WORLD WATER DAY
March – 2012

On the Theme of
"Water and Food Security"

Celebrated by
PAKISTAN ENGINEERING CONGRESS

Centenary Celebrations

1912 - 2012

PAKISTAN ENGINEERING CONGRESS
(4th Floor) Pakistan Engineering Congress Building,
97-A/D-1, Liberty Market Gulberg – III, Lahore 54660
(Near Liberty Roundabout)
Phone: (042)35784235-40 Fax: (042)35784236
Web-site: www.pecongress.org.pk
E.mail : info@pecongress.org.pk

ISBN 978-969-603-013-3

ON BEHALF OF PAKISTAN ENGINEERING CONGRESS

Pakistan Engineering Congress as a body does not hold itself responsible for the opinions expressed by the different authors in this Volume

Compiled and Edited
By
Engr. Ch. Ghulam Hussain
Vice President / Convener Publication Committee

Price Rs. 500/-
Members Free

Can be had at
PAKISTAN ENGINEERING CONGRESS
(4th Floor) Pakistan Engineering Congress Building,
97-A/D-1, Liberty Market Gulberg – III, Lahore 54660
(Near Liberty Roundabout)
Phone: (042)35784235-40 Fax: (042)35784236
Web-site : www.pecongress.org.pk
E.mail : info@pecongress.org.pk

PAKISTAN ENGINEERING CONGRESS
THE EXECUTIVE COUNCIL FOR THE 72nd SESSION

PRESIDENT

Engr. Riaz Ahmad Khan

Immediate Past President

Engr. Husnain Ahmad (President 71st Session)

VICE-PRESIDENTS

1. Engr. R. K. Anver
2. Engr. Ch. Ghulam Hussain
3. Engr. Ch. Muhammad Arif
4. Engr. Shabbir Ahmad Qureshi
5. Engr. Pir Muhammad Jamil Shah
6. Engr. Syed Mansoob Ali Zaidi
7. Engr. Dr. Izhar ul Haq
8. Engr. Syed Saleem Akhtar
9. Engr. Khalid Javed
10. Engr. Tariq Rasheed Wattoo
11. Engr. Ali Arshad Hakeem
12. Prof. Dr. Ing. Syed Ali Rizwan
13. Engr. Faqir Ahmad Paracha
14. Engr. Akhtar Abbas Khawaja
15. Engr. Muhammad Amin

OFFICE BEARERS

1.	Engr. Akhtar Abbas Khawaja	Secretary
2.	Engr. Najam Waheed	Joint Secretary
3.	Engr. Khalid Javed	Treasurer
4.	Engr. Ch. Foad Hussain	Publicity Secretary
5.	Engr. Iftikhar Ahmad	Business Manager

EXECUTIVE COUNCIL MEMBERS

1. Engr. Ch. Muhammad Rashid Khan
2. Engr. Anwar Ahmad
3. Engr. Nayyar Saeed
4. Engr. Najam Waheed
5. Engr. Iftikhar Ahmad
6. Engr. Malik Ata ur Rehman
7. Engr. Jamil Basra
8. Engr. Ahmed Nadeem
9. Engr. Ijaz Ahmad Cheema
10. Engr. Muhammad Ibrahim Malik
11. Engr. Prof. Zia ud Din Mian
12. Engr. Ch. Foad Hussain
13. Engr. Brig. Sohail Ahmad Qureshi
14. Engr. Liaqat Hussain
15. Engr. Shaukat Ali Shaheen
16. Engr. Ch. Aftab Ahmad Khan
17. Engr. Capt. (R) M. Qadir Khan
18. Engr. Iftikhar ul Haq
19. Engr. Rana M. Aslam Chohan
20. Engr. Malik Ahmad Khan
21. Engr. Syed Anwar ul Hassan
22. Engr. Zaffar Ullah Khan
23. Engr. Pervaiz Iftikhar
24. Engr. Syed Nafasat Raza
25. Engr. Muhammad Sharif Shah
26. Engr. Muhammad Sarfraz Butt
27. Engr. Sheikh Saeed Tahir
28. Engr. Syed Abdul Qadir Shah
29. Engr. Tariq Iqbal Mian
30. Engr. Faisal Shehzad
31. Engr. Ch. Sarmad Akhtar

WORLD WATER DAY
March-2012

Table of Contents

Address of Welcome
By
Engr. R. K. Anver
Vice President
Pakistan Engineering Congress
On
World Water Day 24th March, 2012
At
"Mashhadi Hall" of Pakistan Engineering Congress

Honorable Chief Guest

Executive Council Members

Fellow Engineers

Ladies & Gentlemen!

It is the importance of water in the life of individuals and nations that the United Nations Conference on Environment Development (UNCED) held in Rio de Janerio in 1992 declared 22nd March as "World Water Day". Since then, it is being celebrated the world over. At the occasion of World Water Day, experts on "Water Resources" speak on the theme and related issues specified for that particular year.

The theme for this year is:

"Water and Food Security"

Ladies & Gentlemen!

The Allah Tabarak wa Ta'ala, Himself through numerous verses in the Holy Quran signifies about the crucial role played by "Water" in the socio-economic life of mankind.

"And He is Who created the Heavens and the Earth in six days and His Throne was on water". (Sura Hud)

"He showeth you the lightening for a fear and for a Honor sendeth down water from the sky and thereby quincheneth the earth after death". (Sura Rome)

"It is He Who sends down (rain) drinking water and from which (grow) trees among which you graze your cattle". (S. 16 Al-Nahl i.e. The Ant)

"He grows thereby crops, olives, palms, grapes and every kind of fruit for you; surely in this is a sign for people who ponder". (S. 16 Al-Nahl i.e. The Ant)

These are some of the verses from the Holy Quran taught the mankind fourteen hundred years ago, and what **"Economists and Water Resources"** icons are emphasizing today i.e.:-

- Water is essential for the survival of individuals / communities, is the harbinger of socio-economic advancement and should be valued and given due importance.
- That this precious / free bounty of nature should be used economically and conserved (through construction of canals, barrages, dams).
- That effort need to be made to augment the production of food and fibers as well as stored / preserved for future use in times of droughts, floods and Lean years of production.

Ladies and Gentlemen!

Let us go a little deeper to evaluate the situation in our Country:-

<u>Population Explosion</u>

The world population has reached 7-billion (to reach 9-billion mark by the 2050) out of which 2.9-billion are concentrated in China, India, Pakistan, Bangladesh.

The present population of Pakistan is 180 million and with growth of 2.05 percent a year would touch 210- million mark by the year 2020. The family planning people visualize the population will be a staggering 342-million by 2050 (162 million increase in the next 38 years). In China, there will be 24-million increase by 2020. 21-million increase in India by 2035. To sum all, 1-billion increase in China / India / Pakistan and Bangladesh alone in about 25-years from now.

Food Insecurity

Spiraling population in Pakistan is creating issues of Food and Fiber inadequacy / insecurity. The following report will be an eye-opener:-

"Despite being an agricultural country, the food insecurity in Pakistan is 58% of which 28.4 % population faces food insecurity 19.8 percent are food insecure with moderate hunger and 9.8 percent are insecure with severe hunger".

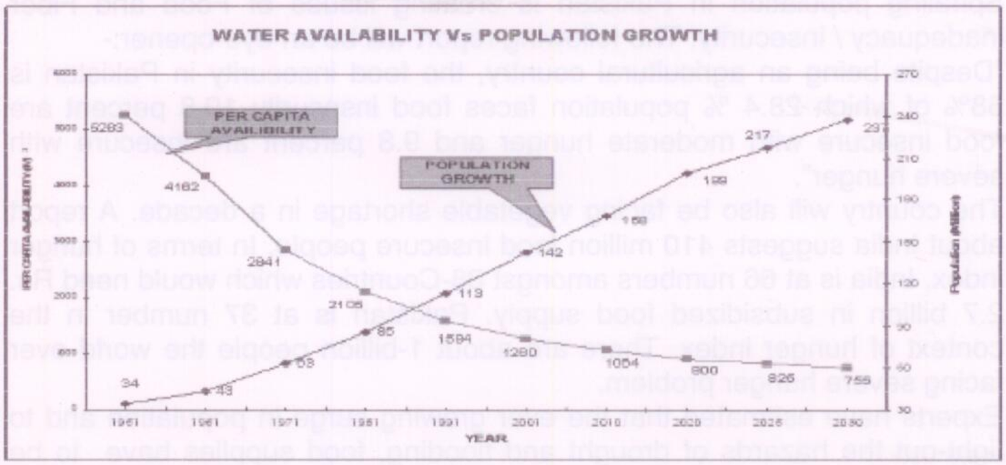
The country will also be facing vegetable shortage in a decade. A report about India suggests 410 million food insecure people. In terms of hunger index, India is at 66 numbers amongst 88-Countries which would need Rs. 2.7 billion in subsidized food supply. Pakistan is at 37 number in the context of hunger index. There are about 1-billion people the world over facing severe hunger problem.

Experts have estimated that the ever growing surge in population and to fight-out the hazards of drought and flooding, food supplies have to be augmented by 70% to 100% in the next 25-30 years from the existing land under cultivation.

Pakistan Water Scenario

In 1951, per capita water availability was 5260 (Cubic Meter) which has steeped down to 1038 (Cubic Meter) in 2010, of course a very disconcerting position. With the country's population increased from 34 million to 180 million and now projected at 342 million by 2050, the country will be a severely water scarce country with per capita water availability reduced to a miserable 575 (Cubic Meter) an alarming and distressing scenario indeed.

A diagrammatic presentation would further clarify the position:-



Year	Population (million)	Water Availability (m^3)	Global Criteria
1951	34	5263	1000 m^3 per capita is the threshold value
2010	168	1064	
2020	199	900	(Falkenmark & Wedstrand 1992)
2025	217	825	

What are the reasons behind this woeful fate and what is in store for us in future?

The people at the helm of affairs of the country as well as the planners of socio-economic development schemes without exception have shown gross indifference towards building-up of water reservoirs. Almost 3-precious decades have been wasted away in political wrangling about the construction of Kalabagh Dam – a shock absorbing mega project sacrificed at the altar of political expedience.

In this connection, the following figures of constructed Dams unravel the poignancy of tragedy highlighting the gross failure of planning on part of our people at the helm of affairs.

Sr. No.	Country	Number of Dams
1.	China	26000
2.	India	4050
3.	Turkey	673 (146 under construction)
4.	Iran	588 (137 under construction)
5.	Pakistan	71

In order to ensure adequate and timely supply of water for domestic, agricultural, industrial purposes, it is imperative to make all out efforts to conserve water. This is because with limited rainfall, over exploitation of underground water resources as well as the surface water resources, there is a dire need of building storages for meeting the seasonal demands, to fight out drought and period of lean rainfall. And above all, this would minimize power outages which have hitherto crippled the economy of Pakistan. However, now we have awakened for exploitation of Hydroelectric potential, but the speed is not commensurate with the urgency of the situation and leaves much to be desired.

Major projects under execution with storage capacity of 4.725 million acre feet:-

S#	Name of Project	PC-I Cost (Rs. in Million)	Storage Live (MAF)	Power (MW)
1.	MANGLA DAM RAISING	101,384	Additional 2.88	644 GWh Additional
2.	GOMAL ZAM DAM	12,829	0.892	17.4
3.	SATPARA DAM	4,480	0.053	17.36
4.	KURRAM TANGI DAM	17,205	0.90	83.4
	Total		4.725	118.16 MW & 644 GWh

Major Hydropower Projects under execution that will generate 1422 MW of electricity during 2011-2012:-

HYDROPOWER PROJECTS

Sr #	Name of Project	PC-I Cost (Rs. Billion)	Hydropower (MW)
1.	DUBER KHWAR Kohistan, KPK	16.324	130
2.	ALLAI KHWAR – Battagram, KPK	13.835	121
3.	JINNAH HYDROPOWER, Jinnah Barrage	13.546	96
4.	NEELUM JHELUM Neelum, AJK	84.502	969
5	GOLEN GOL Chitral, KPK	7.035	106
	Total	135.242	1422

New Hydropower Project with storage capacity of 9.4 MAF feet to be completed by 2020-21:-

NEW HYDROPOWER PROJECTS

S#	Project	River	Capacity (MW)	Storage (MAF)	Estimated Cost (US$ Million)	Expected completion
1.	DIAMER BASHA – Gilgit Baltistan	Indus	4500	8.1	11178	2020-21
2.	TARBELA 4TH EXT. – Khyber Pakhtunkhwa	Indus	1410	-	826	2016-17
3.	MUNDA – FATA/KPK	Swat	740	1.3	1401	2019-20
				9.4		

Recommendations

- There is no substitute of megadams for conservation of water and power supplies and have to be implemented on war footings.
- Resurrect Kalabagh dam on fast track mode, technically the most feasible option but presently relegated to oblivision for political expediency.
- Construction of small/medium dams all over the country to ensure safe water supplies to rural population.
- Govt. is establishing a "National Water Council" comprising of stakeholders to take a multipurpose view of Country's water requirements, infrastructure etc.
- Water courses lining to be conducted under "NPIW" (National Programme for Improvement of Watercourses) – to check wastage of water.
- Drip irrigation needs to be adopted on an extended scale.
- Proper management of rangelands, so important for exploiting agricultural potential / arresting degradation of these lands.
- Mangrove forests are source of agriculture, supply of cheap fire wood, marine food as well as checks intrusion of sea water. Mangrove forests cover has declined from 604870 hectares to 104000 hectares which is a cause of great concern and needs to be reversed.
- Waste water after treatment is being used for irrigation of almost 20-million of crop land the world over. It is estimated that 10 percent of world population is being fed by food produced through use of waste water. Pakistan also needs to use its waste water prudently to bring more land under cultivation. However, it is to be used with caution.
- Increase rain fed land productivity by 15% to 25%.
- Regulate exploitation of groundwater resources (being over-exploited).

Ladies and Gentlemen

I would like to thank you all once again for being with us.

God bless you all

Pakistan Paindabad.

ADDRESS BY
SYED RAGHIB ABBAS SHAH
MEMBER WATER WAPDA
ON WORLD WATER DAY
MARCH 24, 2012
AT PAKISTAN ENGINEERING CONGRESS

President Pakistan Engineering Congress,

Learned Delegates

Members Pakistan Engineering Congress

Ladies and Gentlemen!

It is commendable to know that Pakistan Engg. Congress is commemorating World Water Day regularly since 2006. During the last six seminars, papers highlighting the importance of water for life and development have been presented at the Congress forum. This year's theme **"Water and Food Security"** is the most important. According to Quran, "And we made every living thing of Water". Life is not possible without water. The population of Pakistan is increasing and the availability of water per capita is reducing. Pakistan is almost on the limit of water stressed countries.

Wapda's charter is development of water and power resources of Pakistan. Since its creation in 1958, Wapda built Indus Basin replacement projects: Mangla, Tarbela Dam, five barrages and eight inter river link canals to ensure water supply to the bread basket of Pakistan. Wapda completed more than seventy SCARPs for reclaiming the productivity of agriculture lands. Wapda has recently completed Mirani, Sabakzai, Satpara, Mangla Dam Raising and Gomal Zam dams. Wapda has started land acquisition and construction of infrastructure for Diamer Basha Dam Project. Work on the construction of dams would be started soon. Construction of Kurram Tangi dam has started. Design of Munda dam is being done. Work on construction of six small to medium dams is also being started in the four provinces for local agriculture use.

In addition to storage of water, Wapda is trying to line the canals to reduce seepage losses, treat saline water to make it useable for agriculture and manage the sediments to enhance the life of storage reservoirs.

In order to make optimal use of water, Wapda has set up model farms at Mirani and Sabakzai dams for efficient use of water through drip and sprinkler methods.

Wapda is fully cognizant of the water escapages below Kotri and storages are being planned for bringing the additional land under agriculture. This would not only ensure our food security but also produce agriculture surplus for the development of the economy. The storages of water would not help during the drought and water shortages but also mitigate the floods.

As Wapda plays a pivotal role in development of water resources of Pakistan, it is privileged to commemorate the World Water Day on "Water and Food Security" with Pakistan Engineering Congress. The standard of the papers presented at Pakistan Engineering Congress seminar on World Water Day is of international level. I must eulogise the effort of Pakistan Engineering Congress in this regard.

Ladies and gentlemen, Chairman Wapda had the opportunity to participate and address the 6th World Water Forum at Marseille, France during the last week. The parliamentarians and water experts around the globe discussed in depth "The Water, Food and Energy Nexus" the solutions and commitments. It is universally recognized that providing water means ensuring life, health and food, economic and social vitality, development and harmony. The full week was consecrated to increase global mobilization on questions concerning water.

In the context of Global warming Pakistan faces the greatest challenge as regard water for sustainable development.

Pakistan is a member of the regional organizations and ICIMOD for sharing the transboundry information regarding water. We must benefit from the international experience and global water Partnership. We have to make sustainable use of our ground water. We must conserve water, grow more crops for every drop of water, only then we can survive.

There are conferences on Water, Power and Food Nexus every other day. It is good to highlight and create the awareness on water. We must act, conserve and use this precious source judiciously and ensure sustainability.

In the end I thank Pakistan Engineering Congress for its commitment to the goal of World Water Day. I would be looking forward to see the recommendations of the seminar.

Thank you all.

SUSTAINING IRRIGATED AGRICULTURE FOR FOOD SECURITY A PERSPECTIVE FROM PAKISTAN

Asad Sarwar Qureshi and Aamira Fatima[1]

Abstract

Humanity is facing an enormous challenge in managing water to secure adequate food production. By the middle of this century, the world's population is projected to reach 9.1 billion, 34 percent higher than today. Nearly all of this increase will occur in developing countries. In order to respond to the expected demand of this larger, more urban and, on average, richer population, food production must increase by about 70% as estimated by the FAO. It is an enormous task because the required increase in food production to meet future needs will have to be achieved with fewer land and water resources. Food insecurity in Pakistan is a product of poverty and inadequate food availability. During the past two decades, 1987-2007, food poverty incidence in the country shows that about one-third of the households were living below the food poverty line and they were not meeting their nutritional requirements. The incidence of food poverty is higher in rural areas (35%), than in urban areas (26%). In Pakistan, irrigated agriculture is vital for future food security because it produces more than 90% of the total grain production. With the decreasing amounts of available water, the challenge of sustaining irrigated agriculture is increasing by the day. This paper reviews the situation in Pakistan and suggests pathways to sustain irrigated agriculture in order to meet future food requirements.

Keywords: Irrigated agriculture, food security, Pakistan, water resources, water productivity

Introduction

Feeding the world's growing population and finding the land and water to grow the food continues to be a basic and sizeable challenge. By the middle of this century, the world's population is projected to reach 9.1 billion, 34 percent higher than today (GWP, 2011). Nearly all of this increase will occur in developing countries. In order to respond to the expected demand of this larger, more urban and, on average, richer

[1] Senior Water Expert and Research Officer, International Water Management Institute (IWMI), 12 KM, Multan Road, Thokar Niaz Beg, Lahore, Pakistan. Email: a.sarwar@cgiar.org

population, food production must increase by about 70% as estimated by the FAO.

The Indus River basin forms the back bone of Pakistan's economy. It supplies water to the largest contiguous irrigation system in the world that provides 90% of the food production and contributes 25% to the GDP. But it is also one of those countries that could face severe food shortages which are intimately linked to water scarcity. It is projected that population of Pakistan will increase to 250 millions in 2025 reducing the water availability per capita to less than 600 cubic meters (Bhutta, 1999). The shortfall of water requirements would be about 32 percent which will result in 70 million tons of food shortages by the year 2025 (ADB, 2002). Therefore, the need for further development of new resources, adoption of water-conservation measures and improving the productivity and performance of existing irrigation system is being stressed at all forums.

Recent estimates suggest that the surface irrigation system of the Indus Basin will reduce its surface storage capacity by 30 percent by 2025 due to climate change and siltation of main reservoirs. This reduction in surface supplies and consequent decreases in groundwater abstraction will have serious effect on irrigated agriculture, which produces most of the agricultural production in Pakistan. This situation has threatened the food security of 180 million people living in Pakistan.

Climate change also is posed to adversely affect agricultural production. It is predicted that after an initial period of high flows in the form of storms due to faster glacial melt there will be a terrifying decrease in inflows of anywhere between 30-40 percent into the Indus river system (World Bank, 2006). Similarly IFPRI projects that decreased flows will reduce grain yields by 15-20 percent in Asia. While the actual affects are likely to be heterogeneous and region specific, yet in most cases it will hurt poorest the most because they will have the least capacity for adaptation.

The food insecurity-poverty nexus is also pervasive in Pakistan. The government's task force on food security has underscored the importance of achieving an average agricultural growth of at least 4% per annum in the next decade to ensure food security and poverty reduction. Supply side solutions aimed at providing more water will not be available as in the past. Current low productivity in comparison to what has been achieved in other countries under nearly similar conditions points to the enormous potential that exists. Since agriculture in Pakistan is essentially irrigated agriculture, it is imperative to assess the current performance of the Indus basin irrigation systems, diagnose causes and constraints for low productivity and suggest strategies to ensure sustainability of the basin and livelihood of millions who are dependent on this basin. This paper suggests the importance of improving sustainability of irrigated agriculture to ensure food security for Pakistan.

Increasing gap in supply and demand

Population growth in Pakistan has been, and continues to be, high. The total population in 1950 was 40 million, which grew up to 80 million in 1980 and has reached to an estimated 185 million in 2010 (UN, 2009). More than 4 million people are added every year and according to UN estimates the population in Pakistan will reach to 250 million in 2025 and 335 million in 2050. The percentage of urban population will increase from the current 35% to 52% by 2025. As a result, water demand for domestic, industrial and non-agricultural uses will increase to 10% of the total available water resources by the year 2025 (Bhutta, 1999).

The per capita water availability in Pakistan has already fallen from 5,000 m^3 in 1951 to just 1000 m^3 in 2005 and is expected to reduce to about 700 m^3 by 2025 and 525 m^3 by 2050 (Figure 1). This is roughly the value below which water availability becomes a primary constraint to life (Engelman and Leroy, 1993). Although the surface flows of the Indus River and its tributaries available to Pakistan are quite significant, these are characterized by a great variation. Against the average annual inflow of 175 BCM, the historic data from 1922-97 indicates a high of 230 BCM (34% higher than average in 1960) and a low of 120 BCM (30% lower than average in 1975). About 65% of the total river flows comes from the Indus alone, while the share of Jhelum and Chenab is 17 and 19 percent, respectively. The Kabul River contributes a maximum of 42 BCM and a minimum of 15 BCM with an annual average of about 25 BCM to Indus.

The water requirements for irrigation in the Indus Basin are estimated at 250 BCM in 2025 against the projected availability of 185 BCM. Even by exploiting the full groundwater resources, the water availability will not be more than 190 BCM. Considering the reduction in present storage capacities and non-availability of additional storage facilities, the shortfall of water requirements would be about 50 percent by the year 2025 (Alam and Bhutta, 1996). This large shortfall in water availability will lead to serious food shortages and rising food prices. As opportunities for development of new water resources diminish and costs rise, increasing the productivity of existing water resources becomes a more important and attractive alternative. Therefore there is every motivation to designate more capital and efforts to increase the productivity of land and water and the sustainability of water resources management[1].

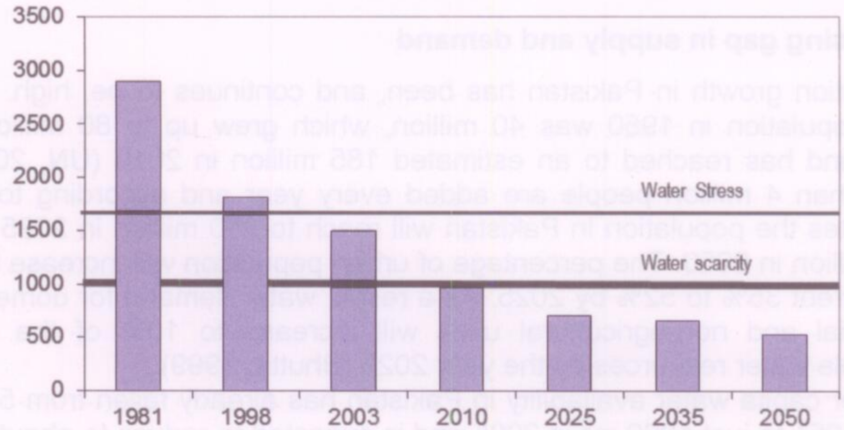


Figure 1. Declining availability of water in Pakistan (m^3/capita/year).

Irrigated Agriculture in Pakistan

The greatest water problem, which made most of the Asian countries still far away from achieving food security, is our failure and inability to link environmental security, water security and food security (Figure 2). Irrigated agriculture is the center stage of this because more than 80-90 percent of the fresh water resources are used for agriculture. On the other hand, agriculture is also the biggest source of water wastage due to its low usage efficiency. Therefore, improving irrigation water management to reduce the losses even by 10%, will lead to an enormous increase in the available water resources.

---

[1] Productivity of water (kg m^{-3}) is expressed in terms of yield (kg ha^{-1}) produced per unit evapotranspiration (m). Sustainability refers to management of water systems which does not lead to environmental degradation (waterlogging, salinization and desertification).

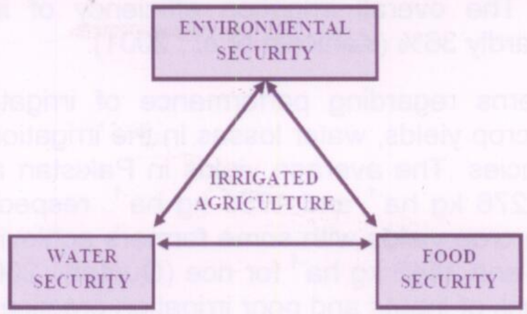


Figure 2. Food security, water security and environmental security relationship (Source: Hamdi, 2004)

Due to arid and semi-arid conditions prevailing in most parts of Pakistan, annual evapotranspiration (ET) in the Indus basin varies between 800 mm in the north to 2000 mm in the south. The rainfall amounts follow the similar trends with only 100-150 mm per year in the south to 700-800 mm per year in the north. The direct contribution of rainfall to total crop water requirements is only 15% and the rest has to come from irrigation supplies (Qureshi et al., 2007). Therefore irrigated farming is the most economical and remunerative form of agriculture. Irrigated lands provide more than 90% of the agricultural production and are major user of the water resources. As the surface water supplies are neither sufficient nor reliable to meet the crop water requirements, groundwater resources are widely exploited to fill the gap between supply and demand (Shah et al., 2003). Currently 1.2 million private tubewells are exploiting about 50 BCM of water annually, which accounts for 50% of the total water available for agriculture (Qureshi et al., 2008). The estimated number of users is over 2.5 million farmers who exploit groundwater directly or hire the services of tubewells from their neighbors.

With a served area of 16.7 million hectares and available irrigation water of 136.7 billion cubic meter (BCM), the applied gross water depth comes to 820 mm. Rainfall retained in the root zone effectively adds an estimated 200-300 mm to the crop water availability in the north and only 50 mm in the south. In view of the high evapotranspiration (ET) and severe salinity environment under which the irrigated agriculture in the Indus basin is practiced, the available water is only marginally sufficient for basin wide year round high intensity cropping (Bhutta and Smedema, 2007). Despite the enormous water shortage, water for agriculture in Pakistan is still not used efficiently. Conveyance losses in unlined canals and watercourses are 25% and 30%, respectively. The application losses in the field are around 25-40%. The overall irrigation efficiency of irrigated areas is estimated to be hardly 36% (Kahlown et al., 2001).

The major concerns regarding performance of irrigated agriculture in Pakistan are low crop yields, water losses in the irrigation system and low water use efficiencies .The average yields in Pakistan are low for wheat and rice, being 2276 kg ha^{-1} and 1756 kg ha^{-1}, respectively. There is a great variability in crop yields with some farmers achieving yields of 3874 kg ha^{-1} for wheat and 3545 kg ha^{-1} for rice (Qureshi, 2004). In addition to water shortage, lack of inputs and poor irrigation practices, soil salinization is the major factor for low crop yields. Salt-affected soils have become an important ecological problem in the Indus Basin—an estimated 6 million ha are already afflicted, about half of which are located in irrigated areas (Qureshi et al., 2004).

Irrigated Agriculture and Food Security

Irrigated agriculture is a vehicle for the provision of basic needs and the reduction of vulnerability to food security. Analysis of information in Asia shows that irrigation has helped in increasing the most crop yields by 100-400 % (FAO, 1996a). This has continued to decrease food prices. These reductions have had a positive impact on the real increases of the urban and rural poor, who spend a large proportion of their income on basic foodstuff.

On the other hand Pakistan has built a huge irrigation system but in spite of this Pakistan's agriculture continues to suffer from low productivity relative to world levels (GOP, 2000). Agricultural growth rates have dwindled down to 2-3 percent per annum from 1994-95 to 1999-2000, which fell further to minus 2.5 percent during 2000-2001 (GOP, 2000). Average yields of all crops especially irrigated wheat, rice, cotton, sugarcane and oilseeds are one of the lowest in the world and significantly low as compared to countries like USA, China, France, Mexico, Egypt, Thailand and India (Table 1) (Qureshi, 2008).

Table 1. Average yields of major crops in Pakistan and range of other countries (Kgs/ha).

Country	Wheat	Cotton	Rice	Maize	Sugarcane
World	2720	1788	3916	4343	65802
India	2670	754	3210	2160	68049
China	4780	3978	6340	5410	66802
Egypt	6006	2654	-	-	119838
Mexico	5151	-	-	2437	74746
France	7449	-	-	9914	-
Pakistan	2770	1867	3190	3240	60852

Low efficiency of irrigation system and poor irrigation management at farm and system levels has led to reduction in crop yields (a reduction 25% overall and a high of 40-60% in Sindh), lower overall agricultural productivity and loss of cultivable land. As discussed before, system losses are very high therefore increasing irrigation efficiency will result in improved crop yield and overall agricultural productivity. In the "*business as usual*" scenario, shortfall of water will result in serious food shortages in the years to come and will severely hurt the national economy and livelihood of millions. Estimated requirements of the agricultural commodities for the project population in 2025 are given in Table 2.

Table 2. Projected food requirements and productions for the year 2025 (Million Tons).

Crops	Requirement	Production	Shortfall
Food-Grains	50	31.5	18.5
Sugarcane	82	46.4	35.4
Cotton (lint)	3.5	2.7	0.8
Pulses	1.9	1.4	0.5
Oilseed	3.3	1.5	1.8
Vegetables	14.3	9.0	5.3
Fruits	16.1	9.0	7.1
Total	171	102.8	69.4

Source: ADB water Sector strategy for Pakistan, 2002.

It is estimated that to meet the food requirements of the country, cultivated area of wheat would need to increase by 46% at present yield levels. Similarly areas for other crops will need to be increased. However, given the present situation of water resources, it will not be possible. Therefore the only way to achieve this food target is to increase water productivity. The productivity of water in Pakistan is about the lowest in the world. Figure 27 shows that for wheat, for example, it is 0.5 kg/m^3 as compared to 1.0 Kg/m^3 in India and 1.5 Kg/m^3 in California (IWMI, 2000). The maize yields in Pakistan are very low and there is a tremendous scope for substantial improvements in the maize yields. In terms of water productivity, maize has a factor of nine between lowest in Pakistan (0.3 Kg/m^3) and highest in Argentina (2.7 Kg/m^3). This reveals that there is a substantial scope for increasing water productivity which needs to be harnessed.

For sustainable rural development and to enhance food security, food production should be increased in a sustainable way. This will involve education initiatives, utilization of economic incentives and the development of appropriate and new technologies, thus ensuring stable supplies of nutritionally adequate food, employment and income generation and natural resources management and environmental protection.

The development of irrigated agriculture brings a range of potential benefits at regional and national level. It contributes to economic growth by generating export crops, reducing imports and thus saving foreign exchange and increase food supplies, which may lead to lower prices. Irrigated agriculture contributes to increase income from production and employment, so that families can gain access to schooling, health and welfare services.

Figure 3 describes the key elements for assessing food security. Food security is basically governed by the balance between food demand and supply, both of which are primarily governed by the biophysical and socio-economic resources and constraints of the region. Food demand is a function of population size, its income and the diet used by an average person. On the other hand, regional food production depends on the agro-technical feasibility of various land use types considering the regional resources and constraints. In combination with environmental impact assessment and socio-economic possibilities, gross food production is assessed. Together with food stock and possible food aid, net food supply can be determined (Aggarwal et. al., 2001).

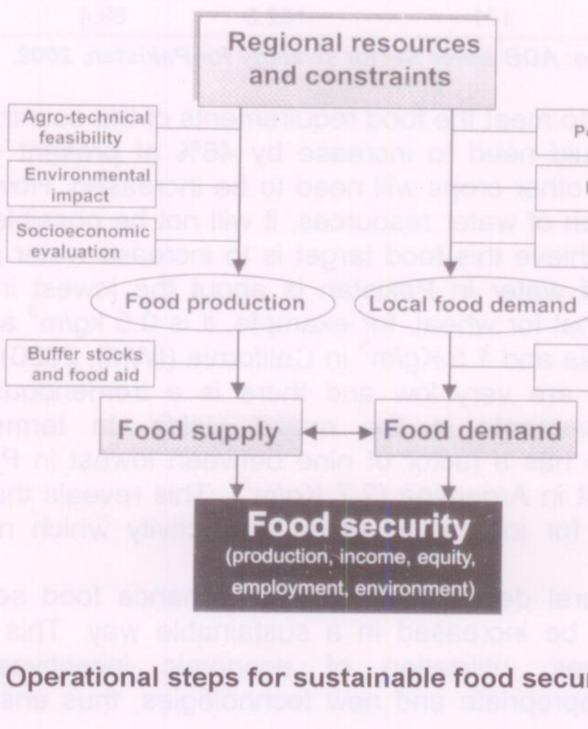


Figure 3: Operational steps for sustainable food security in Pakistan

Ensuring Food Security

An abundance of food at low prices in the world markets does not ensure food security at the country or household level, nor does it help countries to purchase imports to supplement national food supplies (World Bank, 1996a). The poor tend to spend a high proportion of their income, perhaps 50-80 %, on food consumption and water. Hunger and poverty are therefore closely linked. In order to alleviate poverty, poor people need adequate means to obtain food in the quantities and qualities needed for healthy life and generate access to skills, technology, markets and productive resources such as land and capital.

Over the past 25 years, there has been progress in improving the living standards of the people in developing countries. However, even today when the world is producing enough food to provide every person with more than 2700 calories per day, there are still over 800 million people in the developing world who suffer from chronic under nutrition. Severe in-equality in land and income distribution prevents the poor from reaping the full benefits of food availability (IPTRID, 1999).

Although the overall per capita dietary energy supply in South Asia has increase from 2330 calories per day to 2400 calories per day, the absolute number of malnourished people has gone up. Currently, over 350 million people are chronically malnourished. The crises of food insecurity in this region are related to low access rather than low availability. Food insecurity in Pakistan is a product of poverty and inadequate food availability. The term food poverty is commonly used to determine the level of poverty viz-a-viz food security in a country. During the past two decades, 1987-2007, food poverty incidence in the country shows that about one-third of the households were living below the food poverty line and they were not meeting their nutritional requirements. The incidence of food poverty is higher in rural areas (35 per cent), than in urban areas (26 per cent). Urban and rural areas, however, did not differ much in terms of calorie intake per capita, the differences across the four provinces were also not substantial.

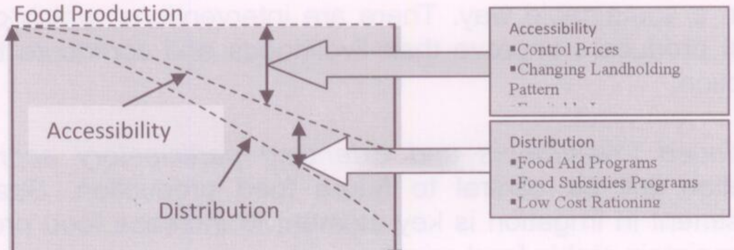


Figure 4: Poverty reduction trend with food accessibility and distribution

Abundant food does not automatically mean people have access. Access to adequate food depends upon household income and food prices. For instance, in India and Pakistan, despite an increase in the total food availability from 1980 to 1999, the incidence of poverty has gone up and in recent years it has been reached to alarming levels. At present, about one-third of the households in Pakistan are living below the income poverty line and are thus unable to meet their minimal nutritional requirements (HDC, 2002). The access to adequate food for all segments of the population also depends upon the pattern of land holdings, income distribution and employment opportunities (Figure 4).

An efficient distribution of food is as important as its production. Even in the presence of excess supply, inefficient distribution among different segments of the society may lead to inadequate consumption and under-nourishment. In order to secure adequate food for the low-income groups, government should encourage food aid, food subsidies and low cost rationing programs. These programs have not been very successful in the past due to their cost and wrong targeting. The price supports and regulations mostly favored consumers and harmed producers, which depressed the production of domestic food.

The intra-household food security in Pakistan is usually dictated by traditions, with women eating's last and the least amount of food that is available to a household. The gender disparity in access to good food is evident from the fact that about 550 million women live below the poverty line (60 % of the world's rural population). This represents a 50% increase for women over the past 20 years, compared with a 30 % increase for men (IFPRI, 1995). The gender bias in access of food is mostly due to perceived differences in social and economic benefits that families supposed desire from boys and girls.

CONCLUSIONS

Irrigated agriculture is a vehicle for the reduction of vulnerability to food security. For sustainable food security, food production should be increased in a sustainable way. There are interventions, which can help the smallest producers improve their livelihoods and contribute to future food production.

> *Continued investments and extending participatory approach* in irrigation will be central to future food production. Strategy to investment in irrigation is key element to increase food production and maintain stable food prices.

- *Involvement of small-scale farmer's* support is needed to improve management and institutional structures so that poor smallholders benefit from reliable water supplies. Moreover the *initiatives that involve the landless* gaining access to the benefits of irrigation require greater exposure. New concentrations of the poor in peri-urban areas and regions where water resources are scarce and risk-prone need to be targeted.
- *Technology affordable and easy to maintain and operate* through which equitable water distribution system especially in difficult and marginal areas, where the poorest lives needed much more attention in order to alleviate poverty.

Effective water governance should be a priority action to resolve the complex challenges in the water sector. We have the knowledge and tools to increase irrigation efficiency, reduce losses and save more water in the agricultural sector. By improving the productivity of water in irrigated agriculture, we can have more production in food with less need to expand irrigated area. In a broad sense, increasing water productivity in agriculture contributes not only to the overall food security equation but also to water security.

Rain-fed agriculture is often ignored in the water and food security puzzle. There are number of water harvesting techniques, groundwater use, storage and water application practices that can be used by smallholder farmers of the rain-fed areas. Development of drought resistance crop varieties, frequent tillage practices to conserve water (fallow) and low cost technologies or simple water harvesting structures to provide access to water at the critical growth stages of the growing crops are few practical options for these areas. Supplementary irrigation with freshwater and even with low quality and saline or treated waste water at the critical growth stages of cereals and, particularly at the flowering and seed filling stages.

References

ADB, 2002. Water resources strategy study. Report Vol. 1, Islamabad, Pakistan.

Aggarwal, P.K., R.P. Roetter, N. Kalra, H. Van Keulen, C.T. Hoanh, H.H. Van Laar, editors, 2001.Land use analysis and planning for sustainable food security: with an illusion for the sate of Haryana, India. New Delhi: Indian Agricultural Research Institute: International Rice Research

Alam, M., M.N. Bhutta, 1996. Availability of water in Pakistan during 21st Century. Evapotranspiration and Irrigation scheduling. Proceedings of the International Conference, Nov., 3-6, San Antonio, Texas.

Bhutta, M. N., and L. K. Smedema, 2007. One hundred years of waterlogging and salinity control in the Indus valley, Pakistan: A historical review. Irrig. And Drain. 56:581-590.

Bhutta, M.N, 1999, Vision on Water for Food and Agriculture: Pakistan Perspective: Regional South Asia Meeting on Water for Food and Rural Development, New Delhi, June 1-3, 1999.

Briscoe, J., Qamar, U., 2006. Pakistan's water economy: running dry. The World Bank Report, Oxford University Press, Washington, 125 pp.

Engelman and Leroy, 1993. Sustaining water: Population and future for renewable water supplies. Population and Environmental Program. Washington, D.C.: Population Action International.

FAO, 1996a. Agriculture and food security. World Food Summit, November 1996, Rome.

Government of Pakistan (GOP), 2000. Agricultural statistics of Pakistan. Islamabad, Pakistan: Ministry of Food, Agriculture and Livestock, Economics Division, and Govt. of Pakistan.

GWP (2011). Climate Change, Food and Water Security in South Asia: Critical Issues and Cooperative Strategies in an Age of Increased Risk and Uncertainty. Synthesis of Workshop Discussions, A Global Water Partnership (GWP) and International Water Management Institute (IWMI) Workshop, 23-25 February 2011, Colombo, Sri Lanka.

