriculture. A health survey was conducted in which the questions regarding diarrhea, skin and nail diseases, typhoid fever, cholera and hepatitis were asked.

Information on wastewater use, payments for wastewater, changes in cropping pattern over time, and reasons for growing specific crops in wastewater-irrigated fields was obtained through farmer interviews. In order to assess the costs and benefits of wastewater agriculture to farmers, a number of 40 farmers were interviewed in both canal water and wastewater irrigated areas to collect information on the areas under certain crops, sufficiency of irrigation water, cost of farm inputs, farming practices, crop yields and the prices received for crop produce.

3.3.3 Results of the Haroonabad study

3.3.3.1 Wastewater production and reuse

On average 43 liter/sec wastewater was produced during the study period. The maximum average daily wastewater production was in July, which was 56 liter/sec whereas the minimum wastewater was produced in the month of January, 25 liter/sec. The wastewater production depended upon the water use in the city, mainly for domestic purposes. For detailed analysis the wastewater production was also monitored on hourly basis. It was observed that the peak wastewater production hours were from 0900 to 1100 hrs. Whereas there were also such times when no wastewater was available at the pumping station, usually was in the late night hours as shown in Figure 1. All of the wastewater was used for irrigation purposes and high values crops like vegetables were mostly grown in the wastewater irrigated fields.

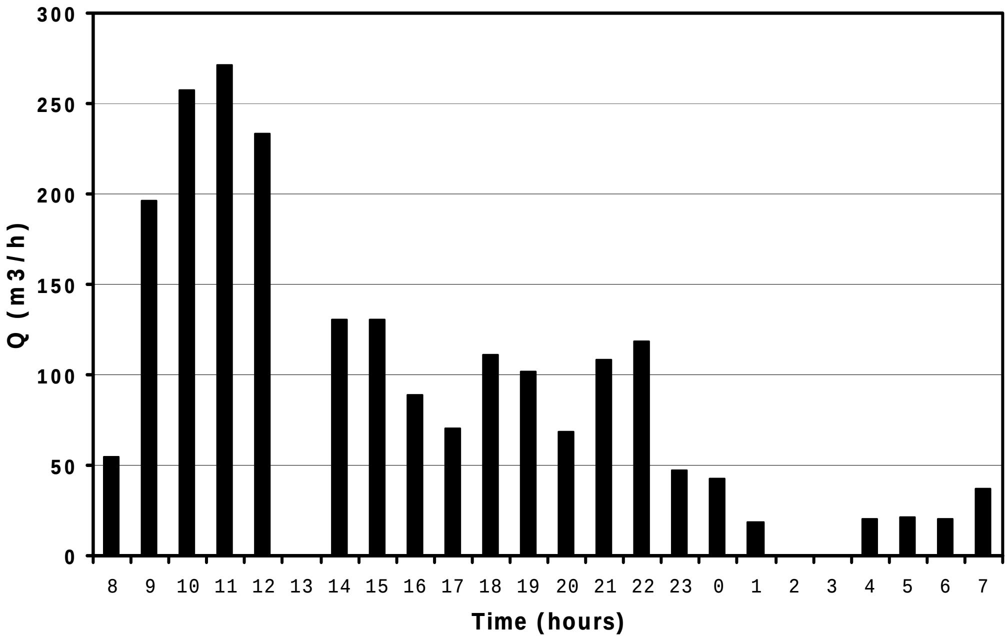

Figure 1: Hourly wastewater production (March 2000)

3.3.3.2 Irrigation Water Quality

Traditionally, irrigation water is grouped into various quality classes that provide a rough indication of potential adverse effects on crop growth, which are salinity (EC), total dissolved solids (TDS), and the sodium adsorption ratio (SAR). According to FAO guidelines (Pescod 1992), TDS as well as EC would place the wastewater in Haroonabad in the "severe" restriction on use group, while the restriction on use based on the measured SAR would be "slight to moderate." While nutrients such as nitrogen, phosphorus, and potassium are beneficial to plants, the level of nitrogen in the wastewater was too high and could lead to excessive vegetative growth. The high *e. coli* and nutrient content in canal water was due to usual animal bathing in the canals. All of the tested heavy metals found within standards for irrigation set by the government of Pakistan. Table 5 gives the results of water quality on wastewater and canal water.

Table 5. Quality of wastewater and canal water (Hakra-4/R canal) in Haroonabad in relation to internationally recommended quality standards.

Parameter	Unit	Wastewater*	Canal water	Irrigation water quality standard
E. coli	No./100 ml	6.3×10^7	1.6×10^3	1.0×10^3
Helminth eggs	No./ml	100	Not detected	1
Total Dissolved Solids (TDS)	mg/l	2076	202	450
Electrical conductivity (EC)	dS/m	4.4	0.4	0.7
Sodium (Na)	mg/l	199.0	46.8	70
Sodium adsorption ratio		4.5	1.0	3.0
Total Nitrogen	mg/l	78.3	8.0	5.0
Total Phosphorus	mg/l	8.6	0.2	-
Total Potassium	mg/l	34.7	7.1	-
Manganese (Mn)	mg/l	0.07	0.12	0.20
Chromium (Cr)	mg/l	0.23	0.03	0.10
Lead (Pb)	mg/l	0.04	0.13	5.00
Nickel (Ni)	mg/l	0.14	0.17	0.20
Copper (Cu)	mg/l	0.35	0.12	0.20
Cobalt (Co)	mg/l	0.06	0.09	0.05
Cadmium (Cd)	mg/l	0.01	0.02	0.01
Iron (Fe)	mg/l	0.22	0.01	5.00
Zinc (Zn)	mg/l	Not detected	0.10	2.00

*Source: IWMI Research Report No. 63

3.3.3.3 Groundwater Quality in wastewater and canalwater irrigated areas

In general groundwater was saline in the study area and was not used for drinking purposes. However, the groundwater under wastewater irrigated fields had higher EC, e. coli and nitrate levels as compared to the wastewater from canal water irrigated fields. as give in Table 6. The water table depth was on average 1.46 meters.

Table 6: Groundwater quality under agricultural lands irrigated by wastewater and canal water.

Parameter	Unit	Wastewater Irrigated field*	Canal water irrigated field
Electrical Conductivity (EC)	dS/m	5.4	2.8
E. Coli	No./100 ml	338	20
Nitrate (NO_3)	mg/l	67.9	47.0

*Source: IWMI Research Report No. 63

3.3.3.4 Human Health Impacts

A detailed health survey was conducted among the wastewater and canal water farmers in which all farmers and their families were interviewed. Farmers and their families who were irrigating their land with untreated urban wastewater around Haroonabad had a significantly higher occurrence of diarrheal diseases than those who irrigated their land with canal or tube-well water, as given in Table 7. The group exposed to wastewater reported more nail problems than those in the control group. Nail problems were most frequently observed in male adult farmers, and the most common nail problem was koilonychia (spoon formed nails), which is associated with iron deficiency anemia. The only problems frequently mentioned in open questions on health were fever and colds, which therefore, appear as indicated in table 7.

Table 7. Prevalence of self-reported diseases by exposure to wastewater.

