WORLD WATER DAY
MARCH-2015

on the theme of
"WATER & SUSTAINABLE DEVELOPMENT IN PAKISTAN"

Celebrated by
PAKISTAN ENGINEERING CONGRESS

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ON BEHALF OF PAKISTAN ENGINEERING CONGRESS

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By:
Engr. Iftikhar-ul-Haq
Member Executive Council / Convener Publication Committee

Published *By:*
Engr. Syed Mansoob Ali Zaidi
Member Executive Council / Secretary (PEC)

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
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Phone: (042) 35784238, (042) 35784235 Fax: (042) 35784236
Web-site: www.pecongress.org.pk
E-mail: info@pecongress.org.pk
ISBN No: 978-969-603-027-0

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WATER & SUSTAINABLE DEVELOPMENT IN PAKISTAN

Dr. Izhar Ul Haq[1]

Asim Rauf Khan[2]

ABSTRACT

Pakistan is located in arid to semi region. There is seasonal and temporal variation of surface water availability. Storage of water is crucial to sustained agriculture.

Population is increasing and the per capita water for annum water availability is reducing. Pakistan has not built any major dam after Tarbela. The existing storage is depleting due to sedimentation. Pakistan's storage is only 10% against world average 40%. Climate change is posing a new threat to the availability of water in space, time and quantum across Pakistan.

Pakistan needs to conserve waster. There is considerable loss from the canal head works to the farm gate. The canals need to be lined. On farm water management is necessary. Efficient use of irrigation water such as drip and sprinkler should be adopted. Rain water needs to be harvested.

In order to meet the Agriculture demands, farmers are pumping out ground water more than the recharge in certain sweet waster zone areas. This needs to be regulated. In order to make the infrastructure sustainable, water should be realistically priced.

INTRODUCTION

All the ancient civilizations and big cities were founded on river banks. The civilizations flourished on water and vanished either due to drought or floods. Two-thirds of the world is covered with water and only one third is land. About 97% of the world water is saline and only 3% is sweet water. Most of the sweet water is in the form of snow and glaciers locked up in the mountains or lakes. A part of it runs through

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the rivers due to snow melt and rains. The natural cycle of evaporation from the sea and lakes, condensation into precipitation and then run off into streams constitutes the renewable source.

Pakistan is located in an arid to semi-arid region. The summer rainfall resulting from monsoon systems occurs mostly during the months of July and August. Runoff from snow melt during May and June and from glacial melt during July and August also gets added to the Indus River System. Pakistan receives 80% of the water during 100 days and 20% during rest of the 265 days. Therefore, Pakistan needs to store water for sustained development. Pakistan uses more than 94% of its water for Agriculture while only 6% is used Domestic and Industrial use.

AVAILABILITY OF WATER

The Indus River and many of its tributaries, Kabul, Jhelum, Chenab, Ravi, and Sutlej Rivers, originate in the Karakoram, Hindukush, and the Himalayan regions along the north and north eastern borders of Pakistan (Figure-1), and descends south towards the Arabian Sea. Availability of surface water in Pakistan is about 145 MAF per annum measured at the rim stations i.e., where the Indus and its major tributaries enter from the mountainous Upper Indus Basin into the Indus Plains: Indus at Masan gauge station near Kalabagh, Jhelum at Mangla and Chenab at Marala.