Hamdy, A.; Liuzzi, G.T. (2004). Water Scarcity Management Towards Food Security In The Middle-East Region. ressources.ciheam.org/om/pdf/a65/05002193.pdf

HDC, 2002. Human development in South Asia: Agricultural and rural development. The Mehbub-ul-Haq Human Development Centre, Islamabad.

IFPRI, 1995. Population and Food in the Early Twenty-First Century: Meeting Future Food Demand of an Increasing Population. International Food Policy Research Institute (IFPRI) Washington D.C.

IPTRID, 1999. Poverty reduction and irrigated agriculture. International programme for technology and resources in irrigation and drainage. Issue paper No.1

IWMI, 2000. Water issues for 2025. A research perspective. Research contribution to the World Water Vision. Colombo. Sri Lanka. International Water Management Institute.

Kahlown, M.A. and Azam, M., 2001. Environment-friendly On-farm water management Technologies, Journal on Science, Technology and Development. Vol. 20 (4):49-55.

Qureshi, A.S., P.G. McCornick, M. Qadir, Z. Aslam., 2007. Managing salinity and waterlogging in the Indus Basin of Pakistan. Agricultural Water Management, 95:1-10.

Qureshi, A.S., M.A. Gill, A. Sarwar, 2008. Sustainable groundwater management in Pakistan: challenges and opportunities. Irrig. And Drain. 57:1-10.

Qureshi, A.S., M. Akhtar, and Shah, T., 2004. Role of changing energy pricing policies on groundwater development in Pakistan. Journal of Applied Irrigation Science. Vol. 39, No. 2: 329-342.

Qureshi, A. S., 2005. Climate Change and Water Resources Management in Pakistan. In: Climate Change and Water Resources in South Asia (M.M.Q.Mirza and Q.K.Ahmad Editors). Taylor & francis, UK., 197-230 pp.

Qureshi, A.S., M.N. Asghar, S. Ahmad, I. Masih, 2004. Sustaining crop production under saline groundwater conditions: A case study from Pakistan. Australian Journal of Agricultural Sciences. Vol. 54 (2): 421-431.

World Bank, 1996. Global foods supply prospects. A background paper prepared for the World Food Summit, Rome, November 1996. World Bank Technical Paper No. 353. Washington DC.

MANAGING DEMAND SIDE OF WATER SCARCITY EQUATION – PROSPECTS AND POTENTIAL OF DRIP IRRIGATION

Chaudhary Mohammad Ashraff, Malik Muhammad Akram, Dr. Maqsood Ahmed and Hafiz Qaisar Yasin

ABSTRACT

Irrigated agriculture is at risk for its sustainability because of intensified cropping under escalating water shortages; especially in the Punjab. An efficient and judicious use of available irrigation supplies through resource conservation technologies like drip irrigation is inescapable. Realizing the situation, government has taken a mega initiative for promotion of drip irrigation technology on large scale through public private partnership. The same has been evaluated through impact assessment studies for various crops. Drip irrigation resulted in 57 percent water saving for sugarcane while 50 percent for both citrus and potato crops against conventional irrigation methods, respectively. The increase in yield was 34, 39 and 105 percent for potato, sugarcane and citrus, respectively beside copious allied remunerations including better input management and application, curtailing irrigation cost, enhancing quality of produce etc. There are some potential areas (Thal, Pothwar etc.) where this technology may be promoted with full diligence to utilize the scarcely available water. An efficient water conservation planning, wrapping all issues in adoption of drip irrigation technology may pave the way towards efficient utilization of available farm level irrigation supplies for sustainable expansion of irrigated agriculture in the Punjab.

INTRODUCTION

Agriculture is the lifeline of Pakistan's economy contributing over 21 percent of gross domestic product (GDP) out of which 90 percent share comes from irrigated lands. The sector is so intimately interwoven with almost all other major sectors that it acts as engine of growth for rest of the economy. More importantly, it employs 45 percent of country's total labour force **(PES, 2010)**. The performance of agriculture sector in terms of water use and capacity as well as quality has remained very low for the last four decades. Resultantly, Pakistan has been rated as very poor

Director General Agriculture (Water Management) Punjab, Provincial Project Director (HEIS), Soil Scientist and Assistant Director (Technical) at Directorate General Agriculture (Water Management), 21-Davis Road, Lahore.
Ph: 042-99200703, Fax: 042-99200702, E-mail: pipipwm@gmail.com.

performer in terms of water use in Asia **(AWDO, 2007)**. The water and crop productivity are, however, far lowest than its potential as existing conservative production technologies do not offer effective and efficient utilization of agricultural resources, particularly the water. Water productivity in Pakistan is less than 0.1 kg/m3 as compared to 0.39 kg/m3 in 2 India **(PES, 2010)**. Extremely low water use efficiency has led to wastage and depletion of limited water resources besides environmental degradation. Furthermore, Pakistan has entered into a band of water scarce countries with per capita water availability of only 1,000 m3 **(World Bank, 2005)**.

The Punjab is the largest province of the country with respect to population. Its total geographical area is 20.63 million hectares or 50.98 million acres, out of which 0.95 million hectares or 2.34 million acres (4.6%) are under forests, 3.04 million hectares or 7.52 million acres (14.7%) are uncultivable, 1.57 million hectares or 3.89 million acres (7.6%) are cultivable waste, 1.54 million hectares or 3.79 million acres (7.5%) are cultural waste, 2.50 million hectares or 6.18 million acres (12.1%) are non reported and 11.03 million hectares or 27.26 million acres (53.5%) are net sown. More than 70 percent cropped area of the Indus food machine is situated in the Punjab. Its share in total agricultural production of the country is more than 80 percent in case of cotton, almost 70 percent for wheat, nearly 60 percent for sugarcane, and 50 percent in rice. Over all contribution of the province towards agriculture sector is estimated to be more than 80 percent and about 90 percent of it is produced in the irrigated areas **(PDS, 2011)**. The Punjab is situated at the center of the World's largest Indus Basin link canal irrigation system and has the greatest irrigated area and largest amount of irrigation assets in Pakistan **(ADB, 2005)**. These facts and figures evidently accentuate the importance of sustainable irrigated agriculture of the province.

Water scarcity is the biggest challenge confronted by agriculture sector in the Punjab. The level of agricultural production heavily depends on availability and efficient use of water as a major input. The expansion of water resources during last three decades did not commensurate with population growth. The irrigation efficiencies at the farm level are dismally low that is a major constraint in attaining potential production from otherwise highly productive agricultural lands. On the basis of current water shortages and rapidly increasing future demands, the foreseen situation would simply be unsustainable for irrigated agriculture. There is, therefore, an urgent need to maximize per unit production of water by effective, efficient, and judicious use of this precious resource. This requires large scale promotion of water conserving technologies and irrigation methods offering better demand management like drip systems.

Adoption of drip irrigation would, however, require a paradigm shift in existing agricultural practices and cropping patterns. 3

The prominence of water cannot be laid aside while talking for economic development of country as it serves as spine of the economy. In the current water scenario, where no new water reservoirs are in sight and India is threatening not only its western rivers after hogging eastern ones under the Indus Basin Water Treaty, adoption of water efficient and conservative technologies viz-a-viz drip and sprinkler technology is inevitable.

Drip Irrigation Technology

Drip irrigation also called as trickle/micro irrigation is the most efficient technology that makes highly effective use of water, fertilizers, and nutrients. Its main principle is to apply water and other inputs slowly, regularly, and frequently as close to the plant roots as possible through emitters installed on plastic pipes laid out in the field (**Figure-1**). Regular and timely availability of nutrients throughout the plant growth period as per exact requirements and maintenance of favorable soil moisture conditions facilitate to maximize crop productivity. Drip irrigation technology is best suited for orchards and high value row crops such as vegetables, fruits, cotton, maize, sugarcane etc. The system is versatile in its applicability that may be adopted on lands of uneven topography, rolling sandy areas etc. It has become the most valued innovation, which optimizes use of water and fertilizers by enhancing the irrigation efficiency as much as 95 percent **(CWP, 1991; INCID, 1994).** The drip irrigation method is the most efficient as illustrated in **Figure-2**.

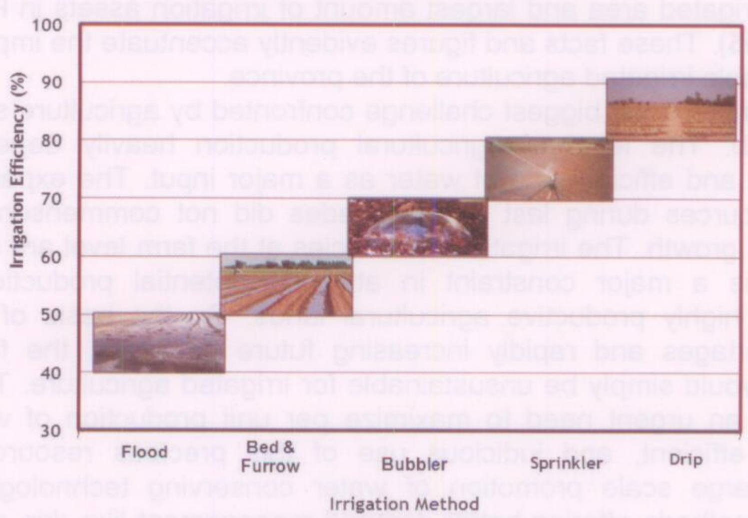


Figure-2: Efficiency of Irrigation methods

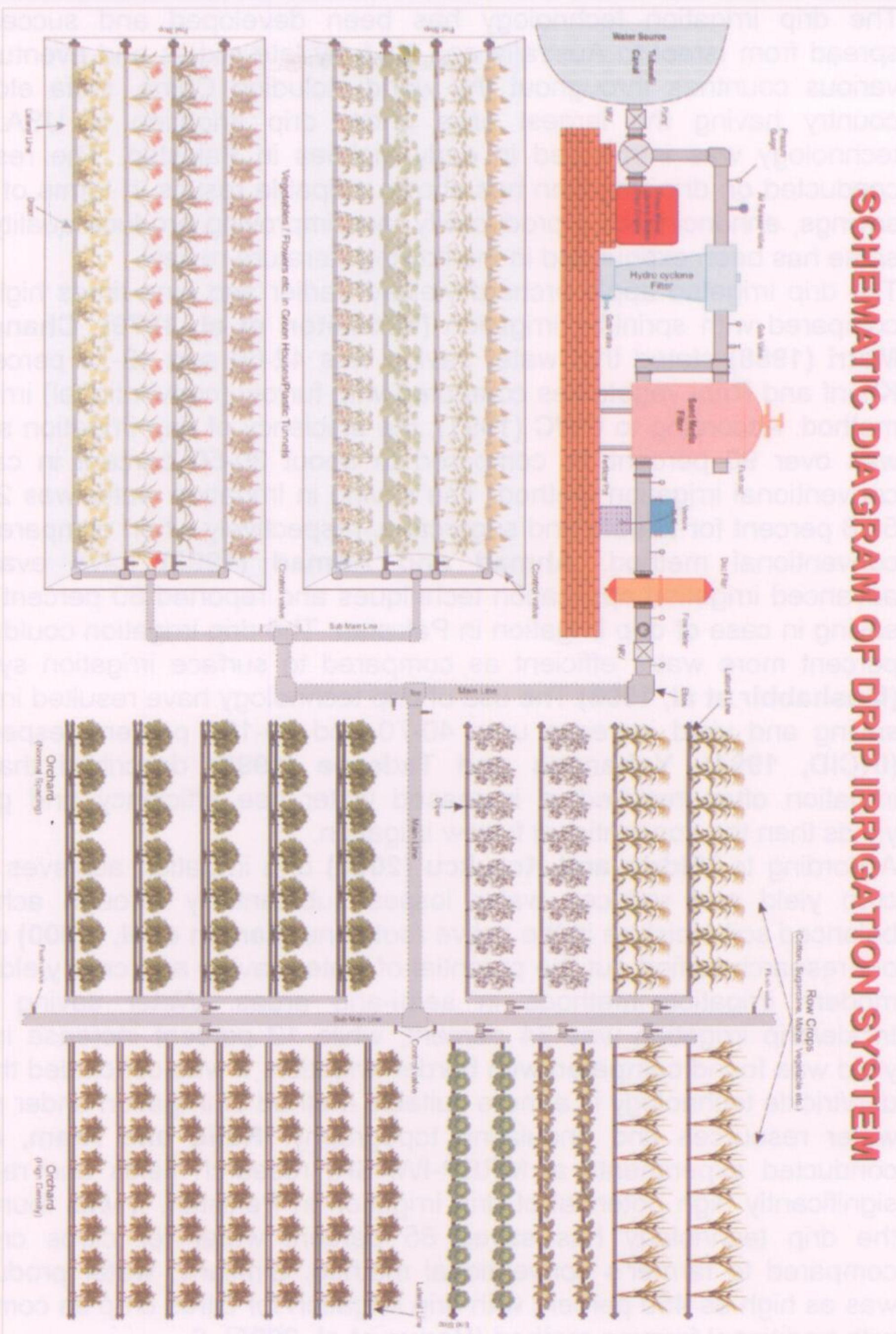


Figure-1: A Typical Layout of Drip Irrigation System

The drip irrigation technology has been developed and successfully spread from Israel to Australia and USA by late sixties and eventually in various countries throughout the world including China, India etc. The country having the largest area under drip irrigation is USA. This technology was introduced in early eighties in Pakistan. The research conducted on drip irrigation has shown palpable results in terms of water savings, enhancing crop productivity, and improving produce quality. The same has been expounded in the flowing literature review.

The drip irrigated apple orchard yielded earlier and nine times higher as compared with sprinkler irrigation **(Middleton et al, 1979)**. **Chang and Marri (1988)** stated that water saving was 42-60 and 12-74 percent for Kharif and Rabi vegetables compared with furrow (conventional) irrigation method. According to **CWC (1991)**, the efficiency of drip irrigation system was over 90 percent as compared to about 30-50 percent in case of conventional irrigation method. The saving in irrigation water was 27 and 59.8 percent for tomato and sugarcane, respectively when compared with conventional method. **Ahmad and Ahmad (1993)** have evaluated advanced irrigation application techniques and reported 80 percent water saving in case of drip irrigation in Pakistan. The drip irrigation could be 50 percent more water efficient as compared to surface irrigation systems **(Moshabbir et al, 1993)**.The use of drip technology have resulted in water saving and yield increase upto 40-70 and 10-100 percent respectively **(INCID, 1994)**. **Yohannes and Tadesse (1998)** described that drip irrigation often resulted in increased water use efficiency and greater yields than the conventional furrow irrigation.

According to **Yildrin and Korukcu (2000)** drip irrigation achieves better crop yield and reduces water losses substantially through achieving balanced soil moisture in the active root zone. **Zaman et al, (2000)** carried out research to find out the potential of water saving and crop yield using modern irrigation methods in semi-arid areas. Water saving under trickle/drip irrigation was 34 percent, while 12 percent increase in crop yield was found compared with border irrigation. It was concluded that the drip/trickle technology is a more suitable method of irrigation under scarce water resources and undulating topography. **Rafiq and Alam, (2004)** conducted experiments at MREP-IWASRI research fields and reported significantly high potential of drip irrigation in Pakistan. It was found that the drip technology has saved 85 percent water for citrus crop as compared to farmer's conventional method. Similarly, water productivity was as high as 450 percent with drip irrigation for citrus crop as compared with traditional farming method **(Haque et al, 2005)**. 6

Bakhsh et al, (2008) have reported that drip irrigation has the potential of increasing water productivity even under deficit irrigation environment. The deficit irrigation of 30 percent (D_{30}) and 15 percent (D_{15}), produced cotton yields of 2,078 and 2,862 kg ha^{-1}, respectively in comparison to 3,112 kg ha^{-1} for no deficit (D_0). The water use efficiency was 0.61, 0.64, and 0.55 kg m^{-3} for D_0, D_{15}, and D_{30} respectively. It was concluded that D_{15} treatment has resulted in better water productivity in water stressed areas. **Tahira (2010)** carried out study on water saving and energy saving in case of drip/trickle irrigation when compared with conventional irrigation system. The water saving was 50, 47 and 43 percent for cotton, sugarcane and chillies, respectively. Moreover, energy saving per acre was 26 percent in cotton, 22 percent in sugarcane, and 25 percent in chillies.

This paper will investigate the prospects of successful drip irrigation technology, allied benefits, and potential areas in the Punjab province as well as recommendations in this regard for sustainability of irrigated agriculture in the province.

Performance Review of Drip Irrigation

Only a few projects have been undertaken in the past for introduction of drip irrigation in the Punjab that too, on a very limited scale. By virtue of implementation of such schemes, awareness has been created amongst farmers for efficient utilization of scarce and expensive water resources and keen interest has been shown by them in drip and sprinkler irrigation. The primary causes for failure of drip irrigation systems installed under previous projects are summarized below.

a) Lack of organization/institutional support for technical assistance, capacity building, research & development for backstopping the implementation of new interventions.
b) Insufficient technical expertise, particularly for designing, installation and operation of pressurized irrigation systems.
c) Absence of complete technological package for crop establishment, fertigation, plant protection and other agronomic practices.
d) Inadequate participation of all stakeholders at planning, designing, installation and operation stages of pressurized irrigation schemes.
e) Ineffective follow-up for assisting the farmers to successfully adopt the new technology.
f) Incorrect assessment of availability of expertise, experience, and human resource in the country, in general, as well as required capability and capacity of private sector supply and services companies (SSCs) and public sector departments, in particular 7.

It is indicated that considerable advancements have taken place over the years all over the world in computer assisted design tools, better simulations, and analysis techniques to achieve the most reliable and optimum designs. Similarly, developments in manufacturing technology have also significantly reduced the initial cost of installation of drip irrigation systems that was a major deterrent for adoption of these technologies. Furthermore, acute water shortage and trend towards growing high value crops have motivated farmers to these technologies.

The causes of failure and constraints experienced during implementation of previous projects were considerably incorporated in the development of modified approach. Accordingly, installation of drip irrigation system has been successfully promoted by the government through a mega initiative of public private partnerships under "Water Conservation and Productivity Enhancement through High Efficiency (Pressurized) Irrigation Systems" and "Pilot Project for Promotion of Cotton Cultivation with Drip Irrigation in Thal Region". The government has pre-qualified supply and services companies (SSCs) for installing the systems on turnkey basis as well as to provide post installation backup assistance to the farmers. Drip irrigation has been promoted on about 15,126 acres (6,124) at over 350 sites in the Punjab including 3,374 acres (1,366 ha) for orchards and 1,877 acres (760 ha) for row crops as shown in **Figure-3.**

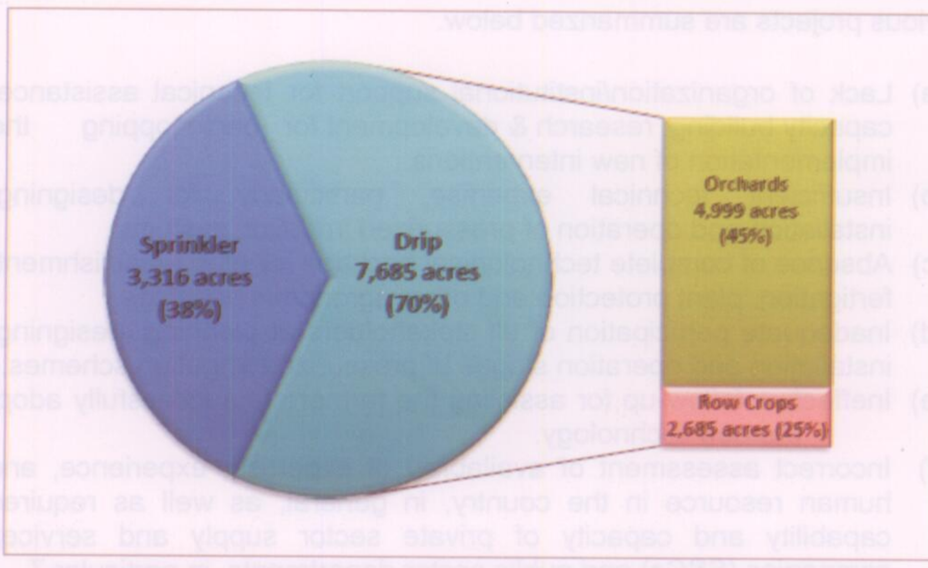


Figure-3: Distribution of drip irrigated area under various crops under HEIS project in the Punjab

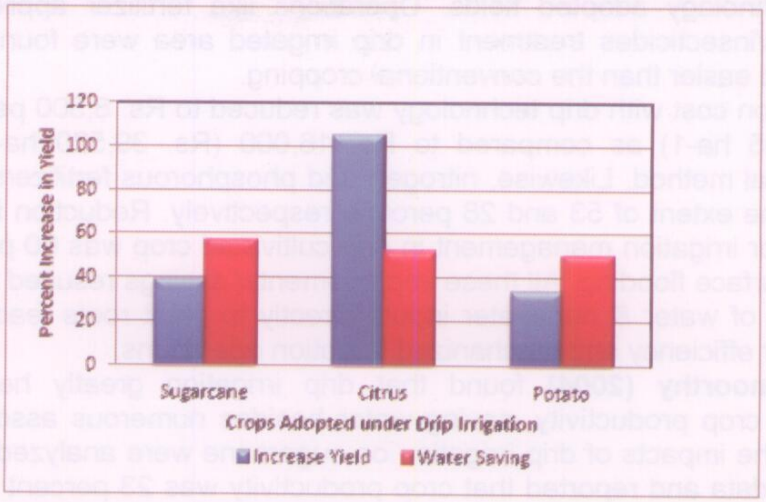


Figure-4: Water saving and increase in yield under drip irrigation

The impact assessment studies for performance evaluation of installed drip irrigation systems have been carried out on sugarcane, citrus, and potato crops. These technologies have exhibited substantial impacts against conventional irrigation methods. The performance of the drip irrigation system showed 57 percent water saving in case of sugarcane while 50 percent for both citrus and potato crops against conventional irrigation methods. The increase in yield was 34, 39 and 105 percent for potato, sugarcane and citrus, respectively as shown in **Figure-4**.

Sugarcane

A complete sugarcane production technology involving paired row sowing, proper seed treatment, mechanical seed bed preparation, recommended doses of fertilizers etc. was adopted after installation of drip irrigation system. Input management was the key difference in drip irrigation over the conventional surface flooding method by providing efficient, balanced, and timely nutrients. Accordingly, the fields under drip irrigation exhibited uniform sugarcane stand with 16 percent longer nodes, 25 percent more tillers, and 24 percent lengthy millible cane.

An average girth increase of 0.16 inches (0.40 cms) as well as healthy and prominent eye buds was other improvements in drip irrigated sugarcane. All these factors contributed towards significantly increased weight per cane in fields under drip irrigation. Enhanced sugar recovery, less lodging and more pest resistance were further advantages observed in the technology adopted fields. Operations like fertilizer application, weedicides/insecticides treatment in drip irrigated area were found less costlier and easier than the conventional cropping.

The irrigation cost with drip technology was reduced to Rs. 8,500 per acre (Rs. 20,995 ha-1) as compared to Rs. 16,000 (Rs. 39,520 ha-1) for conventional method. Likewise, nitrogen and phosphorous fertilizers were saved to the extent of 53 and 28 percent, respectively. Reduction in cost of labour for irrigation management in drip cultivated crop was 60 percent vis-a-vis surface flooding. All these improvements/ savings resulted due to application of water & non-water inputs directly to plant roots leading to their higher efficiency and mechanized irrigation operations.

Narayanamoorthy (2004) found that drip irrigation greatly helps in enhancing crop productivity, saving water besides numerous associated benefits. The impacts of drip irrigation on sugarcane were analyzed using farm-level data and reported that crop productivity was 23 percent higher when compared with conventional (flood) method of irrigation. Furthermore, saving in water and electricity per hectare was 44 percent and 1059 kwh, respectively. Resultantly, it was concluded that sugarcane cultivation under drip irrigation is economically viable even without subsidy.

Figure-5: A view of installed drip irrigation system for sugarcane (district R. Y. Khan)

Citrus

The drip irrigation of citrus orchards started exhibiting its effects after a very short period in terms of visual plant growth. Moreover, Drip irrigation offers/facilitates dense orchard planting which is the simplest and most effective means of increasing yield. Planting of about 10,329 extra plants (47 plants per acre) could be possible only with drip irrigation by reducing interplant distance due to judicial use of water. There was about 58%

increase in plant population per acre which will manifold the benefits of drip irrigation on reaching to fruiting stage. The mortality rate of 10-15 % under flood irrigation became negligible with drip irrigation of young plants because of timely and balanced application of inputs.

The irrigation cost with drip technology was reduced to Rs.714 per acre (Rs. 1,764 ha-1) as compared to Rs. 2,560 per acre (Rs. 6,323 ha-1) for conventional method. Operations like fertigation, weedicides/insecticides application etc. in drip irrigated area became less costly and easier than the conventional method because of properly designed input application facility in drip irrigation system. The sale price of drip irrigated citrus orchard was increased by 76 percent because of improved fruit quality, less favorable environment for onset of diseases, higher fruit bearing and proper irrigation with same available water due to precise and timely application of water and nutrients.

Furthermore, the citrus produced under drip irrigation have better physiochemical characteristics. Size is the most common and impressing factor used for assessing the quality of citrus. The citrus produced under drip irrigation was found intact, sound, clean, and more importantly of uniform size. The average weight, size, peel thickness, peel content, TSS and juice percentage are contributing factors towards improved fruit quality under drip irrigation which ultimately led to higher sale price of the orchard. The quality characters of citrus grown with drip irrigation fulfill all minimum quality requirements set by Pakistan Horticultural Development and Export Board.

Rafiq and Alam, (2004) reported that drip technology has saved 85 percent water for citrus crop as compared to farmer's conventional method. Another study carried out by **Haque et al, (2005)** have shown that water productivity with drip irrigation for citrus was as high as 450 percent as compared with traditional farming method

Potato

Drip technology maintains an optimum moisture level in the plant root zone at all times and better fertigation management ultimately produced better quality potato which is practically free from sprouts, foreign smell, external & internal defects etc. The average size of tuber was 80 mm in drip irrigated area. The yield obtained under drip irrigation was 43.5 tons ha^{-1} which is about 246 percent higher as compared to Punjab average of 17.67 tons ha^{-1} **(PES, 2010)**. Drip irrigated field gave 34 percent more yield as compared to flood irrigation. In addition to tremendous increase in yield under drip irrigation, 50 percent saving of water and 30 percent reduction in weeds attack were observed which ultimately produced better quality potato. Input management played a pivotal role in producing intact, firm and clean potato. This has already been clearly studied and indicated in several other studies **(Shock et al, 1994; Wang et al, 2006, 2011)**.

Figure-6: A view of installed drip irrigation system for potato (district Chiniot)

Cotton

Cotton cultivation with drip irrigation in desert environment has been successfully demonstrated on about 2,000 acres under "Pilot Project for Promotion of Cotton Cultivation in Thal Region with Drip Irrigation" during two years (2009-10 to 2010-11). It has been reported that cotton yielded upto 50 maunds per acre with an average of 26 maunds per acre against 15 maunds per acre average in the area. The intervention also made it possible to grow other cash crops first time on sand dunes without land leveling in the project area.

A field study was piloted at NIAB, Faisalabad for evaluating potential of drip irrigation under water stress conditions for cotton crop and found that technology has the capability of giving appreciable results even under deficit irrigation environment **(Bakhsh et al, (2008).Basel eta la, (2009)** have also reported definitive advantages of employing deficit irrigation under limited water supply conditions.

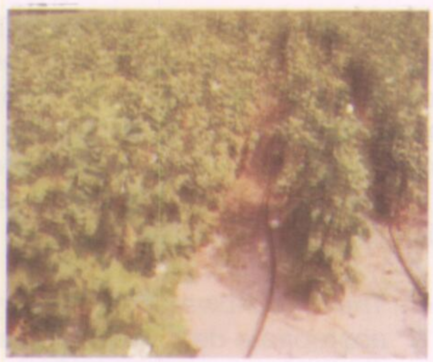


Figure-6: A view of installed drip irrigation system for cotton (district Bhakkar)

Prospects of Drip Irrigation

Water is increasingly becoming a scarce input for irrigated agriculture, especially in non-canal commanded areas and brackish groundwater areas of the province. Rain-fed (barani) lands, in general, have much lower productivity than irrigated areas due to subsistence holdings, unreliable rains, inadequate input use etc. The topography of most of the lands is highly undulating which is a major hurdle in irrigating fields through gravity irrigation from tubewells and other sources. Likewise, the gravity irrigation through conventional practices on sandy soils is grossly inefficient resulting in precious water wastage through seepages. Moreover, the water supplies in canal irrigated areas are designed only for 60-70 percent of cropping intensity because of which vast land remains uncultivated every year **(I&PD, 2011)**.

Furthermore, the climate is favorable for irrigated agriculture on these fertile soils having no major problem of salinity and water logging. Hence, there exists vast unyoked potential for further development of irrigated agriculture in these areas. As such, availability of assured irrigation supplies is the only one constraint for expansion of irrigated agriculture in the province. The issue can, however, be addressed to a great extent by adopting water conservation technologies for efficient utilization of available limited water supplies under such conditions. Drip irrigation is a versatile technology that allows evenly spoon-feeds precious water and nutrients directly to every plant's root zone despite variable soil conditions, undulating terrain, odd field dimensions or long lengths of run. It therefore, needs no emphasis that drip technology would be promoted with full vigor so that the available limited water in these scarce areas may be utilized with full diligence for sustainability of irrigated agriculture in the Punjab. Some of the potential areas in this regard are described below.

Thal is a vast desert in the Punjab lying cultureable waste land with much potential for its development for irrigated agriculture. The general topography of Thal region is highly undulating consisting of large sand dunes, which often keep on shifting from one place to another due to wind storms action. Soil of the area is mostly sandy in nature having extremely low water holding capacity. There is high potential for drip irrigation in this region due to following comparative advantages.

- The groundwater is mostly fit for irrigation and available at appropriate depth which is recharged by perennial rivers (Indus and Jhelum).
- The upper layer of the sandy soils in the area is very fertile having no waterlogging and salinity problems.
- Drip irrigation does not require leveling of undulating sand dunes that entails huge capital investment, time, and heavy machinery.
- Desert environment is less susceptible to insect/pest and diseases due to dry conditions.
- Climate is very conducive for cultivation of high value sensitive crops e.g. Cotton.

In addition to Thal and Mazaffargarh canals, the Punjab Government is further providing irrigation supplies out of provincial share as per Water Accord-1991. Phase-I of Greater Thal canal and its distribution network has, accordingly, been completed to provide surface water for 350,000 acres of land during summer months (Kharif season).
The neighbouring countries like China and India are already obtaining better crop yields through drip irrigation systems in poorly fertile sub-mountainous soils. Thal can benefit from their experience particularly for better crop production as the region has similar soil and climatic conditions. Promotion of drip irrigation for orchards, vegetables and other row crops like cotton as well as provision of requisite technical assistance to the farmers at their door step would be the most appropriate strategy for improving water and crop productivity in the area to contribute significantly in poverty reduction and livelihood enhancement in Thal. The efficient

utilization of water resources may pave the way towards horizontal expansion of irrigated agriculture in the province.

The Pothwar Plateau is characterized with semi-arid to sub-humid mild climate. The occurrence of rainfall is highly erratic both in space and time which demands water harvesting, storage and supplemental irrigation during the months of April to June and October to December for successful crop production in the region. The soils are very fertile without any constraint like salinity, waterlogging etc. as well as infrastructure is well developed and large market is available very close to area. Nevertheless, there is high potential for the development of irrigated agriculture in the area, as crop yields can be increased many-folds by managing supplemental irrigation through storage of runoff water and irrigation with drip technology.

Small Dams Organization (SDO) has constructed 48 dams in Pothwar region since 1973 and the organization has planned to construct several new dams as well. It is reported that the actual command area developed so far is far less than the planned. As such, there exist large potential for irrigated agriculture in the region by adding remaining command of existing small dams as well as new dams. Irrigated agriculture in their command, however, may be expanded by reducing water losses through efficient irrigation system i.e. drip system. The potential of these fertile soils may be explored through improvement of irrigation infrastructure (small dams and irrigation systems) and then promotion of drip irrigation for cultivating high value crops. The crop productivity can be increased manifolds by irrigated agriculture through these interventions.

There are some pockets in the southern Punjab having brackish groundwater except along the irrigation canals and the river. The area is canal irrigated where the canal water supplies are limited only for 80 percent of cropping intensity because of which vast land remains uncultivated every year which could be brought under cultivation through drip irrigation systems under limited water supplies. The adoption of these technologies having irrigation application efficiencies upto 95 percent would ensure efficient utilization of limited available water supplies in these areas.

Conclusion and Recommendations

Better management of scarce water resources may help to tackle all other issues confronted in expansion of irrigated agriculture in the province for sustainability of irrigated agriculture. Realizing the notions such as "more crops per drop" emphasizing on demand side water management (drip irrigation) and increasing overall water productivity in true sense may help to achieve sustainable self sufficiency in food.

Conclusion

i. Drip irrigation has saved water upto 57 percent and increased yield to about 105 percent beside several concomitant benefits.
ii. Acquired benefits of this resource conserving technology suggest its adoption on large areas to mitigate the prevailing water and sugar crisis. It will not only minimize the existing yield gaps but also improve the production quality.
iii. The technology can give more dividends in the Punjab as it contributes more than 80 percent in agriculture sector of the country.
iv. Drip irrigation can facilitate successfully raising of tropical crops like sugarcane in arid climates of Pakistan.
v. Promotion of cotton cultivation with drip irrigation in Thal desert has been proved highly efficacious. Greater government financial support would, however, be required to upscale the intervention (drip irrigation technology) for increasing water use efficiency and productivity of cotton as well as vegetables and fruits.
vi. The accumulated benefits of drip irrigation necessitate enhancement in government support (subsidy level) to stimulate the farmers for installation of drip irrigation system on high value crops i.e. fruits and vegetables.
vii. Drip technology encouraged highly dense planting of orchard which is the most effective means of increasing yield per unit area.
viii. The on and off modes of HEIS project during past two years have discouraged the private sector to fully develop its capacity and build confidence about continuity of government support.
ix. There is lack of technical support to the farmers for installation, operation, maintenance, and troubleshooting etc. of drip technology as well as indigenous capacity of readily available spare-parts.

Recommendations

i. The government should prepare and implement an efficient water conservation plan and intensively monitor its effective implementation at the farm/field level for survival of the largest sector of the economy. The focus should be on "Every Drop of

Water Conserved is Water Generated" under the prevailing water scarcity situation of the country.

ii. A phased program may be formulated for promotion of drip irrigation for expansion of irrigated agriculture in the Punjab to enhance water and crop productivity.

iii. The active participation of all stakeholders i.e. government, agriculture industry, farmers private sector drip system installation companies are required to collaborate for mobilizing initial investment, its repayments, and follow-up assistance for successful crop cultivation with drip irrigation for sustainability of irrigated agriculture.

iv. The new and on-going irrigation projects envisaging development of commands of small dam, new canals commands etc. should be given high priority to promote drip irrigation technology for optimal use of very limited water resources. It should be made mandatory to install high efficiency irrigation systems, especially drip technology to get water rights under command area development projects.

v. As the technology is nascent, the continuity of government support is very much essential to build confidence of service providers for assured sizeable market/clientage. It will create enabling environment for pipe, plastic, pump etc. industry to start local manufacturing of drip/sprinkler components for technology indigenization.

vi. A well established and time tested farmers' institution of water users association (WUA) can play a vibrant role in technology dissemination. The capacity building of beneficiary farmer must be ensured to reap the real benefits of drip irrigation technology.

vii. The coordination among various stakeholders (OFWM, research, extension service, beneficiary farmers, supply and service companies etc.) is fundamental to accelerate technology adoption.

viii. The research and development activities need to be prioritized for indigenization of drip irrigation systems.

References

1. A. Narayanamoorthy (2004), "Impact Assessment of Drip Irrigation in India: The Case of Sugarcane" Development Policy Review, Volume 22, Issue 4, pages 443–462.
2. Ahmad M and Ahmad, R. (1993), "Advanced Irrigation Application Techniques and their use in Balochistan" USAID, ISMR Project Report, P&I Directorate (South), Wapda Report # 389.

3. Asian Development Bank (2005), "Technical Assistance to the Islamic Republic of Pakistan for Preparing the Punjab Irrigated Agriculture Development Sector Project" TAR: PAK 37231, ADB Publication.
4. Asian Water Development Outlook (2007), "Achieving Water Security for Asia" ADB Publication.
5. Bakhsh, A., A. Hassan and M.R. Chaudary, (2008),"Virtual Water Reality: Pakistan's Perspective" In: Proceeding of Conference on: Agriculture; Challenges, Opportunities and Options under Free Trade Regime held in University Agriculture of Faisalabad on 28-29 May, 2008.
6. C. Shock, R. Flock, E. Eldredge, A. Pereira, and L. Jensen (2006), "Drip Irrigation Guide for Potatoes in the Treasure Valley" Sustainable Agriculture Techniques, EM 8912-E (http://extension.oregonstate.edu/catalog/pdf/em/em8912-e.pdf)
7. Chang, M. H., and M. K. Marri, (1988), "Performance of trickle and pitcher irrigation system" International Seminar on Hydrological Aspects of Drainage of Irrigated Areas, Drainage and Reclamation Institute of Pakistan, Tandojam: IQ-25.
8. CWC (1991), "Drip Irrigation System and Its Relevance in Better Water Use" Irrigation Research Management Improvement Organization, Central Water Commission, New Delhi, April 1991.
9. Feng-Xin Wang, Yaohu Kang and Shi-Ping Liu (2006), "Effects of Drip Irrigation Frequency on Soil Wetting Pattern and Potato Growth in North China Plain" Agricultural Water Management 79 (2006) pages 248–264.
10. Feng-Xin Wang, Xiu-Xia Wu, Clinton C. Shock, Li-Yun Chu, Xiao-Xiao Gu and XuanXue (2011), "Effects of Drip Irrigation Regimes on Potato Tuber Yield and Quality under Plastic Mulch in Arid Northwestern China" Field Crops Research, Volume 122, Issue 1, Pages 78-84.
11. Haque, BU, Saleem, M., and Bhutta M.N. (2005),"Evaluation & Comparison of Sprinkler, Drip and Bed & Furrow Irrigation" Mona Reclamation Experimental Project, Bhalwal, MREP Internal Report No. 2005/01.
12. H. Basal, N. Dagdelen, A. Unay and E. Yilmaz, (2009), "Effects of Deficit Drip Irrigation Ratios on Cotton (Gossypiumhirsutum L.) Yield and Fibre Quality" Journal of Agronomy and Crop Science Volume 195, Issue 1, Pages 19–29.
13. INCID (1994),"Drip Irrigation in India" Indian National Committee on Irrigation & Drainage, Ministry of Water Resources, Government of India, New Delhi.

14. John Brisco and Usman Qamar (2005), "Pakistan's Water Economy, Running Dry" World Bank Publication.
15. Middleton, J. E., E. L. Proebsting and S. Roberts, (1979)"Apple orchard irrigation by trickle and sprinkler" Transaction of ASAE.
16. Moshabbir, PM., Ahmad, S., Yasin, M., and Ahmad M.M. (1993), "Indigenization of Trickle Irrigation Technology"Proceedings; USAID-ISMR Symposium, IIMI, Lahore.
17. Pakistan Economic Survey (2010), Ministry of Finance, Government of Pakistan, Islamabad.
18. Punjab Devolvement Statistics (2011), Planning and Development Department, Government of Punjab, Lahore.
19. Punjab Irrigation and Power Department (2011), Briefing to the Minister for Irrigation, Government of Punjab dated 21-03-2011.
20. Rafiq M. and M.M.Alam (2004), Annual Report 2003-04, International Waterlogging and Salinity Research Institute, Lahore.
21. Tahira Muhammad Ali (2010), "Adoptability of Trickle Irrigation System for Small farmers in Punjab" M.Sc. Thesis, Center of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore.
22. Waheed-uz-Zaman, M. Arshad, M. Asghar Rana and M. Shafi Sabir (2000), "Water Saving and Crop Yield Potential of Modern Irrigation Methods in the Semi-arid Area" Pakistan Journal of Agricultural Sciences lb/.3 7(3-4).
23. Yildirim, O. and A. Korukcu, (2000), "Comparison of Drip, Sprinkler and Surface Irrigation Systems in Orchards" Faculty of Agriculture, University of Ankara, Ankara Turkey 47p.
24. Yohannes, F. and T. Tadesse. (1998)'"Effect of drip and furrow irrigation and plant spacing on yield of tomato at Dire Dawa, Ethiopia"Agricultural Water Management, Volume 35, Issue 3, Pages 201-207.

MANAGING WATER RESOURCES FOR FOOD SECURITY IN PAKISTAN

By

Irshad Ahmad[1], Dr. Allah Bakhsh Sufi [2] and Talib Hussain[3]

Abstract

Food security is a complex phenomenon that is attributable to a range of factors that vary across regions; in the form of availability, accessibility and affordability. Pakistan seems lagging behind at present in these three factors, to become a food secure nation. In spite of the significant progress Pakistan has made in food production over the last 60 years, the majority of the population still faces uncertainty in food security on a daily basis. The problem of availability of food in Pakistan is mainly due to difficulties in production and productivity of its agriculture industry. The country has been on a good track of development, but during the present decade, the food security has deteriorated due to natural calamities, global food price increases, militancy, loss of land due to residential and industrial development and uncertain water availability due to climate change phenomena.