Disease	Wastewater farmers	Canal water farmers
	n = 203	n = 329
Diarrhea	11.8	5.5
Skin problem	3.0	4.9
Nail problems	7.9	4.3
Fever/cold	11.8	11.9

Additionally it was found that the prevalence of hookworm and roundworm infections was higher in the population exposed to wastewater than in the control group. The prevalence of hookworm among adult, male wastewater-farm workers was 80 percent, which is an extremely high figure for Pakistan. In children, however, there was no significant difference between the exposed group and the unexposed group.

3.3.3.5 Economics of Wastewater Agriculture

Whereas the wastewater farmers cultivated vegetables, which required intensive labor inputs than canal-water farm crops, like cotton and wheat. Overall, there was no significant difference in total cash costs of farm inputs between wastewater farms and canal-water farms. Wastewater farmers spent more on land preparation, seeds, and pesticides. On the other hand, they applied significantly lower doses of fertilizer and no farmyard manure at all. The canal-water farmers, however, used almost twice the amount of nitrogenous fertilizer as the wastewater farmers. The total cost of wastewater irrigators was higher as compared to canal water irrigators. This was mainly due to high cost of labor, which required in large number in case of vegetable cultivation.

The major advantage of the wastewater farms was the high crop production. In addition, despite the perishable nature of vegetables and price cycles, their gross product value remained significantly higher than that of the canal-water farms. The gross margins of wastewater farmers were not much higher than those of the canal-water farmers as shown in Figure 2. While the land productivity was significantly higher at the wastewater farms. With all farmers growing similar crops and marketing the produce during the same period in a limited market, there was an excess supply in the market during peak seasons, which resulted in a drop in prices and a decline in returns to the farmers.

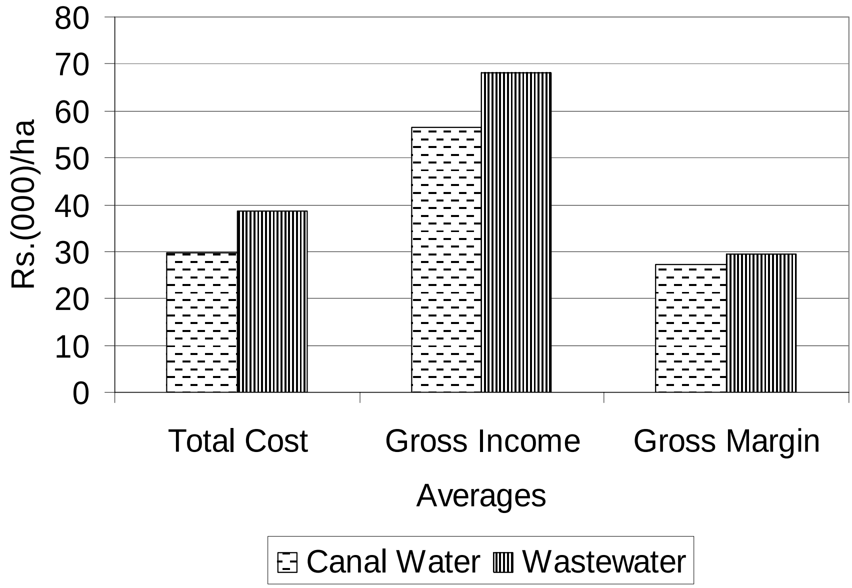

Figure 2: Gross margin comparison between wastewater and canalwater farmer

4. Conclusions

This study concludes that on Pakistan basis a total amount of 2.54 million cubic meter wastewater is produced daily and an area of 32,500 hectares is irrigated with wastewater, which seems though much less as compared with the irrigated area or Pakistan but it is very important as most of the vegetables about 26 percent are produced from this wastewater irrigated area. Whereas from Faisalabad city the average wastewater production was 5.2 m^3/sec from which 1.6 m^3/sec wastewater was used for irrigation whereas rest of the wastewater was disposed to the nearby drains. By farmer interview and surveys it was found that a total of 1630 hectares of land was irrigated with wastewater around Faisalabad city. Haroonabad wastewater study showed that the wastewater had high concentrations of N, P and K and was also available in a reliable manner. The cropping intensities were much higher in wastewater irrigated areas, around 300 percent The heavy metal concentration were in limit and was not a serious threat. The ground water from wastewater irrigated fields had more *e.coli* and nitrates as compared to the groundwater from canal irrigated areas. There were potential health risks associated with wastewater. Economically farmers did not have big margin with wastewater irrigation because of high labor costs and unpredictable vegetable prices.

Wastewater reuse can be made more useful by introducing effective health protection measures that should include health education, and regular antihelminthic medication of exposed people. Using untreated urban wastewater is undesirable and even unacceptable, but it is of great importance for many poor farmers who are unlikely to benefit from wastewater treatment facilities in near future. These studies suggest that it is possible to further increase benefits of urban wastewater by adopting certain health protection measure.

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EFFICIENT IRRIGATION TECHNIQUES TO COPE WITH WATER SCARCITY

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1. INTRODUCTION

Water is a precious, scarce and a finite natural resource. It plays a key role in photosynthesis. It is a medium for transport of nutrients to the crops and plants. It covers about 70 percent of the earth surface. Out of this total, only about 2.5 percent is fresh water, and most of this is frozen in the ice-caps, found as soil moisture or in deep aquifers not readily accessible for human use. Indeed less than one percent of the world's fresh water that is found in lakes, rivers, reservoirs and underground aquifers shallow enough to be taped economically (World Meteorological Organization, 1977). This represents about 0.007 percent of all the water on earth. Water is the basic element and no life can exist without it.

Water development and irrigation are essential for food security. Water shortage is becoming a critical constraint in many countries. Water resources which were considered cheap and plentiful are now recognized as scarce and valuable. Global irrigation expansion has declined from 2.5 percent in the 70s to 0.7 percent per year in the recent years. Highlighting the contribution of water in crop production Dr. Norman Borlaug said, "in order to expand food production for a growing world population within the parameters of likely water availability, the inevitable conclusion is that human kind in the 21^{st} century will need to bring about a "Blue Revolution" to complement the "Green Revolution" on the 20^{th} century (Rajaram & Borlaug, 1977)". The annual withdrawal of water per capita is less in low income groups or less developed countries as compared to high income groups (Table 1). The maximum share of water is consumed in agriculture sector by low income groups, may be due to low efficiency of the irrigation system. The high income groups consume 39 percent water in agriculture as compared to 91 percent by low income groups. Per capita water use varied from 386 m^3 for low income countries to 1167 m^3 for high income or rich countries (World Bank, 1993).

Table 1. Water withdrawals by different sectors and income groups.

Income group	Annual withdrawal per capita (m^3)	Withdrawals by different sectors					
		Agriculture		Industry		Domestic	
		(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
Low income	386	315	91	19	5	16	4
Middle income	453	312	69	82	18	59	13
High income	1167	455	39	549	47	163	14

Source: World Bank, 1993.

Pakistan is an arid to semi-arid country with an average annual rainfall of about less than 100 mm in parts of lower Indus plains to more than 750 mm in the northern foot hills against crop water requirements ranging from 1487 mm in Jacobabad, Sindh to 900 mm in Parachinar, NWFP, 1280 in Faisalabad, Punjab and 1400 mm in Turbat, Balochistan (Bakhsh and Awan, 2002). Therefore an efficient irrigation system is required to fulfill the crop water needs. Irrigation development is the most effective to poverty aversion than any other public development in arid and semi-arid climate (Caruthers, et al. 1997). Without irrigation, there would not be enough food to feed the present world population of some 6,000 million people.