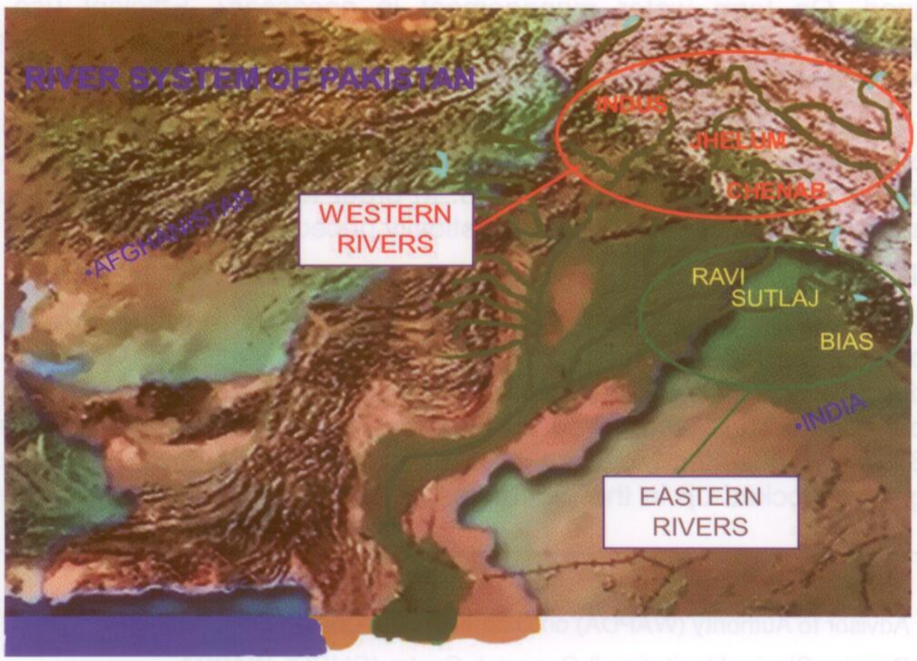

Figure-1. The Indus River System.

As a result of population growth, the surface water availability which was more than 5000 cubic meters per capita in 1950, has now (2015) reduced to about 1000 m^3 per person. Pakistan is at the threshold of being water scarce country (Figure-2).

Pakistan is mining about 50 MAF of ground water to meet the domestic agriculture demand. The current rate of ground water extraction is more than what is being recharged resulting in diminishing aquifer. If not regulated this would not be sustainable.

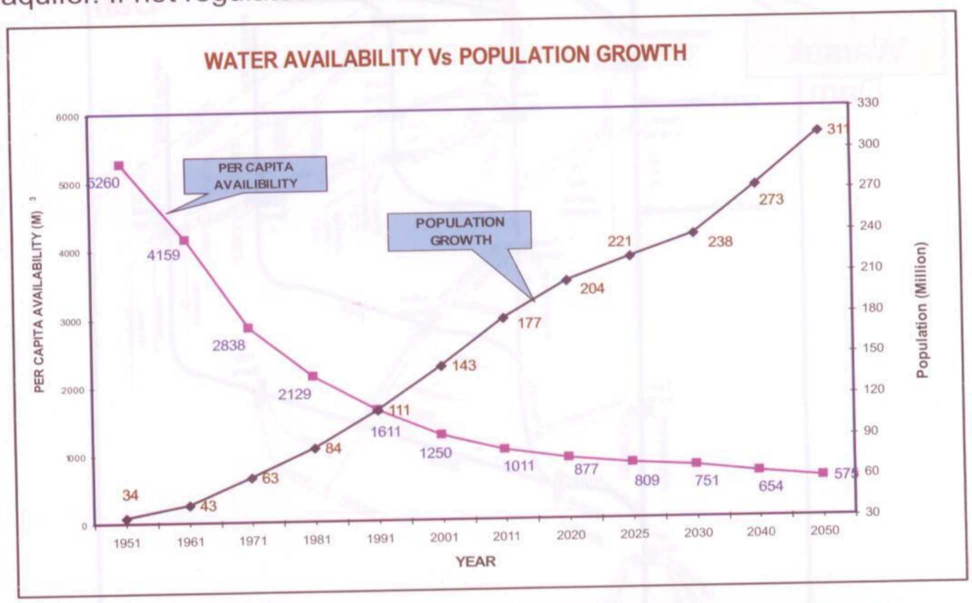

Figure-2. Per Capita Water Availability and Population Growth.

Pakistan has the largest and the oldest contiguous irrigation system (Figure-3). After diversion of water at various barrages, 30 MAF of water, on the average, goes down the last barrage into the Arabian Sea every year (Figures-4 & 5).

Climate and freshwater systems are inter-connected in complex ways. Any change in one of these systems induces a change in the other. It is projected that there will be rise in temperature to the tune of 4 degrees Celsius by the end of current century in the Indus Plains. The impact of climate change on the snow and ice regimes of the Upper Indus Basin which provide more than 70% of the river runoff, also adds uncertainty to Pakistan water system. Water use, in particular irrigation water use, generally increases with temperature. If this be the case, then in Pakistan where water use is dominated by irrigation and accounts for more than 90% of total consumptive water use, we have to take pre-emptive measures to mitigate the negative impacts of Climate Change on water resources. Therefore, for securing the food security and sustainable development, Pakistan should have more capacity to store water and make its optimal use.