Further impediments such as inadequate water supplies, nutrient deficient cultivable land, outdated farming methods and absence of crop rotation added to the limitations in the general supply of food available to the local population. The failure on agriculture supply is unpardonable, mainly because the country is blessed with all the natural assets needed to ensure food for all–land, water and weather. The better agriculture production and productivity through the creation of a reservoir irrigation system, technology based cultivation methods and farm input use, marketing facilities and poverty alleviation to improve affordability for food, can only be achieved with proper policy and efficiency.

The paper discusses the present food production, water resources and future food requirements based on population growth and suggests ways and means to meet future food requirements through integrating water resources management and agricultural development. To meet national requirement of water and food on sustainable and secured manner, the construction of major reservoirs is quite necessary. The water conservation at all levels is must. Per unit water and land productivity has to be enhanced upto the world standards.

---

[1] General Manager (P&D) Water WAPDA, WAPDA House, Lahore.

[2] Consultant (Water Costing) WRPO, P&D (W), WAPDA, Lahore.

[3] Director (Agriculture) WRPO, P&D (W), WAPDA, Lahore.

1. Preamble

Food security emerged as a concept in the mid 1970's after rapid increase of prices causing global food crises. The commonly accepted definition of food security is "when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for active and healthy life". Today the world has more than enough food to feed every one yet 850 million are food insecure. Achieving food security requires adequate food availability, access and use. The world has witnessed the seven billion population mark in July last year and it is projected to rise to 10 billion by 2050. The global challenge of increasing food production, while using less water is exemplified in the case of Pakistan. The population there has increased by over 25 percent in just the last 10 years and continues to expand faster than global averages. Over 90 million people are now barely getting enough to eat with more than 30 million of them are living in abject poverty.

According to some estimates, the existing resources will not be able to support more than half of its present population in the next century. With critical population growth and patterns of human activity (increasing demand for more food, more cars, more fuel and more buildings), science and technology may not be able to prevent the irreversible degradation of the environment. Man-kind today stands at cross roads. The road to further population growth, leads inevitably to starvation, poverty, social dearth. The other road leads to population stabilization at a sustainable level. It leads to a world population in balance with its environment and resources thus creating a condition that will allow the human race to live in peace and prosperity.

Agriculture plays a key role in providing (i) food availability (ii) an important source of income to purchase food; and (iii) foods with high nutritional status. Food security in Pakistan is dependent on agriculture and agriculture depends on land and water. There has neither been any substantial horizontal expansion (new lands coming under cultivation) nor any significant vertical (per acre yield) growth despite having massive potential on each of the two areas. At the same time land and water resources are becoming scarcer every day. The vertical growth has been more difficult and arduous part. Over the last 6 decades, our institutions and relevant agencies have not been able to educate farmers on crop management issues. The farming practices are still archaic and about 30% of horticulture crops are lost at post harvest level. Yields of all major cash and food crops are well below the world average. Pakistan at present does not seem apparently a food insecure country. However, due to non development of resource base, per capita water availability is falling and country is heading fast towards a water deficient country and resultantly a food insecure nation.

With other developing countries, Pakistan is facing the key issues of high demographic pressure, growing rural exodus, and change in food consumption practices, rapid deterioration of natural resources, agricultural low productivity and water scarcity. The issues are becoming drastic in scale and impact. To meet the future food demand and water for competing sectors as well, improvement and modification of agricultural production system and water resources management are determining factors. To ensure food security we have to address not only the issue of water supply but also agriculture in an integrated manner. To achieve food security we need technology transfer and improve the efficient use of water. It is essential to create an enabling environment, which is built upon the principles of sustainable development, poverty reduction, knowledge based institutions and a favorable investment program.

2. Water Resources

Pakistan's water resources comprise of surface and ground water as briefly described below:

a) *Surface Water* – The Indus River System is the major source of surface water which derives mostly from snow and glacial melting. Pakistan receives snowfall only in the Gilgit-Baltistan during winter. Rainfall is markedly erratic in magnitude, time of occurrence and aerial distribution. The mean annual precipitation ranges from less than 100 mm in parts of the Lower Indus Plain to over 750 mm near the foothills in the Upper Indus Plain.

Pakistan is dependent on the three western rivers including Kabul, Indus, Jhelum and Chenab. Post-Tarbela (1976-2010) flows Indus at Kalabagh, Jhelum at Mangla and Chenab at Marala and with eastern rivers contribution were 145.63 MAF. The three eastern tributaries of the Indus – Ravi, Sutlej and Beas – were allocated to India for its exclusive use. The Kabul River contributes 21 MAF to the surface supplies of the country.

b) *Ground Water* – Pakistan is extracting about 50 MAF from the aquifers and has already crossed the sustainable limit of safe yield. This over-mining and pollution of aquifers has resulted in secondary salinity and the presence of fluorides and arsenic in water, which in turn is degrading the quality of agricultural lands and health issues. The northern part of the Indus Basin is fresh where as, southern part is saline.

The Indus Waters Treaty led to the construction of multiple hydraulic structures. These enabled Pakistan to enhance water availability at canal head works to about 104 MAF. However, this has now started decreasing because of the lack of surface water development since construction of Tarbela dam and the significant loss of on-line storage capacity due to sedimentation. Of the 104 MAF of annual canal diversion, only 58.3 MAF reaches the farm-gate and remaining 45.7 MAF reaches the ground water.

Pakistan is faced with increasing water scarcity and depending on assumptions of various future demand scenarios. Annual water requirements at canal head could be in the range of 135-170 MAF in the coming years. Existing irrigation mechanism has been reportedly working on 40-45 percent efficiency. The National Water Strategy envisages raising irrigation efficiency to 50 percent from the current level of 40 percent. In order to improve the existing system, various steps such as On-Farm Water Management Programme (OFWM) projects have been started in all provinces, including Gilgit-Baltistan, Azad Jammu & Kashmir and Islamabad Capital Territory areas. The projects undertaken are: - National Programme for Improvement of Watercourses in Pakistan, Chaghai Water Management and Agriculture Development Project (IDB Assisted), National Project to stimulate the Adaptation of Permanent Raised Beds in Maize-Wheat and Cotton-Wheat Farming System in Pakistan. Efficient irrigation system is a pre-requisite for higher agricultural production as it helps in increasing the crop intensity. Despite the existence of a good irrigation canal network in Pakistan, it suffers from wastage of a large amount of water in the irrigation process. The canal head withdrawals in Kharif 2010 (April-September) decreased by 21 percent and stood at 57.72 Million Acre Feet (MAF) as compared to 73.34 MAF during the same period last year. The decreased release is probably due to heavy rains and flood in the country. During the Rabi season 2010-11 (October-March), the canal head withdrawals showed a significant change, as it remained at 37.29 MAF compared to 28.59 MAF during the same period last year. Province-wise details are given in Table-1.

Table-1: Canal Head Withdrawals (Below Rim Stations) (MAF)

Provinces	Kharif (Apr-Sep) 2009	Kharif (Apr-Sep) 2010	%Change in Kharif 2010 over 2009	Rabi (Oct-Mar) 2009-10	Rabi (Oct-Mar) 2010-11	%Change in Rabi 2010-11 Over 2009-10
Punjab	36.37	29.00	-20	14.28	18.73	31
Sindh	29.77	22.61	-24	10.25	14.51	42
Balochistan	1.91	1.12	-41	0.79	0.88	10
KPK	5.29	4.99	-6	3.29	3.17	-4
Total:	**73.34**	**57.72**	**-21**	**28.59**	**37.29**	**23**

Source: Hydrology & Water Management Directorate, WAPDA, Lahore.

Water is the key input for agriculture, industry and urban development, as well as achieving Millennium Development Goals and targets and reducing poverty. The water sector gained major focus throughout the last decade in the development programs. Since water availability is persistently decreasing, the challenge is to formulate an effective and comprehensively efficient system of water resource management. The focus areas of investments in water sector are:

a. Augmentation of surface water resources by construction of small/medium and large dams.
b. Conservation measures (lining of irrigation channels, modernization/ rehabilitation of irrigation system, lining of watercourses and efficiency enhancement etc.
c. Protection of infrastructure from onslaught of floods and water logging and salinity.
d. Adoption of resources conservation technologies.

The Major Water Sector Projects under Implementation are given in Table-2.

Table-2: WAPDA Major Water Sector Projects under Implementation/nearly Completed

Projects	Location	Live Storage (MAF)	Area Under Irrigation (Acres)
Gomal Zam Dam	Khyber Pakhtunkhwa	1.14	163,086
Greater Thal Canal (phase-I)	Punjab	-	355,000
Rainee Canal (phase-I)	Sindh	-	412,000
Kachhi Canal (phase-I)	Balochistan	-	102,000
Raising of Mangla Dam	AJ & K	2.88	All over Pakistan
Satpara Dam	Skardu	0.05	15,536
Diamir Bhasha Dam	GB/KPK	6.4	All over Pakistan

In addition to the storage and irrigated projects, to upgrade irrigation for 291,000 acres, a programme has been started under "National Program for Water Conservation through High Efficiency Irrigation System (drip & sprinkler)" in Pakistan.

3. Water Sector Issues

There are many water sector issues faced by the country and major are as follows:

• **Water Shortage:** Pakistan is one of the world's most arid countries, with an average rainfall of under 240 mm a year. According to the benchmark water scarcity indicator (the Faulkenmark Indicator), Pakistan's estimated current per capita water availability of around 1,030 M^3 (Table-3) places it in the "high water stress" category (Table-4).

The water shortage scenario in Pakistan is further aggravated with high variability of rainfall. The onset of climate change and global warming is likely to severely affect the availability of water. After the loss of 3 major rivers, Ravi, Sutlej and Beas, to India under the Indus Waters Treaty 1960, India's construction of water storage infrastructure at Baghlihar and Kishanganga, is threatening the uninterrupted flow of water downstream into Pakistan.

Table-3: Per Capita Water Availability

Year	Population (Million)*	Per Capita Water Availability (M^3)
1951	34	5260
1961	46	3888
1972	65	2751
1981	84	2129
1991	115	1565
2002	139.5	1282
2010	173.51	1030
2015	191.71	932
2020	210.13	850
2025	227.35	786
2030	242.05	738

**Year 1951 to 2002 population adopted from WSIP study. For the year 2010 to 2030 adopted from Pakistan Economic Survey # 2010-11 and per Capita water availability computed accordingly.*

Table-4: Water Scarcity (Faulkenmark Indicators – 1992)

>1700M^3/Capita	Water Scarcity Rare
<1700M^3/Capita	Country faces seasonal or regular water-stressed conditions
<1000M^3/Capita	Water shortages hamper the health and well being of the human beings-Economic activities are affected.
<500M^3/Capita	Shortages are severe constraints to human life

Low Water Productivity: Whatever water is available is utilized in an inefficient manner. A comparison of wheat yields in California (USA), the Indian Punjab and the Pakistan Punjab shows that productivity in Pakistan relative to India and California is about 3:6:10 per unit of land and about 5:8:10 per unit of water.

- **Aging and Outdated Infrastructure:** Pakistan is blessed with one of the largest contiguous irrigation infrastructure. However, it was designed for water requirements of the 20th century and not for the 21st century. The design of system was for 60% cropping intensity and now the cropping intensity has crossed over 120%. Further the cropping pattern on which water demands and withdrawals were worked out was not supposed to cater to crops like sugarcane and rice which require high water use.

- **Low Water Charges:** The water charges are low and covers only 19% of O & M cost. The system maintenance requires a lot more attention due to deferred maintenance over the last 100 years.

- **Innovative Knowledge Based Management:** Challenges of the 21st century require the frontiers of knowledge and innovative approaches rather than historic practices. The institutions need redefining of their roles and to develop their capacities according to new responsibilities.

- **Ownership, Reforms and Joint Management:** The irrigation infrastructure operation and on loss of storage, agriculture of Pakistan is facing shortage during low-flow season. According to Indus River System Authority (IRSA) the shortage has gone up to 30 percent. Loss of storage of reservoirs is shown in Table-5.

Table-5: Loss of Storage of Reservoirs (MAF)

Reservoir	Original			Present			Loss		
	Gross	Live	Dead	Gross	Live	Dead	Gross	Live	Dead
Tarbela	11.620	9.690	1.930	7.635	6.557	1.078	3.985	3.133	0.852
							34%	32%	44%
Mangla (1242)	8.778	8.237	0.541	7.490	7.392	0.098	1.288	0.845	0.443
							15%	10%	82%
Chashma	0.870	0.720	0.150	0.320	0.260	0.060	0.550	0.460	0.090
							63%	64%	60%
Total:	**21.268**	**18.647**	**2.621**	**15.445**	**14.209**	**1.236**	**5.823**	**4.438**	**1.385**
							27%	**24%**	**53%**

- **Un-captured Water:** Despite acute water shortage in the system, data shows that a substantial amount of water escapes below Kotri to the Arabian Sea. Post-construction of Tarbela (1976-2010) average annual escapage below Kotri are 31.48 MAF, with a maximum of 91.83 MAF in 1994-95 and minimum of 0.79 MAF in 2000-01. Most of the flow to the sea occurs during Kharif season and very little during Rabi season. For better water management, storage capacity should be equivalent to at least 40 percent of total water availability but Pakistan's live storage capacity is about 7 percent. Pakistan needs to create a minimum of 65 MAF of storage for effective resource management.

- **Groundwater:** Groundwater under the Indus Irrigation System is plentiful and is derived from infiltration of surface water as well as local rainfall. However, depending upon the quality, the useable groundwater is confined to an area of 10 million hectares. The development of this resource is through private tubewells and account for a gross abstraction of about 50 MAF per annum. The surface water and groundwater in all canal commands are being used in conjunctive environment. In many canal commands, pumpage is greater than recharge, thus causing subsidence. There is no regular and proper monitoring of private tubewells capacity, their pumping hours and utilization. The private tubewells have been increased over one million exploiting groundwater indiscriminately and over mining is occurring in certain areas. Due to this situation saline water intrusion is causing pollution of fresh water aquifers. Thus ground water regulation is necessary to overcome this problem.

4. Present Population and Food Security

Pakistan is the world's sixth most populous country. With an estimated population of 173.51 million as at the end – June 2010, and an annual growth rate of 2.05%, it is expected that Pakistan will become the fourth largest nation in population terms by 2050. The proportion of population residing in urban centers has risen to 36%. Since 1950, it is estimated that Pakistan urban population has expanded over sevenfold. Future population growth at various index years upto 2030 is given in Table-6. The population of about 242 million will have to be provided food in year 2030.

Table-6: Future Population Growth

Year	Population(Million)
2010	173.51
2015	191.71
2020	210.35
2025	227.35
2030	242.05

Source: *Pakistan Economic Survey 2010 – 11. Page 154*

According to a Report titled "Food Insecurity in Pakistan 2009", it is observed that state of food security in Pakistan has deteriorated since 2003. The conditions for food security are inadequate in 61 percent districts (80 out of 131 districts) of Pakistan. There is a sharp increase from 2003, when conditions for food security were inadequate in 45 percent districts (54 out of 120 districts) of Pakistan before 2003. In terms of population almost half of the population of Pakistan (48.6%) does not have access to sufficient food for active and healthy life at all times. FATA has highest percentage of food insecure population (67.7%) followed by Balochistan (61.2%) and Khyber Pakhtunkhwa (56.2%). The lowest percentage of food insecure population (23.6%) is in Islamabad. Dera Bugti has the highest %age of food insecure people (82.4%).

Balochistan has the maximum number of districts with worst conditions in terms of food security. The 20 districts of Pakistan with worst conditions for food security include 10 districts from Balochistan 5 from FATA, 3 from KPK and 1 from Gilgit Baltistan and Sindh each. Dera Bugti, Musa Khel, Upper Dir, North Waziristan, Kohistan, Mohmand, Dalbaudin, South Waziristan, Orakzai and Panjgur are the 10 districts with worst conditions of food security in Pakistan.

The consumption of wheat in Pakistan declined by 10% in 2009-10 due to lack of purchasing power as result of price hike assuming safely that ensuring food security is much beyond increased wheat production. Only 7.6 percent districts fall in the category of having reasonable conditions for access to food. The third pillar of food security is food absorption measured through state of sanitation, drinking water, female literacy etc. Only 7.6% district met pre-requisites for reasonable food absorption in 2009 which was 9% during 2003. It is revealed that individual security in Pakistan has deteriorated from 2003 to 2009. The four levels of security: individual, national, regional and global are inter-connected and ignoring any one of them may threaten rest of the three levels of security.

This growing population will need more food, water, fibre and energy to meet the requirements. Fifty years ago, the world had fewer than half as many people as it has today. They consumed calories, ate less meat and thus required less water to produce their food. Today the competition for scarce water resources in many places is intense which will become acute in coming years. The feeding habits will have to change. As population grows, it will demand for more food and water. The future food requirement projections will be determined by the driving factors such as, population growth and dietary changes. With rising incomes and urbanization food habits change towards more nutritious and more varied diets; a shift from cereals to livestock and fish products and high value crops. Keeping the case simple, income elasticity factor has not been taken into account and food grain projections have been worked out taking annual rate of consumption (kg/capita) for various commodities (food grains & edible oils) as given in WSIPS Report 1990 and National Water Policy 2003 Report. The detail is given in Table-7.

Table-7: Projected Food Production Requirements, 2010 to 2030

Commodity	Rate of Consumption* Kg/capita/ annum	Production Requirement (Million Tonnes)**				
		2010	2015	2020	2025	2030
Wheat	128	24.43	26.99	29.59	32.01	34.08
Rice	15	2.76	3.05	3.34	3.61	3.85
Maize	9.8	1.87	2.07	2.27	2.45	2.61
Pulses	6.3	1.35	1.50	1.64	1.77	1.88
Other grains	3.8	0.73	0.80	0.88	0.95	1.01
Edible Oils	11.4	1.98	2.19	2.40	2.59	2.76

* *Source: Water Sector Investment Planning Study Main Report Dec.1990 & National Water Policy 2003.*

** *Assuming wastage & seed requirement for wheat, maize and other grains @ 10%, for rice @ 6% and for pulses @ 24%.*

5. Shortages in Water Availability and Food Grains

The scarcity of water and shortages of food grains are described as under:

5.1 Water Requirements VS Availability

Pakistan's population of 173.5 million in the year 2010 will reach 242 million by the year 2030. Population rise, rapid urbanization and better socio-economic conditions, will bring about increasing pressure on water resources. Future water requirements for all sectors are given in Table-8 and discussed as under.

Table-8: Future Water Requirements at Farm Gate (MAF)

Sector	Year					
	2000*	2010**	2015**	2020**	2025*	2030**
- Water Supply & Sanitation	4.5	6.0	7.5	9.0	10.5	12.0
- Industry	3.5	3.8	4.1	4.5	4.8	5.1
- Agriculture	99.0	104.0	109.0	114.0	119.0	124.0
- Environmental Protection	1.3	1.4	1.5	1.6	1.7	1.8
Total:	**108.3**	**115.2**	**122.1**	**129.1**	**136.0**	**142.9**

Source: **For Year 2000 & 2025 National Water Policy Vol II, January 2003*
***For years 2010, 2015, 2020 & 2030 computed on proportional basis.*

a) *Agriculture* - The total area of the country is 79.61 Million hectares (Mha) of which 23 Mha is designated as cultivated area. About 19.6 Mha cultivated land is served by irrigated water, while the remaining 3.4 Mha is rain fed. Almost 90 percent of water resources are being used to meet crop water demand. Increases in agricultural production to meet the needs of a rising population, will require additional water. Based on population growth projections, by 2030 an estimated additional 20 MAF over year 2010 will be needed for agriculture at the farm gate (assuming a 50 percent increase in crop yields from non-water inputs).

b) *Municipal Use* – The current total water use for domestic and municipal purposes in both urban and rural areas are estimated at 4.5 MAF. By 2030 requirements for water supply, rural potable water and sanitation are estimated to be 12.0 MAF resulting in shortfall of 7.5 MAF.

c) *Industry* - There are over half a million large and small industrial units in the country, of which nearly 120,000 are engaged in textile, chemical, fertilizer, tanneries and other manufacturing and processing activities. The water use by all industries and mines in year 2010 is estimated to be 3.8 MAF. This is expected to rise to 5.1 MAF by 2030, i.e. an additional requirement of 1.3 MAF.

d) *Environment* - In order to ensure adequate water throughout Pakistan for wetlands, environmental protection and increased irrigated forestry, about 1.8 MAF water will be required by the year 2030. The equivalent water requirement for 2010 is about 1.4 MAF.

Water availability in Pakistan is 1,030 m^3 per capita/year (2010); this is already well below the 1,700 m^3per capita/year threshold for water stressed conditions. Thus Pakistan is already fast moving into a condition of 'water scarcity'. This situation is likely to deteriorate in future as the gap between supply and demand widens. However, the gross additional water demand (at the farm gate) for all sectors over year 2010 will be about 27.7 MAF (20 MAF for agriculture and 7.7 MAF for municipal water supply, rural potable and sanitation, industry and the environment). The corresponding requirement at the canal head (including provision for system losses where applicable) would be nearly 39 MAF. Water available for future development is about 31 MAF including 21.5 MAF of river flow, 6.4 MAF from groundwater and 3 MAF from rainfall harvesting.

This shortfall of about 39 MAF of water by the year 2030 is to be met through creating storage facilities and diverting 21.5 MAF to canals which at present is flowing to sea after allowing 10 MAF for environmental flows. This additional diversion of 21.5 MAF at canal head would add about 15.6 MAF at farm gate. Taping a potential of 6.4 MAF pumpage from ground water and 3 MAF from rain water harvesting will add to this making additional water availability at farm gate upto 25 MAF. The program of water course improvement by 2030 will cover all the water courses of country enhancing water course efficiency upto 92% and will save wastage of about 10 MAF in the irrigation system and thus the total water availability at farm gate would be about 143 MAF. The future water requirement of about 143 MAF for all sectors by 2030 will be safely met as discussed.

5.2 Food Grains Requirement Vs Availability

Food grains are to be supplied through reliance on our agriculture. The Agriculture sector continues to play a central role in Pakistan's economy. It is the second largest sector, accounting for over 21 percent of GDP, and remains by far the largest employer, absorbing 45 percent of the country's total labour force. Nearly 62 percent of the country's population resides in rural areas, and is directly or indirectly linked with agriculture for their livelihood. The Agriculture sector's strong linkages with the rest of the economy are not fully captured in the statistics. While on the one hand, the sector is a primary supplier of raw materials to downstream industry, contributing substantially to Pakistan's exports, on the other, it is a large market for industrial products such as fertilizer, pesticides, tractors and agricultural implements. Despite its critical importance to growth, exports, incomes, and food security, the Agriculture sector has been suffering from secular decline (Table-9).

Table-9: Historical Agricultural Growth Performance

Years	Percent
1960's	5.1
1970's	2.4
1980's	5.4
1990's	4.4
2000's	3.2

Source: Pakistan Economic Survey 2010-11

Growth in the sector, particularly in the crop sub-sector, has been falling in the past three decades. Productivity remains low, with yield gaps rising i.e. 36 percent in case of rice, paddy and 52 percent in case of wheat and cotton seed. (Table-10) Critical investments in new seeds, farming technology and techniques, and the water infrastructure are not being made. Without major new investments in Agriculture, it is unclear how prepared Pakistan would be to tackle emerging challenges such as declining water availability, climate change and food insecurity.

Table-10: Comparison of National Crop Yields with Major Growing Countries (kg/ha)

Country	Wheat	Percent of Best*	Sugarcane	Percent of Best*	Rice (Paddy)	Percent of Best*	Cotton Seed	Percent of Best*
World	3086	65	71510	59	4309	44	2099	54
China	4762	100	73114	60	6556	67	8906	100
India	2802	59	68877	57	3370	35	1206	31
Pakistan	2451	52	51494	43	3520	36	2046	52
USA	3018	63	73765	61	7672	79	2250	58
Brazil	-	-	79709	66	4229	44	3757	96
Egypt	-	-	121136	100	9731	100	2333	60

*Note: *Best = 100*

Source: *Ministry of Food and Agriculture, 2008*

5.2.1: Past Crop Production Trends

To meet the food requirements, future crop production targets have to be set keeping in view the past growth trends and potential to accelerate the growth. Crop production increases from 1990-95 to 2005-10 based on five years averages are given in Table-11 and averages were analyzed and compared to Medium Term Development Framework (MTDF 2005-10) targets in terms of annual growth rate. The annual growth rates for various crops ranged from -0.7 to 11.4 percent over a period of 15 years. There was a decrease in production of other grains (barley, jowar, bajra etc). The production targets of MTDF were achieved in the range of 22 to 96 percent in various crops. The historic annual growth rates in cropped area and yields per hectares over a period of 15 years are given in Table 12 & 13 respectively.

Keeping in view the past growth rate in cropped area and yields, future projections of area and yield have been made as given in Table 14 & 15. There was a negative trend in area under pulses and other grains where as for future the area growth for these crops was projected at annual rate of one percent. While projecting future crop yields, the potential gap was also considered and attainable level was targeted. Based on these projections of area and yield, future food production availability is worked out and given in Table-16.

Table-11: Crop Production Targets and Achievements *(Million Tonnes)*

Crop	Achievement				Growth Rate (%) 1990-95 to 2005-10	MTDF Target		Achievement as	
	1990-1995	1995-2000	2000-2005	2005-2010		Production 2009-10*	Annual Growth rate (2005-10)	% of production Target	% of Annual Growth rate
Wheat	16.12	18.24	19.51	22.57	2.7	25.44	3.80	88.7	71.0
Rice	3.41	4.49	4.61	6.08	5.2	6.37	5.00	95.4	104.0
Maize	1.23	1.57	1.95	3.33	11.4	3.46	4.50	96.2	250.0
Pulses	0.68	0.90	0.82	0.86	1.8	1.56	8.40	55.1	21.4
Other Grains	0.57	0.56	0.52	0.51	-0.7	0.70	3.50	72.8	-
Edible Oil seeds	1.17	1.32	1.45	1.65	2.7	7.49	5.00	22.0	54.0

Source: *Agricultural Statistics of Pakistan, 2009 – 10 and Medium Term Development Framework (MTDF) 2005-10.*

Table-12: Historic Cropped Area Growth During 1990-95 to 2005-10 (mha)

Crop	1990-1995	1995-2000	2000-2005	2005-2010	Annual Growth Rate (%)
Wheat	8.17	8.31	8.17	8.75	0.47
Rice	2.10	2.33	2.34	2.71	1.94
Maize	0.87	0.94	0.95	1.02	1.15
Pulses	1.48	1.54	1.42	1.45	-0.13
Other Grains*	0.98	0.92	0.87	0.84	-0.95
Edible Oil Seed	0.54	0.65	0.62	0.69	1.85

* *Other grains include Jowar, Bajra and Barley.*

Source: *Agricultural Statistics of Pakistan, 2009-10.*

Table-13: Historic yield of Food Crops During 1990-95 to 2005-10

(Kg/ha)

Commodity	1990-1995	1995-2000	2000-2005	2005-2010	Annual Growth Rate (%)
Wheat	1974	2196	2388	2589	2.0
Rice	1626	1922	1969	2240	2.5
Maize	1410	1658	2050	2050	3.0
Pulses	459	517	543	589	1.9
Other Grains*	659	588	687	703	0.4
Edible Oil Seed	692	742	662	645	-0.4

* Other *grains include Jowar, Bajra and Barley.*
Source: *Agricultural Statistics of Pakistan, 2009-10.*

Table-14: Future Projected Cropped Area under Various Crops

(mha)

Crop	Base Year (2009-10)	2015	2020	2025	2030	Annual Growth Rate (%)
Wheat	9.13	9.29	9.46	9.62	9.79	0.4
Rice	2.88	3.10	3.33	3.58	3.84	1.7
Maize	0.94	0.98	1.02	1.06	1.11	0.9
Pulses	1.39	1.47	1.54	1.62	1.70	1.0
Other Grains	0.81	0.85	0.89	0.94	0.99	1.0
Edible Oil seeds	0.62	0.66	0.72	0.78	0.84	1.8
Total:	**15.77**	**16.35**	**16.96**	**17.60**	**18.27**	**0.8**

Table-15: Future Projected Yields for Various Crops (Kg/ha)

Crop	Base Year (2009-10)	2015	2020	2025	2030	Annual Growth Rate (%) (2010-30)	Yield of 2030 as % of present yields of main growing countries
Wheat	2553	2767	2999	3251	3524	2.0	75 (China)
Rice	2387	2688	3027	3408	3837	3.0	58 (China)
Maize	3488	3902	4365	4883	5463	2.8	67 (Egypt)
Pulses	547	587	630	670	719	1.6	-
Other Grains	679	690	702	714	726	0.4	-
Edible Oil seeds	311	342	376	424	455	2.3	80 (China)

Table-16: Future Projected Food Requirements vs Availability (million tonnes)

Crop	Base Year 2009-10			2015			2020			2025			2030		
	Requi-rement	Avail-ability	Differ-ence	Requi-rement	Avail-ability	Differ-ence	Requi rement	Avail-ability	Difference	Requi rement	Avail-ability	Differ-ence	Requir-ement	Avail-ability	Differ-ence
Wheat	24.43	23.28	-1.15	26.99	25.71	-1.28	29.59	28.36	-1.23	32.01	31.28	-0.73	34.08	34.51	+0.43
Rice	2.76	6.88	+4.12	3.05	8.33	+5.28	3.34	10.08	+6.74	3.61	12.19	+8.58	3.85	14.75	+10.90
Maize	1.87	3.26	+1.39	2.07	3.82	+1.75	2.27	4.47	+2.18	2.45	5.19	+2.74	2.61	6.06	+3.45
Pulses	1.35	0.77	-0.58	1.50	0.87	-0.63	1.64	0.97	-0.67	1.77	1.09	-0.68	1.88	1.22	-0.66
Other Grains	0.73	0.55	-0.18	0.80	0.59	-0.21	0.88	0.62	-0.26	0.95	0.67	-0.28	1.01	0.72	-0.29
Edible Oil	1.98	0.19	-1.79	2.19	0.23	-1.96	2.40	0.27	-2.13	2.59	0.33	-2.26	2.76	0.38	-2.38

5.2.2. Gaps in Food Production

The food requirements and food production targets for various index years have been compared in Table-16 to assess shortfall or surpluses in various crops. It is obvious from the table that wheat, rice and maize are surplus to the requirements even after meeting seed, feed and wastage requirements. The rice being the exportable crop has sufficient surplus for earning foreign exchange. The edible oil shortfall continuous to increase and will have to rely on export unless special emphasis is given to bring more area under oilseed crops and develop high yielding crop varieties.

5.2.3. Role of Water in Bridging the Production Gap

The additional supplies of irrigation water are necessary to irrigate the increased cropped area given in Table-17 and also to achieve the high yields as shown in Table-15. Table-18 gives the additional water requirements at Farm Gate considering the projected food requirements of the rapidly growing population and export targets. The food production targets are to be achieved on the basis of increased cropped area and yield. The potential for future expansion in cropped area and yield increase as compared to major growing countries present yield were considered. About 2.5 million hectares additional cropped area would be required during 2030 for meeting the food requirements as given in Table-17. Based on this additional cropped area 20 MAF water would be required at farmgate as given in Table-18. Summary of food requirements, food production and shortfall are given in Table-19.

Table-17: Additional Crop Area Requirements to Meet Production Targets

(mha)

Crop	Base year 2009-10 cropped area	2015	2020	2025	2030
Wheat	9.13	0.16	0.33	0.49	0.66
Rice	2.88	0.22	0.45	0.70	0.96
Maize	0.94	0.04	0.08	0.12	0.17
Pulses	1.39	0.08	0.15	0.23	0.31
Other Grains	0.81	0.04	0.08	0.13	0.18
Edible oil seeds	0.62	0.04	0.10	0.16	0.22
Total :	**15.77**	**0.58**	**1.19**	**1.83**	**2.50**

Table-18: Additional Water Requirements at Farm Gate to Meet Crop Production Targets Based on Area and Yields

(million acre feet)

Crop	Water requirement (AF/acre) at		2015	2020	2025	2030
	Root zone*	Farmgate @ 81% efficiency				
Wheat	1.08	1.33	0.53	1.08	1.61	2.17
Rice	5.00	6.17	3.35	6.86	10.67	14.50
Maize	2.08	2.57	0.25	0.51	0.76	1.08
Pulses	0.83	1.02	0.20	0.38	0.58	0.78
Other Grain	1.08	1.33	0.13	0.26	0.43	0.58
Edible oil seeds	1.33	1.64	0.16	0.41	0.65	0.89
		Total:	**4.52**	**9.50**	**14.70**	**20.00**

* Water Sector Investment Planning Study Report, 1990.

Table-19: Summary of Population, Food Requirements, Estimated Production, Additional Area & Water Need v/s Surpluses/ Short Falls

Projection	2010	2020	2030
a) Population (millions)	**173.51**	**210.35**	**242.05**
b)Production Requirements (million tonnes)			
Wheat	24.43	29.59	34.08
Rice	2.76	3.34	3.85+
Maize	1.87	2.27	2.61
Pulses	1.35	1.64	1.88
Other Grains	0.73	0.88	1.01
Edible Oils	1.98	2.40	2.76
c) Estimated Production (million tonnes)			
Wheat	23.28	28.36	34.51
Rice	6.88	10.08	14.75
Maize	3.26	4.75	6.06
Pulses	0.77	0.97	1.22
Other Grains	0.55	0.62	0.72
Edible Oils	0.19	0.27	0.38

d) Requirements			
Additional Irrigated Area (mha)		1.19	2.50
Additional Water (MAF)	-	10.85	23.00
e) Surplus/Deficit (million tonnes)			
Wheat	-1.15	-1.23	+0.43
Rice	+4.12	+6.74	+10.9
Maize	+1.39	+2.48	+3.45
Pulses	-0.58	-0.67	-0.66
Other Grains	-0.18	-0.26	-0.29
Total Grains	+3.6	+7.06	+13.83
Edible Oils	-1.79	-2.13	-2.38

6. Future Strategic Areas for Water Management to Ensure Food Security

The following core areas require immediate attention while formulating contingency action plan and management/policy plans:

6.1. Water Demand Management

Water availability is diminishing with a growing population and increasing urbanization. The need for better water demand management is well established. The following represent some areas of immediate attention:

- Promoting efficient use
- Pricing water better
- Optimizing cropping pattern
- Integrated use and recycling of water

6.2. Climate Change Impact on Water and Agriculture

Pakistan has been cited amongst the most vulnerable country due to extreme weather, change in temperature and rainfall. To mitigate impacts of climatic change, the following actions will be required:

- Need for carry over dams
- Efficient irrigation (water conservation & demand management)
- Controlling population growth rate
- Changed cropping pattern

6.3 Saline water potential

Pakistan's groundwater aquifer consists of adjoining layers of fresh and saline waters and the existential proportion of these layers varies from place to place. Today's groundwater pump age is around 50 MAF which can be increased by harnessing additional pumpage of ground water and utilization of saline drainage surplus upto 6.4 MAF. The bio-saline technology is to be promoted. The investment will be required in future for adoption of bio-saline agricultural technology.

6.4 Increasing the productivity of land and water

The hope lies in closing the gap in agricultural productivity. Gaining more yield and value from less water can reduce future demand for water, limiting environmental degradation and easing competition for water. Adoption of best agriculture practices and resource conservation technologies can help gain more yield per land and drop of water.

7. Conclusions and Recommendations

Based on the preceding discussions, the following conclusions and recommendations are framed:

7.1 Conclusions:

- At present estimated population is over 173 million.
- The available surface water resources of Pakistan are 145.63 MAF.
- The present water requirement at farm gate is about 115 MAF for all sector against availability of 108 MAF including groundwater.
- The food security in Pakistan has deteriorated since 2003 and almost half of the population at present, does not have access to sufficient food for active and healthy life at all times.
- The per capita water availability reduced from 5260 m^3 (1951) to 1030 m^3 (2010).
- The live storage capacity of reservoirs has reduced from 18.647 to 14.209 MAF indicating 24% water storage loss.
- Food security situation at present is not satisfactory and in future by 2030, an additional population of about 68.5 million will require additional food grains of about 12.3 million tonnes and edible oil of about 0.8 million tonnes. The additional area of about 2.5 million hectares and additional 20 MAF water at farm gate will be required to meet food requirements of additional population. The business as usual will not meet the food requirements unless special efforts are made for development and management of water resources and agriculture.
- Land and water productivity are low as compared to World Standards.
- Low water charges covering only 19% of O & M cost.

7.2 Recommendations:

- The construction of major reservoirs is urgently needed for storage and better regulation of water.
- The rain water harvesting and groundwater recharge are to be established.
- Per unit of water and land productivity enhancement is the need of the time without any further delay. Best management practices for agriculture development need to be adopted by farmers with the adequate support of agriculture extension services. Resource conservation technologies to save water and increase crop yields need to be extended all over the country.
- Climate change impact on water and agriculture are showing negative effects and need to be looked into carefully as its impacts will be impeding economic growth of the country.
- The groundwater is being mined due to surface water shortage. Thus water conservation at all levels including saline water treatment etc, needs attention in view of additional future needs as each drop for crop basis.
- A comprehensive study at national level is required to precisely estimate the water, crop area and food requirements under changing consumption pattern and income elasticity to feed the growing population on sustainable basis.

References:

1. Agricultural Statistics of Pakistan 2009-10.
2. Integrated land and Water Management of Food & Environment Security - Research Summaries and Policy Recommendations-Annual Report 2002-2003 International Water Management Institute. (IWMI).
3. National Water Policy 2003, Federal Flood Commission/ Chief Engineering Advisor MOWP, Islamabad
4. Pakistan National Committee on Irrigated and Drainage (PANCID) Irrigation, Drainage and Flood Control in Pakistan October, 2008.
5. Pakistan Economic Survey 2009-10 and 2010-11.
6. Proceedings World Water-Day 2010. Pakistan Engineering Congress Lahore.
7. Pakistan & Gulf Economist March, 2009, July, 2011.
8. Project Impact Evaluation Study (PIES) for the project National Program for Improvement of Water Courses in Pakistan (NPIWC) final report April, 2011, MINFA, GOP, Islamabad.

9. SDPI Research & News Bulletin Islamabad, Vol. 17 No. 2 April, June 2010.
10. Water Figures Turning Research into Development News letter of the International Water Management Institute (IWMI) special issue 2010.
11. Water Saving in Agriculture Publication No. 95 (ICID) 2008.
12. Water for Food, Water for life. A Comprehensive Assessment of Water Management in Agriculture. Summary, IWMI, 2007.
13. Water Sector Investment Planning Study Report 1990.

DISCOVERING LINKAGES BETWEEN WATER AND FOOD SECURITY DIMENSIONS

by

Ali Hasnain Sayed

Manager Policy, WWF – Pakistan

&

Ms. Dure Shahwar

Project Officer – WWF – Pakistan

(The Authors would like to thank Dr. Ejaz Ahmed, Senior Director, WWF- Pakistan, who helped with the reviewing of the paper and gave useful suggestions towards its finalization)

Abstract

Water is one of the gifts of Nature that has been taken for granted by mankind. It ensures sustenance of almost all the life forms on planet earth but unfortunately, it has been exploited in a very unsustainable way. It is because of the mismanagement, over-exploitation and poor governance of water that the entire world is facing the threat of looming water scarcity further translating into Food and Energy crises. Being the sixth most populous country in the world, with around 60% of the total employment associated with the agriculture sector, Pakistan is a country considered to be on the brink of food insecurity. However this asks for a better understanding of the relationship between water and food security in the right context concerning Pakistan. Keeping that in perspective, the paper will discuss the dimensions of Food security and their linkages to water. A study based upon food availability, accessibility, stability and utility along with the role of water has been conducted to draw the linkages between them. The dimensions of food security and water have been observed under economic, health and natural circumstances. In conclusion it reflects upon suggestions that can help towards attaining water and food security. It further stresses on the need of understanding the concept of food security in the right context so as to develop a pragmatic approach towards countering its affects.

Background

Around 700 million people in 43 countries suffer today from water scarcity.[1] By 2025, 1.8 billion people will be living in countries or regions

---

[1] International Decade for Water for Life 2005-2015: Water Scarcity See online: http://www.un.org/waterforlifedecade/scarcity.shtml

with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions.[2] Population growth, increasing food requirements, higher per capita water requirements, economic growth, increasing water infrastructure, climate change, collapsing wetland, river, lake and estuary ecosystems are all contributors to water scarcity.[3]

Pakistan is a highly water stressed country (<1066 m^3/capita)[4] and is expected to reach water scarcity (<1000 m^3/capita)[5] in the coming few years.