1.1 Importance of Irrigated Area

Agriculture is the major user of water. It covers about 17 percent of cultivated land which is about 275 million hectare (mha) (IPTRID, 1999). Irrigated agriculture accounts for two-third of the water withdrawn from the earth's rivers, lakes and aquifers and produces approximately 40 percent of total food production (UNCSD, 1997). According to Shiklomanov (2000), irrigation sub-sector is the largest single water user on earth. Some 70 percent of the surface water and groundwater abstraction worldwide is used for irrigation purposes. In semi-arid countries the figure can be as high as 90 percent (FAO AQUASTAT-database, http//www.fao.org/ag/agl/aglw/aquastat/main/index.stm, 2005). The total water use for irrigated rice production alone amounts to some 1,500,000 million cubic meter annually. In many countries about 60 percent of cereal production is obtained from irrigated area. In Egypt all crop production is contributed from irrigated lands and in Pakistan more than 90 percent of food production comes from the irrigated agriculture.

The irrigated area of the world was 8 mha in 1800 that increased to 48 mha in 1900 and now it is about 272 mha (Schultz et al., 2005). According to world statistics, India has the largest irrigated area of 55 mha followed by China, USA and Pakistan (Table 2). The irrigated area of Pakistan is 18 mha. It accounts for 7 percent of the world irrigated area. Pakistan stands at 4th place by the irrigated area but its irrigation system is the largest contiguous irrigation system in the world. Globally irrigation consumes 70 percent of waters withdrawn from rivers and groundwater but in Pakistan about 95 percent water is used in irrigation. Therefore a small improvement in the performance of irrigation system will have large impact on crop production.

Table 2. Cultivated and irrigated areas for the top ten countries with the largest irrigated area.

Country	Cultivate Area (mha)	Irrigated Area	
		mha	Percent
India	170	55	32
China	136	54	40
USA	179	22	12
Pakistan	22	18	82
Iran	16	8	50
Mexico	27	7	26
Thailand	18	5	28
Indonesia	34	5	15
Russia	127	5	4
Turkey	27	5	19
Total	**755**	**184**	**24**
World	**1497**	**272**	**18**

Source: Schultz et al., 2005.

2. CONSTRAINTS OF IRRIGATION SYSTEM

2.1 Initial Objectives of Irrigation in Pakistan

- The extensive development of canal irrigation system started in the sub-continent of India and Pakistan about in the middle of 19^{th} century with the following objectives:
- To protect the region from the threat of famine.
- To open up new areas for settlement to generate income for the government.
- To maximize the production of per unit of available water.
- To achieve maximum social benefits from distribution of available surface water resources.

The canal water was spread thinly over as large an area as possible with the objective of maximizing the production per unit of available water. The water provided was sufficient to irrigate only one third of the command area (Bandaragoda and Badruddin, 1992). Now about 80 percent cropped area is irrigated and 90 percent agricultural output is obtained from the irrigated area. There is a strong need to employ innovative irrigation techniques to cope with the present demands of irrigation.

2.2 Major Issues and Challenges

Irrigated agriculture is under tremendous pressure throughout the world. The major issues are as under:

- Water scarcity due to rapid increase in population resulting in less water availability per capita.
- Stagnation in water resources development
- Increase in the frequency of droughts and floods due to climate change.
- Inadequate water storages and sedimentation of existing reservoirs.
- Low irrigation efficiency and productivity.
- Groundwater mining due to over-pumping.
- Degradation of irrigated lands due to waterlogging and salinity.
- Pollution of both surface and groundwater resources due to extensive use of pesticides and fertilizers and disposal of untreated industrial and domestic effluents into water bodies.

2.3 Issues of Irrigated Agriculture in Pakistan

The irrigated agriculture of Pakistan is facing many challenges which hamper to feed the growing population and in attaining self sufficiency in food.

2.3.1 Lack of Reservoirs:

Pakistan has very little storage capacity that is hardly 15 percent of the annual river flows while it is 400 percent in Colorado river basin in USA (Frederiksen, 1996). According to World Bank (2005), Pakistan can store about 30 days of water, whereas India can store between 122-220 days, South Africa 500 days and Colorado river can hold 900 days of the river flow. Similarly water storage capacity per capita in Pakistan is 150 m^3 whereas it is 2,200 m^3 in China, and in USA it is 5,000 m^3 per capita.

2.3.2 Population Pressure:

The population of Pakistan is increasing at a fast rate (Table 3). The water availability per capita has reduced from 5,300 m^3 in 1951 to 1,200 m^3 in 2000, as against the international standard of 1,500 m^3 (Bhatti, 1999).

Table 3. Population of Pakistan (1951-2012).

Year	Population (million)
1951	33.80
1961	42.90
1972	65.30
1981	85.10
2000	139.76
2002	145.96
2007	163.00
2012	195.10

Source: Kahlown and Majeed, 2004.

2.3.3. Waterlogging and Salinity:

The agriculture of Pakistan is facing the twin menace of waterlogging and salinity due to arid climate, flat topography, excessive seepage, poor water management practices, inadequate drainage, insufficient supplies of irrigation water and use of poor groundwater. In early 1960's, it was estimated that about 40,000 ha of cultivable land was being lost annually due to waterlogging and salinity. By June 2001, WAPDA provided surface and sub-surface drainage facilities on an area of about 7.35 mha to overcome the problems of waterlogging and salinity (WAPDA, 2003).

2.3.4. Low Crop Yield and Productivity:

Although the climate is favourable and land and water resources are vast, yet the average yield of most of the crops is low as compared to other countries. The wheat yield in Pakistan is half that of India and only 30% of USA (Figure 1).

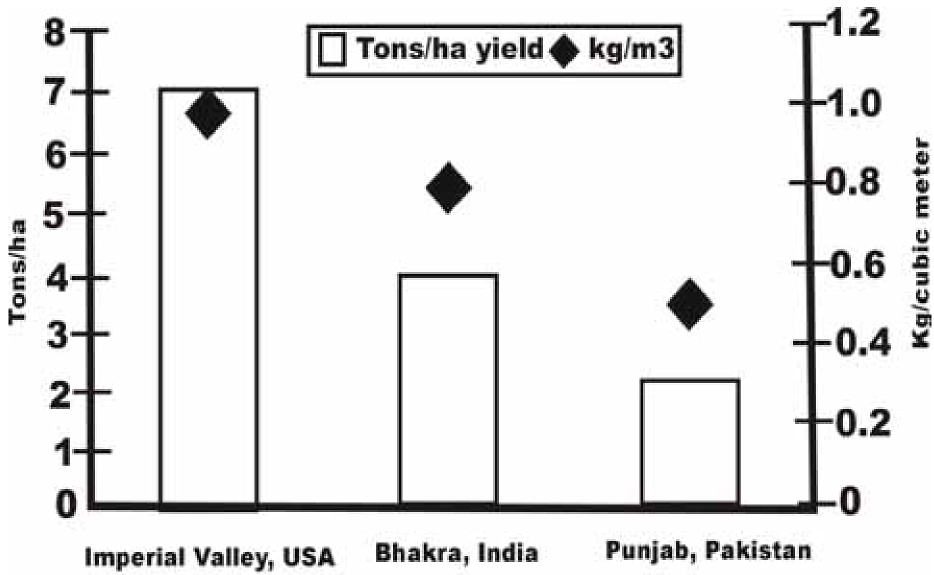

Figure 1. Comparison of wheat yield per unit area and water.