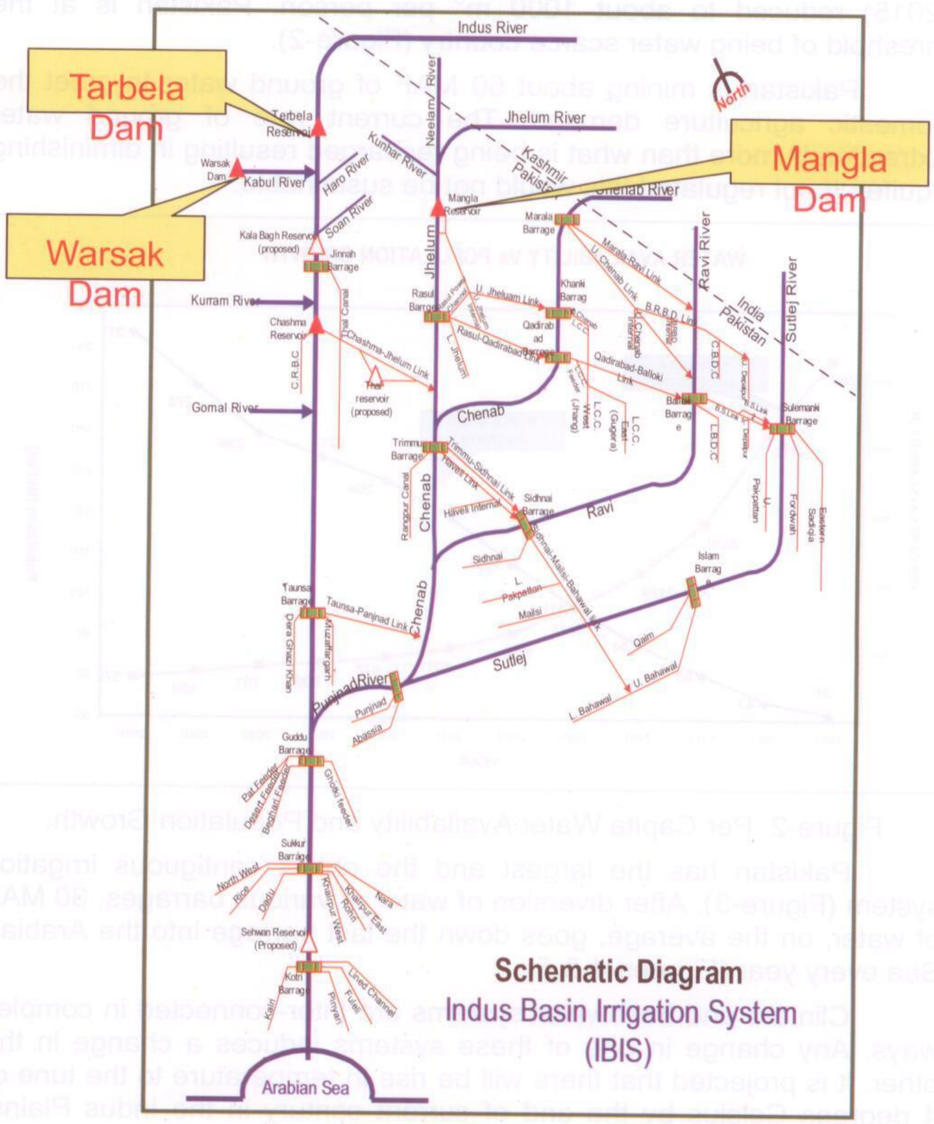

Figure-3 The Indus Basin Irrigation System.