Majority of the population of Pakistan is dependent upon the Indus River system for their water needs and activities because of which it is under immense pressure. The agriculture sector plays a dominant role in economy as it contributes 21% of the Gross Domestic Product (GDP), employs 45% of the labor force, and directly and indirectly serves the rural population of Pakistan i.e. 60% of total population.[6]

---

[2] Ibid

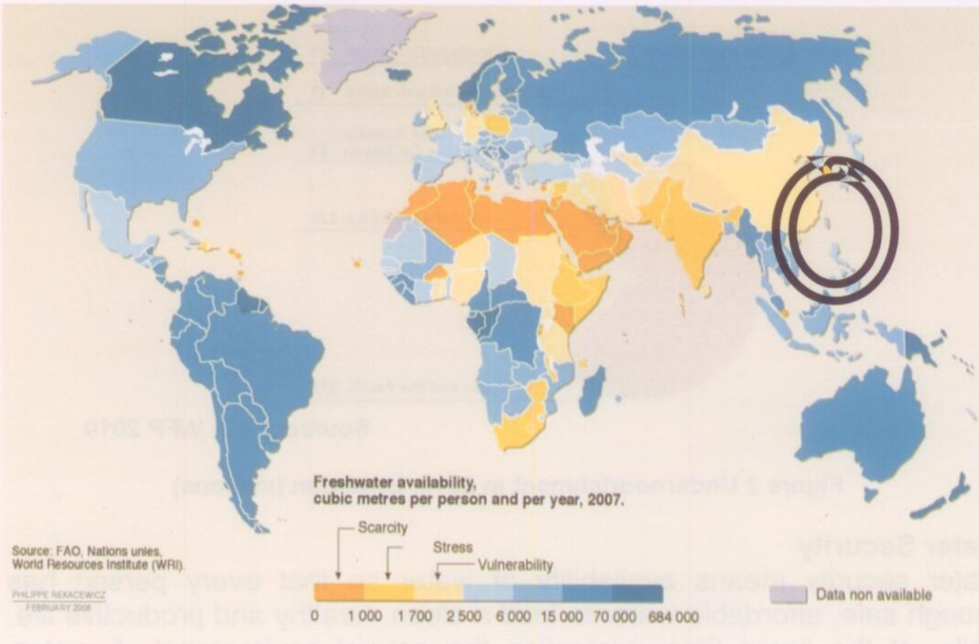
[3] WWF and Lloyds, "Lloyd's 360° Risk Insight Global water scarcity: risks and challenges for business', 2010

[4] Ahmad, S. & ADB, "Present Situation and Future Strategy", National Seminar on Water Conservation, PARC, PMPIU, MoW & P, 2009

[5] Briscoe, J. and Qamar, U., Pakistan's Water Economy: Running Dry (World Bank/Oxford University Press, 2006)

[6] Economic Survey of Pakistan 2010-2011

*Undernourished are those who receive less than 90 percent of the minimum dietary intake over a long-term time period: they lack energy for an active, productive life and are more susceptible to infectious diseases. (See online: http://www.mhhe.com/biosci/pae/glossaryu.html)



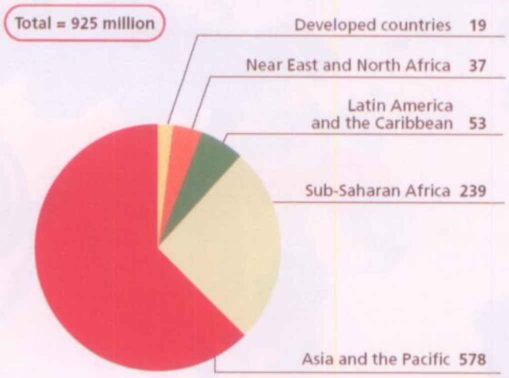
Source: FAO, *World Resource Institute (WRI) 2007*

Figure 1 Global Freshwater Availability, 2007

Based on the latest available data, the total number of undernourished* (refer to footnote) people in the world is estimated to have reached 1 023 million in 2009 and is expected to decline by 9.6 percent to 925 million in 2010. Developing countries account for 98 percent of the world's undernourished people and have a prevalence of undernourishment of 16 percent (Figure 2). The majority of the world's undernourished people live in developing countries. Two-thirds live in just seven countries (Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia and Pakistan) and over 40 percent live in China and India alone.[7] In Pakistan almost 26% of the population is undernourished[8], which being an agricultural country is a big question mark.

[7] FAO; WFP: The State of Food Insecurity in the World, Addressing Food Insecurity in Protracted Areas, 2010

[8] See online: www.foodsecurityportal.org/pakistan



Source: FAO; WFP 2010

Figure 2 Undernourishment in 2010, by region (millions)

Water Security

Water security means availability of water so that every person has enough safe, affordable water to lead a clean, healthy and productive life, while, at the same time, protecting the natural environment. A water-secure world integrates concern for the intrinsic value (visible + virtual) of water and its use for human survival and well-being, and includes the use of water for agriculture, economic activity and environmental protection. Both water quantity and water quality aspects must be considered, as poor water quality affects its use value and its impact on the environment.[9] Pakistan stands on the 7th position among the top ten "water insecure" countries of the world and as revealed in 2010 Water Security Risk Index[10] (refer to footnote).

Food Security

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." (World Food Summit, 1996)

The term food security was coined in 1974 when World Food Conference was held in the wake of the food supply and availability at national and international levels. It was then, when food security was ever defined as

---

[9] Global Water Security, Submission by the Global Water Partnership, 2009

[10] New Maplecroft index rates Pakistan and Egypt among nations facing "extreme" water security risks. See online: http://maplecroft.com/about/news/water-security.html

The index is calculated by measuring the four key areas. These include: access to improved drinking water and sanitation; the availability of renewable water and the reliance on external supplies; the relationship between available water and supply demands; and the water dependency of country's economy.

"Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices".[11] The definition has been redesigned a number of times after mid 70s but the theme always remained the same "FOOD AVAILABILITY, STABILITY and ACCESS". In a broader perspective food security has its linkage directly and indirectly with WATER- a natural resource which sustains life on earth.

Food Insecurity

Food insecurity exists when people are undernourished as a result of the physical unavailability of food, their lack of social or economic access to adequate food, and/or inadequate food utilization. Food-insecure people are those individuals whose food intake falls below their minimum calorie (energy) requirements, as well as those who exhibit physical symptoms caused by energy and nutrient deficiencies resulting from an inadequate or unbalanced diet or from the body's inability to use food effectively because of infection or disease (FAO 2012).[12]

Three general types of food insecurities have been defined; Chronic food insecurity, Transitory food insecurity and Seasonal food insecurity.[13]

-Chronic Food Insecurity *occurs when people are unable to meet their minimum food requirements over a sustained period of time. It is long-term or persistent and results from extended periods of poverty, lack of assets and inadequate access to productive or financial resources.*

-Transitory Food Insecurity *occurs when there is a sudden drop in the ability to produce or access enough food to maintain a good nutritional status. It is short term and temporary and results from short-term shocks and fluctuations in food availability and food access, including year-to-year variations in domestic food production, food prices and household incomes.*

-Seasonal Food Insecurity *falls between chronic and transitory. It occurs when there is a cyclical pattern of inadequate availability and access to food. This is associated with seasonal fluctuations in the climate, cropping patterns, work opportunities and disease.*[14]

---

[11] FAO: Food Security, Policy Brief, Issue 2, 2006.

[12] FAO 2012 See Online: http://km.fao.org/fsn/resources/glossary0/en/

[13] FAO: An introduction to the Basic Concepts of Food Security, Food security Information for Action, Practical Guides, 2002

[14] Ibid

Dimensions of Food Security

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."(WFS 1996)

It can be inferred from the definition that Food security is a multi-dimensional term. Therefore, these dimensions have been further elaborated.

1. Food Availability

Food availability is achieved when sufficient quantities of food are consistently available to all individuals. Sources of such a food supply could be household's own production, other domestic output, commercial imports or food assistance.[15]

2. Food Stability

To be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (e.g. seasonal food insecurity). The concept of stability can therefore refer to both the availability and access dimensions of food security (FAO).[16]

3. Food Accessibility

Access to food is ensured when a household and all members of the household have enough (economic) resources to acquire food meeting the nutritional requirements and dietary needs of the household. Access is thus primarily a function of a household's income, its distribution within the household and the price of food, besides the physical aspect. Economic accessibility implies that personal or household financial costs associated with the acquisition of food, to meet dietary needs adequately, should be at such a level that the attainment and satisfaction of other basic needs are not threatened or compromised.[17]

---

[15] *Food Insecurity in Rural Pakistan 2003,* World Food Program (WFP) Pakistan, SDPI, Islamabad

[16] FAO: An introduction to the Basic Concepts of Food Security, Food security Information for Action, Practical Guides, 2002

[17] *Food Insecurity in Rural Pakistan 2003,* World Food Program (WFP) Pakistan, SDPI, Islamabad

4. Food Utility

Food utility can be defined as Utilization of food through adequate diet, clean water, sanitation and healthcare to reach a state of nutritional well-being where all physiological needs are met. This brings out the importance of non-food inputs in food security (FAO).[18]

Linkages between Water and Food Security Dimensions

One of the main factors limiting future food production will be water.[19] Especially in areas like Pakistan where water scarcity has already reached its limits and where 95% of the water is consumed by agriculture.[20] Being an agro-based country Pakistan relies heavily on the availability of water. There are certain connections between the dimensions of food security and water. Water's abundance and absence can cause floods on one hand and droughts on the other which directly and indirectly affect the quantity, quality and accessibility of food touching all other dimensions. For a clearer picture water's role and its link to the dimensions are further explained as follows:

1. Food Availability and Water:

In this context water plays a significant role in making sure that the crop water requirement is fulfilled or there is enough water for the crop to grow. Currently, net water availability for crop consumptive requirement is around 78.79 MAF, whereas the net water requirement for crop consumptive use for existing cropping pattern is around 95.8 MAF, considering all the crops and total irrigated cropped area. Thus the shortfall is 17.01 MAF (17.8 %) without rainfall contribution and shortfall of 3.61 MAF (3.8 %) considering rainfall contribution of 13.4 MAF in a mean year.[21]

Domestic production, commercial imports, and food aid are the main constituents of food availability at the national level.[22] Nationally, the average yield of sugarcane, as given in Table 1, is the highest; whereas, cotton's production is the lowest amongst other staple crops. Pakistan's average production is lesser as compared to the other countries internationally.

---

[18] FAO: An introduction to the Basic Concepts of Food Security, Food security Information for Action, Practical Guides, 2002

[19] UNEP- IWMI "An Ecosystem Services Approach to Water and Food Security", 2011

[20] CPI and WWF's Unpublished Report on "Water Stewardship: The role of Industry", 2012

[21] Federal Bureau of Statistics, "Pakistan Statistical Year Book", Government of Pakistan, NBF Pakistan, 2010

[22] Ahmad, M. The State of Food Security in Pakistan: Future Challenges and Coping Strategies, Paper Submitted for Presentation at the "26th AGM and Conference of PSDE being held on 28-30 December 2010

Table 1: Comparison of National Average Yields of Pakistan and other Countries

Country	Average yield (kg / hectare)				
	Wheat	Cotton	Rice	Maize	Sugarcane
World	2,720	1,788	3,916	4,343	65,802
India	2,770	754	2,915	1,705	68,049
China	3,885	3,978	6,266	5,022	66,802
Egypt	6,006	2,654	-	-	119,838
Mexico	5,151	-	-	2,437	74,746
France	7,449	-	-	9,914	-
Pakistan					
National Average	2,262	1,867	2,882	1,768	48,056
Progressive farmer	4,500	2,890	4,580	7,455	106,700

Source: ZTBL, 2010

Table 2: Per capita availability of Food item

Food item	Unit	1989-90	2008-09
Wheat	Kg	129.4	125.0
Rice	Kg	20.7	14.6
Other grains	Kg	9.7	11.4
All cereal	Kg	160.7	151.0
Pulses	Kg	5.4	8.0
Milk	Kg	107.6	175.2
Edible oil	Kg	10.3	12.6
Meat	Kg	17.3	20.5
Fruit & Vegetables	Kg	82.2	77.6
Sugar	Kg	27.0	29.3
Eggs	Dozen	2.1	5.2
Calories	Number	2324	2363
Protein per day	Gram	67.4	70

Source: Economic Survey of Pakistan 2007-08

A study published by Falkenmark, Rockström and Karlberg (2009) presents a very bleak picture of Pakistan in terms of water shortage and potential of increasing food production through expansion in area by 2050. In terms of area, very low potential left since most arable land is already in use, while the freshwater will be the most fundamental constraint in food production in coming decades.[23]

[23] Falkenmark, M., Rockström, J., Karlberg, L., Present and future water requirements for feeding humanity. Food Security 1: 59-69. 2009

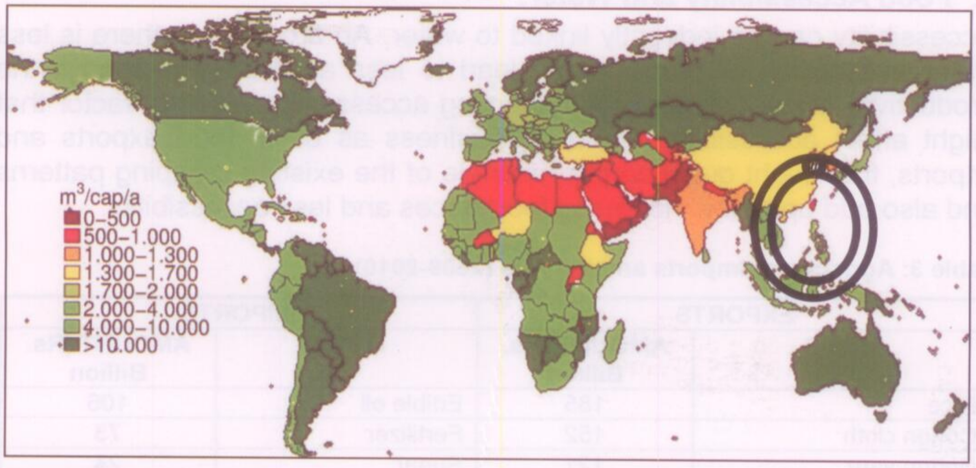


Figure-3 Countries colour coded according to water availability for food self-sufficiency. Those with<1,300 m3/capita/year are in deficit. Details can be seen from Rockström et al. (2008) cites in Falkenmark, *etc* (2009)

2. Food Stability and Water:

A slight shock in water cycle and fluctuations in water availability can cause famine, drought and malnutrition among nations, regions and communities. Food stability may be affected by the adverse weather conditions, political instability or economic factors.[24]

In the 2010 Floods of Pakistan, the damage to agricultural crops, livestock, irrigation systems and infrastructure has been substantial. The floods have caused extensive damage to the major monsoon season (*kharif*) crops: *basmati* rice in northern Punjab and cotton in southern Punjab and northern Sindh in the country. These floods have also caused significant damage to maize and other crops.[25] The after effects of these floods also resulted in medium and long term consequences e.g., farmers not being able to plant next season's crop and diminished food supply among some of the affected regions.[26] In this scenario the stability and the consistency in supply of food has been adversely affected by the flood waters.

---

[24] Ibid

[25] Dorosh, P. et al. "Rehabilitating Agriculture and Promoting Food security following the 2010 Pakistan Floods, insights from South Asian Experience." IFPRI Discussion Paper 01028, Oc. 2010

[26] See online http://fpc.state.gov/documents/organization/150191.pdf

3. Food Accessibility and Water:

Accessibility can be indirectly linked to water. An area where there is less water availability for crops, might lead to less availability of food if the productivity is not optimum thus affecting accessibility. Another factor that might affect accessibility could be business as usual food exports and imports, that might question the rationale of the existing cropping patterns and also add up to the increased food prices and less accessibility.

Table 3: Agricultural Imports and Exports (2009-2010)

EXPORTS		IMPORTS	
ITEMS	**AMOUNT (Rs. Billion**	**ITEMS**	**AMOUNT (Rs. Billion**
Rice	185	Edible oil	106
Cotton cloth	152	Fertilizer	73
Cotton yarn	121	Sugar	24
Fruits & vegetables	30	Tea	22
Fish & fish preparations	19	Insecticides	12

Source: Federal Bureau of Statistics, Pakistan

In order to substantiate the above assertion, table 4 shows haphazard government attitude that leads to the lack of accessibility of wheat. The domestic availability of wheat in 2008-9 was 21.9 million tons. Whereas, the exports made were 2 million tons which lead to an import demand of 2.750 million tons to fulfill the requirements of the country.[27]

Table 4: Wheat Supply/Demand Balance, May 2008/April 2009 ('000 tonnes)

Domestic Availability	21,900
Production	21,800
Stocks draw-down	100
Utilization	24,650
Food use	20,070
Feed use	400
Seed use	765
Losses	1,415
Exports (formal and informal)	2,000
Total Import Requirements	2,750

Source: UN Inter agency Mission Assessment, 2008

[27] High Food Prices in Pakistan, Impact Assessment and the Way Forward by The UN Inter Agency Assessment Mission, 2008

The 2010 Flood had also taken its toll on the food prices. The damage to crops worth 281.6 billion rupees ($3.27 billion) has been calculated destroying rice, cotton and sugar.[28] The country lost 2.39 million metric tons of rice, 0.5 million metric tons of wheat and 10.4 million metric tons of standing sugar cane.[29] Food prices increased dramatically putting an economic strain on the country and making it hard for people to access the basic necessity of life- FOOD.[30]

In Pakistan a majority of poor who are food insecure, live in rural areas or areas having lower economic access to food as compared to urban areas[31]. Pakistan ranks 145th in the Human Development Index (HDI) and with 22.6% of people living below poverty line suffer from low social indicators.[32]

4. Food utility and Water:

Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, and diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals (FAO)[33]. People suffering from nutritional deficiencies are exposed to high level of infectious diseases because of unsafe and insufficient water supply and inadequate sanitation.[34]

Both malnutrition and inadequate water supply and sanitation are coupled with poverty[35]. People are categorized as malnourished if they are unable to fully utilize the food they eat especially due to diseases like diarrhea (water-related diseases) or if their diet does not provide adequate calories and protein for growth and maintenance.[36] Malnutrition has its roots linked

[28] Rupert, J., Ahmed, K. "Pakistan Floods Destroyed $3.27 Billion in Rice, Cotton, Sugar Production" 2010
See online http://www.bloomberg.com/news/2010-09-28/pakistan-floods-destroyed-3-27-billion-in-rice-cotton-sugar-production.html
[29] Ibid
[30] Alan, K. et al, Flooding in Pakistan: Overview and Issues for Congress, Congressional Research Service, 2010.
[31] World Bank, *World Development Report*, P.96. *2008*
[32] See online: http://hdrstats.undp.org/en/countries/profiles/PAK.html
[33] FAO: An introduction to the Basic Concepts of Food Security, Food security Information for Action, Practical Guides, 2002
[34] Ibid
[35] See online: http://www.who.int/water_sanitation_health/diseases/malnutrition/en/
[36] Ibid

with water as well. It is a major health problem in developing countries. Pakistan is already a country which is food insecure in terms of consuming <2350 calories (see table 4). This is less than the Recommended Daily Allowance of 2550 calories.[37]

The burden of undernourishment in Pakistan is high, with a prevalence rate of 26 percent; where almost 38 percent are children [38] and 40% of the children are underweight.[39] Around 44% of the population of Pakistan lives without access to safe drinking water while 90% of rural population lacks such access.[40] The raised food prices after the floods of 2010 and 2011 exacerbated these already worsened socio-economic condition of the country.[41] Table 5 shows the Food security indicators of Pakistan.

Table 5: Pakistan's Food Security Indicators

Indicator	Value
Inflation (2010) -*WDI 2012*	12.00%
Net Receipts of Food Aid (Cereals, tonnes, 2004-06 –*FAO 2011*	17,716
Children Undernourished (2003-2009)-*UNICEF 2009*	38.00%
Calorie Supply per Capita (2007)-*FAO 2011*	2,293
Under 5 Mortality Rate per 1,000 (2009)-*UNICEF 2011*	130.00

Source: foodsecurityportal.org/pakistan

The urban population of Khyber Pakhtunkhwa has the highest rate of children suffering from diarrhea in the country in 2002 as shown in following table:

---

[37] See online: http://www.buzzle.com/articles/recommended-daily-allowance.html
[38] See online: www.foodsecurityportal.org/pakistan
[39] *The World Bank (2009)*. "World Bank Report on Malnutrition in India" http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/0,,contentMDK:20916955~pagePK:146736~piPK:146830~theSitePK:223547,00.html
[40] **44% Population Lacks Access to Safe Drinking Water Published on 06/13/2011 See online: http://peakwater.org/2011/06/44-population-lacks-access-to-safe-drinking-water/**
[41] Pakistan: Floods worsen child malnutrition, Published in IRIN Asia, Humanitarian news analysis. 2010

Table 6: Children 5-Years and Under Suffering from Diarrhea

(Percentage)

Region	Urban	Rural	Both Areas
Punjab	11	12	12
Sindh	13	8	9
KPK	20	16	17
Balochistan	12	15	14
Overall	12	12	12

Source: **Public Health Information System PHIS-2001-02**

Discussion

Being an agro-based country, where 95% of the water is consumed by agriculture Pakistan relies heavily on the availability of water. But water scarcity has already reached its limits as the country stands on the 7th place among the top ten "water insecure" countries of the world.

Table 2 concerning per capita availabilities of different crops shows mixed trends however table 1 clearly reflects upon our national average yields which are on a very low side. Hence the inputs to agriculture, which includes water as the most important one, are not being utilized to the best. Further, the national average for cereal crops is low but even in these circumstances; the country is exporting certain crops as shown in table 3.

In the after math of 2010 Floods of Pakistan the damage to agricultural crops, livestock, irrigation systems, and infrastructure has been substantial. The after effects of these floods also resulted in medium and long term consequences e.g., farmers not being able to plant next season's crop and diminished food supply among the affected regions. The 2010 Flood had also taken its toll on the food prices. The damage to crops worth 281.6 billion rupees ($3.27 billion) has been calculated. Country lost 2.39 million metric tons of rice, 500 thousand metric tons of wheat and 10.4 million metric tons of standing sugar cane. Hence it was a factor contributing towards inflation in the local market thus highlighting food insecurity.

Malnutrition has its roots linked with water as well. Pakistan is already a country which is food insecure in terms of consuming less than 2350 calories as an average; where as the recommended daily average allowance is 2550 calories. The burden of undernourishment in Pakistan is high, with a prevalence rate of 26 percent; where almost 38 percent are children and 40% of the children are underweight. Around 44% of the population of Pakistan lives without access to safe drinking water while 90% of rural population lacks such access. According to UN sources 20-40% occupancy in hospitals is due to water borne diseases and 33% deaths happen due to the same[42].

The above discussion has viewed the rationale of food security in light of different dimensions and has shown the vulnerability to insecurity relating to availability, stability, accessibility and utility. It has shown the linkages with water under the circumstances of scarcity and natural occurrences that can trigger the said crises in the economic and health domains as well.

Recommendations:

In view of the above discussion, some of the recommendations are listed as below:

- One of the most fundamental aspects of food security is its availability. Our discussion above shows that at the moment the country might not have availability issues but in order to counter the future challenges in wake of growing population, Pakistan has to think towards increasing the productivity by optimally utilizing the agricultural inputs such as water
- In order to make optimal water use, conjunctive water utilization and the economics of water has to be taken into considerations in light of green economy
- Water in context of Pakistan is a scarce commodity. Agriculture is already utilizing 95% of the total fresh water in excuse of food security. However the future growth of industries and domestic sector can challenge the allocation to agriculture. A body needs to be devised that can act as custodians of Indus and can broker deals within sectors for water sharing /trading in an amicable way. This might be a step towards integrated water resource management in Pakistan
- The concept of Water Stewardship shall be highlighted and private sector shall also be made an integral partner on policy issues relating to water management

42 WWF – Pakistan.2007. Pakistan's Water's at Risk.

- Better Management Practices (BMPs) in agriculture have the potential of increasing the economic viability of farmers by reducing input expenses along with less water use. These practices are developed and have been put to action by organizations like WWF – Pakistan. It should be considered by agriculture extension departments for wide spread dissemination where ever possible
- Creating markets that respond to BMP products will also be a step towards convincing farmers as an incentive to adopt these practice
- The age old cropping patterns should be analyzed and be researched whether they are feasible or not in the present economic settings and global scenario.
- Floods can be detrimental in terms of accessibility and economics of food security. According to UNFCCC there could be a greater incidence of floods and droughts in the coming years. Proper flood plain management (that is participatory as well) and employing natural solutions can help in reducing the threat
- Review cropping pattern and water availability and use water efficient crops especially in water close water basins.

SUSTAINABLE USE OF GROUNDWATER IN LOWER BARI DOAB CANAL COMMAND

By
Dr. Muhammad Nawaz Bhutta[1]

ABSTRACT

Groundwater is playing an important role to meet the rapidly increasing agriculture, domestic and industrial requirements. The paper is aimed to identify challenges being faced in groundwater use and management in LBDC command. Groundwater potential in Lower Bari Doab Canal (LBDC) command is mainly due to recharge from irrigation system, rivers and rainfall. Canal supplies during the recent past years have been decreased due to reduced storage capacity of reservoirs. Population pressure, inadequate supply of canal water and development of local tubewell technology have encouraged farmers to invest in the groundwater development. Subsidy on electricity has also encouraged especially the large farmers to pump more groundwater. Water table is dropping at a rate of 30 cm per year. The challenges being faced are: groundwater quality deterioration, protection of groundwater from pollution, reversing lowering of water table and groundwater monitoring. Recommended priority areas for action are: re-examine irrigation duties, promoting and supporting local groundwater management, avoid groundwater disaster at critical areas and institutional measures.

1. BACKGROUND

Groundwater is playing an important role to meet the rapidly expanding urban, industrial and agricultural water requirements. It is recognized as an important resource for poverty alleviation and increasing agricultural productivity. Irrigated agriculture is the major user of groundwater. Farmers are more depending on groundwater due to increased demand of water and limited canal supplies. The use of the groundwater permits the farmers to exercise greater control over the available water use and results in timely application of water for crops. Domestic and industrial requirements are mainly met from the groundwater.

2. OBJECTIVES

This paper is meant to highlight:

- The challenges faced in sustainable use of groundwater in LBDC command and
- Suggest priority areas for action sustainable use of groundwater.

[1] 164 K-1 WAPDA Town Lahore, Pakistan. Cell 00923004754050 nbhutta@brain.net.pk

3. LOWER BARI DOAB CANAL

Lower Bari Doab Canal (LBDC) offtakes from left bank of Baloki headwork of Ravi River. Its design discharge is 9000 cfs. LBDC's gross command area (GCA) is 1971060 ac (798000 ha) and culturable command area (CCA) is 1737843 ac (703580 ha) in Districts Qasur, Okara, Sahiwal and Khanewal of Punjab Province. The water allowance for LBDC is 4 cfs per 1000 ac.

4. RAINFALL

Effective rainfall is that portion of rainfall, which directly meets the crop water requirements. The effective rainfall for most representatives meteorological in LBDC is given in Table 1. Annual effective rainfall for LBDC is 266.5 mm. This is equivalent to 1518476 AF over the CCA of LBDC. The rainfall during June, July, August and September is 67 percent of total rainfall. The rest of 33 percent is during the remaining 8 months.

Table 1 Effective Rainfall for LBDC Command Area (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Multan	5.9	11.8	12.3	15.2	16.3	19.2	47.6	38.7	34	8.2	1	4.2
Faisalabad	10.8	17.1	17.3	26.8	14	48.1	69.5	58.9	41.4	7.7	1.6	5.4
LBDC Command	8.4	14.5	14.8	21	15.2	33.7	58.6	48.8	37.7	8	1.3	4.8

5. NET CROP CONSUMPTIVE USE

The net consumptive use in LBDC command is the total consumptive use (mm) reduced by effective rainfall (mm). The net consumptive use depth is multiplied with cropped area and converted into volume – acre feet. The monthly crop water requirement in volume for LBDC is shown in Figure 1 and totals as 5.2 MAF per annum. The total annual evapotranspiration (ETo) for LBDC command is 1897 mm per year.

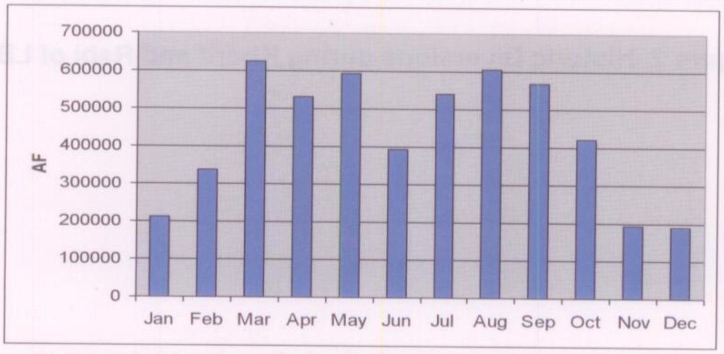


Figure 1. Monthly Crop Water requirements (AF)

6. CANAL WATER AND GROUNDWATER SUPPLIES

Historic canal deliveries during Kharif and Rabi for LBDC are shown in Figure 2. Average annual withdrawals at head of LBDC for the period 2001-09 are 4.118 MAF. Its CCA is 1.737843 Mac (0.703580 Mha). The canal diversions after 2001 has been decreased significantly (Figure 2). Canal water supplies reaching at Outlet/Moga and Nakka/field have been calculated in Table 2. Canal water available at field/Nakka during Kharif is 1.644 MAF, during Rabi 0.886 MAF and annual are 2.530 MAF. If canal supplies reaching at Nakka are divided over CCA (1.737843 ac), it is equivalent to 0.946 ft (289 mm), 0.510 ft (155 mm) and 1.456 ft (444 mm) during Kharif, Rabi and annual. The annual canal supplies are 444 mm at Nakka are much lower than annual evapotranspiration of 1879 mm. The farmers are trying to fill the gap with the use of groundwater.

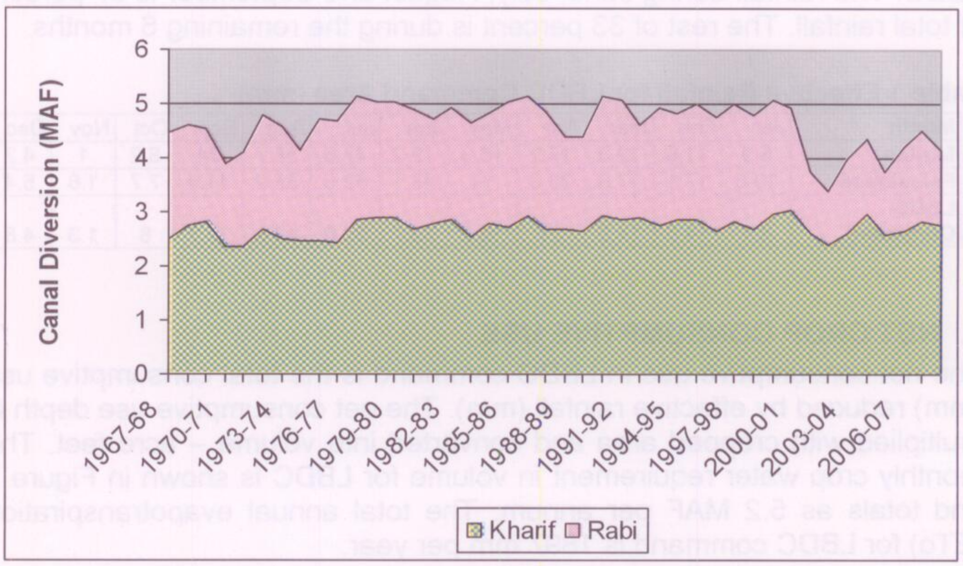


Figure 2. Historic Diversions during Kharif and Rabi of LBDC

Table 2. Canal Supplies reaching at Nakka (MAF)

Sr. No.	Description	Kharif	Rabi	Total
1	Volume at Baloki Barrage	2.709	1.409	4.118
2	MP Diversion	0.184	0.054	0.238
3	Plus seepage losses in LBDC	0.018	0.005	0.024
4	Total to MP Link	0.203	0.059	0.262
5	Available in LBDC =(1-4)	2.506	1.350	3.856
6	Seepage Losses in Canal (10%)	0.251	0.135	0.386
7	Seepage Losses in Disty/minor (8%)	0.201	0.108	0.309
8	Total Diverted to Moga	2.055	1.107	3.162
9	Losses in watercourses (20%)	0.411	0.221	0.632
10	Available at Nakka	1.644 (289 mm)	0.886 (155 mm)	2.530 (444mm)

Water and agriculture studies NESPAK 2005 reports that about 3.885 MAF (4792 MCM) groundwater is being abstracted annually for irrigation of crops in LBDC command area. Field channel losses of tubewell are generally taken as 15 percent. Therefore groundwater availability at Nakka is 3.302 MAF. Thus total water availability from canal (2.53 MAF) and groundwater at Nakka is 5.832 MAF and the ratio of canal to groundwater is 0.43:0.57. In LBDC existing pumpage is more than the potential. Therefore watertable has been depleting during past decade.

7. GROUND WATER BALANCE

Annual seepage and recharge from LBDC canal diversions, return flows and rainfall has been calculated in Table 3. Total annual recharge is 980346 AF. In addition there will be some recharge from Ravi River during June, July and August. The recharge value in LBDC command is much lower than total groundwater pumpage. Therefore groundwater is depleting throughout the command area. About ninety percent of groundwater recharge is linked with surface water supplies and ten percent with rainfall.

Table 3. Annual Recharge from Irrigation System and Rainfall

Source	At Head (AF)	Loss %	Loss AF	Recharge %	Recharge AF
LBDC Canal	4117667	10	411767	75	308825
Distributaries	3808842	8	304707	75	228531
Watercourses	3580311	20	143363	60	86018
Field	3494294	30	100354	90	90318
Crop use	3403975				
	Sub-Total				**713692**
Tubewells	3885000	15	100354	60	86018
Field	3798982	30	100354	90	90318
Crop use	3708664				
	Sub-Total				**176336**
Rainfall	1517476	30	100354	90	90318
	Sub-Total				**90318**
	Total				**980346**

8. GROUNDWATER QUALITY

Recently, Groundwater samples from these DC have been collected and tested in the Laboratory. The groundwater quality is 78 percent useable, 9 percent marginal and 13 percent hazardous. The mineralisation of groundwater increases away from the Ravi River. The quality near the river is better. Shallow groundwater has also better quality than deep layers in LBDC command.

9. GROUNDWATER TABLE TREND

Before LBDC construction, groundwater table was deep (100 ft) and not easily accessible for irrigation. The present available groundwater potential is due to recharge of over a period of hundred years of irrigation, rainfall, floods and Ravi River flow.

SCARP Monitoring Organization (SMO) has been collecting depth to water table data for all canal commands including LBDC. Therefore SMO data have been collected. The ranges of depth to water table are: 0-150 cm, 150-300 cm, 300-450 cm, 450-600 cm and >600 cm. Historic pre-monsoon data of LBDC have been plotted in Figure 3 for the period from 1981 to 2010. It is obvious that shallow water table in LBDC command has disappeared with the passage of time.

SMO is collecting data for identifying waterlogged area. But when it goes beyond their defined maximum limit there is no information available with SMO.

Declining rate of water table in Bari Doab is evident. If this trend is not arrested by improved management this resource will disappear in the next two decades especially for the small farmers who are unable to pump from deep layers.

The water table fluctuations were analyzed for middle reach of the canal. Observation wells were selected in head middle and tail reaches of LBDC. Average depth of water table was calculated to analyze the data for middle reach of the canal. The results revealed that water table is depleting at rate of 29.54 cm per year in middle reach. As also evident from Figure 4 water table has gradually dropped.

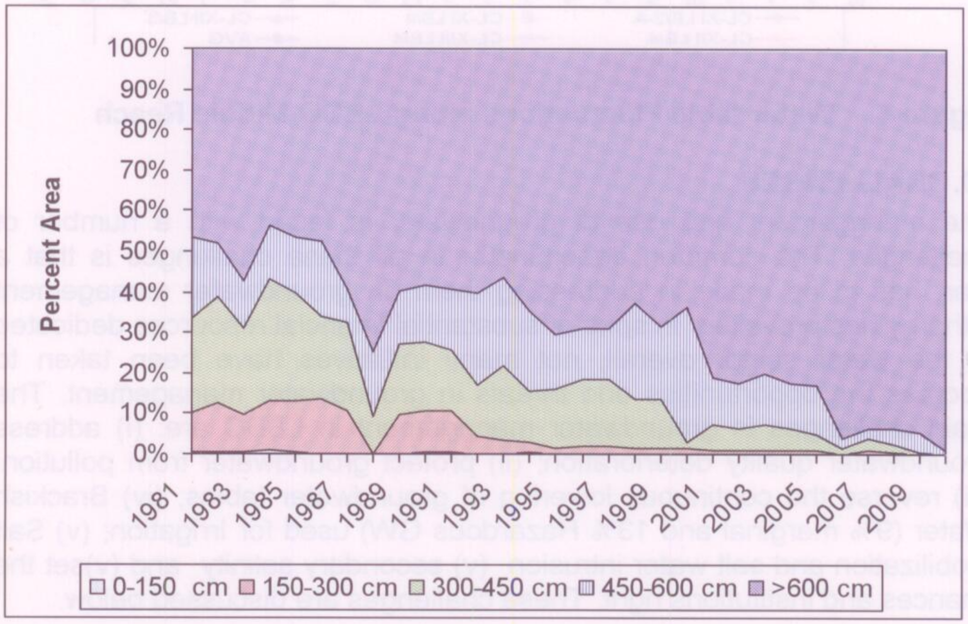


Figure 3. Area under Different Depths to Water table in LBDC-Pre-Monsoon

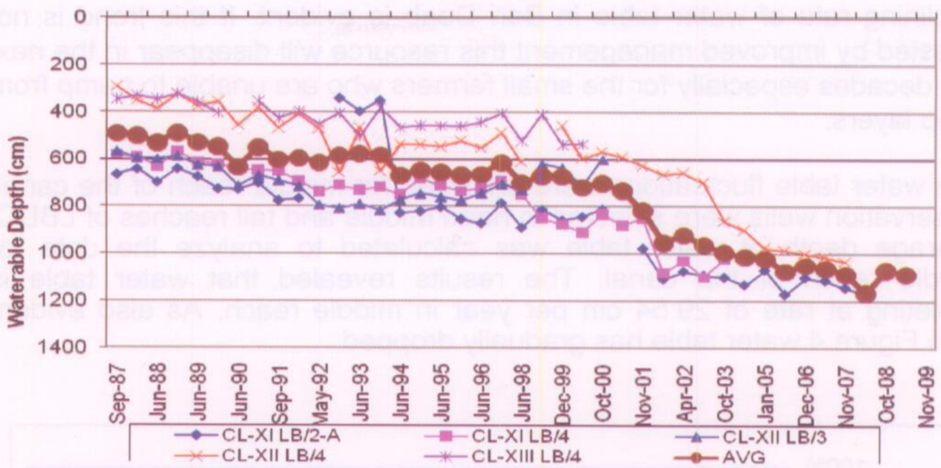


Figure 4. Water table Fluctuations along LBDC-Middle Reach

10. CHALLENGES

The management and use of groundwater is faced with a number of challenges. The common denominator in all these challenges is that a start has to be made in addressing them. In groundwater management lethargy has prevailed. In spite of substantial financial resources dedicated to the water sector overall, not many initiatives have been taken to address the opportunities and threats in groundwater management. The main challenges in groundwater management in LBDC are: (i) address groundwater quality deterioration; (ii) protect groundwater from pollution; (iii) reverse the continuous lowering of groundwater tables; (iv) Brackish Water (9% marginal and 13% Hazardous GW) used for Irrigation; (v) Salt mobilization and salt water intrusion (v) secondary salinity and (v)set the finances and institutions right. These challenges are discussed below.

10.1. Addressing Groundwater Quality Deterioration

Due to changed water management scenario concerns on groundwater quality, LBDC has taken a new dimension. In groundwater quality, increased salinity and sodicity are the main concerns. In addition there is point source of pollution near municipal and industrial areas.

There is concern that the heavy use of groundwater is increasing the salinity and sodicity of groundwater, especially in the very crucial central alluvial aquifer, in the areas where fresh and saline groundwater zones border. The heavy pumping in fresh groundwater areas invites saline groundwater from adjacent saline zones or causes up-coning from deeper and more saline layers. The salinity of pumped water in the tube wells increased due to the lateral movement of saline groundwater from the central part of the Doab. The areas most prone to this salinization are fresh water zones hydrogeological downstream of the saline areas.

Another development that has been suggested that could cause increased groundwater salinization is the heavy reliance on groundwater in selected spots, in particular tail-end areas of LBDC canal command. Groundwater after being pumped recharges back in the shallow aquifer from where it is reused again. This recycling has increased salinity levels.