The above mentioned problems stress that efficient irrigation systems should be adapted to apply water to meet the crop water requirements, maintain application and uniformity efficiencies at a desired level and to improve water productivity and water use efficiency.

2.3.5. Shortage of Irrigated Area:

Out of a total geographic area of 80 mha, it is estimated that about 29.6 mha area is suitable for agriculture in Pakistan. About 9.7 mha land can be made productive if water supplies are available (Table 4).

Table 4. Land utilization in Pakistan.

Description	**Area**	
	mha	**Percent**
Culturable Command Area (CCA) Designated for perennial irrigation Designated for non-perennial irrigation	 8.3 5.3	 10.3 6.6
Sub-total:	**13.6**	**16.9**
Other Cultivated Area Irrigated from wells, streams, tanks, etc. Rainfed (Barani) Riverain	 0.7 3.2 1.2	 0.9 3.9 1.5
Sub-total:	**5.1**	**6.3**
Culturable Waste and Forest Culturable waste Forest area	 9.7 1.2	 12.0 1.5
Sub-total	**10.9**	**13.5**
Total Suitable for Agriculture and Forestry	**29.6**	**36.7**
Unsuitable for Agriculture and Forestry Mountains and deserts Unrecorded, towns, water areas, etc	 40.5 10.5	 50.2 13.1
Sub-total	**51.0**	**63.3**
Total	**80.6**	**100.0**

Source: Kahlown & Majeed (2004).

Shortage of Water Against Demand:

The demand for water is increasing day by day and availability of water is limited. Biswas (1996) has summarized the demands of water resources of the developing countries as under:

- More water will be required to support an increasing population in terms of food sufficiency.
- Water demands for other purposes such as domestic and livestock, industrial development and electricity generation will also increase.
- Water for ecosystem preservation will become an increasingly important socio-political issue.
- New water resources development projects will be more expensive, technologically more difficult and will take more time to construct as the easily exploitable sources of water have already been developed.

Similar situation has been depicted for Pakistan in the Ten-Year Perspective Development Plan 2001-2011 (Table 5). There was shortage of available water by 5 and 11 percent during year 2001 and 2004, respectively. The shortfall in the available water will be about 21 percent in year 2011. According to a report of the Pakistan Water Partnership domestic and industrial water use will increase in 2025 by 15 percent of the available water as against the present use of 3 percent (PWP, 1999). A WAPDA study indicated that the annual shortage of water supplies over crop water requirements is 18 percent. Thus, there will be insufficient water to satisfy the demands and share of irrigation water will decline. Therefore, irrigation will have to become more efficient.

Table 5. Water availability and demand at the farm-gate.

Item	**2001**	**2004**	**2011**
	Water Availability (mha m)		
Surface water	10.41	10.47	11.96
Groundwater	6.17	6.17	6.17
Total	**16.58**	**16.64**	**18.13**
	Water Demand (mha m)		
Irrigation	16.67	17.68	20.93
Non-irrigation	0.73	0.80	1.09
Total	**17.40**	**18.48**	**22.02**
Shortfall	0.82	1.84	3.89
Shortfall (%)	5	11	21

Ten Years Perspective Development Plan 2001-2011 (GOP, 2001).

3. EFFICIENT IRRIGATION METHODS

Surface irrigation is the most common method of irrigation and accounts for 95 percent of the irrigation in the world. It still accounts for upto 70 percent irrigation in the USA.

3.1 Innovative Surface Irrigation Techniques

The Pakistan Agricultural Research Council evaluated performance of innovative surface irrigation techniques especially for orchards at the National Agricultural Research Centre, Islamabad (Bhatti et al., 2005). The innovative irrigation techniques were borders, round basin, modified round basin and modified furrows. The irrigation data revealed that on an average, there was a saving of 6.03, 5.25 and 5.98 m^3 of irrigation water in round basin, modified round basin and modified furrows as compared to borders, respectively. Similarly, the saving in irrigation duration was 33.2, 29.28 and 31.98 minutes in round basin, modified round basin and modified furrows, respectively.

3.2 Resource Conservation Technologies

Ashraf et al., 2001 evaluated resource conservation technologies such as zero tillage, bed furrow and flat sowing method for wheat crop at Bhalwal, District Sargodha. The water use efficiency was 1.22, 1.41 and 0.63 $kg.m^{-3}$ for bed-furrow, zero tillage and farmer's basin, respectively. The farmer applied almost double amount of water as compared to scheduled plots.

3.3. Irrigation Application Techniques

Chaudhry & Qureshi (1991) evaluated border, furrow-ridge and furrow-bed methods of irrigation for maize crop at Shah Kot Field Area. They found that furrow-bed method saved more that 30 percent of irrigation water as compared to flat border

3.4. Improved Methods for Irrigation and Planting in Waterlogged Areas

Kahlown et. al., 2002 evaluated different improved irrigation and planting methods for wheat and cotton crops in the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project area during 1996-97 and 1997-98 under <1m, 1-2m and 2-3m water-table depths. The wheat was planted on 70, 95 and 120 cm wide beds and cotton was planted on ridge top, ridge side and bed furrows. The flat basins were taken as control for both the crops. The water use efficiency of the bed and furrow method was higher than other methods for cotton in all the water-table depths. Higher water use efficiency was obtained at water-table depths of 1-2m. Most probably, a water-table depth of < 1m kept the cotton rootzone too wet, whereas the depth beyond 2m, capillary rise did not occur. Traditional flat planting of the cotton crop not only resulted in lower yield, but also used more than double the amount of water needed in bed and furrow method.

The 120 cm wide bed proved most efficient at a water-table depth of 1-2 m for wheat crop. This method saved 54 percent water as compared to flat method. The flat plating method, for both cotton and wheat, was risky because heavy rains usually damage the crop, while excessive rainwater could be easily drained out from the field with the furrow bed method. Reduced surface applications to cotton restricted excessive vegetative growth, promoted flowering/fruiting and rendered early maturity. These phenomena lead to an early vacation of field for wheat crop.

3.5 Efficient Use of Irrigation Water

Mahmood et al., 1999 evaluated different irrigation techniques for wheat and cotton at the University of Agriculture, Faisalabad Research Farm. The irrigation techniques for wheat were 100, 80 and 60 percent ETo. The wheat was sown by keeping rows at 25 cm apart with a single-row hand drill. The cotton was sown on furrow-ridges, furrow-beds and normal flat (control). The row spacing was 75 cm apart. Equal amount of irrigation was applied to all treatments of cotton. Grain yield of wheat obtained in 100 percent and 80 percent was higher than 60 percent ETo. The water use efficiency decreased with an increase in the amount of water applied. When irrigation water utilization is under consideration, water use efficiency should be the prime objective. Considering both grain yield and water use efficiency, 80 percent ETo was the best treatment.