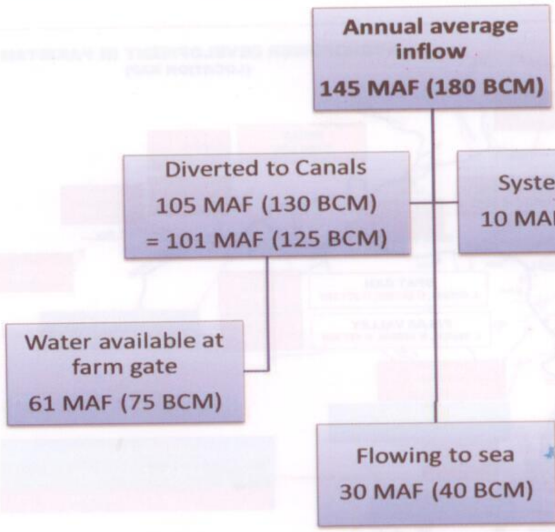

Figure-4 Surface Accounting for the Indus River System.

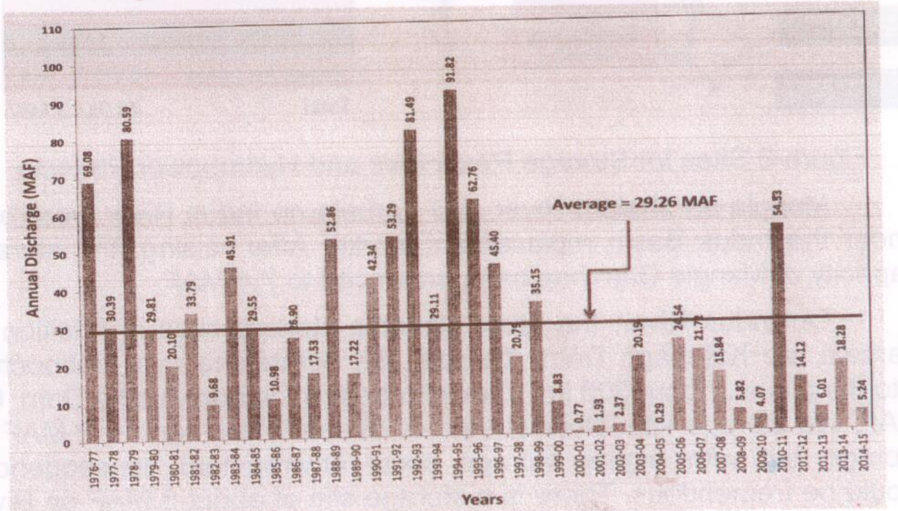

Figure-5 Escapages below Kotri Barrage into the Arabian Sea.

STORAGE OF WATER

There are many run-of-the river hydropower sites on all major rivers in the Indus Basin and their tributaries, but only a few sites suitable for building large reservoirs (Figure-6).

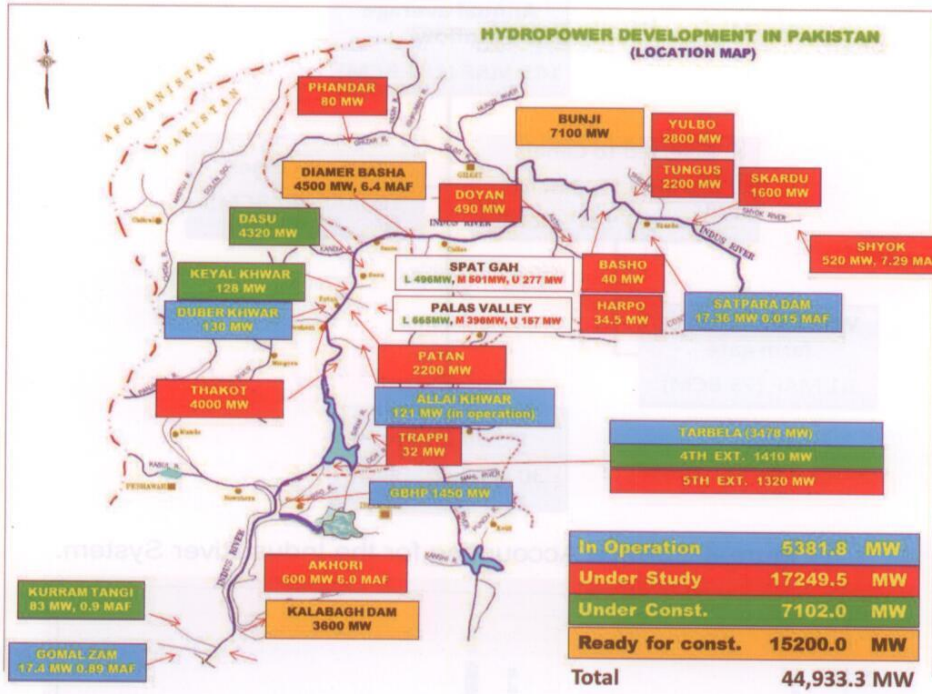

Figure-6 Sites for Storage Reservoirs and Hydropower Projects.