10.2. Protecting Groundwater from Pollution

A second important challenge concerning groundwater quality is to protect groundwater from pollution. There is point source of pollution near municipal and industrial areas. The uncontrolled discharge of industrial effluent and municipal sewerage poses a threat to the availability of potable water, especially in major urban centers (Okara, Sahiwal and Khanewal). There is no adequate information to catalogue the specific 'hot spots' and undertake remedial and mitigation measures in a systematic manner. Urban and industrial effluent should be treated before disposing off into water bodies or water channels.

10.3. Reverse the Lowering of Water table

Though the intense use of groundwater has boosted the agricultural production in LBDC for years, the lowering of the water table has at the same time caused considerable hardship. It has undermined livelihoods and affected the availability and access of irrigation water for small farmers.

In the LBDC canal command the overuse and lowering of the water table increases pumping costs and induces ingression of saline water into fresh groundwater areas. The decline in water tables has also caused changes in access to groundwater. The cost of these deep tube wells is high (Rs 1,000,000 and more) and can only be afforded by a privileged few with access to financial resources of their own or of banks.

This increase in pumping cost with the decline in water tables is a general trend. In the unconfined shallow aquifer of the LBDC command for instance centrifugal pumps are most common. These pumps have a maximum suction depth of 20 feet. Beyond this depth farmers have to construct a sump. With gradual increase in water table depth, the farmers have to deepen their sumps and this is not only uneconomical but also hazardous at depths more than 50-60 feet. Below that depth, deep well turbine pump has to be used as prime mover. This more than doubles the cost - from Rs 60,000 to around Rs. 300,000, taking groundwater use out of the reach of small farmer. Similarly the pumping cost increase from around Rs. 2000 to more than Rs. 4000 per acre-foot of water.

10.4. Dormant saline aquifer overlain by shallow layer of fresh water

Dormant saline aquifer overlain by shallow layer of fresh water should not be tempered.

10.5. Setting the finances right

A final challenge is to address the continued financial support to the overuse of groundwater through subsidies on pumping, both in the private and the public sector. Tariffs for agricultural tube wells are approximately 35 % below rates for the domestic or industrial uses. The cost of producing and transporting power is well above that is charged to the agricultural consumer. In the current scenario such financial incentives are an anomaly, yet they continue to be used with considerable political opportunism.

As a corollary there has been substantial discussion on energy pricing for agricultural usage. An argument, that is made frequently, is that the electricity subsidies for agricultural use should be phased out, in order to encourage farmers to use groundwater more judiciously. This demands management argument, however, has some limited validity. Reduced subsidies would probably only marginally promote efficient water use. Even to a farmer entirely dependent on groundwater the expenditures on diesel or power are less than those on fertilizer or pesticide. Water is a crucial but relatively cheap input and this will not change considerably. It is unlikely that in the foreseeable future the price of pumping will greatly affect the use of groundwater.
There are hence many strong arguments to reform electricity pricing in agriculture, but the most important ones deal with public expenditure management and releasing resources for more meaningful public activities.

10.6. Groundwater Monitoring

Monitoring of groundwater quality is not done systematically and adequately. It is very difficult to manage a resource of which adequate information is not available. Pakistan is one of those countries where no groundwater institute exists. IWASRI-WAPDA is the only institute where some research on groundwater is being conducted.

10.7. Lack of Awareness

Farmers and other stakeholders are not aware of depleting groundwater resource.

11. PRIORITY AREAS FOR ACTION

The recurrent theme is that most of the groundwater issues in LBDC need more management. At present the groundwater exploitation is a predominantly private affair, requiring regulation rather than financial support. Regulation needs to be seen in a broad context – depending on the location either stimulating private groundwater exploitation or restricting it. We want to advocate that regulation is not the behold of the government and top-down only but that local regulation needs to be stimulated in equal measure. There is a need to revisit the current institutional and financial arrangements in groundwater. Public funds in the groundwater sector in particular should not be directed at subsidizing overexploitation, but at augmenting supplies. This supply augmentation should be complemented by improving local groundwater governance. A final priority is to tackle groundwater contamination and overuse, particularly in those locations where the problems are largest. The priority areas for action first and foremost concern:

i. Re-examine irrigation duties in LBDC canal command.
ii. Promote and support local groundwater management.
iii. Avoid groundwater disasters at hot spots.
iv. Initiate institutional coordination.
v. Stop financing overuse.
vi. Invest in recharge.
vii. Tackle groundwater pollution in selected places.

11.1. Re-examine irrigation duties

In LBDC canal command the most important strategy in balancing supplies and demand in groundwater is to re-examine surface water supplies. High density of tube wells in the LBDC system, conjunctive water use in fact presents itself as the most powerful mechanism for water management. Water allowance in the LBDC canal is 4 cusecs/ 1000 acres which is equivalent to 1.5 mm/day at Nakka. ET0 in LBDC command varies from 1.5 mm/day to 9.25 mm/day.

So far the issue of re-examining canal supplies has been a political no-go area. However, there has never been a systematic discussion on the merits, including the considerable possible impact of releasing water for other areas and the considerable benefits of reduced water logging for health and property. A strategy for re-examining canal supplies would need to incorporate a systematic information campaign to avoid dysfunctional polarization.

Action Required

• Re-examining water allocation for LBDC and other canal commands, keeping in mind official irrigation duties, actual deliveries, cropping patterns, groundwater quality, current groundwater use and over- or under-exploitation.

• This needs to be complemented by an extensive information campaign to opinion makers to avoid the discussion becoming captive to politicization.

• Promote skimming wells in areas with saline groundwater to exploit the fresh water lens on top of the saline layers.

11.2. Promoting and Supporting Local Groundwater Management

A broad-based awareness campaign on the limits to groundwater utilization and on effective actions to reverse overuse should be started. Such a campaign should break the grounds for local regulation and familiarize a large number of people with the legal provisions, as they exist. Participatory hydrological monitoring and local micro planning should follow up from the campaign. In participatory hydrological monitoring, groundwater users have to be facilitated to measure groundwater fluctuations and prepare local groundwater budgets. In micro planning a series of PRA tools – resource mapping, transect walks, time lines and local water audits – are used to identify common measures in demand management, social regulation and improved local recharge. The awareness and micro-planning programs should be complemented by the active promotion of alternatives to current intense groundwater use – such as alternative crops, soil water retention measures, affordable high efficiency irrigation systems and local rainwater harvesting techniques.

Local water management can also be strengthened in LBDC canal command by strengthening Farmer Organizations (FOs). In Kamalia local water budgets were prepared and piezometers installed under the PPGSD, which was received enthusiastically and could form the basis for local water resource planning. The importance of the Farmer Organizations however in the end depends very much on the extent to which they are able to improve local water management – not so much whether they are able to bring together the finances for system management. This requires considerable more support to the FOs than has been given so far.

Action Required

• Initiate an awareness campaign that familiarize groundwater user on the local aquifer conditions, risk of overexploitation, legal provisions, water conservation measures and importance of local management.

• Initiate a social mobilization programme to develop local groundwater regulation, focused on participatory hydrological monitoring and micro-planning. Engage PIDA Punjab Irrigation & Drainage Authority and teshil administration in these efforts.

• Strengthen capacity of FOs to manage water resources through training programmes and local water budgeting.

11.3. Avoid groundwater disasters at critical areas

There is also a need at certain hotspots – groundwater quantity or quality wise – to initiate crash programs that combine regulatory and physical measures. Such crash programs could consist of strengthening regulatory and coordinating capacity, updating data sheets, survey and monitoring of abstraction points, awareness building and extension on wise-water use, balanced investment in recharge and promoting integrated water management.

11.4. Institutional Measures

Institutionally groundwater is nowhere and everywhere at present. More than a dozen agencies have been involved in groundwater development and monitoring, but there is no coordination, proper staff availability and adequate logistics. None of these agencies has complete knowledge of the issues and none has operational responsibilities in groundwater management. What is required is to develop a focal point within LBDC command that will promote and enforce regulation, coordinate the activities by various agencies and gradually develop a database. Ideally, PIDA would be overall responsible for groundwater monitoring, management and regulation. The PIDA is to ensure that groundwater monitoring is undertaken and has a mandate to initiate policies to address groundwater management problems. This is very much the need of the day, particularly in LBDC, where the dependence on groundwater is large. A Groundwater Cell is set up in the PIDA. The Groundwater Cell should coordinate the data collection. The Cell should also be the mechanism to assess the requirements by different users (agricultural, industrial and domestic) – that may be diagonally opposite - and should facilitate finding pragmatic solutions.

The establishment of the Groundwater Cell needs to be supported by a package of measures – legislative, in institutional development and in data collection. Without such programs, initiatives will not go very far, as experience with earlier efforts show.

Presently, data on aquifer characteristics, groundwater levels and groundwater quality, in as far as they exist, are scattered over various organizations. The most comprehensive data sets are those with SMO, but their coverage is limited as they were mainly collected to assess the performance of the SCARP wells in controlling water logging. A study on groundwater potential from 1988 (WAPDA 1988) established that the water table was declining during the last 10 years (1978-87) in LBDC command. This did not trigger a change in the monitoring system of SMO. There has also not been systematic data collection for the non-SCARP areas. Particularly, for areas exclusively dependent on groundwater, basic time series are missing. Another shortcoming has been that data have generally not been available to the public at large and to groundwater users in particular. Data are hard to get and often presented in formats that make them complicated to understand to non-experts. Moreover it is need of the time to install deep observation wells for groundwater monitoring in LBDC command. What is required is to start groundwater monitoring programs in a number of hotspots, i.e. areas where groundwater use is intense and essential for domestic water supply, agriculture or other uses. Information sharing should be part of such monitoring programs, communicating results to local media, decision makers and key stakeholders.

What is required is to assess the most pressing data needs, initiate monitoring programs and to make the information that is available easily accessible and packaged in formats that non-expert users can benefit from. Another priority action in this field is the capacity of laboratories. There are few, if any, laboratories, which are able to perform on a routine basis all the 37 tests required for drinking water under WHO standards – for determining the level of physical, chemical, toxic/heavy metals and organic/bacterial parameters. There is a need to upgrade the services in this field, preferably through private sector laboratories with government organizations (such as PCRWR) doing sample checks and quality control.

Various laws and acts of relevance to groundwater management, promulgated over the years, but the common denominator is that none of it has been put in practice. No clear-cut legal framework for groundwater management exists. Efforts in recent past to put in place appropriate legal measures concern the development of a 'Groundwater Regulatory

Framework' for the Punjab Province under PPSGDP. There has however not been any follow-up to these and other proposals. Given the importance of groundwater, the government should see to it that a Framework for Groundwater Management and Regulation comes into existence in LBDC taking into account the hydrologic, social, political and economy aspects. Such legislation would at minimum need to define mandates and procedures for regulation and coordination. It is proposed to avoid at this stage legislation that is overly detailed or only concerned with licensing procedures only. These legal framework need to be complemented by program of implementation, allocating resources for enforcement, legal awareness building and training.

Action Required

- Support the Groundwater Cell by a program of implementation, consisting of building the capacity for enforcement and coordination and awareness building
- Reassess the monitoring of the groundwater - less but sensible. Ensure availability of the funds to the skeleton staff of the monitoring agency on long-term basis under the principles of less and qualified staff, least number of monitoring points and data management on GIS format.
- Package and popularize existing groundwater information
- Assess the capacity of laboratories to provide basic services. – reviewing current workload and screen these as per requirements, support and equip a selected.

11.5. Realign financing mechanisms

In spite of the overuse of groundwater in LBDC, exploitation of groundwater continues to be subsidized. Agricultural electricity tariffs are below cost, recovery is low and in an anomaly. In changing the financing strategies electricity prices need to be revisited. The main argument for setting the house in order, i.e. phasing out energy subsidies and enforcing payment, is that it would release funds for more relevant activities in groundwater management. This could be recharge measures, water harvesting or flood buffering or improved governance.

Action Required

- Phase out electricity subsidies so as to release funds for meaningful investments;
- Improve the recovery rate, by strengthening the collection of revenues and initiate strict action by the government on default.

11.6. Re-route Investment to Groundwater Recharge

It appears more useful to invest in groundwater recharge than groundwater exploitation. The priority action is to develop appropriate and

cost-effective water harvesting packages. Site selection is equally important in groundwater recharge. The locations should be chosen so that they concentrate recharge in areas with fresh groundwater and high value uses (drinking water or high value agriculture) and avoid floodwater and rainwater being lost otherwise to saline playas. In site selection care is required to prevent interrupting existing sub surface flows and natural recharge and a basin approach should be followed, as far as practical. In LBDC command most of the surface drains are dry and carrying only municipal and industrial effluents. Surface drain can be a good site for recharging aquifer, especially during surplus flows or heavy rains.
There is also much scope to introduce some of the floodwater spreading techniques, used in similar climatic conditions in Iran (Kowsar and Pakparvar 2004). What is important is to link investment in groundwater recharge with support to building up local water management. It is important to avoid that watershed management programmes deal exclusively with increased recharge of groundwater, while ignoring the way that water is used. If recharge is not combined with demand management, imbalance will persist.

Action Required

• Invest in recharge structures in carefully selected locations using a basin-management approach – combined with improving local groundwater management

• Increase the repertoire of rainwater harvesting structures, mainstreamed in LBDC.

• Research option of groundwater recharge in LBDC commands as part of conjunctive water management strategy.

11.7. Combating Groundwater Contamination

The population of LBDC command depends on groundwater as the source of drinking water. This may be individual wells, community systems or municipal water supply. Therefore groundwater quality issues become very pressing. In urban areas – such as Okara, Sahiwal and Khanewal, the greatest threat is the pollution due to the unchecked sewage and industrial discharges and leaking septic tanks. Where there is intense urban or rural industrialization, groundwater is often heavily polluted too.

There is scope to raise awareness and introduce local water quality monitoring and training on effluent standards to those most affected by it.

12. THE WAY FORWARD

This section makes suggestions for a number of activities in groundwater management that may be supported by the PIDA and Government of Punjab.

12.1. Crash Programs in Critical Areas

In a number of locations, groundwater overuse or contamination has taken very serious proportions. A first category of projects would be in the nature of crash programs in such critical areas – introducing integrated packages of supply and demand management measures. Such critical areas can be identified following the Punjab Private Groundwater Development Project approach. The crash programs should start with diagnosing groundwater issues both scientifically and through information sharing and stakeholder consultation. Central to the crash programs would be the preparation of local water management plans. These should be supported by participatory monitoring of groundwater levels and quality. Following this package of measures as appropriate can be introduced – be it local recharge measures, promoting more efficient water use, groundwater zoning, waste water and sewerage treatment.

12.2. Invest in Recharge

There is a case to invest more in artificial recharge and water harvesting, but a wide range of options should be considered, including the cost-effective promotion of flood spreading and innovative groundwater recharge schemes. In general the knowledge base in rainwater harvesting in Pakistan is weak and the number of professionals limited. In planning recharge structures a basin approach should be followed. Equally important is measures to promote local demand management through self regulation – including the establishment of local groundwater organizations cells.

12.3. Promote Efficient Irrigation in Groundwater Scarce Areas

In groundwater scarce areas the introduction of efficient irrigation methods should be developed – such as drip irrigation, sprinkler irrigation or lay-flat hoses. This promotion should include low cost versions of these methods as have been developed for instance in India. What is important is to develop a promotion strategy that gives ample opportunity to the local private sector to develop this service – in manufacturing as well as retail. Ultimately micro-irrigation products need to be purchased as any other farming input. To prime this line of business 'smart subsidies' may be required – whereby farmers obtain the novel products at reduced prices from local suppliers rather than through special governmental delivery channels.

12.4. Institutional strengthening ground water management

Finally and very important, the institutional blank in groundwater management needs to be resolved. The various arrangements as they exist need to be activated, coordinated and strengthened. The PIDA could play a useful role in supporting institutional and regulatory development at LBDC level and in supporting capacity building and social mobilization in support of local groundwater management.

There is also a large need and potential to strengthen local groundwater management. It is already suggested to make this an integral component of crash programs in critical areas and support to rural drinking water supply and artificial groundwater recharge. This should go further by incorporating water management planning systematically in capacity building support to the FOs that are being established in the LBDC command. The FOs can be trained and made responsible for participatory groundwater monitoring, evaluation of water budgets for individual distributaries and minors or parts there of and estimation of groundwater availability – or the safe draft – under wet and dry years. Accordingly, the selection of crops and crop area can be discussed. The results were a shift of paddy cultivation to other crops and water releases to the tail ends of the distributory. Promoting local ground water management should involve traditional leadership and local government, encouraging them to broaden their roles from development to management.

13. REFERENCES

Kowsar S. and Pakparvar M. 2004. Assessment Methodology for establishing an Aquitopia, Iran. In UNESCO-MAB, Sustainable Management of Marginal Drylands, Proceedings of the Second International Workshop Shiraz, Iran, Nov 29 to Dec 2, 2003. Paris.

WAPDA 1988. Groundwater Potential in Canal Command Areas, Lahore. WAPDA

WATER RESOURCES POTENTIAL AND MANAGEMENT STRATEGIES IN CHOLISTAN DESERT – PAKISTAN

By

Zamir A Soomro[1], Asmatullah Khuwaja[2] and M.Tahir Saleem[3]

ABSTRACT

More than 80 percent of Pakistan's area comes under arid and semi-arid zones. The area of about 11 millions hectares (mha) is under deserts which is 14 percent of the total country area. Major deserts of the country are; Thar, Cholistan, Thal, Chagi and Kharan. Cholistan is second largest desert of the country spread over 2.6 mha. Major use of this area is as grazing land. Extreme aridity, predominantly sandy nature of the soils and topography prohibits the use of area as arable. Major source of drinking water is rainwater which is collected in natural depressions and man made ponds. Rainfall in the area is low and variable, ranging between 100-250 mm per annum. Groundwater in most of the parts of Cholistan is saline; however in bed of old Hakra river, usable quality groundwater is available which is about 14 km in width and 100 km in length. It is estimated that about 9.87 billion cubic meters usable groundwater is available in this strip, which has further negligible recharge due to diversion of Hakra river. Pakistan Council of Research in Water Resources (PCRWR) has launched water resources development and management projects in Cholistan desert which include isolated rainwater harvesting, development of silvi-pasture/rangelands and saline agriculture. This paper discusses the water resources potential available, and their management strategies in desert area.

1. INTRODUCTION

Agriculture is the backbone of Pakistan's economy but its production is not increasing with proportional to the human population due to one or the other reason. The demand for food, milk, meat, fodder and fuel is increasing day by day. To cope with food problems, it is essential to bring waste desert lands under cultivation. Desert areas could offer the scope to increase arable land but water is limiting factor. Geographical area of the

Regional Director[1], Regional Office, PCRWR, Main Raiwind Road, Lahore
Assistant Director[2] and Assistant Research Officer[3]
Regional Office, PCRWR 29-Sajid Awan Colony, Bahawalpur

country is about 79.6 million hectares (mha) out of which 11 mha (14% of the country area) are under deserts. Main deserts are: Cholistan, Thar, Thal, Chagi and Kharan. People of the deserts are suffering from acute shortage of water and passing their lives miserable.

Cholistan is second largest desert of the Pakistan spread over 2.6 mha. Like other desert inhabitants, people of this desert also depend on rainwater. Extreme aridity, predominantly sandy nature of the soils, topography and deficiency of water are the main factors which prohibit the area to be used as arable. Due to harsh climatic and environmental characteristics, the use of area is left for grazing only. Livestock is main source of income but availability of drinking water and forage grasses are the main causes of low yield. In low rainfall period, water and fodder become serious issue, ultimately compelling people to migrate from deserts in search of water and fodder towards irrigated areas till the next rainfall. Akram et al., 1996, stated that "Cholistan desert become green and rich in forage grasses immediately after rainfall carrying capacity of range land increasing and enhancing the livestock production. Grazing lands of Cholistan desert contribute a big share in country's livestock production".

1.1 Climate

Cholistan desert is one of the driest and hottest areas in the country; the temperature begins to rise rapidly from April onwards and reaches its peak in late May or June. During this period; hot and dry winds blow throughout the day and occasionally this hot spell is interrupted by dust storms. The mean relative humidity falls below 32 percent due to high temperature which normally exceeds 45^0C. Some times temperature shoot up to 50^0C. The maximum temperature comes down in July due to rains and usually does not rise again in the succeeding months. Wind and severe sand devils are frequent in the Cholistan desert.

1.2 Soils

The soils of Cholistan desert are formed from two types of materials i.e. river alluvium and Aeolian sands. The alluvium consists of mixed calcareous material, which was derived from the igneous and metamorphic rocks of the Himalayas and was deposited by Sutlej and abandoned Hakra rivers most probably during different stages in the sub-recent periods. The Aeolian sands have been derived from the Rann of Kutch, sea coast and partly from lower Indus Basin. The material was carried from these sources by the strong south-western coastal winds.

Main soils in Cholistan desert area are dune land, sandy, loamy and clayey (Akram et al., 1991).

2. EXISTING WATER RESOURCES

Primary source of water in deserts of Pakistan is rainfall which is low and sporadic, causing drought and famine in the area which reduce grazing lands and increase livestock mortality, adding untold miseries to human being. Water harvesting is a process of collecting natural precipitation from a prepared or natural watershed for beneficial use. Water harvesting techniques have generally been used to obtain water for drinking and growing crops. Water harvesting systems are the only way to supply fresh water in the deserts (Akram et al., 1995)

2.1 Tobas

People of the Cholistan desert collect rainwater in natural depressions or man-made ponds locally called Tobas. These tobas are mostly not at appropriate places, the sites have not been identified on scientific data like; contour survey, physical characteristics of soil, infiltration rate, soil porosity etc. These ponds are not properly designed, mostly are in irregular shape. As a result, stored water is wasted rapidly and can not be used for long period. Major water losses from the tobas are seepage and evaporation. Desiltation of tobas is also not done regularly, which further reduces their water storage capacity. There are about fifteen hundred small tobas in Cholistan desert. The size and storage capacity of each toba varies depending on length, width and depth. Accordingly to a rough estimate, water storage capacity of these varies between 1000 and 1500 cubic meters. The total water storage capacity on an average is about 1.7 million cubic meters. Due to seepage and evaporation losses from all these tobas, about 30 percent water is not available for drinking. Therefore, net water storage available for drinking of human and livestock is about 1.19 million cubic meters. The human and livestock population in the Cholistan desert is about 0.10 million and 2.0 million respectively, whereas annual drinking water requirement for this population is about 7.0 million cubic meters. These small tobas including some dug wells in fresh water zone meet drinking water requirement for three to four months after which people migrate along with their livestock towards irrigated areas and stay there till the next rainfall.

2.2 Kunds

Kund is a manhole type structure to store rainwater in Cholistan for drinking of human beings in addition to ponds. Kunds are constructed in circular shape using brick masonry, keeping its bed above the water table level. Their side walls are plastered with cement mortar, bed is sealed with concrete and RCC roof is provided on top. Its roof level is about one meter above the ground surface and bed 3 to 5 meter below ground level. The diameter varies between 8 to 10 meters. Two-four ventilators are placed above the ground surface level having aeration. Water entry opening is allowed at surface level. Kunds are capable to store water for long period but their storage capacity is low with high cost of construction. The people prefer to use water from kunds for drinking purpose for their own selves as it is beyond the access of livestock and having fewer chances of dung and urine added by livestock. The water from kunds is lifted by bucket. There are about 150 kunds in Cholistan desert.

2.3 Dugwells

The secondary source of water in the Cholistan desert is ground water which is mostly saline and not fit for human drinking; but people are compelled to use this water for drinking due to non-availability of other source. The use of dug wells is indigencus practice in desert areas for exploitation of groundwater. The depth to watertable of the wells in Cholistan varies between 20 and 50 meters and water column from 1.21 to 5 meters. The diameter of wells is in between two to six meters. The water from these wells is drawn through leather buckets pulled by camel tied with long rope. The well is property of the tribe who has constructed it. The water of the well is used mostly when rainwater in the toba is exhausted. The rainwater collected in the tobas is preferred as first choice as compared to dug well water for drinking because the toba water contains less concentration of salts. The areas where burnt bricks can not be transported easily, the earthen wells are plastered with locally available lime to keep the walls sustainable. The number of dug wells in Cholistan is about three hundred.

2.4 Tubewells

During the last fifteen years, some tubewells have been introduced by the Cholistan Development Authority (CDA) and Pakistan Council of Research in Water Resources (PCRWR) where usable ground water is available. These are operated by diesel driven engines, as there is no electricity in the area. There is lot of potential of wind and solar energy but yet these are not being used for beneficial purpose. The depth of tubewells varies between 60 and 100 meters.

3. MANAGEMENT STRATEGIES OF WATER RESOURCES.

3.1 Rainwater Harvesting

About 17 percent of the area of Cholistan desert consists of dense clayey soils, devoid of vegetation, mostly flat, impervious, saline-sodic and having pH more than 9.0. These soils are treated as very poor for agriculture as well for pasture but very excellent catchments for rainwater harvesting. Runoff directly depends on quantity of precipitation and characteristics of the catchments soil. Water intake rate of these soils is very poor (almost negligible). Akram, M and M. Akram, 2002 have calculated intake rate of these soils as 0.21 to 0.4 cm/hr and studied the soil profile up to 150 cms which mostly consist of silty clay to hard clay soils.

The extent of such area in Cholistan desert is 441900 hectares. This area is the best catchments for rain water harvesting. Pakistan Council of Research in Water Resources (PCRWR) has established a Field Research Station at Dingarh, Cholistan to conduct research on desert related aspects like; rainwater harvesting, pasture land development, forestation and saline agriculture etc. A 90 hectares suitable catchment area for water harvesting and collection has been identified at the station. The catchments are flat and consist of dense saline-sodic, clayey, impervious, very poorly drained soils. The overall vegetation in the catchments is less than 10%. The catchment's slope from North to South is 0.006%. The rainfall over catchments area is being recorded regularly since 1989 and data of rainfall events for the last ten years (1999-2008) is presented in Table-1. The data shows that about 50% rains of the total are threshold which can produce runoff for harvesting. Practically it is observed that rainfall event over 10 mm is producing runoff and treated as threshold rainfall. The best features of catchments and threshold rainfalls indicate the good potential of rainwater harvesting.

TABLE-1:- Event wise Rainfall (mm) at Dingarh, Cholistan

Months	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
January	1.4 4.0	-	-	-	-	4.0	-	=	8.0 7.0	-
February	6.4	2.8 2.6	-	-	36.0 14.0	-	1.2 4.6 15.0 3.0 7.2 4.0 15.6	=	8.0 7.0 10.0	-
March	-	--	-	-	3.0	-	15.0	5.0 12.0 9.0	6.0	-
April	-	-	5.4	-	-	-	10.0	-	-	5.0
May	-	-	4.6 6.4 15.0	-	1.4	-	6.0	-	-	15.0 40.0
June	9.0	-	4.0	2.0	5.0 6.0	2.0 4.2 17.0	2.0	28.0	30.0 23.0 4.0 6.0	4.0 6.0
July	4.0	7.0 14.0 1.0 4.0 20.0 12.0 13.0	3.0 20.0 20.0 5.3 20.0 14.0	-	6.0 22.0 3.0 1.0 6.0 3.0 6.0 1.0 8.0	1.2 4.6	3.0 27.0 6.0	20.0	19.0	4.0
August	-	50.0	11.5 6.2 2.4 8.4	-	7.2 23.0 1.4 14.0 25.0 30.0 8.0	22.0 3.0 8.0 6.0 3.0 2.0 6.0	-	35.0 30.0 2.0 3.0	5.0 8.0	35.0 45.0 40.0 35.0
September	-	-	-	-	-	-	13.5	-	10.0 18.0 14.0	12.0 45.0
October	-	-	-	-	-	2.0	-	-	-	-
November	-	-	-	-	-	-	-	-	-	-
December	-	-	-	-	-	6.0 7.8	-	8.0 5.0	-	3.0 6.0 2.0
Total (mm)	24.8	126.4	146.2	2.0	230.0	98.8	133.1	157.0	183.0	297.0

3.2 Potential Runoff Available and its Harvesting

Cholistan desert falls under arid zone where rainfall is very low and sporadic. However, catchments of the desert are very favourable having flat surface, hard clay soil and no vegetation or any other obstacle on the surface. The seepage is negligible; therefore runoff is generated very quickly which is ready for harvesting. If any pond/reservoir is not available, the water is standing in these flat areas and being evaporated within a few days. Extent of such area is about 0.442 mha in the Cholistan which is about 17 percent of the whole Cholistan area. Table-2 presents annual rainfall, potential available for harvesting and actual rain harvested. The data of last 14 years shows that the average annual potential rainwater harvesting is about 330 million cubic meters whereas maximum storage capacity available during period was 4 million cubic meters. The storage capacity is equal to about one percent of the potential and rest of the water is being evaporated. If the storage capacity is increased, no doubt that not only the drinking water requirement of human and livestock (7.0 million cubic meters) could be met but sufficient water be available for growing orchard, vegetable, or rangeland development.

Table 2: Runoff Potential Available from in Cholistan (Catchments area is 0.442 mha)

Year	Rainfall (mm)	Gross Potential (mm)	Net Potential available for harvesting (million m^3)	Rainwater harvested (million m^3)
1995	213	201.32	561.0	1.7 *
1996	152	135.45	377.0	1.7 *
1997	201	165.06	460.0	1.7 *
1998	172	143.39	399.0	1.7 *
1999	25	10.73	30.0	1.7 *
2000	124	111.73	311.0	1.7 *
2001	146	123.79	345.0	1.7 *
2002	2	-	-	-
2003	230	208.34	580.0	2.5 **
2004	108	89.23	249.0	2.85 **
2005	101	78.89	220.0	4.0 **
2006	157	114.30	505.2	4.0**
2007	101	137.27	401.2	4.0 **
2008	297	238.50	650.0	4.0 **

Source: Regional Office, PCRWR, Bahawalpur

(*) About 1500 local ponds having average storage capacity of 1130 m^3

(**) PCRWR (92), CDA (61) ponds having storage capacity of 15000 m^3 each added.

3.3 Exploitation of Usable Groundwater

The salinity level of groundwater in Cholistan desert varies from site to site. EC of groundwater in the area of about 31 percent area is below 2.5 dSm^{-1} 23 percent area in between 2.5 to 5.0 m^{-1}, 11 percent area 5 to 7.5 dSm^{-1}, 6 percent in between 7.5 and 10.0 m^{-1} and 29 percent area has EC above 10 dSm^{-1}. Relatively better quality groundwater is available at few locations, mostly under the abandoned bed of Hakra River. The abandoned bed of the 'Old Hakra' commences just east of Fortabbas and extends down stream west to south-west of Moujgarh. Its maximum width is about 14 km and about 100 km length. The estimated total quantity of this fresh groundwater is 9.87 billion cubic meters (8.0 million acre feet) (Technical report Vol.1, 1991). The recharge of this water is negligible due to diversion of the Hakra River. Pakistan Council of Research in Water Resources (PCRWR) has installed twenty deep tubewells in this area for drinking water supply to human and livestock population. These deep tubewells supply groundwater when rainwater from ponds is exhausted. These tubewells play their secondary role for water supply in drought conditions. The sites of tubewells were identified by Resistivity Survey and best options received by the survey were validated through hand percussion trial bore up to 100 meters. The soil and water samples were collected from each 3 meters interval and analyzed for soil texture and water quality. After the detailed study of soil and water profiles, suitable column was selected for putting filter pipe of the tubewell whereas unsuitable column was closed with blind pipes. As a result best fit quality groundwater among the available source is pumped. Tubewells installation in this abandoned bed of old Hakra River are not suggested for huge cropping as this reserve is limited due to no recharge further. Hence this precious water should be used only for drinking of human and livestock in emergency when rainwater is not available as per demand. It can be used for micro level orchards and vegetables with high efficiency irrigation system. Ground water quality of tubewells installed by PCRWR is given in Table-3.

TABLE – 3: Groundwater quality of tubewells installed by PCRWR

Site	Water Quality		
	$EC \times 10^6$	SAR	RSC
Dingarh	6500	16.8	Nil
Kheersar	950	8.5	Nil
Qaim sar	2740	5.0	Nil
Noorsar balochan	1020	7.4	Nil
Marot Fort	570	5.4	Nil
Chadhran	1910	8.6	Nil
Chapu wali	855	8.3	Nil
Kundai	1580	11.4	Nil
Janu wali	3110	12.3	Nil
Jamal de sar	1400	10.0	Nil
Chandani	860	5.5	Nil

3.4 Desalination of Groundwater.

Cholistan desert is divided into two distinct parts i.e. greater and smaller Cholistan. Smaller part of Cholistan consists of small sand dunes and mostly flat lands (catchments). The bed of old Hakra River also lies in this part. Whereas greater part of Cholistan has mostly series of high crest sand dunes, the catchments for rainwater harvesting are very rare in this part. Groundwater quality is totally unfit for drinking in this area. This area has rich rangelands as compared to smaller part but shortage of drinking water prohibits utilizing this grazing land by livestock. One of the options is to desalinize the groundwater to make it potable. Reverse Osmosis Plants of small and medium size having desalination capacity between two and four thousand gallons per day can fulfill the drinking water requirement of human and livestock, drinking in one village depending upon population. The quantity of desalinized water can be increased by mixing appropriate quantity of saline water keeping the quality within the permissible limits of water quality standards for drinking of livestock. The Pakistan Council of Research in Water Resources has installed two Reverse Osmosis Plants in the Cholistan desert at Dingarh and Thandikhui villages with desalination capacity 4000 and 2000 gallons per day respectively. However, the repair and maintenance of these plants is a problem. Local people and government agencies (both) are not willing to bear this responsibility.

3.5 Introduction of High Efficiency Irrigation System for Forage crops

Livelihood of the Cholistani people is livestock rearing; whereas water scarcity and fodder intricacy are the main obstacles of the area in livestock production Soomro etal, 2008, conducted a study to grow fodder crops with use of least groundwater quantity through pressurized irrigation method to enhance the water use efficiency. Millet and Cluster bean (guara) crops were grown mixed in the barren desert land of Hyderwali, Cholistan at the area of 2 hectares. Hyderwali site lie in old Hakra River belt and its groundwater quality is good as EC 0.85 dS/m. In the study conducted, green fodder yield of millet and Cluster bean (guara) crops were obtained 19.03 ton/h, water productivity 12.77 kg/m^3 and net monetary water value was Rs.10.04/m^3 (30-50% more than Pothohar Plateau) and benefit cost ratio of 1.7 was achieved. Initial results gave the encouraging trend for use of rain gun irrigation method for growing fodder crops on barren desert land to enhance the livestock production.

3.6 Conjunctive Use of Rainwater and Saline Ground Water.

Availability of irrigation water is fundamental in deserts to produce timber, forages and herbs to increase in livestock and its production. There is no canal, river or any other source of fresh water except rain water in Cholistan. Rainfall is low and could not support alone for growing trees, shrubs, fodder grasses, fodder crops and arid horticulture plants. The ground water is mostly saline. In such conditions, conjunctive use of rainwater and saline ground water become important to be used for beneficial purposes. The salinity level of ground water varies from site to site in the Cholistan (Table-4 presents the ground water quality collected from different sources in Cholistan desert). Saline water can be used with rain water under conjunction on deep sandy soils for growing forest trees and arid horticulture plants for income generation and to provide forage for livestock as well as for shelter during hot summer. This will improve livestock production as well as environmental conditions of deserts to be utilized for other beneficial purposes. (Akram and Chandio 1998).

Thousands of the literature items are available to support the use of saline water for crop growing with different management strategies. To test this hypothesis, Soomro et al, 2001 conducted a research study by using different quality waters to know the adverse effects of saline water on the environment of the soil. A computer model was calibrated which gave close predicted results to actual field data. The soil of Cholistan is of sandy nature which is porous and excessively drainable. These types of soil give better option for use of saline water in isolation or conjunction with fresh water (Rainwater).

Table-4: Groundwater quality of different sources in Cholistan Desert

Location	Water table depth (m)	EC x 10^6	Water Quality		
			pH	SAR	RSC
Dingarh	18-19	4200-8000	7.2-7.6	14-32	5.6-14.49
Bariwala	15-16	11000	7.6	43	8.2
Kura khu	24	10000	8.3	76.75	13.0
Bhambowala	17-18	12400	8.0	73.30	11.8
Balouchni wala	11	22000	8.3	88.5	10.5
Channanpir	11-12	29800	8.8	207.85	54.0
Nagarwala	14-15	3900	8.5	18.54	6.5
Malkana	17-18	3600	7.6	13-14	-
Maujgarh	19-23	3000-16500	8.2-8.9	4.45-67	12-13.4
Dakwala	27-29	1354	8.5	4.45-67	12-13.3
Sahibwala	18-19	6000	7.9	14.5	0.6
Passed wala	19-20	6000	8.3	14.19	1.2
Islamgarh	38-40	2400-5000	7.2-7.8	0.97-1.36	0.9-5.8
Bhaikhana wala	31-32	4400-6000	7.3-7.8	2.0-2.7	5.2-22
Kalar wala	35-36	5700-5900	6.5-6.7	1.61-1.73	4.2-4.6
Nidam wala	18-19	7630	7.5	16.8	-
Kheersir	18-19	2570	8.1	15.0	-

3.7 Impact of Water Management Practices

The research results of rainwater harvesting and storage experiments carried out at Dingarh Field Research Station in the Cholistan desert for the last 15 years provided base for its multiplication in the whole Cholistan desert. Government of Pakistan allocated funds for rainwater harvesting in the Cholistan desert. Ninety two rainwater harvesting reservoirs having storage capacity of 15000 cubic meters each have been constructed after required surveys, identification of catchments, topography, soil profiles, vegetation, hummocks, seepage, evaporation. Twenty deep tubewells have been installed by identifying relatively better quality water through resistivity survey and trial bores. The discharge of these twenty tubewells is one cusec. Two Reverse Osmosis Desalination Plants have been installed to desalinate highly saline ground water for drinking purpose. The desalination capacity of these two plants per year is 0.01 million cubic meters. The water resources developed through rainwater harvesting systems, pumping good quality ground water and desalination are steps forward for achieving the goal of water requirement. It is obvious that in most of the areas water is available. As a result of water source development, migration of human and livestock has been reduced and losses caused due to reduction in livestock production in the form of mortality, diseases etc has also been reduced. Further, micro-climate around the reservoirs has also become friendly for lives. The birds and other wild animals are visible frequently around the reservoirs and different vegetation species are also seen growing.

4. REFERENCES

1) Akram, M., Abdulllah, M., and Khan, A.D. 1990. Management of resources in deserts for the development, in: proceedings of National Seminar on Water Resources Development and its Management in Arid areas, 6-8 October, 1990 at PCRWR, Quetta, Pakistan. Pp 44-51.

2) Akram, M., Abdullah, M. and Majeed, A. 1991. Role of surface and ground saline water for agriculture development in Cholistan desert, Proceedings of the National Seminar of the People's participation in the management of resources in arid Lands, 11-13 Nov. 1990, Bahawalpur, Pakistan. PP. 53-60.

3) Akram, M., Abdullah, M., Khan, W.A. and Sheikh, B.A., 1995. Desertification status in the Cholistan desert. In: Proceedings of the Sixth all Pakistan Geographical conference, 26-29, Dec.1993, Islamia Univ. Bahawalpur. pp.12-31.

4) Akram, M.,Malik, M.K., Khan, W.A., Sheikh, B.A. and Khan, A.D.1996. Transformation of sand dunes in to forest and grassland. A Geographical case study of Cholistan desert. Journal of pure and applied Sciences, Vol.15, No.2, pp.27-38, Islamia University, Bahawalpur, Pakistan.

5) Akram, M., Abdullah, M, Khan, W.A and Sheikh, B.A (1997). Management strategies for water resources development in Cholistan desert for human, livestock and small scale agriculture. In:Proceedings of the International Symposium: Water for the 21st Century, June 17-19, 1997 Lahore. pp. 121-130.

6) Akram, M and Chandio, B.A (1998). Conjunctive use of rainwater and saline ground water for desertification control in Pakistan through agro-forestry and Range management. In Journal of Arid land studies; Vol.75, 161-164. Proceedings of Desert Technology IV, Sep.21-26, 1997, Kalgoorlie, W.Australia.pp. 161-164.

7) Akram, M, and Akram, M., 2002. Water and water quality management in the Cholistan desert for drinking and integrated farm production. In: Proceeding of the Water Quality Seminar held at PCRWR, Islamabad (Pakistan), March 8,2002. pp.37-44.

8) Akram, M., Kahlown, M.A., and Soomro, Z.A, 2006. Water resources management for drkinking and farm production in Cholistan desert – Pakistan. In: Proceedings of the International Scientific Conference on Desertification and drylands research "The future of drylands held at Tunis, Tunisia 19-21, June, 2006.

9) Technical Cooperation Project No.84.2066.3., 1991. Ground water investigations in desert areas of Pakistan, vol.1 Islamic Republic of Pakistan and Federal Republic of Germany.

10) Soomro Z.A, H.M.Memon and A.Majeed (2001). Calibration of Computer Model for Management of Saline Water Use for Irrigation", Proc. National Seminar on Drainage in Pakistan, MUET, Jamshoro, August 16-18, 2001, pp.159-168.