In case of cotton, it was observed that time of advance in flat method of sowing was 28.85 and 37.76 percent higher as compared to furrow-ridge and furrow-bed method, respectively. It was further revealed that 32-33 and 28-29 percent irrigation water was saved by using furrow-bed and furrow ridge methods, respectively. Mahmood et al., 1999 also compared continuous furrow irrigation with alternate furrow irrigation method. The water saving of 40.6 percent was achieved in case of alternate furrows. The cotton seed yield was statistically similar in both the treatments.

3.6 Water Saving by Sprinkler Irrigation

IWASRI, 2004-05 conducted research at Mona Reclamation Experimental Project, WAPDA, Bhalwal and found 55 and 57 percent saving in water through sprinkler irrigation system for wheat and maize crops, respectively as compared to farmers' practice of basin irrigation.

3.7 Benefits of Supplemental Irrigation in Barani Environments

The Water Resources Research Institute, NARC conducted a study of supplemental irrigation to wheat crop with raingun sprinkler at Islamabad where Rabi rainfall ranges between 123 to 650 mm. The study was conducted during 1989-90, 1990-91 and 1991-92 growing seasons. The total rainfall was more than the seasonal crop evapotranspiration during these years. During 1989-90, no irrigation was applied. During 1990-91 and 1991-92 the distribution of rainfall was not uniform, although total rainfall was more than crop evapotranspiration. About 44 percent increase in yield was found with pre-sowing irrigation (Rauni) of 10 mm during 1990-91. An increase in yield of 95 and 117 percent was achieved with 80 and 135 mm supplemental irrigation, respectively during 1991-92 (Bhatti et al., 1993).

4. CONCLUSION

Pakistan is a water stressed country. The agriculture sector is facing the problem of scarcity of water. The possible solution may be to increase productivity of per unit of available water through innovative, improved and efficient irrigation techniques. The efficient surface irrigation techniques such as furrow-ridge, furrow-beds, alternate furrow irrigation can save irrigation water and increase water productivity. The pressurized irrigation systems, through which small quantity of water can be applied, may be used in water stressed areas and bringing more areas under cultivation.

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GROUNDWATER SUSTAINABILITY TO COPE WITH WATER SCARCITY

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Abstract:

Groundwater is of prime importance to meet rapidly expanding urban, industrial and agricultural water demands, particularly in arid and semi arid areas of Pakistan. Growing national, regional and seasonal water scarcities in much of the world tend to pose severe challenges to agriculture in terms of increasing costs of new water developments, degradation of soils in irrigated areas, depletion of groundwater, water pollution, and wasteful use of already developed water supplies. The groundwater recharge contribution from the canal and distributary was assessed through a groundwater flow model, utilizing the observed/collected data on watertable, climate, crop, soil, hydraulic conductivity, evapotranspiration and physical characteristics of aquifer. Assessment of net groundwater recharge in a selected command area within the Rechna Doab was also carried out using Inverse Modeling. This assessment utilized meteorological, hydrological and irrigation data. It was concluded that model predicted monthly recharge rate for the canal ranging from 2850.48 to 3884.088m^3/d/100m of canal length or 10.64 to 14.50m^3/s/million-m^2. The average annual recharge rate for the Upper Gogera Branch was found to be 12.10m^3/s/million-m^2. The model predicted average monthly recharge rate for the distributary was 83.100 m^3/d/100m of running length of canal or 3.48m^3/s/million-m^2. Inverse Modeling approach estimated the net recharge fluctuated between +0.36 to –0.44mmd^{-1} with an average of +0.13mmd^{-1} during Kharif season while in Rabi, no recharge occurred and average net recharge was –0.22mmd^{-1}, which showed that the aquifer was depleted over the period.

INTRODUCTION

Groundwater is of prime importance to meet rapidly expanding urban, industrial and agricultural water demands, particularly in arid and semi arid areas of Pakistan. Growing national, regional and seasonal water scarcities in much of the world tend to pose severe challenges to agriculture in terms of increasing costs of new water developments, degradation of soils in irrigated areas, depletion of groundwater, water pollution, and wasteful use of already developed water supplies. A significant percentage of irrigated area in Pakistan is totally dependant on groundwater alone and on the larger part it is used in conjunction with surface water supplies. The dependence on groundwater is increasing due to the unique advantages associated with its use and is accelerated by inadequacy, variability and unreliability of the surface water supplies.

Groundwater recharge is a critical hydrological parameter that, depending on the application, may need to be estimated at a variety of spatial and temporal scales. Quantification of water fluxes from the atmosphere to underlying aquifer is important for global water budget. As aquifers are depleting, recharge estimates have become more essential in determining appropriate levels of groundwater withdrawal. Moreover, water loss estimates are essential to water resource assessment and management, which are function of their availability. Mining of groundwater resources became now a threat to irrigated agriculture. In the context of change in hydrological balance over the years, accurate and reliable assessment of net groundwater recharge is of great importance for the efficient management of already exhausted groundwater resources. During the last 10 to 20 years, there has been a significant increase in the utilization of groundwater resources for agricultural irrigation, because of their widespread distribution and low development cost (Clarke *et al.*, 1996).

Groundwater contributes about 40-50% of over all crop water requirements in Pakistan and is no more a supplemental to surface supplies but it is an integral part of the irrigated agriculture (GOP, 2004). During the last few decades, development of groundwater resources has increased manifold to meet growing demand of water for agriculture (Bhatti, 2004). The extensive groundwater development has helped in increasing crop productivity and socio-economic uplift of the poor rural communities, however, at the same time the massive groundwater exploitation has threatened the sustainability of this precious resource. If the installation of tubewells at the present rate is continued, the problem of secondary salinization and waterlogging become more acute and serious in the years to come.

A significant percentage of irrigated area in Pakistan is totally dependant on groundwater alone and on the larger part it is used in conjunction with surface water supplies. The dependence on groundwater is increasing due to the unique advantages associated with its use and is accelerated by inadequacy, variability and unreliability of the surface water supplies (Sarwar and Ilyas, 2002).

With the advancement of numerical modeling, new ways have been developed to assess the recharge of groundwater for the proper management of the precious resource, based on the large number of parameters including topography, geology, aquifer, storage coefficient and hydraulic conductivity. Thus, there is a need to assess the potential contribution of groundwater recharge in the irrigated areas for the efficient management of groundwater for its long term sustainability.

MATERIALS AND METHODS

Recharge is the downward flow of water reaching the watertable, forming an addition to the groundwater reservoir. The proposed study focused on the assessment of recharge from main canal, distributary and command area of Rechna Doab of Punjab, Pakistan. The recharge through each of the components was estimated using the following procedures.

- Assessment of recharge through the canal and distributary was carried out through a groundwater flow (MODFLOW; a modular three-dimensional groundwater model) model utilizing the observed/collected data on watertable, climate, crop, soil, hydraulic conductivity, evapotranspiration and aquifer physical characteristics.
- Assessment of net groundwater recharge in a selected command area was conducted within the Rechna Doab using Inverse Modeling. This assessment utilized meteorological, hydrological and irrigation data.