Mangla on Jhelum River and Tarbela on Indus River were built under the Indus Basin replacement works. After raising, the storage capacity of Mangla Dam has been enhanced to 7.4 MAF.

On Indus River, the other sizeable storage sites in addition to Tarbela are Kalabagh Dam, the last site before the river debouches into the plains. About 300 km above Tarbela is Diamer-Basha Dam, 6.4 MAF, live storage site. Downstream of Skardu there can be 2 MAF of storage but with higher storage socio environment consequences would be tremendous. There is a storage site of about 6 MAF on River Shiger. In addition, there is an off-channel storage site on River Indus i.e., Akhori Dam site with a storage capacity of 6 MAF. Similarly, on river Jhelum there is an off-channel storage site of Rohtas Dam. There is no site on river Chanab except a small storage of 1 MAF near Chiniot. There are about 150 small to medium dams in Pakistan for domestic water supply and local agriculture use.

Pakistan stores hardly 10% its surface waters against world average of 40%. Table-1 gives the storage capacity of some of World Rivers.

Table-1 Average Annual Flow and Storage Capacity of Dams for Some Major River Basins in the World.

S #	RIVER BASIN	AVERAGE ANNUAL FLOW (MAF)	NO. OF DAMS	STORAGE CAPACITY (MAF)	%AGE STORAGE
1	Colorado	12	3	59.62	497
2	Nile	47	1	132	281
3	Sutlej Beas	32	5	11.32	35
4	Yellow River	345	7	68.95	20
5	Indus & Others Rivers	145	3	18.37	13*
6	World Average	20,000	-	8,000	40

The current storage capacity of our major reservoirs is 14.2 MAF and is expected to increase to 19 MAF after commissioning of Diamer-Basha Dam (Figure-7).

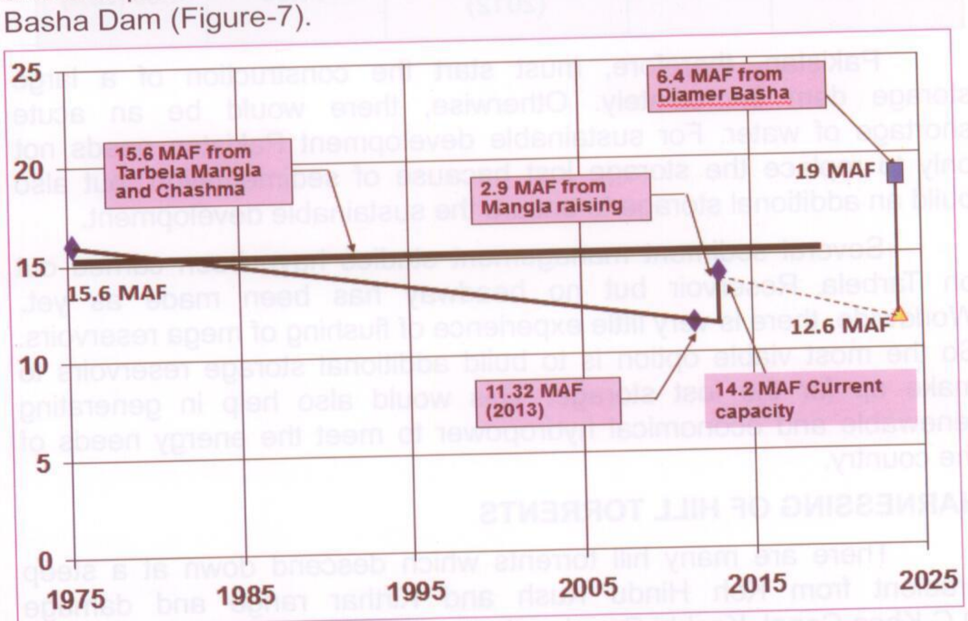

Figure-7 Reservoir Storage Capacities in the Indus River System.