11) Soomro, Z.A, M.T.Saleem and A.Khuwaja "Enhancement of Water Productivity by use of High Efficiency Irrigation in Desert Environment. In proceeding of Workshop on Capacity Building and Training in Water Sector; the Role of Young Professionals organized by ICID 17th October, 2008 at Lahore (Pakistan) pp 43-50.

QUALITY OF DRAINAGE WATER AND ITS IRRIGATION PROSPECTS IN SINDH PROVINCE OF PAKISTAN

By

Khalid Mahmood Subhani, Zafar Iqbal Raza and Dr. Muhammad Mehboob Alam[1]

ABSTRACT:

Agriculture of Pakistan is predominantly dependent on a big irrigation network. The supplies of canal water are not sufficient to meet the crop water requirements. To augment the inadequate supplies of canal water, the poor quality groundwater, drainage and waste water is being utilized for irrigation purposes without giving due consideration to its adverse effects on soil health, crops and environment. Therefore, it is imperative to monitor and know the quality of irrigation water other than canal water and also to suggest measures/methods for its sustainable agricultural use. The research findings on saline agriculture indicate that poor quality water can be used for growing salt tolerant crops, trees and grasses applying recommended management and reclamation techniques. The main objective of this paper is to identify surface drains and lakes in Sindh province where drain water can be used for agro-forestry. The water quality data collected from various sources has been used in preparing the paper. The data show that water quality of Left Bank Outfall Drain (LBOD) is mostly hazardous along the entire length. However, there are possibilities of use of LBOD water from RD 812 to RD 722 for saline agro-forestry. There is no significant trend in temporal change of water quality of LBOD. Water quality of Right Bank Outfall Drain (RBOD) system falls under marginal to hazardous range and can be used for growing salt tolerant crops and trees. Manchar and Hamal Lakes water falls under marginal to hazardous range and can be used for growing saline agro-forestry. Water of LBOD and its lateral drains could be used for saline agro-forestry. Water of RBOD and its lateral drains can be curiously used for sustaining agriculture either in conjunction with canal water or altering with canal water at hazardous ranges. RBOD and Main Narra Valley Drainage systems must be protected from urban and industrial waste water to protect the water quality of Hamal Lake and Manchar Lake. The drain water of poor quality should be treated with some acid or gypsum before its use. Water quality of drainage system should be monitored regularly for evaluating its quality. Proper soil amendments like F.Y.M, gypsum r press-mud should be used to avoid the

[1] Additional Senior Research Officer, Director (Salinity & Environment) and Director General, International Waterlogging and Salinity Research Institute (IWASRI) Near Muhammad Pura Village, P.O Box Thokar Niaz Baig, Raiwind Road, Lahore-53700.Tel 92-42-35303390-92, Fax.92-42-35303393, E.mail: kmsubhani@hotmail.com, iwasri@brain.net.pk

deleterious effects of brackish water on soil quality.

INTRODUCTION

The agriculture in Pakistan is mainly dependent on a well-developed big irrigation system, but the good quality canal water is not sufficient to meet the crop water requirements. To augment the inadequate canal water supplies, ground water and city sewage is being used for irrigation purposes. The quality of ground water varies from usable to hazardous and indiscriminate use of poor quality water deteriorates soil and environment. The water quality criterion for irrigation developed by WAPDA is given in Table 1. (IWASRI publication No. 293).

Table 1. WAPDA Water Quality Criteria for Irrigation.

Water Quality	TDS (ppm)	SAR (mmol L^{-1})	RSC (me L^{-1})
Usable	<1000	<10	<2.5
Marginal	1000-2000	10-18	2.5-5.0
Hazardous	>2000	>18	>5.0

Good quality water is a scarce resource in the world as well as in Pakistan. Irrigation is the major user of water in Pakistan, amounting to 96% of total water. Irrigation supplies of good water quality are mainly from river diversions of Indus River and its tributaries. During flowing downstream, drainage water also enters in the rivers. Drainage water has salt contents and pollutants. Generally the farmers use brackish water in conjunction with the canal water when available. The farmers also apply cyclic irrigations of canal and groundwater. The idea of cyclic use of waters of low and high salinity with proper management as conceived by the Rhodes (1984) prevents the soil from becoming saline and allows for the substitution of brackish water for 50% of the irrigation needs. The quality of brackish water can be improved by the use of certain amendments like gypsum, sulfuric acid, hydrochloric acid and other acid forms etc. (Qureshi et. al., 1975; Ahmed et. al., 1979, Ayers west cot, 1985; Ghafool et. al. 1987, Chaudhry et. al. 2004).

The study is limited to Sindh Province. It includes addressing the water quality of LBOD and RBOD system and lakes of Sindh Province. Each crop, plant and tree has certain threshold limit of salt tolerance for its proper growth and yield potential (Table 2 & 3). This paper was prepared with the objective to identify surface drains and lakes in Sindh province where drain water can be used for agro-forestry.

TDS: Total Dissolved Solids
SAR: Sodium Absorption Ratio
RSC: Residual Sodium Carbonate

METHODOLOGY

A desk study was carried out to monitor the quality of drainage water in Sindh province and possibilities of its use for Agro-Forestry. The available data collected by SCARP Monitoring Organization (SMO), Lower Indus Water Management and Reclamation Research Project (LIM) and Surface Water Hydrology (SWH) of WAPDA has been used in preparing the paper (IWASRI publication No. 293 & 2008/4)

Table 2: Yield Potential of Selected Crops as Influenced by Irrigation Water Salinity

FIELD CROPS	Water Quality (ppm). and Yield Potential (%)				
	100%	90%	75%	50%	0%
Barley (*Hordeum Vulgare*)	3392	4288	5568	7680	12160
Cotton *(Grosspium hirsutum)*	3264	4096	5376	7680	11520
Sugarbeet (beta vulagris)	3008	3712	4800	6400	11520
Sorghum (Sorghum bicolour)	2880	3200	3584	4288	5568
Wheat (Triticum aestivum)	2560	3136	4032	5568	8320
Wheat, durum (Triticum turaidwn)	2432	3200	4416	6400	10240
Soybean (Glycine max)	2112	2368	2688	3200	4288
Cowpea (Vigna unguiculata)	2112	2432	3008	3840	5632
VEGETABLE CROPS					
Squash, zucchini (curgette) (Cucurcita pepo melopepo)	1984	2432	3136	4288	6400
Beet, red (Beta vulgaris)	1728	2176	2880	4096	6400
Squash, scallop (Cucurbita eopo melopepo)	1344	1664	2048	2688	4032
GRASSES					
Wheatgrass, tall (Agropyron elongatum)	3200	4224	5760	8320	13440
Wheatgrass, fairway crested (agropyron cristatum)	3200	3840	4736	6272	9600
Bermuda grass (Cynodon dactylon)	2944	3584	4608	6272	9600
Barley (forage) (Hordeum vulgare)	2560	3136	4096	5568	8320
Ryegrass, perennial (Lolium perenne)	2368	2944	3776	5784	8320
Trefoil, narrowleaf birdsfoot (Lotus corniculatus tenuifolium)	2112	2560	3200	4288	6400
Harding grass (Phalaris tuberose)	1984	2496	3392	4736	7680
Fescue, tall (Festuca elatior)	1664	2304	3328	4992	8320
Wheatgrass, standard crested (Agropyron sibiricum)	1472	2560	4160	7040	12160
Vetch, Common (Vicia angystifolia)	1280	1664	2240	3200	5184
Sudan Grass (Sorghum sudanense)	1216	2176	3648	6144	10880
FRUIT CROPS					
Date palm (Phoenix dactylifera)	1728	2880	4672	7680	13440

Source: Mass and Hoffman (1977), Mass (1986), FAO (1982)

RESULTS AND DISCUSSION

1. WATER QUALITY OF LEFT BANK OUTFALL DRAINAGE SYSTEM

1.1 WATER QUALITY OF SPINAL DRAIN LBOD

LBOD is on the Left Bank of Indus River which includes command area of Nara Canal and Rohri Canal. Originally drainage tubewells, pipe drainage system and surface drains were generating the drainage effluent. However, most of the drainage tubewells and pipe drainage systems have gone out of order. At present, mainly surface drains are intercepting the surplus water and generating drainage effluent. Drainage facilities have been provided to Nawabshah, Sangar, Mirpur Khas and Badin Districts. Mean monthly, maximum and minimum TDS (ppm) is shown in Figure 1, while water quality of spinal drain at different locations is shown in Figure 2. It is evident that water is of hazardous quality. However, from RD 812 to RD 722, the drain water can be used for salt tolerant trees and crops after its treatment with amendments. Annual mean TDS values of spinal drain during different time periods are shown in Figure 3. There is no significant trend of increase or decrease in TDS values over the period of 2003 to 2009 and water quality remained in hazardous limit.

Table-3 Tolerance of Common Plants to Total Salts in Irrigated Water

Water Salinity	Tolerance	Suggested plants
ppm 0-495	Highly salt-sensitive plants	**Pastures:** Ladino clover, alsike clover, white clover. **Fruit:** Persimmon, passionfruit, strawberry, raspberry, avocado, loguat, almond, stone fruit, citrus fruit, apples, pears. **Vegetables:** Green beans, parsnips, celery, radish, squash, peas, onion, carrot. **Ornamentals:** Primula, gardenia, star jasmine, begonia, rose, azalea, camellia, ivy, magnolia, fuchsia.
ppm 495-1485	Mildly salt-sensitive plants	**Pastures and fodders:** Strawberry clover, maize, lovegrass, cocksfoot, oats (hay), wheat (hay), rye (hay), luceme. **Fruit:** Mulberry, grape. Vegetables: Cucumber, capsicum, lettuce, sweet corn, rock melon, potatoes, cauliflower, cabbage, water melon, broccoli, pumpkin, tomato. **Ornamentals:** Hibiscus, geranium, gladiolus, bauhinia, zinnia, aster, poinsettia, lantana. Thuja orientalis, hop bush, (Dodonea attenuate) banana (Musa), emu bush (podocarpus), Juniperus chinensis, Callistemon viminalis.
ppm 1485-3493	Slightly salt-sensitive plants	**Pastures and fodders:** Paspalum dilatatum, birdsfoot trefoil, phalaris, sudan grass, perennial ryegrass, millet, annual ryegrass, barley, pangola grass, tall fescue, Rhodes grass, kikuyu, couch grass, tall wheat grass. **Fruit:** Olive, fig, pomegranate **Vegetables:** spinach, asparagus, kale, garden beets. **Ornamentals:** Stock, chrysanthemum, camation, cleander, rosemary, bougainvillea, vinca, coprosma, Ficus spp., false acacia (Robinia pseudoacacia), Queensland pyramid tree (Lagunaria patersonil), NZ christmas bush (Metrosideros tomentosa), Bangalay (Eucalyptus botryoides), river red gum (E. camaldulensis), Rottnest teatree (Melaleuca cupressiformis), Rottnest Cyprus (Callitris robusta), Acacia longifolia, buffalo grass, kikuyu grass, portulaca, mesembryanthemum, boobialla (myoporum acuminatum),morel (E. oleosa), swamp yate (E.occidentalis),York gum (E.loxophleba), swamp mallet (E.spathulata), couch grass, bamtoo, kondinin blackbutt (E. kondininensis), naïve pine (Actinosfrobus pyrimidalis).
ppm 3493-13008	Salt tolerant plants	**Pastures:** Saltwater couch (Paspalum vaginatum), puccinellia, sand couch (Sporobolus virginicus). **Fruit:** Date palm **Ornamentals:** Canary palm (phoenix canariensis), salt river gum (E.sargentil), saltwater couch, Melaleuca thyoides, salt sheoaks (Allocasuarina cristata and A. glauca), tamparisks, saltbushes

Source: Department of Agriculture and Food Australia, Publication No. 71/99.

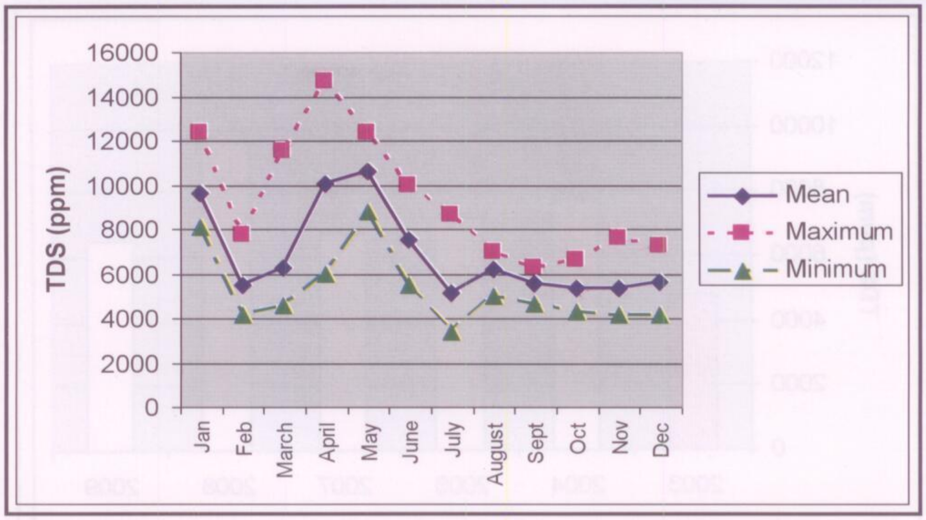


Figure 1 Mean Monthly TDS Values of Spinal Drain-LBOD

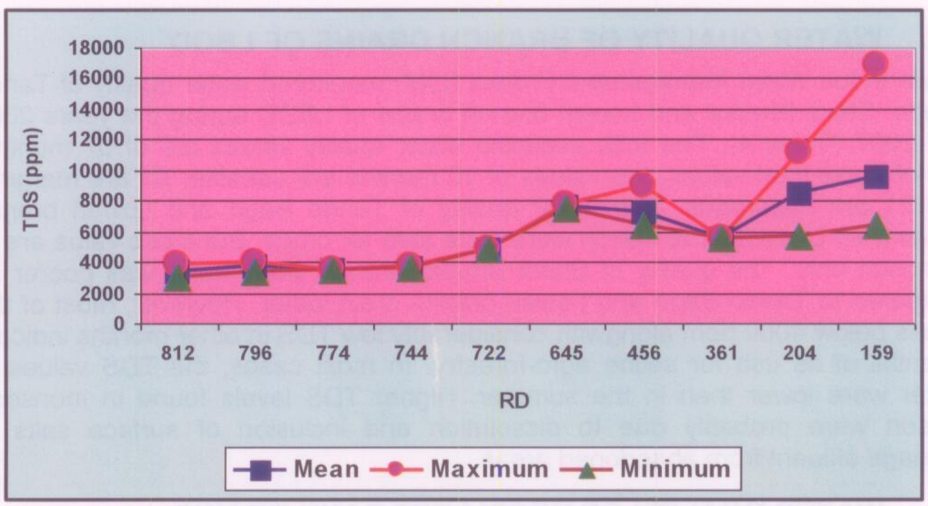


Figure 2 Water Quality at Different Locations of Spinal Drain LBOD

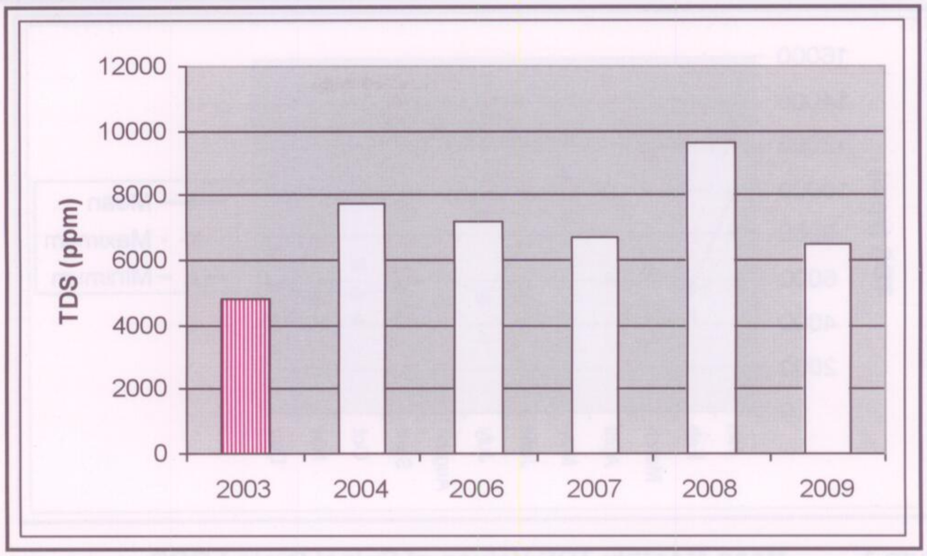


Figure 3 Annual Mean Water Quality of Spinal Drain during different time periods.

1.2 WATER QUALITY OF BRANCH DRAINS OF LBOD

Lower Indus Water Management Project (LIM) monitored water quality of Tando Bagho, Shadi Bhadur and Lowari branch drains of LBOD during the years 2006 and 2007 (Table 4). The total available water quality values are of 37 months. Out of these total values, the values of 10 months are useable, six are marginal and 21 are hazardous. The water quality of Tando Bago and Lowari branch drains from December to March were quite safe for crops. But these value are of a season only. The quality of Shadi Bhadar branch drain water was poorer as compared to Tando Bago and Lowari branch drain water. However, most of the values below 4000 ppm alongwith considerably low TDS in other months indicate potential of its use for saline agro-forestry. In most cases, the TDS values in winter were lower than in the summer. Higher TDS levels found in monsoon season were probably due to dissolution and inclusion of surface salts in drainage effluent from abandoned areas.

1.3 WATER QUALITY OF KOTRI LEFT BANK DRAINS

LIM monitored water quality of four outfall drains namely Nagan Dhoro, Karo Ghungro, Fulleli Gunni and Jati of Kotri Left Bank (Table 5). There are total 55 monthly values, out of which 13 are useable, seven are marginal and 35 are hazardous. The highest TDS values in all drains were recorded in the month of April. There were abrupt changes and significant variations in most month-wise TDS values. Therefore, there is need to check the source of drainage effluent in future water quality monitoring programme. There is limited potential of use for saline agro-forestry but with much curative and management measures/practices.

Table 4 Water Quality of Branch Drains of LBOD TDS (ppm)

Year	Months												Mean
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
(i) Tando Bago Branch Drain													
2006									1664	1088	3712	704	1792
2007		640	768	1920	1472		1664	1164	1219	1088			1157
Mean		640	768	1920	1472		1664	1164	1442	1088	3712	704	1475
(ii) Shadi Bahadur Branch Drain													
2006									3200	1920	640	896	1664
2007		1664	1920	4480	2560		7680	3840	4800	1920			3360
Mean		1664	1920	4480	2560		7680	3840	4000	1920	640	896	2512
(iii) Lowari Branch Drain													
2006									4480	1920	1280	446	2032
2007		640	704	1792	448	704	1664	2176	2080	2112			2096
Mean		640	704	1792	448	704	1664	2176	3280	2016	1280	446	2064

Table 5 Water Quality of Kotri Left Bank Drains TDS (ppm)

Year	Months												Mean
	Jan.	Feb.	Mar.	April	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
(i) Nagan Dhoro Outfall Drain													
2006					6080				1408	1504	2048	832	2374
2007	1920	640	704	8320	576	640	1088	2304	1856	1408	1344	1792	1883
2008	1408	1152	4480										2347
Mean	1664	896	2592	8320	3328	640	1088	2304	1632	1456	1696	1312	2244
(ii) Karo Ghangro Outfall Drain													
2006									1792	1728	2304	1344	1792
2007	5120	960	2560	4800	768	1088	1664	2464		1536			2329
Mean	5120	960	2560	4800	768		1664	2464	1792	1632	2304	1344	2310
(iii) Fuleli Gunni Outfall Drain													
2006									1536	1408	1728	2304	1744
2007	4480	1088	2432	14720	704	1024	1536	2432	1952	2844			3321
Mean	4480	1088	2432	14720	704	1024	1536	2432	1744	2126	1728	2304	3027
(iv) Jati Outfall Drain													
2006									1920	1600	705	640	1216
2007	1536	896	960	5120	512	640	1600	3392	1984	2048			1869
Mean	1536	896	960	5120	512	640	1600	3392	1952	1824	705	640	1648

2. WATER QUALITY OF RIGHT BANK OUTFALL DRAINAGE SYSTEM (RBOD)

Water quality of Right Bank Drainage system is described as below.

2.1 Hair Din Drain

Hair Din Drain provides drainage facility to Pat Feeder Canal Command and Desert Canal Command areas. Mean, maximum and minimum monthly TDS (ppm) values of Hair Din Main Drain from the year 2001 to 2009 are shown in Figure 4. There are total 56 values of TDS for different months, out of which 13 values are useable, 26 are marginal and 17 are hazardous. It seems that canal water is entering the Hair Din drainage system at certain locations. During the field visit it has been observed that farmers are using the drainage water for growing crops. Water quality is useable or marginal for 75 percent of the time. There are two extreme values during April 2008 and May 2006 which might be due to canal closure periods.

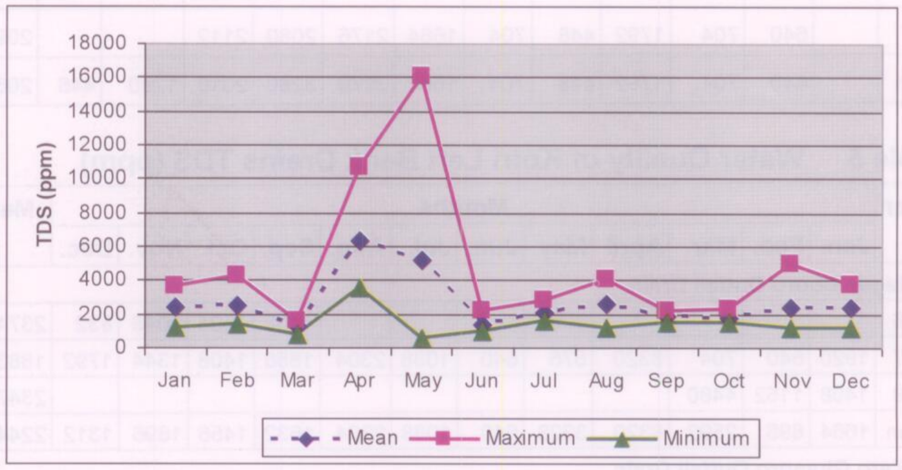


Figure 4 Mean, Maximum and Minimum TDS Values of Hair Din Main Drain

2.2 Shahdad Kot Main Drain

There are total 54 months values. Out of which one is useable, 32 are marginal and 21 hazardous. This water can be used for salt tolerant crops and trees applying proper water/soil ammendments. Mean, maximum and minimum TDS values of Shahdad Kot Main Drain are shown in Figure 5. Like that of Hair Din drain there is one exceptionally high value for May 2002. TDS values during June to September are usually low.

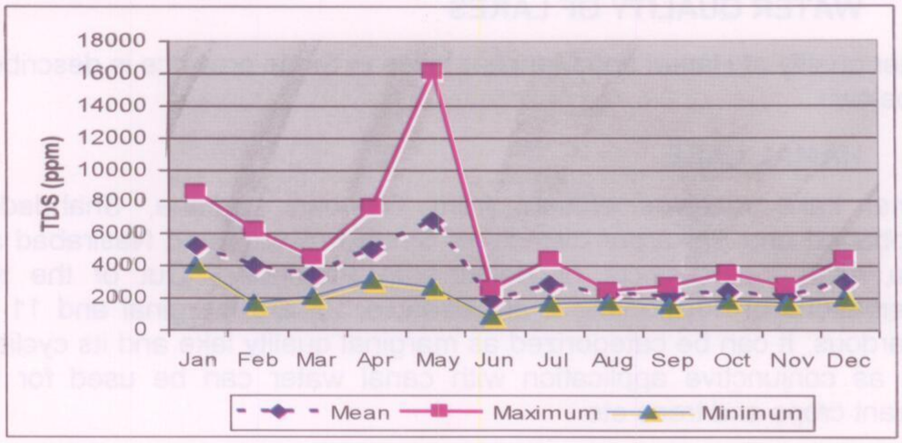


Figure 5 Mean, Maximum and Minimum TDS Values of Shahdad Kot Main Drain

2.3 Main Nara Valley Drain

Main Nara Valley Drain (MNVD) receives effluent from Hamal Lake, Ghar Main Drain, Mehr Main Drain and Kakar Drain etc. Out of the total 54 months TDS values, 3 are useable, 13 are marginal and 38 are hazardous, which leave little room for its application to crops as well as trees except highly salt tolerant bushes.

Mean, maximum and minimum TDS values of MNVD are shown in Figure 6. Mean values for August, September and October are low and come under marginal range.

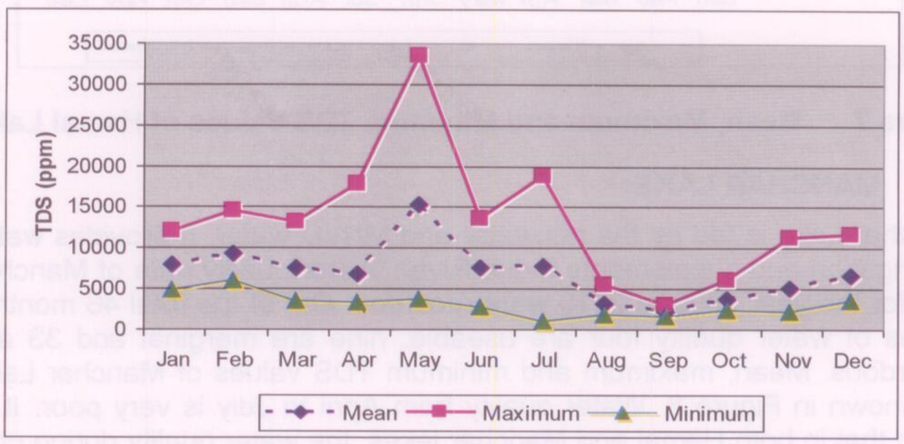


Figure 6 Mean, Maximum and Minimum TDS Values of MNVD.

3. WATER QUALITY OF LAKES

Water quality of Hamal and Manchar lakes in Sindh province is described as below.

3.1 HAMAL LAKE

Hamal Lake receives effluent from Qambar, Larkana, Shahdadkot, Jacobabad and Shikarpur districts of Sindh Province and Nasirabad and Dera Allah Yar Districts of Balochistan Province. Out of the total observations of 38 months, 2 are useable, 25 are marginal and 11 are hazardous. It can be categorized as marginal quality lake and its cyclic as well as conjunctive application with canal water can be used for salt tolerant crops and trees etc.

Mean, maximum and minimum TDS values of Hamal Lake are shown in Figure 7. Water quality during April and May becomes hazardous. High fluctuation in water quality has been observed which is mainly dependent on resource area of recharge.

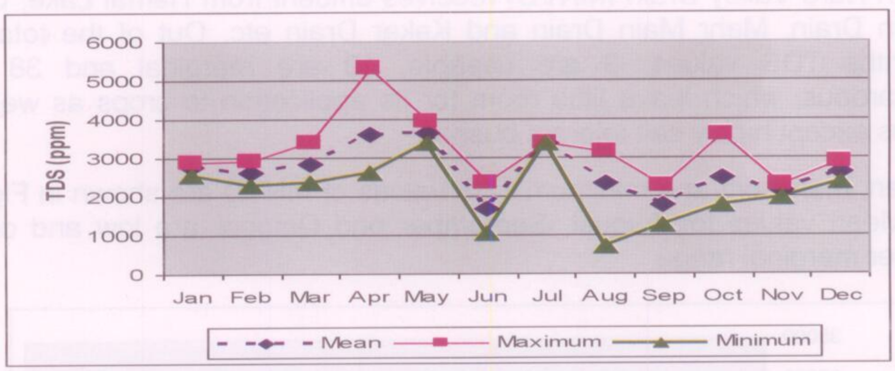


Figure 7 Mean, Maximum and Minimum TDS Values of Hamal Lake

3.2 MANCHAR LAKE

Manchar Lake is fed by the rainwater and MNVD water. It provides water for irrigation and supplements Indus River. Water quality data of Manchar lake for the year 1999 to 2010 were recorded. Out of the total 46 monthly values of water quality four are useable, nine are marginal and 33 are hazardous. Mean, maximum and minimum TDS values of Manchar Lake are shown in Figure 8. Water quality from April to July is very poor. It is found that in both Hamal and Manchar lakes, the water quality during pre-monsoon period is comparatively poorer than that of in post monsoon period, mainly due to the entrance of monsoon water in lakes.

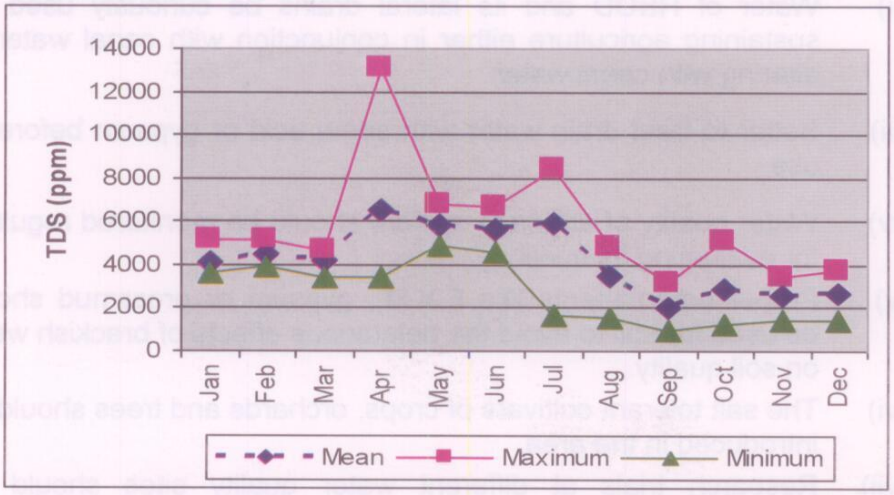


Figure 8 Mean, Maximum and Minimum TDS Values of Manchar Lake

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

(i) Water quality of LBOD is mostly hazardous along the entire length. However there are possibilities of use of LBOD water from RD 812 to RD 722 for saline agro-forestry. There is no significant trend in temporal change of water quality of LBOD.

(ii) Water quality of RBOD system falls under usable to hazardous range and can be used for growing salt tolerant crops and trees.

(iii) Water of Manchar and Hamal Lakes fall under marginal to hazardous range and can be used for growing saline agro-forestry.

(iv) The water of Hair Din drain can be successfully applied for irrigation in conjunction as well as cyclic use with canal water.

4.2 RECOMMENDATIONS

(i) Water of LBOD and its lateral drains could be used for saline agro-forestry at certain locations.

(ii) Water of RBOD and its lateral drains be curiously used for sustaining agriculture either in conjunction with canal water or altering with canal water.

(iii) Better to treat drain water with some acid or gypsum before its use

(iv) Water quality of drainage system should be monitored regularly for evaluating its quality.

(v) Proper amendments like F.Y.M., gypsum or pressmud should be used for soil to avoid the deleterious effects of brackish water on soil quality.

(vi) The salt tolerant cultivars of crops, orchards and trees should be introduced in the area.

(vii) Research trials at different water quality sites should be conducted to study the possibilities of sustainable use of poor quality drainage water under various soil, water and crop conditions.

REFERENCES

1. Ahmad, B. W.D. Kemper, G. Naider and M.A. Niazi. 1979. Use of gypsum to lower the SAR of irrigation water. Soil Sed. Soc. Am. J., 43: 698-702.
2. Ayers, R.S., and D.W. Westcot. 1985. Water Quality for Agriculture. FAO irrigation and drainage paper 29. Rev. 1. FAQ, Rome.
3. Bhatti, H.M., M. Yaseen and M. Rashid. 1985. Evaluation of Sesbania green manuring in rice-wheat rotation. Proc. Int. Symp. On Nitrogen and Environment. Lahore, Pakistan. July 7-12, 1984. 99: 275-284.
4. Bhutta, M. N. et. al. (2010). Surface water quality in Sindh province. IWASRI Publication No. 293. pp. 40.
5. Chaudhry, M.R., M.S. Rafiq, A. Haider and I.A. Shahid. 2004. Ameliorative effect of gypsum on soil properties and crop yield irrigated with high SAR water. Mona Rec. Expt. Project. WAPDA, Pub. No.144: 8-14.
6. Department of Food & Agriculture (2005). Tolerance of Plants to Salty Water, Farm Note (Reviewed 2005) Department of Food and

Agriculture, government of Western Australia, Farm Note No. 71/99. Web site. www.agric.wa.gov.au

7. Drainage/River Indus Basin Water Quality data at the Kotri Command for the year 2006, 2007 and 2008 under LIM Project Hyderabad.

8. Food & Agriculture Organization (1982). Fruit bearing forest trees, FAO Forestry Paper 34, Rome, pp 177.

9. Ghafoor, A., S. Muhammad and M. Yaqub. 1987. Use of saline-sodic water for reclamation of a salt affected soil and for crop production. Pak. J. Soil Sci., 2: 17-21.

10. Ishaque, M. et. al. (2008). Water quality of drains and Indus river system in Pakistan IWASRI, Internal Report No. 2008/4. pp. 70.

11. Mass, E. V. 1986. Salt Tolerance of Plants. Applied Agriculture Research, 1, 12-26.

12. Mass, E.V. and Hoffman, G.J. 1977. Crop salt tolerance- current assessment. Journal of the Irrigation and Drainage Division. American Society of Civil Engineering, 103, 115-134.

13. Qureshi, R.H., M. Hanif, M.I. Rajoka and G.R. Sandhu. 1975. Use of saline sodic waters for crop production. The Optimum Use of Water in Agriculture, CENTO Sci. Program. Turkey. Pp. 123-197.

14. Rhoades, J.D. 1984. Use of saline water for irrigation. California Agriculture, 38: 42-43.

15. SMO, WAPDA. (2006) River/Canal and drainage water quality under IEM Study for the year 2006.

INTERNATIONAL EXPERIENCES IN GROUNDWATER MANAGEMENT AND THEIR VIABILITY IN PAKISTAN FOR RESOURCE SUSTAINABILITY

Muhammad Basharat[1] and S. Javed Sultan[2]

ABSTRACT

Groundwater development has seen an unprecedented growth in many parts of the world during the last couple of decades. Especially in populous Asian countries like India, China and Pakistan, exponential growth rates, in terms of number of wells and estimated accumulated pumping volumes, give an impression of an explosion, within a short time span of about forty years. Like many other countries, groundwater in Pakistan is under increasing threat from over-development, over-extraction and pollution, the major cause being population pressure. Different countries are adopting different approaches depending upon their socio-economic setup, professional and financial resources availability. But in Pakistan, there is little evidence that government has re-engineered their capacity and funding to deal with this great challenge which is likely to further intensify with the passage of time. Any delay in capacity building to tackle the issue may be fatal, because the longer it takes to develop such actions, greater would become the depth to groundwater, and higher would be costs of "equilibrium" solution. In this paper, experiences in developing and developed countries are reviewed in context to their applicability in Pakistan.

Keywords: groundwater management, depletion, regulation, recharge, rainwater harvesting.

1. INTRODUCTION

In Pakistan, groundwater has become the most important source for agricultural, domestic as well as industrial consumption. It is the groundwater that has contributed more than the surface water for the increased water requirements almost in every water use sector in the last 20-40 years. Thus, the sustainability of our groundwater resources so far, has played the key role in overall development of our country. It is a unique resource, widely available, providing security against cyclical droughts and yet closely linked to surface water resources and the hydrological cycle. Its reliable supply, good quality and suitable temperature, relative turbidity and pollution free, minimal evaporation losses, and low cost of development are attributes making groundwater

[1] Senior Engineer (Drainage), IWASRI, WAPDA. Email: basharatm@hotmail.com

[2] Director/PRO (Drainage), IWASRI, WAPDA.

more attractive. With rapid growth in population, urbanization, industrialization and competition for economic development, groundwater resource has become vulnerable to extreme depletion and degradation. For an effective, efficient and sustainable groundwater resources development and management, the planners and decision makers have future challenges to assess the inextricable logical linkages between water policies and ethical consideration. Groundwater being a hidden resource is often developed without proper understanding of its occurrence in time and space; this is especially true for developing countries where governments do not own this precious resource. Thus groundwater management on scientific lines under the auspices of the government is the key for sustainability of this vital resource.

1.1 Increasing Role of Groundwater and Associated Problems in Pakistan

Pakistan is already a water stressed country. Per capita water availability in Pakistan fell from 5000 cubic meters per annum in 1951 to 1100 cubic meters per annum in 2006. With the population reaching to 180 million now, the per capita availability of fresh water is estimated to have fallen to 1000 cubic meters, the threshold figure for a country to be declared `water scarce'.

Increasing urban and rural population is causing substantial pressures on surface and groundwater resources. While addressing a function marking the World Population Day, Prime Minister of Pakistan, Mr. Yousaf Raza Gilani said it was very important to make a plan to balance population growth with the country's resources equitably and prudently. The prime minister said that Pakistan was the sixth most populated country in the world with the highest population growth rate at 2.03 percent among the SAARC countries, resulting in an annual addition of 3.6 million people (World Population Day, 2011). With the aforementioned growth rate it is projected to reach 255.8 million by the year 2027 and double i.e. 360 million by 2045 in next 34 years. With these population projections, the per capita water availability is likely to dip further down to almost 700 and 500 cubic meters per capita by 2025 and 2045, respectively.

The primary reason for Pakistan's inability to tackle the problem of water scarcity is inadequate water storage capacity. Pakistan's per capita storage capacity is merely 100 cubic meters in comparison to 5000 cubic meters in the US and Australia and 2200 in China (John, 2011). In 1970s and 80s canal water was the main driver of irrigated agriculture in the country. About twenty years later, groundwater successively became the primary irrigation source. This means that groundwater is no longer supplemental to canal water, but is an integral part of the irrigated agricultural environment. Tail end areas are not only deprived of their fair share of surface water, they have to pump proportionately more groundwater which shows decreasing quality towards the tail (Latif and Ahmad, 2009).

Intensified groundwater use has been the single most important contributor to agricultural growth in Pakistan in the last thirty to forty years. Groundwater is also the source of drinking water for over 70% of the population of Pakistan. Also, considerable number of industries use groundwater for their process requirements. Past research in the country has focused mainly just to highlight the quantum of problem rather than any concerted effort towards the solution of depleting and deteriorating groundwater in barani and irrigated areas. At present, no practical provision exists in Pakistan to manage groundwater, which is an important component of the overall economic performance of the country. The studies indicate that if the present trend of excessive pumping of groundwater through installation of burgeoning tubewells continue, it will not be possible to pump groundwater by centrifugal pumping system because of declining water table at a very fast rate. Many of the farmers had to convert to turbine pumps at a very high cost in order to irrigate their fields even in canal irrigated areas having highest depletion rates.
IWMI (2002), based on the work in India and Pakistan, has concluded that groundwater irrigation has surpassed surface irrigation as the primary source of food production and income generation in many rural areas. The key question for policy makers and planners is how to tap this resource without exhausting the supply. IWMI (2005) has concluded that by considering groundwater availability and quality when allocating surface water, water managers could improve the equity, sustainability and productivity of irrigated systems. The prevailing situation-where there is separate management of groundwater and surface water has contributed to land salinization in areas with poor quality groundwater and to low agricultural productivity and high vulnerability for farmers in the tail ends of systems. In irrigated areas, much of the groundwater that is pumped by the farmers is actually a by product of canal irrigation systems at various levels (Basharat and Tariq, 2012), yet these resources are often managed in complete isolation to each other.

Over withdrawal of the resources to meet the needs of increasingly intensive cropping has given rise to lowering of watertable in several areas, particularly in southern parts of Bari Doab (Basharat and Ali, 2012) as shown in Figures 1 and 2. Continuously declining watertable obliges the farmer to dig deeper, lower their submersible pumps and use more electric/diesel power to lift water from increasing depths. The ability to access groundwater plays a major role in reducing risk and increasing incomes, especially when other modes of irrigation are absent (Moench et al., 2003). The cost of installing tubewell in areas where watertable depth is more than 24 meters is 7 times higher as compared to those areas where watertable depth is around 6 meters (Qureshi et al., 2003). Similarly energy cost for pumping increases by three times for the aforementioned groundwater depletion (Basharat and Tariq, 2012b). Therefore, the sustainability of this precious resource is highly at stake in many of the urban and irrigated areas of the country. The issue therefore is how to control over pumping and maintain groundwater levels in order to avoid saline intrusion and depletion of the resource.