Recharge from Canal and Distributary

Seepage from the canal system is the major source of recharge. It can be determined by physical, empirical, and mathematical techniques. Empirical formulae have been developed to describe the relationship of seepage rates with canal and aquifer parameters (Sharma, 1938; ICID, 1967; WAPDA, 1978 and Garg, 1989). These empirical relationships are based on the results obtained from physical measurements and therefore, are site specific.

Much of development in the 20th century for the analysis of seepage and groundwater flow has been done by means of mathematical models. The two types of mathematical methods for the analysis of seepage and groundwater flow are analytical and numerical. Analytical methods involve the solution of mathematical equations, which could yield good result when all the factors governing the flow can be measured accurately. There are however, many groundwater flow problems for which analytical solutions are difficult because of their complexity and possessing non-linear features that can not be handled in analytical solutions. Alternately, the numerical modeling provides reliable prediction of seepage and groundwater behavior when coupled with the field observations. In the present study a numerical model “MODFLOW” was used to assess the recharge from the canal and distributary.

Description of "MODFLOW" model:

The partial differential equation describing the three-dimensional movement of groundwater through porous material can be written as:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]-W=S_s\frac{\partial h}{\partial t} \qquad (1)$$

Where;

x, y and z = three dimensional coordinates along the major axes of hydraulic conductivity i.e. K_{xx}, K_{yy} and K_{zz} [LT^{-1}].

h = potentiometric head [L].

W = volumetric flux per unit volume and represents sources and/or sinks of water [T^{-1}].

S_s = the specific storage of the porous material [L^{-1}].

t = time [T].

In general S_s and K_{xx}, K_{yy}, K_{zz} are the functions of space, while h and W are functions of both space and time. The hydrogeologic layers can be simulated as confined, unconfined, or a combination of both. External stresses, such as well or a sink, can also be simulated. Boundary conditions include specified head, specific flux and head-dependent flux. The model simulates groundwater flow within the aquifer in three dimensions using a block-centered finite difference approach.

Description of model domain for canal and distributary:

The cross-sectional model grid for the canal, 723 m in length from east to west, consisted of 3 rows, 20 columns and 4 layers. The model grid contained 240 cells, out of which 80 (row-2) were active and 160 (row 1 and 3) were inactive. The widths of all the cells (Δy) of row-2 were 100 m.

The cross-sectional model grid for the distributary, 405.33m in length from west to east, consisted of 3 rows, 14 columns and 4 layers. The model grid contained 168 cells, out of which 42 (row-2) were active and 126 (row-1 and 3) were inactive. The widths of all the cells in all the rows (Δy) were 100 m.

Estimation of Recharge from the Irrigated Area by Inverse Modeling

Boonstra (1996) used inverse modeling for net recharge estimation and developed a SGMP for groundwater modeling purpose. The model can be run both in normal and inverse mode. The advantage of assessing the net recharge using SGMP in the inverse mode is that only watertable data alongwith aquifer characteristics is required.

Description of "SGMP" model:

The model is based on the two well-known equations: Darcy's law and the equation of conservation of mass. The combination of these two equations results in a partial differential equation for unsteady flow:

$$\frac{\delta}{\delta x}\left(KH\frac{\delta h}{\delta x}\right)+\frac{\delta}{\delta y}\left(KH\frac{\delta h}{\delta y}\right)=-N \qquad (2)$$

Where;
K (x, y) = hydraulic conductivity of the aquifer (L/T)
H (x, y, t) = saturated thickness of the aquifer at time t (L)
H (x, y, t) = hydraulic head in the aquifer at time t (L)
N (x, y, t) = source or sink term at time t (L/T)

The left-hand side of Eq. 2 represents the horizontal and the right-hand side vertical flow. Vertical flow (N) consists of different flow components, depending upon the type of aquifer. For unconfined aquifers N is the sum of three terms:

$$N = R - P - S_Y\frac{\delta h}{\delta t} \qquad (3)$$

Where;
R(x, y, t) = net rate of recharge (L/T)
P(x, y, t) = net rate of abstraction (L/T)
S_y(x, y) = specific yield of the aquifer (dimensionless)
h(x, y, t) = hydraulic head in the aquifer (L)
t = time (T)

The term S_y *(δh/δt)* is related to the movement of the free watertab1e in case of unsteady flow. When the watertable moves downward or upwards, water is released from or taken into storage, respectively. It will be assumed that the values of S_y for upward and downward movement of the watertable are equal and that the gravity yield is instantaneous. This is the classical, simple assumption usually made.

In unconfined aquifers the saturated thickness H is not a constant, but is a function of the position of the free watertable at time t. For confined aquifers N is the sum of only two terms and if S is the storage coefficient of the aquifer then is given in Eq. 4:

$$N = -P - S\frac{\delta h}{\delta t} \qquad (4)$$

The impermeable covering layer allows neither recharge from percolation nor the formation of a free watertable in this layer. The storage coefficient in Eq. 4 is therefore, not related to the effective porosity or drainable pore space but to the elasticity of the grain material and that of the water. For confined aquifers S is called the storage coefficient and is defined in the same way as the specific yield for unconfined aquifers. The saturated thickness H of confined aquifers is constant.

Numerical approach used in "SGMP":

In SGMP, the discretization in space is done with a nodal network. A distinction is made between internal and external nodes. Each internal node represents a particular nodal area whereas the external nodes act as boundary conditions. The aquifers underlying is the part of a larger physical groundwater reservoir, so that the location of external boundaries can be considered as arbitrary and artificial. Instead of using transmissivity, separate values for the hydraulic conductivity and thickness of the aquifer must be supplied. In this study, a uniform hydraulic conductivity value to all the nodal areas has been applied because there was no indication of a clear spatial variability of this parameter in the study area.

RESULTS AND DISCUSSIONS

The recharge contribution, estimated from Upper Gogera Branch Canal and Ghourdour Distributary is shown in Table-1. The results show that the operational canal flow rate ranged from 56.40 to 134.67m^3/s. During the month of January 2004, there was no flow in the canal (canal closure). The minimum flow rate was observed during the months of February and March 2003, (i.e. after the canal closure) when water started to flow in the canal. The maximum flow rate was observed during the month of June 2003. The average monthly flow rate of the canal for the whole modeled period was 105.91m^3/s.

Table 1: Recharge Contribution from Upper Gogera Branch Canal and Ghourdour Distributary

Month	Flow rate of canal (m^3/s)	Flow rate of distributary (m^3/s)	Recharge from canal (m^3/d/100m canal length)	Recharge from distributary (m^3/d/100m canal length)
Feb-03	56.40	0.000	1425.240	00.000
Mar-03	56.40	1.085	1772.642	20.700
Apr-03	125.46	0.862	1824.301	52.200
May-03	131.29	0.877	1908.690	53.100
Jun-03	134.67	0.788	1896.101	47.700
Jul-03	130.64	0.818	1942.044	49.500
Aug-03	133.52	0.966	1846.132	58.499
Sep-03	131.29	1.011	1727.879	61.199
Oct-03	124.88	0.937	1715.271	56.700
Nov-03	130.06	0.788	1866.128	47.700
Dec-03	116.25	0.848	1517.209	51.299
Jan-04	000.00	0.000	0000.000	00.000
Average for half side	105.91	0.748	1620.136	41.550
Average for the canal/disty			3240.272 =(1620.36 x 2)	83.100 = (41.55 x 2)

Thus, the model predicted recharge as presented in Table-1, indicated that monthly recharge rate for the canal operation period ranged from 1425.240 to 1942.044 m^3/day/100m of canal length for right half side of the canal. Minimum recharge rate1425.240 m^3/d/100m through the right half side of the canal was found during the month of February 2003, while the maximum recharge rate 1942.044 m^3/d/100m was predicted during the month of July 2003. The average recharge rate for the whole year (12 months) for the Upper Gogera Branch canal was estimated as 3240.72 m^3/d/100m of canal length.