DEPLETION OF RESERVOIR STORAGE

As the Pakistani mountains are relatively younger and the river gradients are steep, the rivers carry a lot of sediments. On the average, about 200 M. Tons of sediments are deposited every year in the Tarbela Reservoir. About 60 M. Tons are deposited in Mangla Reservoir per annum (Table-2). Pakistan has already lost 4.68 MAF of live storage of the three reservoirs.

Table-2 Loss in Storage Capacities of Major Pakistani Reservoirs.

RESERVOIR	LIVE STORAGE CAPACITY			STORAGE LOSS
	ORIGINAL		YEAR 2015	YEAR 2015
TARBELA	9.69 (1974)		6.4	3.29 (34%)
MANGLA	5.86 (1967)	4.6+2.88 = 7.48 (2012)	7.4	0.85 (10%)
CHASHMA	0.72 (1971)		0.26	0.46 (64%)
TOTAL	16.27	17.89 (2012)	14.06	4.60 (28%)

Pakistan, therefore, must start the construction of a large storage dam immediately. Otherwise, there would be an acute shortage of water. For sustainable development Pakistan needs not only to replace the storage lost because of sedimentation, but also build an additional storage to ensure the sustainable development.

Several sediment management studies have been carried out on Tarbela Reservoir but no headway has been made as yet. Worldwide, there is very little experience of flushing of mega reservoirs. So the most viable option is to build additional storage reservoirs to make up for the lost storage. This would also help in generating renewable and economical hydropower to meet the energy needs of the country.

HARNESSING OF HILL TORRENTS

There are many hill torrents which descend down at a steep gradient from Koh Hindu Kush and Kirthar range and damage D.G.Khan Canal, Kachhi Canal and other infrastructure in D.I.Khan and D.G.Khan districts before joining river Indus on right bank. Their combined annual discharge is of the order of 10 MAF. These runoff in these torrents needs to be harnessed by constructing storages on them and utilizing the regulated flows (Figure-8).

Figure-8 Harnessing the Water Flow of the Hill Torrents on the West Bank of Indus River in Districts D.G. Khan and Rajanpur (Punjab).

EFFICIENT USE OF WATER

Pakistan is using century old, gravity flow, flood irrigation system. There is a lot of wastage of water in this mode of irrigation. About 1/3rd of the water at farm-gate is used by the crop and 2/3rd is lost in evaporation and percolation.

Low lying areas in the fields are flooded while higher areas remain dry. The farmers have started laser land leveling to supply water uniformly to the fields. This also helps in saving water.

If drip and sprinkler systems are adopted, there would be much less wastage of water and crops can be watered according to the requirement. This would help sustainable development. Upfront investment would be required in the piping and water pumping system.

Experience has shown that furrow plantation requires less quantity of water. Zero tillage method for sowing wheat crop after harvesting the paddy has also been practiced successfully in certain areas obviating the first watering and ploughing.

Due to water transmission losses and theft, tail-enders do not get their due share of water. Equitable distribution of water is required for sustainability.

All the above method and techniques help in improving the productivity of water i.e., ***more crop per drop***. It is important that we adopt this performance indicator of water productivity (e.g., kg/m ^{3}) for our irrigated agriculture in addition to the currently more common indicator of land productivity (e.g., kg/acres).

Some of the crops use high amount of water while others use less. In some of the Canal Commands, delta is very high. This encourages water wastage and low output due to standing water in the root zone. Therefore in order to make the sustainable use of water, suitable delta for canal commands and crops should be selected.

LINING OF CANALS

From barrage diversions to the farm-gate about 1/3rd water is lost in conveyance. To minimize the seepage of water, main canals, distributaries and water course need to be lined. Concrete lining is better than brick-tile lining. This would help sustainable development of water. Presently, WAPDA is engaged in lining of D.G.Khan Canal and Muzaffargarh Canal. CRBC was lined from the start. Kachchi Canal is also being lined.