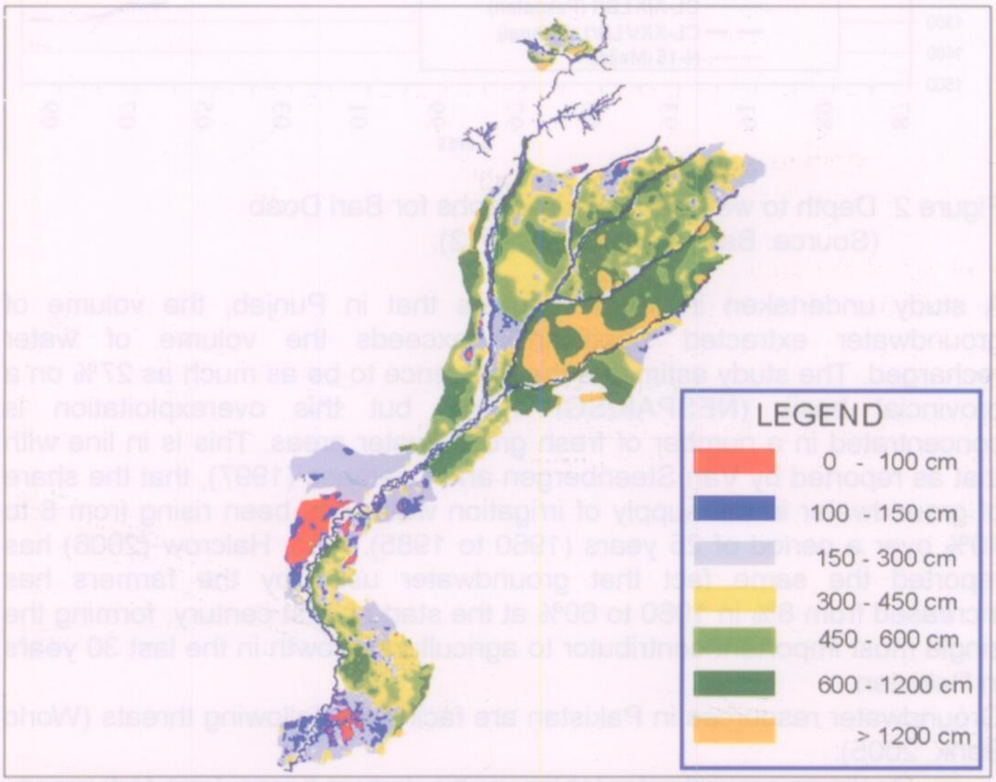


Figure 1: Areas under different depths to watertable (October, 2002) in IBIS (Source: Basharat and Ali, 2012).

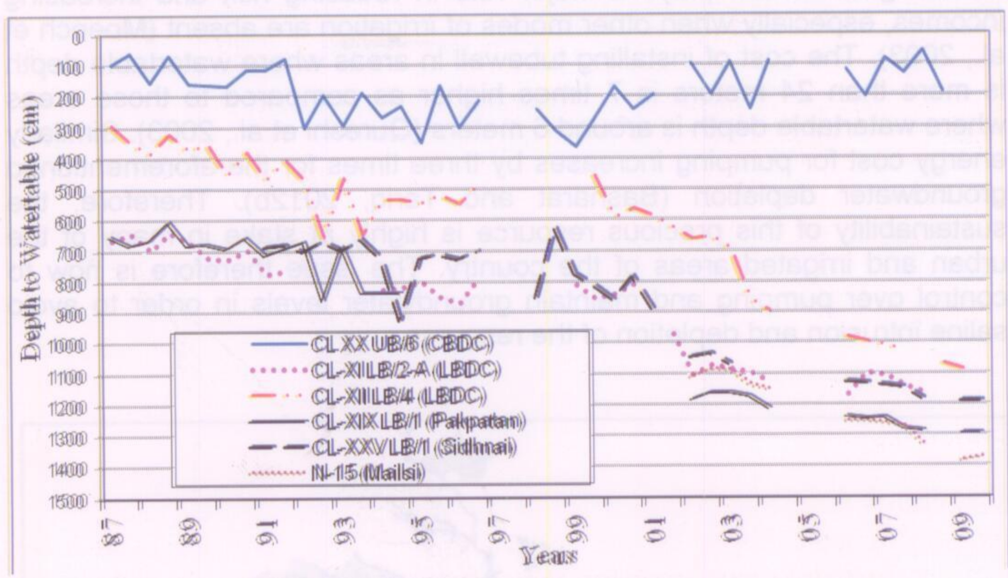


Figure 2: Depth to watertable hydrographs for Bari Doab
(Source: Basharat and Ali, 2012).

A study undertaken in 1990 suggests that in Punjab, the volume of groundwater extracted significantly exceeds the volume of water recharged. The study estimates the difference to be as much as 27% on a provincial basis (NESPAK/SGI 1991), but this overexploitation is concentrated in a number of fresh groundwater areas. This is in line with that as reported by Van Steenbergen and Oliemans (1997), that the share of groundwater in the supply of irrigation water has been rising from 8 to 40% over a period of 25 years (1960 to 1985). Also, Halcrow (2006) has reported the same fact that groundwater used by the farmers has increased from 8% in 1960 to 60% at the start of 21st century, forming the single most important contributor to agricultural growth in the last 30 years in Pakistan.

Groundwater resources in Pakistan are facing the following threats (World Bank, 2005):

- Declining groundwater tables, particularly in barani (rain-fed) areas.
- Saline water ingression in canal commands.
- Pollution of aquifers.
- Concerns on sodification and arsenic contamination.

In another World Bank (2005a) paper, it has been pointed out that the realistic water requirements of the canals are required to be re-calculated keeping in view various factors under the present situation. It means that the water allowances are required to be revised accordingly.

2. INTERNATIONAL EXPERIENCES IN GROUNDWATER MANAGEMENT

2.1 India

India being a big country is facing different challenges in different areas, so the government has different approaches for these areas suitable to the local conditions.

2.1.1 Legislation

In its effort to control and regulate the development of groundwater, India started its efforts since 1970 in the form of Model Bill. The Indian constitution provision stipulates water as a state subject. Persuasion is being made with state governments/union territories (UTs) for inclusion of roof-top rainwater harvesting in building bye-laws, also nine states have already made it mandatory for special category of buildings. In two states, namely Gujarat and Maharashtra, the bill has been passed but not enacted. Action on the model bill has been initiated in 16 states/UTs. In urban areas, the Government of India has amended building bye-laws and made rainwater harvesting, as a means of artificial recharge, mandatory. So far, Tamil Nadu, Delhi, Haryana have taken action. Other states are in the process of amending the building bye-laws to make rainwater harvesting mandatory in the special class of buildings (Mehta 2006 and Romani 2006). Many states in India have yet to legislate on the regulation and management of groundwater. The few states that have legislation in this area have done so by adopting (with some modifications) the model groundwater bill. The basic scheme of the model bill is to provide for the establishment of a groundwater authority under the direct control of the government. The authority is given the right to notify areas where it is deemed necessary to regulate the use of groundwater. The final decision is taken by the respective state government. Wells need to be registered even in non-notified areas. Decisions of the authority in granting or denying permits are based on a number of factors which include technical factors such as the availability of groundwater, the quantity and quality of water to be drawn and the spacing between groundwater structures. The states that have adopted legislation that specifically focuses on groundwater include Goa, Himachal Pradesh, Kerala, Tamil Nadu and West Bengal. They differ in their coverage since some apply only to the notified areas while other apply to all groundwater (Philippe, 2010). Central Groundwater Board (CGWB) has been established in India since 1997 in order to cope with the situation of alarming groundwater decline.

The main object of constitution of CGWB is the urgent need for regulating the indiscriminate boring and withdrawal of groundwater in the country. No groundwater development is done without prior approval of CGWB. In case of violations, the state governments have been advised to seal the tubewell or even seize the drilling equipments.

2.1.2 Recharging efforts

The first line of defense is to augment the available ground water. Experience of many NGOs as well as pilot studies on artificial recharge at the behest of the Indian CGWB has shown positive results (Government of India, 2007). In an effort to counter the falling watertables, India's CGWB developed a national blueprint for groundwater recharge in the country which aims at recharging surplus runoff of about 36.4 BCM (29.5 MAF) in an area of about 450,000 sq km identified in various parts of the country experiencing a sharp decline in groundwater levels (Villholth, 2006).

Concern regarding the looming crisis has been mounting in the government, and in 2005 the Planning Commission constituted an expert group to review the issue of groundwater management and suggest appropriate policy directions (Government of India, 2007). The World Bank's Water Resources Assistance Strategy for India (World Bank, 2005b) also emphasized groundwater overexploitation as a critical water sector challenge for India, and advocated developing pragmatic solutions instead of continuing the failed command and control approaches. CGWB has encouraged constructing cost efficient structures to a number of individuals eager to take up rainwater harvesting to arrest the declining groundwater levels.

In Delhi, the depth to bed rock ranges from 25 to 42 m at most of the places whereas at very few places, it goes up to 145 m, so the aquifer is shallow. Therefore, with the rapid population growth, the groundwater supplies are not sustainable. Therefore, though Delhi receives normal rainfall of 611.8mm in 27 rainy days, most of which is going waste as runoff of about 193MCM. It is estimated that the total recharge from rainwater harvesting structures for entire NCT, Delhi is 1390 ha.M (13.9 MCM). The task force constituted for implementation of rainwater harvesting schemes in government buildings, colonies and parks has estimated that about 2.9 MCM rainfall recharge will take place, from the rooftop rainwater harvesting structures constructed in Government buildings in NCT, Delhi during normal monsoon in a year. This will facilitate additional rise in groundwater level to the tune of 0.5 m in alluvium areas and about 1.0 m in hardrock areas (NCT Delhi recharge proposal available at.

http://www.greensystems.net/images/Dr.Sharma%20NCR%20Planning%20board%20proposal.pdf).

2.1.3 Management efforts

Andhra Pradesh is one of the several states underlain by hard-rock aquifers that have suffered considerable depletion of groundwater, largely for irrigation use, in recent decades. The Andhra Pradesh Farmer-Managed Groundwater Systems Project (APFAMGS) has adopted a novel approach to the problem. The core concept of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle, and limited availability. To achieve this end, the project has engaged farmers in data collection and analysis, building their understanding of the dynamics and status of groundwater in the local aquifers. Even farmers with limited literacy skills have demonstrated their ability to collect and analyze rainfall and groundwater data, estimate and regulate their annual water use based on planned cropping patterns, and increase their knowledge of improved agricultural practices through attendance at farmer water schools (at which a third of the facilitators are women). The project does not offer any incentives in the form of cash or subsidies to the farmers. The assumption is that access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding the use of groundwater resources. The core organizational component of the project is the groundwater management committee, a village-level community-based institution comprising all groundwater users in a community. The committees are in turn grouped into hydrological units. Data gathered through hydrological monitoring of rainfall and groundwater levels are used to estimate the crop water budget, which is an aquifer-level assessment of the quantity of water required for the proposed rabi (winter) planting. Awareness of this statistic has become one of the essential variables that farmers take into account when making their cropping decisions for the coming season (World Bank, 2010).

2.1.4 Regulation

The Hon'ble High Court of Kerala in the matter of *Perumatty Grama Panchayat vs. State of Kerala* also known as the landmark "Coca- Cola Case" decided on the issue of the excessive exploitation of ground water as *"Groundwater is a national wealth and it belongs to the entire society---. The State as a trustee is under a legal duty to protect the natural resources. These resources meant for public use cannot be converted into private ownership---."* (Shankar et al., 2011). As regards groundwater regulation, specifically depletion, the Supreme Court of India has passed several orders in 1996, where under it has issued directions to the

Government of India for setting up of Central Ground Water Authority (CGWA) under the Environment (Protection) Act, 1986 and to declare it as an authority under the Environment Protection Act and delegate powers under the said Act to the CGWA for the purposes of regulation and control of groundwater development. The Hon'ble Court further directed that the CGWA should regulate indiscriminate boring and withdrawal of groundwater in the country and issue necessary directions with a view to preserving and protecting the groundwater.

2.2 Bangkok

Greater Bangkok witnessed widespread exploitation of groundwater starting in the 1950s, and by 1980 the abstractions had reached a point where there was evidence of significant land subsidence damaging urban infrastructure and concerns regarding aquifer sea intrusion. The initial approach taken by the Metropolitan Waterworks Authority was to eliminate the utility's abstraction in favor of surface water sources, but the increased domestic, commercial, and industrial tariffs for public water supply triggered a massive increase in the drilling of private wells, whose total abstraction reached over 2,000 million liters per day (818 cfs) in the late 1990s. Measures such as banning water well drilling in critical areas and licensing and charging for metered or estimated groundwater abstractions were introduced, but took some years to be implemented. During 1995–2005 even stronger measures were introduced and implemented (including raising groundwater use charges and more aggressive application of sanctions on well drilling, supported by public awareness campaigns) to constrain groundwater abstraction within environmentally tolerable limits. Total abstraction was reduced from 2,700 million liters per day in 2000 to 1,500 million liters per day in 2005, and land subsidence was also significantly reduced. Political protest by users in some districts was addressed by allowing well users to continue using their wells conjunctively for the period up to their next license renewal (up to 10 years) and to retain their wells as a backup supply for 15 years, provided they were adequately metered and open to inspection (World Bank, 2010).

2.3 China

The situation in China concerning groundwater seems to comply with riparian[3] rights doctrine to some extent, especially for rural region, allowing anyone who has the right to use land to get access to the groundwater to use it. The free occupancy system supports the legal basis for this action, since it regulates that drawing water for family use, livestock drinking,

[3] Riparian rights doctrine is that any person who owns and occupies land on the bank of a natural stream acquires water use rights which are commonly known as "riparian rights" by virtue of the occupation of that land.

emergency use or 'few demands' for irrigation don't need permits. This gives us a kind of misperception: the groundwater rights are attached to land use right. Due to this there is no other rational principle to restrict groundwater abuse, the way "groundwater rights adheres to the land use right" has become a kind of regulation established by usage (Tianduowa, 2009).

2.4 Netherlands

In the Netherlands the regulations related to groundwater roughly fall into two categories. First, related to the protection of the groundwater against pollution. Second and more relevant in the context of this paper is related to the groundwater use. The permits for the use of groundwater are a matter for the provinces in the Netherlands (together with the water boards) according to article 11 of the Dutch Groundwater Law (Dutch government, 2009). Below a certain quantity no registration and permit is needed. Above this quantity registration with the provincial authorities is required.

2.5 Australia

Australia has implemented the following reforms for successful groundwater management:

- State has power and replaced the common law riparian rule and groundwater ownership rule(land owner owns water and can use all he likes) with licensing system soon as agriculture provoked conflict
- Land and water not tied together anymore since 1994 which has created flexibility and retirement of some land from irrigation.
- Facilitated water markets and revisions of water allocation amounts
- Environmental allocations worked out first and the remaining water is the consumptive pool.

2.6 Spain

Spain, like many parts of the world, until 1985, bestowed private property rights over groundwater resources. However, the 1985 Water Act in response to intensive groundwater use changed the rules of the game. For one, groundwater was taken away from the private domain and ownership rights bestowed upon the state. Second, river basin management agencies were given a role in managing groundwater, and finally, they were also vested with the power to grant permits for groundwater use that started after 1985. It also gave authority to the river basin agencies to declare an aquifer as overexploited, and once it was so declared, to formulate an aquifer management plan for recovery of the aquifer. Some features of such a plan were the reduction in volume of withdrawals or rejection of new applications for wells. In addition, all users of the aquifer were required to organize themselves into groundwater user associations in order to encourage user participation. So far, some 16 aquifers have been declared totally or partly overexploited (Hernandez-Mora et al. 2003), while such user associations have been formed in only five and implemented in only two aquifer areas. Further amendments to the act were made in 1999 and 2001, which emphasized the role of the groundwater users in aquifer management.

2.7 Water Sector Reforms in Mexico

Perhaps no other country has reformed its water laws as extensively as Mexico has since 1992. By the law of the Nation's Waters of 1992, water was declared as a national property and it became mandatory for existing users to legitimize their rights through procuring water concessions. The National Water Commission (CNA) was entrusted with the responsibility of registering water user associations, set up a regulatory structure to enforce and monitor their concessions granted and also to collect a volumetric fee from all users, except small-scale irrigators. Aquifer Management Councils (COTAS) were promoted by CNA as user organization aimed at managing groundwater. Response to the reforms so far has been mixed at best. The large industrial and commercial water users have been quick to apply for concession and pay water fees. However, the real challenge has been registering water rights of the agricultural users, who withdraw at least 80% of total volumes withdrawn, and monitor their withdrawals. Among the agricultural users, the tube-well owners have responded to the law quite positively and have applied for water concessions. The major reason for such compliance has been the 'carrot' of subsidized electricity that has been promised to tube-well owners who regularize their connection through registration of the wells with the CNA. This shows that farmers respond well to direct economic incentives. Monitoring of actual extraction has proved more intractable.

2.8 Highlights of Management Approaches Abroad

All over the world, groundwater has long been treated as an infinite resource that can be endlessly exploited. The idea that groundwater, though a common good, belongs to the overlying landowner has shaped thinking about water, even in the developed world. Only after this resource has been overexploited and polluted, do governments and users begin to worry about managing its use? Attempts to allocate groundwater and manage these entitlements in a sustainable manner have achieved only limited success and still pose a major challenge to the water sector.

According to Janakarajan (2000) the important measure would be to separate the right to groundwater use from land ownership titles. In other words, it is necessary to define property rights in groundwater so that all existing ambiguities are removed. Spain & Mexico reformed their water laws to make groundwater a national property. However, their success in getting water rights of agricultural users registered has been insignificant.
According to Shah (2006), sustaining the massive welfare gains groundwater development has created without ruining the resource, is a key water challenge facing the world today. He has quoted that demand restriction has also been tried through combination of pricing, legislative and regulatory action, licensing and permits, and by specifying property rights, direct regulation worked better in countries with a hard state, as in Iran, which imposed an effective ban on new tubewells in 1/3rd of its central plains, or Russia which has banned the use of groundwater for irrigation to protect it for domestic uses.

3 APPROACHES FOR SUSTAINABLE GROUNDWATER MANAGEMENT

International experiences, and experience within India, give insight into the instruments available for groundwater management. This can be categorized as follows:

Rainwater harvesting: In many dry regions the revival of historical water harvesting techniques and recharge is now being considered as a possible way of alleviating water scarcity (Prinz, 1996). The term water harvesting is understood to mean the collection of surface runoff and its use for irrigated crop production under dry and arid site conditions. Physical structures are built to retain runoff and encourage infiltration to groundwater.
Where cities overlie hard-rock aquifers (for example Rawalpindi and Islamabd) this can lead to severe depletion and pollution of the groundwater body. Even cities above the extensive alluvial aquifers (Lahore) are finding the underlying water tables inexorably declining. For such cities a balanced policy dovetailing both surface water and groundwater supply and recharge enhancement will need to be developed, under the auspices of empowered and well-organized regulatory agencies. In rural areas, techniques of artificial recharge by modification of natural movement of water through suitable rerouting such as dry river beds (Sukh Beas) and drains during wet season can be feasible.
Groundwater Governance and regulation: The first step in groundwater governance is adequate and high-quality information, not only

hydrogeological, but also socio-economic as well. In many instances, such information is missing or more possibly not accessible in the public domain due to unwillingness of the government departments (especially the data) to share it with the general public. Effective regulation becomes extremely difficult when there are very large numbers of small users. Pricing measures, including volumetric charges, taxes, and user fees, can act as incentives to conservation and more efficient allocation of water resources, provided they address concerns of equity and affordability to the poor. Such measures can only be successful for a small numbers of severely threatened resource users.

Demand-side measures: aim to reduce consumptive groundwater use, for example through an increase in water tariffs and converting to volumetric billing system in urban settings, or reducing crop water requirements and non-beneficial evapotranspiration from fields in agricultural areas.

Community management of groundwater: Community groundwater management refers not to a specific instrument but to a means of implementing management interventions. The key is that the resource user community (instead of the state) is the primary custodian of groundwater and is charged with implementing management measures. Hence, community groundwater management can involve any mix of instruments, including regulation, property rights, and pricing. Some well-publicized examples of successful community self-regulation have occurred in India but have often been dependent on the influence of a charismatic leader. While community-based management of groundwater is clearly a promising approach in India, global experience offers few models of community management that might be applicable in the sub-continent setting, and a homegrown solution will undoubtedly be needed.

Integrated use of surface and groundwater: Rainfall which is a renewable, natural resource but limited in amount and variable in distribution over space and time. The surface waters from rivers, which are canalized, supplement it and the two together constitute the total available water resource. Similarly, the crop water requirement is spatially variable (Basharat and Tariq, 1012) increasing in downstream direction of the IBIS. The water logged areas in canals command offer scope for groundwater development by lowering the watertable up to 3-6 m. Thus additional water for irrigation can be saved for use elsewhere and induced deeper watertable in these areas will help in rainfall recharge that will help in improvement of soil and water quality. Therefore rationalizing canal water allocations can help improve the groundwater situation both in waterlogged and depleted areas.

4 CURRENT STATUS OF GROUNDWATER MANAGEMENT IN PAKISTAN

Pakistan, still being developing country and equipped with weakened water research, development and management institutions, is considerably lagging behind in converting the existing knowledge base into state of-the-art management policy. In the past, the cushion that groundwater provided during the drought (1999 to 2002) could not be replenished. No groundwater management or regulation regime is in force, both for urban and rural areas. Similarly, there is no regulation of water consumed by cities or industries at large.

Presently, in Pakistan groundwater is an open access common property natural resource and any one can bore a well and pump water till his satisfaction without any limit. In many of the irrigated areas of Punjab and barani areas of Punjab and Baluchistan, groundwater extraction has exceeded annual natural recharge and watertables are going down and down. However, there are also areas which are waterlogged. Farmers lying at the tail of the canal commands are facing with depleting groundwater tables, forcing them to lower their pump sumps every four to five years or totally converting to turbine technology for long-term sustainability of the same as compared to centrifugal pumps. Thus, use of groundwater is solely at the economic condition of the farmers, thus the poor's are suffering more by not pumping water or purchasing at high costs and affording conveyance losses from the tubewell owner to the field.

Rise in watertable in areas where its use is restricted due to quality considerations leading to spread of salinity problems are a matter of increasing concern (e.g. saline areas of LCC command). The major impact of marginal and saline groundwater is in the form of low cropping intensity and very minimal pumping of groundwater by the farmers, thus causing waterlogging of the areas. These specific issues demand proper drainage and optimal use of groundwater resources for which strategic planning and implementation with a good understanding of issues involved is required. The role of farmers, the primary users of groundwater and who are also directly affected is very critical and can have far reaching impact. The regulatory policy regimes and institutional structures for achieving the goals are as necessary as are the availability and acceptance of alternate technologies, cropping and farming practices.

There is lack of professionals to carry out detailed assessment of groundwater resources in different irrigation units of the country. At present not a single water conservation program can be seen in a big and well educated area of Lahore with depleting groundwater resources. No regulation even of the municipal sector consisting of WASA, private housing societies, industry and individual users. The institutions concerned are yet to fully realize that successful water resources management requires a long term planning process.

4.1 Institutional Setup

Agencies mainly responsible for water management for different purposes in the country are:

- Water and Power development Authority (WAPDA): A federal agency for planning, development and management of surface water resources of the country.
- Provincial Irrigation and Power Department (PID): is responsible for distribution of irrigation water and maintenance of irrigation and drainage system in the Punjab Province.
- Water and Sanitation Agency (WASA); a sub-department of urban Development Authority's, responsible for water supply and sewerage services.
- Public Health Engineering Department is responsible for planning and execution of small scale schemes for potable water supply to towns and villages (groundwater source only).

Government management of the irrigation system does not extend beyond the main distribution channels. In effect, the efficiency and effectiveness of water management relies on the way farmers use the system. The capacity of state groundwater institutions need to be developed to ensure that they can perform the key functions of providing information and technical support, enabling community management, and enforcing regulatory measures where necessary and applicable. The present water crisis is "mainly a crisis of governance" as declared by the Global Water Partnership (2000). Vertical and horizontal coordination needs to be strengthened and the divisions of the responsibilities between the institutions need to be clearer and well defined. Currently SMO, DLR IWASRI and PCRWR are mainly involved in monitoring and research regarding groundwater. But, gravity of the situation is that there is no coordinated effort in this regard, rather the data sharing involves too many and difficult steps to conclude. Specifically groundwater monitoring together by SMO and DLR in Punjab is a clear duplication and wastage of meager resources. Any measures would require capacity building of these central and provincial agencies dealing with groundwater.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

It is concluded that the implementation of various clauses of groundwater legislation has proved to be very difficult all over the world. The experience of all these countries bring to the fore the fact that while making law is not very difficult, enforcing one is a challenge, a challenge rarely met in any of the countries discussed before. Above all, proper groundwater management and governance depends on prevailing socio-economic and political structure in a country. That means, not all measures are likely to succeed everywhere and that a tool kit for governance has to be substantially broad based to take into account contextual reality within a temporal framework. Best practice schemes in a long term perspectives has these elements:

- Groundwater use in conjunction with surface water at all levels i.e. local, canal command, provincial and Indus basin level;
- Rainwater harvesting and/or diverting flood flows for groundwater recharge;
- A licensing system for users or another mechanism depending upon extent of depletion;
- Set safe yield and regulates allocation and use accordingly.

With continuously declining water levels, sustainability of irrigation practice is in doubt and such is the case in southern parts of Bari Doab (Basharat and Ali, 2012), and barani areas of Punjab and Balochistan. Specific conclusions with respect to strategic sustainability of groundwater resources are as follows:

- Resolution of these problems both surface and groundwater requires strong political will and support, a public education and information program, and user involvement;
- Groundwater management is becoming more and more a must in developing countries to forestall overexploitation and to foster sustainable use of the water resources. Nevertheless, sound management of groundwater requires an efficient institutional and regulatory framework, which only the full commitment of the government can ensure;
- The strategy of combining demand side measures to control, protect and conserve water resources with supply side measures to augment the resources has the potential for successful implementation in the country.

- The canal water needs to be reduced in waterlogged areas which can be diverted to the falling water table areas in order to compensate for the negative groundwater balance.
- The role of farmers, the primary users of groundwater and who are also directly affected is very critical and can have far reaching impact.

5.2 Recommendations

The climate change will affect all facets of society and environment with strong implications for water and agriculture now and for the future. Fresh canal water is expected to increase in value in the face of population growth, gradual aquifer depletion and groundwater salinity increase. Overcoming future challenges will require clarity on water rights, surface and groundwater, and water to be treated as an economic good. A multipronged integrated approach with a well conceived mix of professional, technical administrative and legal steps with community participation for ensuring sustainable management of groundwater resources is a must for the times to come. Specific recommendations are:

- There is dire need to establish a central groundwater authority at federal level with the mandate for policy and planning, and provincial bodies with implementation and regulation roles;
- In highly depleted areas, all extraction wells should be got registered by the government as first step except domestic and livestock (low discharges);
- Mandatory rain water harvesting in all new constructions in relevant urban areas as well as design techniques for road surfaces and infrastructure to enhance ground water recharge.
- Evolving a groundwater recharge strategy for depleted irrigated and barani areas separately that can contribute through various kinds of recharge measures, e.g. utilizing old bed of Sukh Beas and Sutlej River for diverting surplus river flows;
- Harvesting of rain water and excess monsoon runoff which is going unutilized, to create additional groundwater storage is the most attractive and technically feasible option;
- Long term strategies like formulation of a national water law and regulatory framework on groundwater abstraction, construction of small and large storage reservoirs;
- Role of Federal and provincial institutes e.g. PCRWR and IWASRI, SMO be amended accordingly. These organizations under the federal government can take up the lead role but with proper mandate issued under some legislation. Provincial (such as DLR) and district level

departments having links at the stakeholder level should take the role of involving local community in groundwater management;

- In the wake of depleting groundwater, recommended depth to watertable zoning for irrigated given in Table1.

Table 1: Recommended classification of areas with different depths to watertable.

DTW, m (ft)		Classification
0 (0)	0.9 (3)	Disaster
0.9 (3)	1.5 (5)	Waterlogged
1.5 (5)	3.0	Likely to be
3.0 (10)	6.0	Normal (optimal)
6.0 (20)	9.0	Normal (sub-optimal)
9.0 (30)	13 (43)	Likely to be depleted
13 (43)	18 (59)	depleted
More than 18 (59)		Highly depleted

- Based on the above classification groundwater management areas need to be identified. In addition, it is equally important to manage the different aquifer systems by extending the information on sub-surface aquifer systems to the user groups and the beneficiaries;
- Water withdrawal can be reduced by partly diversifying to low water-requiring crops, and employing water saving production technologies at a field scale. Large-scale adoption of rice-wheat system has been a major factor in over-exploitation of groundwater due to high ET requirements. In kharif, rice may be replaced with maize, pulses and oilseeds; whereas wheat may be replaced with oilseeds and gram. For all the above tasks a dedicated and fully equipped planning agency is required at Federal level with participation from provinces.

REFERENCES

1. Basharat M. and Ali S.U. 2012. Spatial variation in water supply and demand across canal commands in Punjab; evaluation of existing water allocations. Paper to be presented at "Water, Energy, Environment and Food Nexus: Solutions and Adaptation under Changing Climate - 4–5 April, 2012, Lahore, Pakistan.
2. Basharat M. and Tariq A.R., forthcoming 2012. Spatial climatic variability and its impact on irrigated hydrology in a canal command. Accepted for publication by Arabian Journal for Science and Engineering, published by Springer.

3. Basharat M. and Tariq A.R., forthcoming 2012b. Equity considerations in irrigation design and inequitable distribution of groundwater in LBDC command. Accepted by Mehran University Research Journal of Engineering & Technology.
4. Dutch Government, 2009. Groundwater Law, Law of 22 May 1981, Stb 1981, 392 (since amended).
5. Global Water Partnership, 2000. Towards water security: a framework for action, GWP, March 2000.
6. Government of India, 2007. Ground Water Management and Ownership, Report of the expert group to the Planning Commission, Government of India New Delhi.
7. Halcrow, 2006. "Punjab irrigated agriculture development sector project, Final report Annex 5 – Groundwater management. Asian Development Bank TA-4642-PAK, 2006.
8. Hernandez-Mora N, Martinez Cortina L, Fornes J. 2003. Intensive groundwater use in Spain. In: Llamas MR, Custodio E (eds) Intensive use of groundwater: challenges and opportunities. Balkema, The Netherlands.
9. IWMI, 2002. The Socio-Ecology of Groundwater in India, Water Policy Briefing Issue 4 by IWMI-Tata Water Policy Program.
10. IWMI, 2005. Reducing Poverty through Integrated Management of Groundwater and Surface Water, Water Policy Briefing Issue 13 by IWMI and Global Water Partnership, available at www.iwmi.org/waterpolicybriefing.
11. Janakarajan S., 2000. Competition, conflicts and crisis – An example of degraded groundwater regimes and feckless governance in south India. Global Water Partnership, Proceedings of Regional Groundwater Management Seminar, October 9-11, 2000 Islamabad.
12. John, 2011. Water Security in South Asia: Issues and Policy Recommendations. Issue Brief # 26. Observer Research Foundation, 20, Rouse Avenue, New Delhi-110 002. Available at: www.orfonline.org.
13. Latif, M. and M Z Ahmad, 2009. Groundwater and soil salinity variations in a canal command area in Pakistan. *Irrigation and Drainage 58*: 456-468, Wiley Inter Science (www.interscience.wiley.com) doi: 10.1002/ird.417.
14. Mehta, M. 2006. Status of Groundwater and Policy Issues for its Sustainable Development in India. In: Proceedings of IWMI- ITP- NIH International Workshop on "Creating Synergy between Groundwater

Research and Management in South and Southeast Asia" February 8-9, 2005, Roorkee, India.

15. Moench M, Burke J, Moench Y., 2003. Rethinking the approach to groundwater and food security, Water Rep 24. Food and Agriculture Organization, Rome.

16. NESPAK/SGI., 1991. Contribution of Private Tubewells in the Development of Water Potential. National Engineering Services of Pakistan and Special Group Inc., Lahore.

17. Philippe C., 2010. Groundwater Regulation – Need For Further Reforms, IELRC WORKING PAPER 2010 – 01 (http://www.ielrc.org/content/w1001.pdf, accessed on January 18, 2012).

18. Prinz D., Oweis T. and Oberle A., 1996. Rainwater Harvesting for Dry Land Agriculture - Developing a Methodology Based on Remote Sensing and GIS. Accessed on Jan 04, 2012. (lada.virtualcentre.org/eims/download.asp?pub_id=93866&app=0).

19. Qureshi, A. S; Shah, T.; Akhtar, M., 2003. The groundwater economy of Pakistan. IWMI Working Paper 64. Lahore, Pakistan.

20. Romani, S., 2006. National Blueprint for Recharging Groundwater Resources in India. In: Proceedings of IWMI- ITP- NIH International Workshop on "Creating Synergy between Groundwater Research and Management in South and Southeast Asia" February 8-9, 2005, Roorkee, India.

21. Shah T., 2006, Groundwater and Human Development: Challenges and Opportunities in Livelihoods and Environments. In; Proceedings of IWMI- ITP- NIH International Workshop on "Creating Synergy between Groundwater Research and Management in South and Southeast Asia" 8-9 February 2005, Roorkee, India.

22. Shankar P. S. V., Kulkarni H. and Karishnan S., 2011. India's Groundwater Challenge and the Way Forward. Economic and political weekly. Vol XLVI No.2.

23. Steenbergen Van F. and Olienmans W., 1997, "Groundwater resources management in Pakistan" In: ILRI Workshop: Groundwater Management: Sharing Responsibilities for an open access Resource, Proceedings of the Wageningen Water Workshop.

24. Tianduowa, Z., 2009. Integrated Water Resources Management Based on Water Right Institution, M.Sc. Thesis, ITC.

25. Villholth, K.G., 2006. Integrating Science into Groundwater Management Decisions. In; Proceedings of IWMI- ITP- NIH International Workshop on "Creating Synergy between Groundwater

Research and Management in South and Southeast Asia" February 8-9, 2005, Roorkee, India.

26. World Bank 2005a, Water Rights and Entitlements by Don Blackmore and Faizul Hasan; Background Paper # 6 Country Water Resources Assistance Strategy.

27. World Bank, 2005. Groundwater Development and Management in Pakistan by Frank van Steenbergen and M. Shamshad: Gohar; Background Paper No. 11, Country Water Resources Assistance Strategy.

28. World Bank, 2005b. "India's Water Economy: Bracing for a Turbulent Future", World Bank Report, Washington DC available at http://go.worldbank.org/QPUTPV5530.

29. World Bank, 2010. Deep Wells and Prudence: Towards Pragmatic Action for Addressing Groundwater Overexploitation in India. Accessed from http://siteresources.worldbank.org/INDIAEXTN/Resources/295583-1268190137195/DeepWellsGroundWaterMarch2010. accessed on January 12, 2012.

30. World Population Day, 2011. Prime Minister Yousaf Raza Gilani's address on World Population Day on July 11, 2011, available http://www.nation.com.pk/pakistan-news-newspaper-daily-english-online/Politics/11-Jul-2011/High-population-growth-rate-undermining-economic-progress-Gilani (accessed on July 14, 2011).

GROUND WATER TABLE FLUCTUATIONS IN IRRIGATED AREAS OF RECHNA DOAB - PUNJAB

By

Muhammad Saeed, Syed Javed Sultan and Dr. M. Mehboob Alam[1]

Abstract

Field study of Groundwater Management (Recharge Potential and Governance), is being conducted in the Indus Basin by IWASRI and part of this study is to determine the artificial recharge potential in the depleted areas of Indus Basin. Therefore, the main objective of this study was to identify areas of groundwater depletion in the canal commands of Rechna Doab. Under this study, the data of depth to water table in all canal commands is being analysed. The data related to canal supplies, rainfall and depth to water table fluctuation occuring in different seasons have been summarized in the paper. Observation wells have been installed in the study area by SCARP Monitoring Organization (SMO), each observation well individually shows depletion of its representative area.

Historic canal withdrawals from Indus River System during Kharif and Rabi seasons for Rechna Doab, the average values are 10.59-10.92 MAF during 2001-2009 and indicate that average annual canal deliveries to Rechna Doab from Indus Basin Irrigation System during 1967-76 were 9.831 MAF (6.268 MAF in Kharif and 3.563 MAF in Rabi) which increased by 9.9% during 1977-00 and 2.8% during 2001-09. Rabi supplies during 2001-09 significantly reduced by 10.9% as compared to 1967-76.

The average value of annual canal withdrawals for the period 2001-09 is 10.106 MAF. The gross command area of Rechna Doab canals is 2.408 Mha (5.950 MA). To assess the depth of water delivered to Rechna Doab, the delivered water i.e. 10.106 MAF is divided by command area (5.950 MA), it is equivalent to 1.69 ft (515 mm) per year. It is 1.16 ft (354 mm) during Kharif and 0.53 ft (161 mm) during Rabi (Table 3).

In Rechna Doab 42% area falls in the range of 3-6 m and 30% area falls in the range of 6-9 m and 5% area falls in the range of 13-18 m in the canal commands of Rechna Doab.

Artificial Recharge to groundwater should be managed in the highly depleted area during flood season. Surface irrigation water allowance may be increased to compensate the highly depleted areas.

1. INTRODUCTION

Pakistan has a large network of irrigation system. It has supported the needs of increasing population over the years. Canal water supplies have recharged the aquifer and created a groundwater resource in the command areas. Continued abstraction and extensive exploitation of groundwater has resulted in depletion of groundwater table in fresh groundwater areas. Lateral and vertical movement of brackish groundwater has deteriorated the groundwater quality in fresh groundwater areas.

The main purpose of the study is to identify areas where groundwater aquifer is depleting rapidly and the areas where groundwater recharge potential exists. SCARPs Monitoring Organization (SMO) of WAPDA has been collecting the data related to depth of ground water table for the last four decades. For this study the data was collected for Rechna

[1] Senior Engineer, Director and Director General, International Water logging and Salinity Research Institute (IWASRI), Near Village Muhammad Pura, P.O. Box Thokar Niaz Beg, Raiwind Road Lahore-53700, Pakistan. **PBX:** +92-42-5303391-92, **Fax:** +92-42-5303393.
Email: engrsaeed_47@yahoo.com iwasri@brain.net.pk

Doab, Punjab province. After screening, the data has been analysed for the study. The results pertaining to Rechna Doab area of Punjab province are being presented in the paper.

1.1 STUDY AREA

This study aims to analyze groundwater table data of Indus System Irrigated Area of Rechna Doab (Punjab). Upper Chenab, Lower Chenab, Raya Branch (BRBD Internal), Marala Ravi Internal and Haveli Internal Canals irrigated area in Rechna Doab. The groundwater quality is usable i.e. 61% of the total area of 1.311 MA of Rechna Doab, marginal in 32% and hazardous in 7% of the total survey area during (2003). The main objective of the study is to understand groundwater table behaviour in the Indus System Irrigated Areas of Rechna Doab (Punjab).

1.2 SALIENT FEATURES OF CANALS

Upper Chenab and Lower Chenab Canals are the main source in Rechna Doab which derives their flows on perennial basis from Indus Basin System. Other main canals in Rechna Doab include Raya Branch (BRBD), Marala-Ravi and Havel Canals. Salient features of Rechna Doab Canal Commands are given in Table 1.

Table 1 Salient Features of Rechna Doab Canal Commands

Sr. No.	Canal	Barrage/Supply Channel	Designed Discharge (cfs)	GCA (000 ha)
1	Upper Chenab (Internal) Canal	Marala Barrage/Upper Chenab Link Canal	3412	470
2	Lower Chenab Canal	Khanki Barrage	11700	1607
3	Raya Branch (BRBD Internal)	Marala Barrage/Upper Chenab Link Canal/ BRBD Link Canal	1708	183
4	Marala Ravi (Internal) Canal	Marala Barrage/Marala Ravi Link Canal	1347	71
5	Haveli (Internal) Canal	Trimmu Barrage/Haveli Link Canal	869	77
			Total:	**2408**

(RAP, 1979-II and DMP, 2005)

1.3 CANAL DELIVERIES

Historic canal withdrawals from Indus River System during Kharif and Rabi seasons for Rechna Doab, the average values are given in Table 2. It indicates that average annual canal deliveries to Rechna Doab from Indus Basin Irrigation System during 1967-76 were 9.831 MAF (6.268 MAF in Kharif and 3.563 MAF in Rabi) which increased by 9.9% during 1977-00 and 2.8% during 2001-09. Rabi supplies during 2001-09 significantly reduced by 10.9% as compared to 1967-76.

The average value of annual canal withdrawals for the period 2001-09 is 10.106 MAF. The gross command area of Rechna Doab canals is 2.408 Mha (5.950 MA). If it is divided by command area (5.950 MA), it is equivalent to 1.69 ft (515 mm) per year. It is 1.16 ft (354 mm) during Kharif and 0.53 ft (161 mm) during Rabi (Table 3).

1.4 RAINFALL

There are four climatological stations of Pakistan Meteorological Department (PMD) in the canals command area, namely Lahore, Sialkot, Faisalabad and Shorkot, where the Indus system irrigated areas of Rechna Doab are lying. Maximum annual rainfall was recorded as 1232 mm during 1997 for Lahore, 1887 mm during 1973 for Sialkot, 807 mm for Faisalabad during 1997 and 642 mm for Shorkot during 1983. The respective values of minimum rainfall for the four stations are 297 mm (1963), 382 mm (1965), 172 mm (1995) and 86 mm (1972). Mean annual rainfall works out as 627 mm for Lahore, 954 mm for Sialkot, 361 mm for Faisalabad and 282 mm for Shorkot. Average value for the four stations is 556 mm per year.
Five year mean annual rainfall for Lahore, Sialkot, Faisalabad and Shorkot stations is given in Table 4. No significant increasing or decreasing trend is found.