Table-1 also shows that the operational flow rate through the distributary ranged from 0.788 to 1.085m^3/s during the observation period. During the months of February 2003 and January 2004, the seasonal canal closures were observed and consequently, there was no flow in the distributary during this period. The average monthly flow rate through the distributary for the modeled year was 0.748m^3/s.

The predicted results of recharge rate as given in Table-1 show that monthly recharge rate from the distributary ranged from 20.700 to 61.199 m^3/d/100m from left half side of the distributary. The average monthly recharge rate for the distributary was, thus assessed as 83.1 m^3/d/100m of running length.

Estimation of Net Recharge by SGMP

For estimating the net recharge by the SGMP, the model was run for the period of Kharif 1985 to Kharif 2004 by keeping constant time step of 6 months. This yielded thirty eight sets of seasonal nodal net recharges: 19 for Kharif and 19 for Rabi seasons. The model was run with different sets of aquifer parameter values for the model calibration with other methods of net recharge assessment. The hydraulic conductivities were taken as 50, 20 and 5 md^{-1} while values of specific yield were varied 2, 5 and 10%. The basic model run constitutes the mean value of hydraulic conductivity and specific yield being 20 md^{-1} and 10%, respectively.

The result shows that net recharge in the study area fluctuated between +0.36 to –0.44mmd^{-1}. During Kharif, seasonal fluctuations were ranged between +0.36 to –0.09 mmd^{-1} with an average of +0.13mmd^{-1} while in Rabi, negative trend in net recharge was observed, which ranged between +0.09 to –0.44mmd^{-1} and average net recharge was–0.22mmd^{-1} showing that the aquifer was depleting over the period. The results, presented in Fig.1 show that after Rabi 1999 and onward, the net recharge is continuously showing a negative trend.

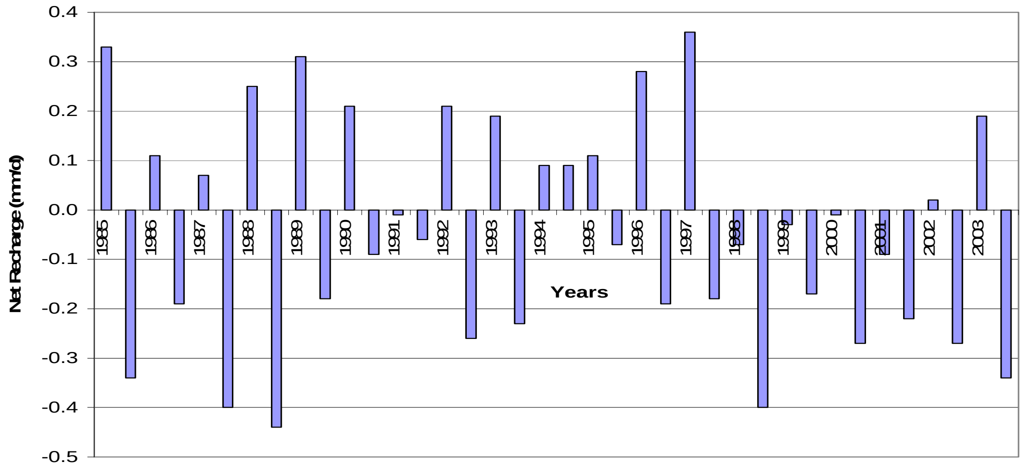

Fig. 1 Net recharge computed using inverse modeling

This behavior of depleting aquifer can easily be understood from the Figs. 2 and 3, which show a continuous trend of lowering net recharge value from Kharif 1985 to Kharif 2003 for all the nodes within the study area with exception of few nodes while between Rabi 1986 and 2004, the negative net recharge values were much increased because of reduced rainfall and increased groundwater abstraction.

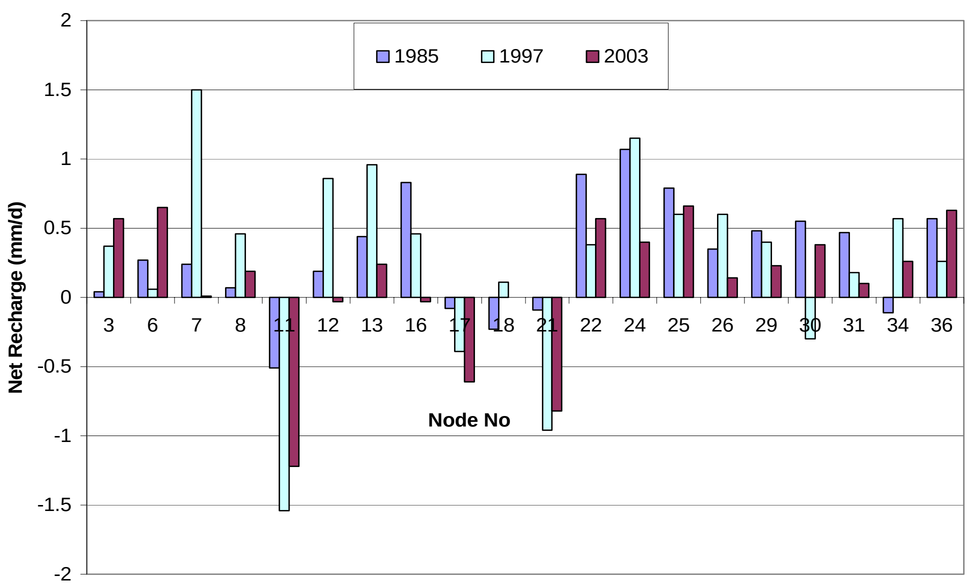

Fig 2. Net recharge computed using inverse model for post-monsoon

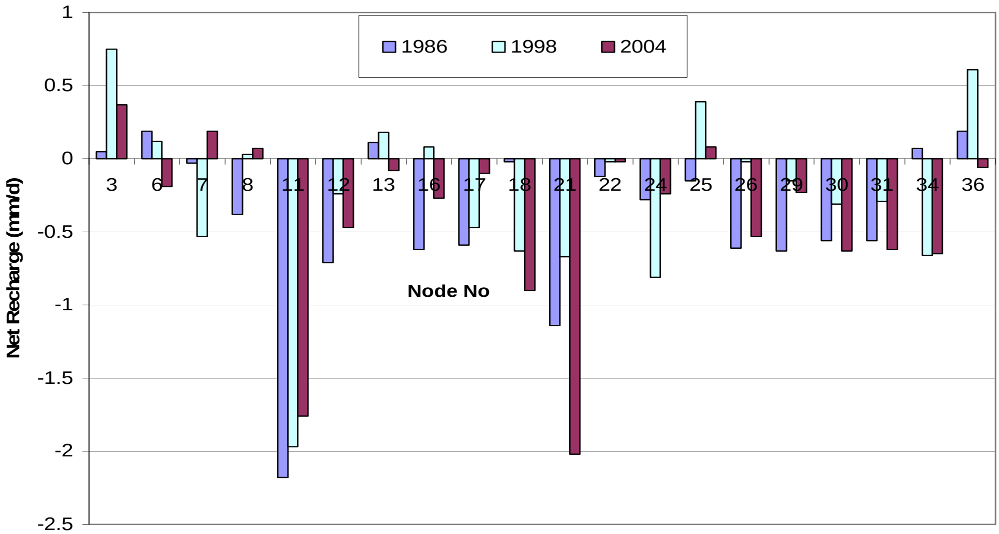

Fig 3. Net recharge computed using inverse model for pre-monsoon

The net recharge (positive/negative) calculated for each time step revealed that during the pre-monsoon season the net recharge value was dropped while post-monsoon period showed a significant rise in net recharge but overall decrease in recharge was observed.

CONCLUSIONS

- The model predicted monthly recharge rate for the canal ranging from 2850.48 to 3884.088m^3/d/100m of canal length or 10.64 to 14.50m^3/s/million-m^2. The average annual recharge rate for the Upper Gogera Branch was found to be 12.10m^3/s/million-m^2. The model predicted average monthly recharge rate for the distributary was 83.100 m^3/d/100m of running length or 3.48m^3/s/million.m^2.
- Inverse Modeling approach estimated the net recharge fluctuated between +0.36 to –0.44mmd^{-1} with an average of +0.13mmd^{-1} during Kharif season while in Rabi, no recharge occurred and average net recharge was –0.22mmd^{-1}, which showed that the aquifer was depleted over the period.

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Concluding Remarks

By

Engr. M. Mushtaq Chaudhry, Member (Water) WAPDA

Honorable Chief Guest Engr. Tariq Hamid, Chairman WAPDA, distinguished Guests, Members of the Congress.

It is my pleasure to conclude the World Water Day of March 2007 with the theme "Coping with water Scarcity". It is well-established fact that water is a finite natural resource providing basis for development of the civilization, agriculture, industrial and municipal aspects of life. We all have to be very conscious for its proper utilization and management on sustainable basis and take care of future generations.

Engineers and Scientists have presented 8 papers relating to water i.e. its surface and sub-surface availability and conservation; its management / mining and use of high efficiency techniques, environmental hazards in the context of water and their solutions etc.

In the first presentation "Water Scarcity and WAPDA Vision – 2005" by Engr. Muhammad Mushtaq Chaudhry and Dr. Allah Bakhsh Sufi, the authors have deliberated and highlighted the urgent need for the development of storage reservoirs as envisaged in Vision 2025. The country has surface water flows of 21MAF available for immediate storage development excluding Mangla Raising Project. A significant part of this storage will compensate the storage capacity loss through sedimentation. At this stage excessive groundwater pumpage is creating secondary salinity and sodicity in the fertile lands of the country for which sustainable groundwater management under proper regulatory framework has been advocated. The authors have indicated that there will be a gap of about 20 MAF between supply and demand by the year 2025 which could be met through the development of Vision Projects. Apart from implementation of Vision Projects, the need for high irrigation efficiency systems has been stressed. The need for the involvement of all stakeholders including women participation regarding water management and its governance has also been highlighted.

The Second paper is on "Combating Water Scarcity" by Dr. Izhar-ul-Haq. The author expressed that country is likely to face serious water, food and power shortages after 2010 and recommended the immediate construction of a large reservoir and Hydropower project. Small storage Dams and Hydropower stations should be built where feasible. The author also endorsed conservation of hill torrents, modern irrigation techniques and groundwater regulation.

The Third paper is on "Role of Groundwater in Coping with Scarcity of Water" by Dr. Muhammad Nawaz Bhutta discussed the groundwater availability, its mining and water quality issues regarding the pollution of lands and aquifers especially near the municipalities and, lack of coordination between various organizations responsible for groundwater management. The author recommended the need for groundwater regulation, rainfall harvesting for additional recharge, supplemental irrigation supplies for reducing the dependence on groundwater extraction.

The Fourth paper, i.e. "Coping with Water Scarcity and Indus Waters Treaty Vision", by Engr. Usman-e-Ghani, Joint Commissioner for Indus Waters, discussed the effects of the allocation of three Eastern Rivers of the Indus Basin, viz. Sutlej, Beas and Ravi, to India, which rendered the vast area, earlier being irrigated by these rivers, arid and dry. He also indicated that Pakistan is keeping a strong and vigilant check on India regarding the projects on the Western Rivers, viz. Sindh, Jehlum and Chenab, the waters of which have been allocated to Pakistan. It was also emphasized that in order to cope with water scarcity, Pakistan should look forwards for an effective management of its existing water resources and the efforts should appropriately be constituted for further developments of such resources.

The fifth paper is on "Growing Scarcity of the Water Resources" by Mr. Shafqat Masood expressed that Pakistan has been included in the list of 17 countries facing absolute water scarcity and would face serious shortfalls by the year 2025 and suggested awareness among the stakeholders regarding water conservation, groundwater regulation, rain water harvesting, hill torrent management and adoption of drip and sprinkler irrigation techniques.

The Sixth paper is on "Waste Water Re-use for Crop Production An Option for Sustainable Agriculture Under Water Scarce Environment" by M/s Sarfraz Munir, Abdul Hakeem Khan, Waqar Ahmad and Amir Nazeer. The authors have presented the results of the study that wastewater is alternative to the scarce fresh water but have cautioned the risk under direct use and proposed conjunctive use with canal water.

The seventh paper "Efficient Irrigation Techniques to Cope with Water Scarcity" by MR. Muhammad Yasin discussed that Pakistan is a water stressed country and suggested to increase productivity of per unit of water through innovative, improved and efficient irrigation techniques advocated by earlier speakers.

The Eighth paper on "Groundwater Sustainability to Cope with water Scarcity" by MR. M. Arashad and Jehanzeb Masood is regarding use of Inverse Modeling for groundwater recharge. The model discussed the assessment of net groundwater rechgare in selected command area with the Rechna Doab for the Upper Gogera Branch and showed that the aquifer was depleted over the period. It is agreeable that numerical models are good tool for assessing the recharge of groundwater for proper management of precious resource and there is need to assess contribution of ground water recharge in the whole Indus Basin for efficient management of groundwater for its long term sustainability.

Thanks to all the authors for their technical contributions based on which valuable recommendations have been framed. The recommendations proposed by this forum will help policy makers in combating water scarcity in the country for its sustainability. WAPDA and Pakistan Engineering Congress are continuing to celebrate this important occasion for the last few years in recognition of its important role for the development of water resources, which is primary, need of the agro-socio-economic uplift of the nation. It is earnestly hoped that WAPDA will continue not only to play its vital role in the development of water resources but also remain associated with Pakistan Engineering Congress in this noble cause for celebrating World Water Day regularly every year to come.

At the end, ladies and Gentlemen, I again thank you all to be with us on this important occasion and the presence of the eminent Engineers and Scientists is encouraging for us which shows your commitment towards combating the water scarcity for the betterment of the society. **Thank you.**