1.5 POTENTIAL EVAPO-TRANSPIRATION

Annual potential evapo-transpiration for Upper Rechna, i.e. Lahore and Sialkot is 1419 mm and 1584 mm, respectively (average being 1502 mm), and for Lower Rechna (Faisalabad), it is 1728 mm (Ahmad, N.). Average of Upper and Lower Rechna is 1615 mm which represents annual potential evapo-transpiration for Rechna Doab. Depth of mean (2001-09) annual canal withdrawals (515 mm) plus mean (1961-09) annual raifnall (556 mm) is equal to 1071 mm. Annual potential evapo-transpiration is 1615 mm which is 1.5 times higher than the depth of mean annual canal withdrawals plus rainfall.

Table 2 Average Withdrawals of Rechna Doab Canals

Season	Average Canal Withdrawals (MAF)			Percent Change Over 1967-76	
	1967-76	1977-00	2001-09	1977-00	2001-09
Kharif	6.268	6.831	6.932	8.98	10.59
Rabi	3.563	3.972	3.174	11.48	(-)10.92
Annual	9.831	10.803	10.106	9.89	2.80

Note: Negative sign shows decrease in canal withdrawals.

Table 3 Average Canal Withdrawals per Unit of GCA in Rechna Doab

GCA = 5.950 MA (2.408 MH)

Season	Average Canal Withdrawals (2001-09)		
	MAF	Per Unit of GCA	
		Ft	mm
Kharif	6.932	1.16	354
Rabi	3.174	0.53	161
Annual	10.106	1.69	515

Table 4 Five Year Mean Annual Rainfall in Rechna Doab Area (mm)

Year	Upper Part of Rechna Doab		Lower Part of Rechna Doab	
	Lahore	Sialkot	Faisalabad	Shorkot
1961-65	548.76	776.00	306.34	
1966-70	456.62	751.48	274.04	
1971-75	535.36	1008.94	291.68	223.58
1976-80	765.56	978.60	505.52	327.86

1981-85	768.30	955.22	435.52	373.38
1986-90	697.92	1112.66	350.02	233.28
1990-95	578.40	1076.66	253.02	299.36
1996-00	788.92	1140.42	376.98	264.50
2001-05	528.86	895.28	384.00	229.13
2006-09	598.08	814.85	456.95	

2. DATA COLLECTION AND ANALYSIS

2.1 EXISTING OBSERVATION WELLS

Out of total 1339 (Nos.) observation wells installed by SMO, WAPDA in Rechna Doab, 39% were operational during the year 2010, while 61% were non-operational due to being filled up/choked. The area per operational observation well varies from 1385 ha for Koranga Branch Canal to 8868 ha for Upper Chenab Canal. It may be due to uneven distribution of observation wells. Depth to water table maps was prepared based on the field observations. Map showing areas of different water table depth ranges for post-monsoon 2010 for Rechna Doab is given in Figure 10.

2.2 WATER TABLE MONITORING

Bi-annual monitoring of water table data for canal commands of Rechna Doab have been done and documented under the following depth ranges by SMO.

(i) 0-90 cm (ii) 90-150 cm (iii) 150-300 cm (iv) 300-450 cm (v) 450-600 cm (vi) > 600 cm

Historic data of areas in percentages, under different depths to water table is given in Tables 5 to 11 for individual canal commands and for Rechna Doab. It indicates area in percent under water table depth 0-150 cm and 150-300 cm has reduced while area under > 600 cm has increased during the year 2009.

2.3 Water Table in Upper Chenab Canal Command

Table 5 gives five years average percent areas under different depths to water table for pre-monsoon period in Upper Chenab Canal Command. As evident, area under water table depth 0-150 cm and 150-300 cm during 2006-10 has decreased as compared to the previous periods, while area under water table depth > 600 cm has increased during this period.

Table 5 also gives five years average percent areas under various water table depths for post-monsoon period in Upper Chenab Canal Command. The results show that area under 0-150 cm and 150-300 cm water table depth during the period 2006-10 has decreased as compared to the previous periods, while area having water table depth > 600 cm has increased during this period.

2.4 Water Table in Lower Chenab Canal Command

Table 6 gives five years average percent areas under different depths to water table for pre-monsoon period in Lower Chenab Canal Command. As evident, area under water table depth 0-150 cm and 150-300 cm during 2006-10 has decreased as compared to the previous periods, while area under water table depth > 600 cm has increased during this period.

Table 6 also gives five years average percent areas under various water table depths for post-monsoon period in Lower Chenab Canal Command. The results show that area under water table depth 0-150 cm and 150-300 cm during the period 2006-10 has decreased over the previous periods, while area under water table depth > 600 cm has increased during the period 2006-10.

2.4 Water Table in Raya Branch (BRBD) Canal Command

Table 7 gives five years average percent area under different depths to water table for pre-monsoon period in Raya Branch Canal Command. Area under 0-150 cm during the last 5 years (2006-10) has decreased over the previous periods, while area under > 600 cm water table depth has increased during this period.

Table 7 also gives five years average percent area under different depths to water table for post-monsoon period in Raya Branch Canal Command. As evident, area under 0-150 cm range during 2006-10 has decreased while area under > 600 cm has increased during this period.

2.5 Water Table in Marala Ravi Canal Command

Table 8 gives five years average percent area under different depths to water table for pre-monsoon period in Marala Ravi Canal Command. The results show that area under 150-300 cm water table depth during the period 2006-10 has decreased over the previous periods, while area under water table depth > 600 cm has increased during this period.

Table 8 also gives five years average percent area under different depths to water table for post-monsoon period in Marala Ravi Canal Command. The pertinent results show that area under 0-150 cm water table depth during 2006-10 has decreased as compared to previous periods, while area under water table depth 450-600 cm and > 600 cm has increased during this period.

2.6 Water Table in Haveli Canal Command

Table 9 gives five years average percent area under different depths to water table for pre-monsoon period in Haveli Canal Command. Area under 0-150 cm and 150-300 cm water table depth during the period 2006-10 has decreased over the previous periods, while area under water table depth 300-450 cm and 450-600 cm has increased during this period.

Table 9 also gives five years average percent area under different depths to water table for post-monsoon period in Haveli Canal Command. It is evident that area under water table depth 0-150 cm and 150-300 cm during the period 2006-10 has decreased over the previous periods, while area under water table depth 300-450 cm and 450-600 cm has increased during this period.

2.7 Water Table in Koranga Branch Canal Command

Table 10 gives five years average percent area under different depths to water table for pre-monsoon period in Koranga Branch Canal Command. The results show that area under water table depth 0-150 cm and 150-300 cm during 2006-10 has decreased over the previous periods, while area under 450-600 cm and > 600 cm water table depth has increased during this period.

Table 10 also gives five years average percent area under different depths to water table for post-monsoon period in Koranga Branch Canal Command. As evident, area under water table depth 0-150 cm and 150-300 cm during the period 2006-10 has decreased over the previous periods, while area under water table depth 450-600 cm and > 600 cm has increased during this period.

2.8 Water Table in Rechna Doab Area

Table 11 and Figure 1 show five years average percent area under different depths to water table for pre-monsoon period for all canal commands of Rechna Doab. The pertinent results reveal that area under water table depth 0-150 cm and 150-300 cm during 2006-10 has decreased over the previous periods, while area under water table depth > 600 cm has increased during this period.

Table 11 and Figure 2 also show five years average percent area under different depths to water table for post-monsoon period for all canal commands of Rechna Doab. As evident, area under water table depth 0-150 cm and 150-300 cm during 2006-10 has decreased while area under > 600 cm range has increased during this period. Reasons for increase in the area under > 600 cm water table depth mainly include reduction in canal supplies to Rechna Doab canal commands socially during Rabi season.

Table 5 Average Percent Area under Different Water table Depths in Upper Chenab Canal

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	>600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	>600 cm
Mean										
1981-85	4.97	29.51	41.02	20.00	4.50	13.34	38.20	32.03	12.15	4.28
1986-90	1.55	12.34	35.28	30.49	20.34	6.87	31.91	32.84	20.81	7.57
1991-95	0.93	13.11	41.94	30.58	13.44	5.75	24.32	40.50	18.98	10.45
1996-00	2.24	12.09	46.68	28.75	10.23	6.09	19.45	42.99	23.04	8.43
2001-05	0.32	2.50	19.66	39.20	38.32	0.41	5.36	23.15	36.41	34.66
2006-10	4.97	29.51	41.02	20.00	4.50	13.34	38.20	32.03	12.15	4.28

Table 6 Average Percent Area under Different Water table Depths in Lower Chenab Canal

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	>600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	>600 cm
Mean										
1981-85	5.42	31.13	31.79	17.23	14.43	10.56	33.73	26.69	15.05	13.97
1986-90	2.27	16.84	28.75	24.03	28.11	3.03	21.21	28.26	26.70	20.80
1991-95	1.18	14.70	30.53	21.23	32.35	2.92	18.74	28.95	20.18	29.21
1996-00	1.28	17.03	29.96	18.77	32.97	3.92	18.46	28.95	18.40	30.28
2001-05	0.70	6.20	17.73	19.87	55.50	1.15	9.51	16.62	17.13	55.60
2006-10	5.42	31.13	31.79	17.23	14.43	10.56	33.73	26.69	15.05	13.97

Table 7 Average Percent Area under Different Water table Depths in Raya Branch (BRBD)

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm
Mean										
1981-85	2.96	20.87	42.71	30.22	3.23	13.61	25.77	37.93	20.67	2.02
1986-90	0.23	11.54	32.07	34.95	21.22	11.82	30.19	28.72	20.54	8.74
1991-95	0.46	16.05	40.55	32.99	9.95	14.89	33.18	26.27	18.15	7.51
1996-00	1.81	17.98	42.74	25.77	11.70	14.22	31.64	30.47	17.91	5.76

2001-05	0.57	7.97	30.77	31.00	29.68	1.47	29.13	30.51	21.82	17.07
2006-10	2.96	20.87	42.71	30.22	3.23	13.61	25.77	37.93	20.67	2.02

Table 8 **Average Percent Area under Different Water Table Depths in M.R. Canal**

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm
Mean										
1981-85	2.12	31.41	45.12	16.70	4.64	26.72	39.96	23.85	8.25	1.22
1986-90	1.94	34.02	30.77	21.65	11.61	27.73	53.08	13.08	4.71	1.40
1991-95	2.17	36.81	44.47	13.63	2.91	22.12	43.10	25.81	8.97	
1996-00	3.79	21.50	38.68	23.64	12.40	9.27	39.07	34.45	13.91	3.29
2001-05	2.09	14.50	32.88	29.98	20.55	1.99	27.94	32.09	24.85	13.13
2006-10	2.12	31.41	45.12	16.70	4.64	26.72	39.96	23.85	8.25	1.22

Table 9 **Average Percent Area under Different Water Table Depths in Haveli Canal**

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm
Mean										
1981-85	8.65	78.92	12.42			20.92	68.58	10.50		
1986-90	6.18	45.43	25.98	21.87	0.55	8.97	60.47	28.26	2.29	
1991-95	9.12	65.27	25.61			13.39	69.41	15.54	1.67	
1996-00	6.42	37.42	41.12	11.20	3.84	6.10	36.38	42.19	12.06	3.27
2001-05	3.91	22.89	53.57	19.62	0.01	5.63	25.92	53.73	14.72	
2006-10	8.65	78.92	12.42			20.92	68.58	10.50		

Table 10 **Average Percent Area under Different Water Table Depths in Koranga Branch**

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm
Mean										
1981-85	12.50	31.92	44.87	10.71		17.70	29.29	43.35	9.66	
1986-90	6.29	24.36	40.82	15.36	13.17	13.56	25.27	49.24	11.93	
1991-95	8.33	34.67	47.00	10.00		11.53	28.15	47.44	12.88	
1996-00	1.12	7.31	43.74	40.54	7.29		24.13	37.74	28.35	9.78
2001-05		6.26	23.05	40.72	29.96	2.55	14.31	18.89	53.30	10.96
2006-10	12.50	31.92	44.87	10.71		17.70	29.29	43.35	9.66	

Table 11 Average Percent Area under Different Water Table Depths in Rechna Doab

Year	Pre-Monsoon (June)					Post-Monsoon (October)				
	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm	0-150 cm	150-300 cm	300-450 cm	450-600 cm	> 600 cm
Mean										
1981-85	5.14	31.60	34.32	18.16	10.79	12.19	35.27	28.12	14.17	10.26
1986-90	2.02	17.02	30.70	25.66	24.60	5.70	27.77	30.89	25.29	10.36
1991-95	1.39	16.97	33.76	22.83	25.05	5.34	23.39	30.65	18.68	21.94
1996-00	1.61	16.89	34.95	21.33	25.21	4.91	21.02	32.65	19.12	22.31
2006-10	0.73	6.38	20.73	24.93	47.23	1.18	11.29	20.59	21.67	45.28

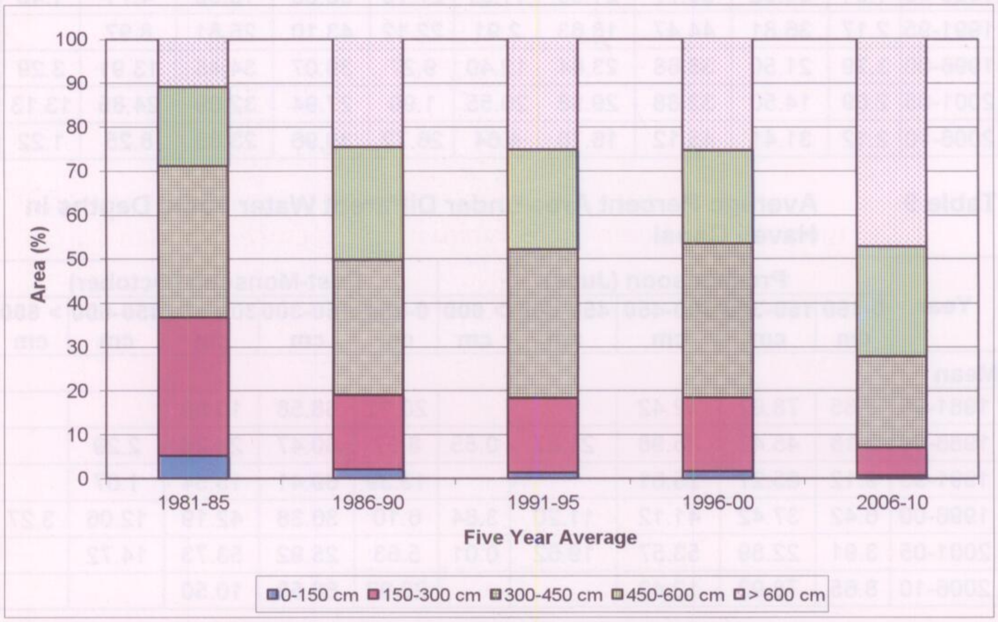


Figure 1 Pre-Monsoon Water Table in Rechna Doab

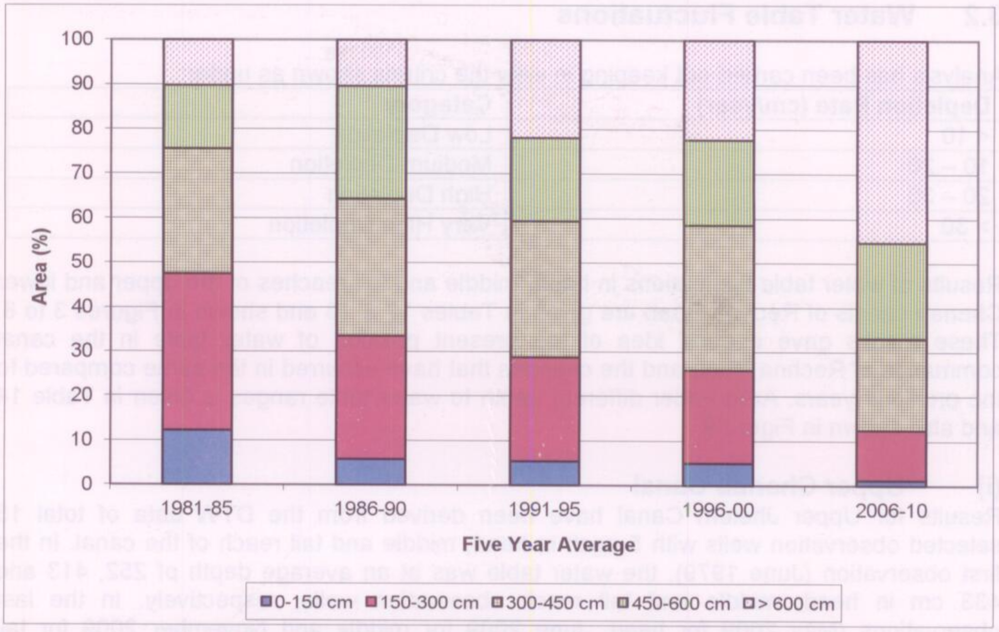


Figure 2 Post-Monsoon Water Table in Rechna Doab

3 HISTORIC WATER TABLE DEPLETION AND RISE

3.1 Methodology

(i) Historic data of depth to water table (DTW) for the canal commands of Rechna Doab, Punjab Province, was collected from SMO, WAPDA.

(ii) The data was analysed for the selected observation wells located in head, middle and tail reaches of the individual canal commands.

(iii) To achieve accuracy of the results, data of only those observation wells was considered for analysis which did not involve too much data gaps.

(iv) Average DTW, alongwith 5-year moving average, were taken to analyse the data for head, middle and tail reaches of the canal commands.

(v) Mean values of pre and post-monsoon depth to water table for the first and last year of measurements were compared.

(vi) Total depletion/rise of water table for the entire period of measurements, was worked- out by subtracting last year mean value of water table depth from the initial/first year mean value.

(vii) Annual rate of depletion/rise of water table was calculated by dividing the total depletion/rise of water table over the total years of observations.

3.2 Water Table Fluctuations

Analysis has been carried out keeping in view the criteria shown as under:

Depletion Rate (cm/year)	Category
< 10	Low Depletion
10 – 20	Medium Depletion
20 – 30	High Depletion
> 30	Very High Depletion

Results of water table fluctuations in head, middle and tail reaches of the upper and lower Chenab canals of Rechna Doab are given in Tables 12 & 13 and shown in Figures 3 to 8. These results gave a good idea of the present position of water table in the canal commands of Rechna Doab and the changes that have occurred in the same compared to the previous years. Area under different depth to water table ranges is given in Table 14 and also shown in Figure 9.

(i) Upper Chenab Canal

Results for Upper Jhelum Canal have been derived from the DTW data of total 15 selected observation wells with 5 each in head, middle and tail reach of the canal. In the first observation (June 1979), the water table was at an average depth of 252, 413 and 433 cm in head, middle and tail reach observation wells, respectively. In the last observations (May 2009 for head, June 2009 for middle and November 2009 for tail reach), the water table dropped to 284, 480 and 774 cm in the respective reaches (Table 12). The results reveal drop of water table over a period of 29-30 years with 32.03 cm in head, 67.12 cm in middle and 340.93 cm in tail reach of the canal command. Water table dropped at the rate of 1.10, 2.24 and 11.21 cm/year in head, middle and tail reaches of the canal, respectively. Overll, the depletion rate in tail reach is higher than 10 cm per year which falls under the "Medium Depletion" Category. Hydrographs showing water table fluctuations in the three reaches of the canal are given in Figures 3 to 5. These hydrographs also show declining trend, more prominently in the tail reach. Compared with the upper reaches, depletion in tail reach is high which reflects increased use of groundwater by the tail farmers to meet their crop water requirements.

Table 12 Water Table Fluctuations in Head, Middle and Tail Reaches of Upper Chenab Canal (1979 to 2009)

Sr. No.	Canal Reach (No. of Obs. Wells)	Mean Depth to Water table (cm)			Period (years)	Rate of Depletion (cm/year)
		Initial Reading	Last Reading	Difference		
1	Head (5)	252.30 (Jun 1979)	284.33 (May 2009)	32.03	29.08	1.10
2	Middle (5)	412.58 (Jun 1979)	479.70 (Jun 2009)	67.12	30.00	2.24
3	Tail (5)	433.43 (Jun 1979)	774.36 (Nov 2009)	340.93	30.42	11.21

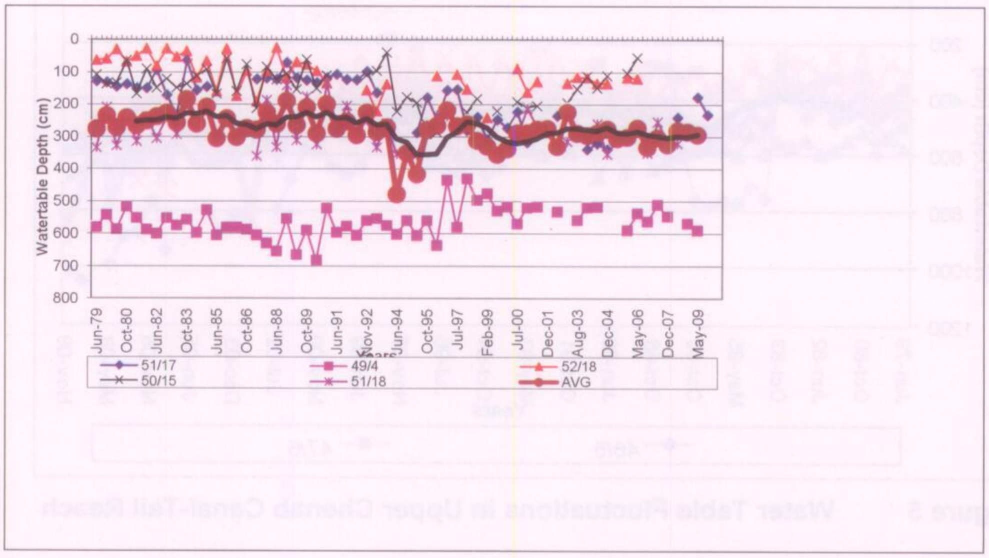


Figure 3 Water Table Fluctuations in Upper Chenab Canal-Head Reach

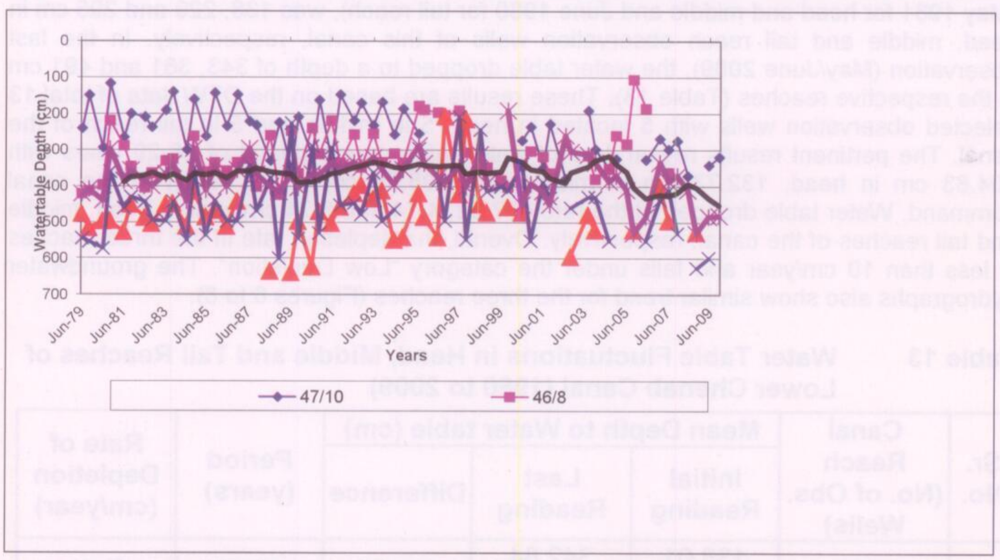


Figure 4 Water Table Fluctuations in Upper Chenab Canal-Middle Reach

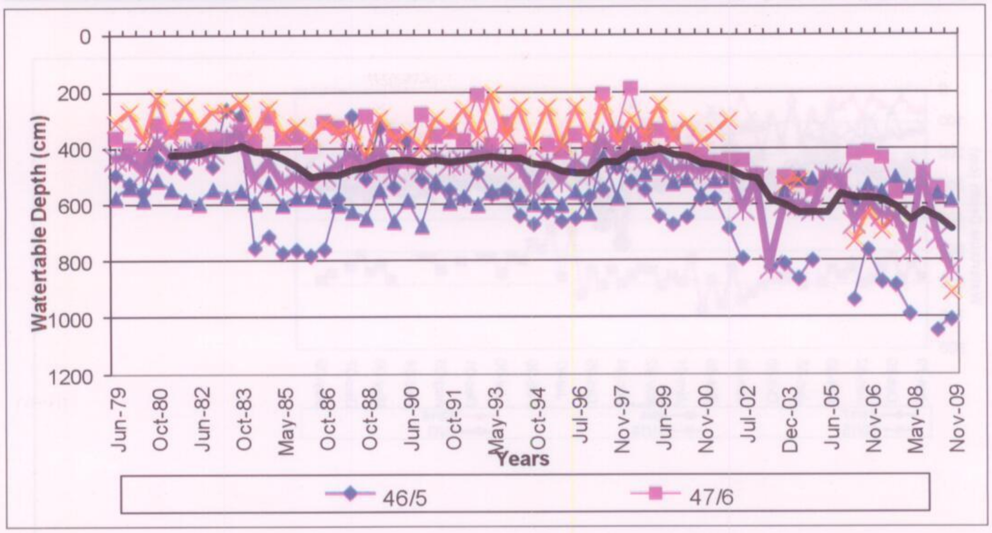


Figure 5 Water Table Fluctuations in Upper Chenab Canal-Tail Reach

(ii) Lower Chenab Canal

Water table depth (mean of pre and post-monsoon observations), in the first observation (May 1981 for head and middle and June 1980 for tail reach), was 138, 229 and 295 cm in head, middle and tail reach observation wells of this canal, respectively. In the last observation (May/June 2009), the water table dropped to a depth of 343, 361 and 491 cm in the respective reaches (Table 13). These results are based on the DTW data of total 13 selected observation wells with 5 located in head, 5 in middle and 5 in tail reach of the canal. The pertinent results reveal drop of water table over a period of 28-29 years with 204.83 cm in head, 132.73 cm in middle and 195.56 cm in tail reach of the canal command. Water table dropped at the rate of 7.32, 4.74 and 6.74 cm/year in head, middle and tail reaches of the canal, respectively. Overall, the depletion rate in the three reaches is less than 10 cm/year and falls under the category "Low Depletion". The groundwater hydrographs also show similar trend for the three reaches (Figures 6 to 8).

Table 13 Water Table Fluctuations in Head, Middle and Tail Reaches of Lower Chenab Canal (1980 to 2009)

Sr. No.	Canal Reach (No. of Obs. Wells)	Mean Depth to Water table (cm)			Period (years)	Rate of Depletion (cm/year)
		Initial Reading	Last Reading	Difference		
1	Head (5)	138.01 (May 81)	342.84 (May 09)	204.83	28.00	7.32
2	Middle (5)	228.69 (May 81)	361.42 (May 09)	132.73	28.00	4.74
3	Tail (5)	295.32 (Jun 80)	490.88 (Jun 09)	195.56	29.00	6.74

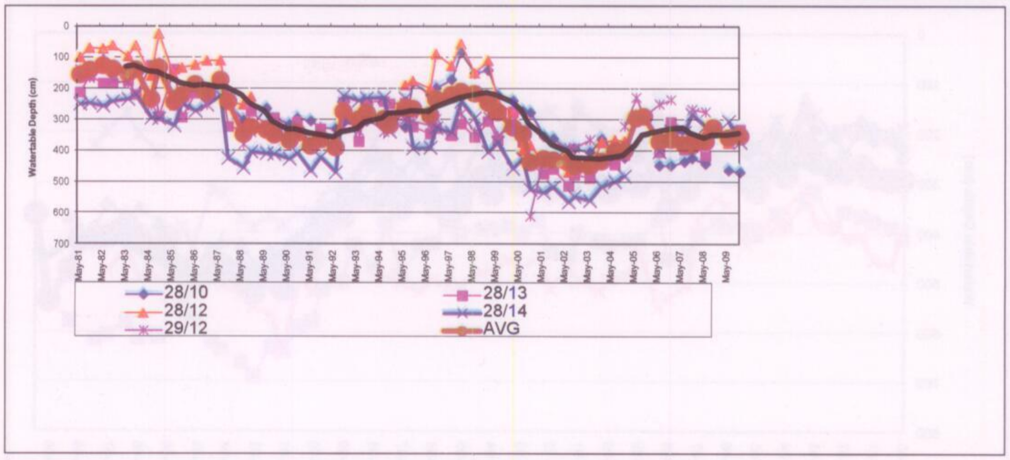


Figure 6 Water Table Fluctuations in Lower Chenab Canal-Head Reach

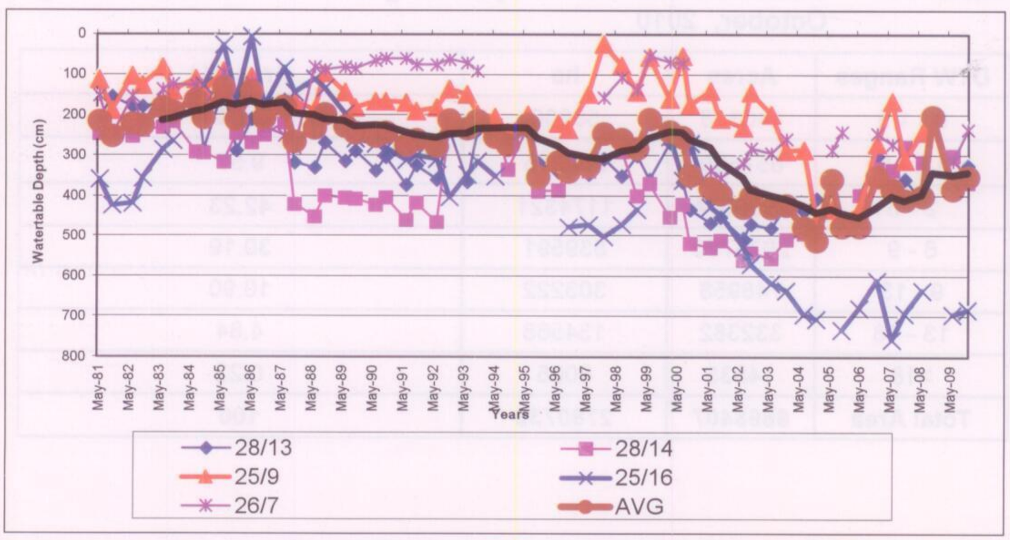


Figure 7 Water Table Fluctuations in Lower Chenab Canal-Middle Reach

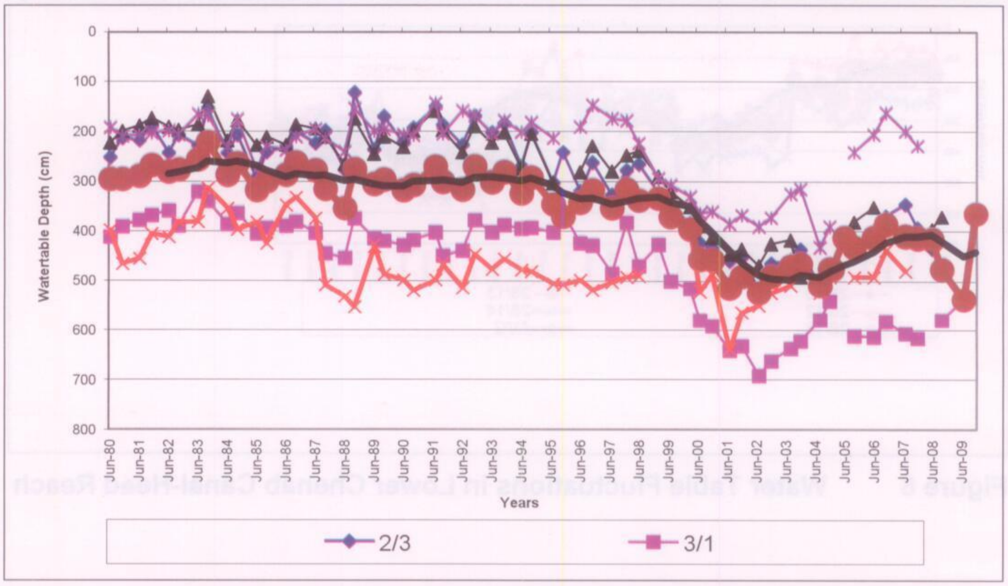


Figure 8 Water Table Fluctuations in Lower Chenab Canal-Tail Reach

Table 14 Different Water Table Depth Ranges in Rachna Doab During October, 2010

DTW Ranges	Acres	ha	Area (%)
0 - 1.5	140318	56809	2.04
1.5 - 3	657550	266215	9.57
3 - 6	2900574	1174321	42.23
6 - 9	2073790	839591	30.19
9 - 13	748958	303222	10.90
13 - 18	332382	134568	4.84
>18	14835	6006	0.22
Total Area	**6868407**	**2780732**	**100**

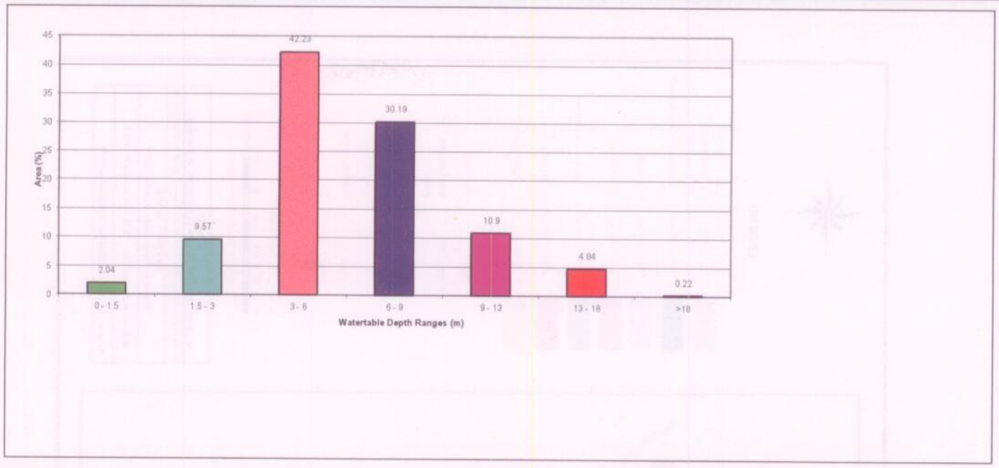


Figure 9 **Different Water Table Depth Ranges in Rachna Doab during October, 2010**

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

(i) Compared with the period 1967-76, average annual canal deliveries to Rechna Doab from the Indus Basin Irrigation System, increased by 10 percent during the period 1977-00 and further by 3 percent during 2001-09. Increase in canal withdrawals was only during Kharif season, while Rabi withdrawals during 2001-09 decreased by 11 percent as compared to 1967-76 periods.

(ii) Maximum depletion of 341 cm over a period of 30 years was observed in tail reach of Upper Chenab Canal. In case of Lower Chenab Canal, maximum depletion of 205 cm in head and 196 cm in tail reach was worked out over a period of 28 and 29 years.

(iv) Area under shallow water table (0-150 cm depth) during pre-monsoon 2006-10 period has reduced as compared to previous periods, while area under deeper water table (> 600 cm depth) has increased during this period.

(v) In this doab 42% area falls in the range of 3-6 m and 30% area falls in the range of 6-9 m and 5% area falls in the range of 13-18 m in the canal command of Rechna Doab.

4.2 RECOMMENDATIONS

(i) Artificial Recharge to ground should be managed in the highly depleted area during flood season.

(ii) In the Shallow groundwater areas surface irrigation water allowance may be decreased to compensate the highly depleted areas by increasing surface water allowance.

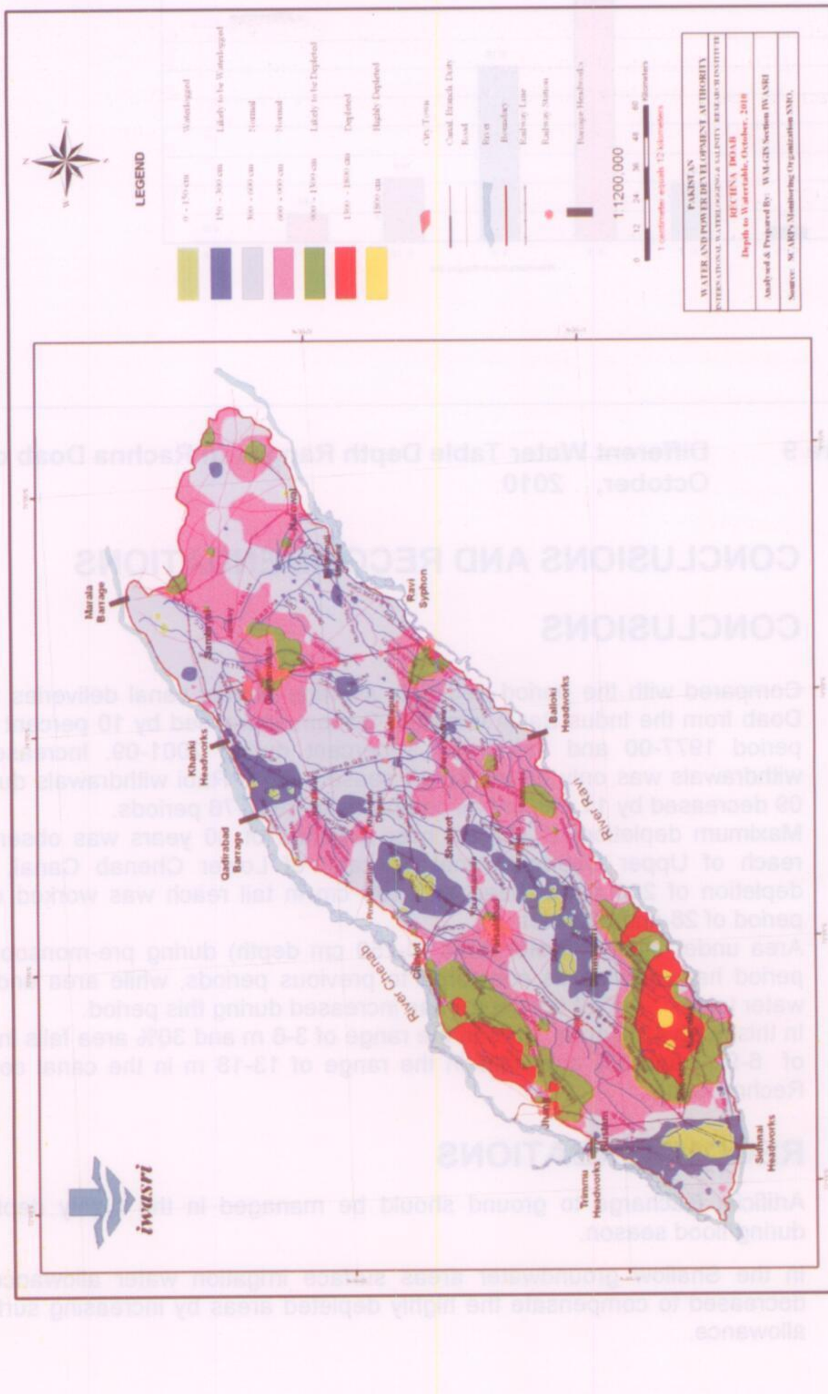


Figure 3.14 Depth to Watertable Map of Rechna Doab for Post-Monsoon, 2010

REFERENCES

Ashraf M. and A. Majeed. 2006. Water Requirement of Major Crops for Different Agro-Climatic Zones of Balochistan. IUCN – The World Conservation. 139 pp.

Ahmad, N. 1982. An Estimate of Water Loss by Evaporation in Pakistan. Planning and Co-ordination Cell, Lahore. Irrigation, Drainage and Flood Control Research Council. 71 pp.

CAD Computer Applications Directorate. Data of Canal Diversions for 1978-79 to 2008-09, WRPO, P&D Division, Water, WAPDA, 214-Wapda House, Lahore.

DMP. 2005. Drainage Master Plan of Pakistan, Volume-III, WRPO (P&D Division) and IWASRI, WAPDA. 251 pp.

PMD Pakistan Meteorological Department, Regional Office, Lahore.

RAP 1979-I Revised Action Programme for Irrigated Agriculture, Supporting Report, Irrigation, Drainage and Flood Management,Volume-I, Master Planning and Review Division, WAPDA. 311 pp.

RAP 1979-II Revised Action Programme for Irrigated Agriculture, Supporting Report, Irrigation, Drainage and Flood Management, Volume-II, Master Planning and Review Division, WAPDA. 567 pp.