TREATMENT OF SEWERAGE WATER & SALINE WATER

The disposal of sewerage water creates pollution. If it is treated, it can be reused and would also reduce environmental pollution. The saline water of the drains, instead of disposing it off to sea, can be treated and reused to make it sustainable. Presently, the treatment cost is high but gradually it would reduce and become sustainable.

RAIN WATER HARVESTING

During monsoon rains most of the roof top and yard water either goes into the sewerage system thus over burdening it or; ponds up in the low lying areas breeding mosquitoes and creating health issues for the population. If it is properly channelized, stored or recharged into the ground water, it would help the sustainable water development. It is being practiced in many water-short countries.

REGULATION OF GROUND WATER PUMPAGE:

Due to shortage of canal water, farmers are pumping out water for irrigation. Presently, the mining of groundwater through tubewells is about 50 MAF out of which 40 MAF is in Punjab. In certain sweet water areas, this has led to over-mining of ground water. This is not sustainable. Therefore ground water pumping needs to be regulated.

WATER PRICING

The capital cost of storage and irrigation projects is normally borne by the Federal Government. Water is released from the reservoirs by WAPDA according to the provincial irrigation indent.

Water price charged by the provinces from to the farmers as Abiana is extremely low and does not cover even the operation and maintenance cost of the canal.

Water is considered to be a free commodity which encourages its wasteful use. The infrastructure is in bad shape of maintenance. Water should be considered as an ***"economic good"*** instead of a free commodity. In order to make it sustainable, water pricing should be done and charged from the users for recovery of the operation and maintenance cost of the water supply infrastructure.

DOMESTIC WATER SAVING

There is a lot of water wastage in the house holds toilets, bathing and washing cloths etc. that could be saved by adopting suitable methods and technologies (Table-3). Use of ***"water-smart"*** technologies in domestic and industrial water supply pipelines and plumbing equipment could help save large quantities of water.

Table-3 Saving of Water in Domestic-use

Activity	Traditional Method		Recommended Method		Water Saving (Liters)
	Action	Water Consumed (Liters)	Action	Water Consumed (Liters)	
Teeth cleaning	Opening water tap for 3 minutes	21	Use of glass of water	1	20
Hand washing	Opening water tap for 2 minutes	14	Keeping water tap closed while putting soap on	2	12
Shaving	Opening water tap for 2 minutes	14	Use of a cup of water	2	12
Ablution	Opening water tap for 3-5 minutes	21-35	Opening water tap for shorter duration	3	19-32
Bathing	Opening water tap/shower for 5-10 minutes	45-90	Keeping water tap closed while putting soap on	20	25-70

Toilet use	Large flushing tank	>9	Putting a 2 liter water-filled polythene bag in the tank	2-7	2-7
Watering plants	Watering for more than 10 minutes	100	Using water bucket or sprinkler	25	75
Washing floors	Use of pipe for upto 20 minutes	200	Using a mop cloth and wiper	36	164
Car washing	Use of pipe for upto 15 minutes	150	Using water bucket	36	114

Source: Federal Environmental Management Unit, National Drainage Program

Awareness should be created among the people through media for water saving. This should be included in the syllabi in schools and students should be told about the importance water saving. This would encourage the sustainable use of water.

CONCLUDING REMARKS

Water is precious resource. Its availability varies in time and space. Climate change has increased the level of uncertainty in the availability of water. Therefore, its optimal use is crucial to the survival of our society.

In view of the impending climate change and its impacts on our water resources, it is extremely important to invest more in hydrological investigations for developing a better understanding of the snow and ice regimes of the Upper Indus Basin (UIB). Monitoring the Upper Indus glaciers in particular for detecting any changes in UIB glaciers by using advance remote sensing and GIS techniques is extremely important in this context. Furthermore, mass-balance studies should be carried out in the field for major glaciers.

By adopting proper practices and through the use of technology and infrastructure development and improvement along with intensive hydrological investigation of our river systems, we could make the most efficient use of water while meeting the requirements for food, agriculture, energy, environment and the general livelihoods of the people of Pakistan.

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WATER AND SUSTAINABLE DEVELOPMENT CONTEXTURAL GLOBAL AND NATIONAL OVERVIEW

Engr. Riaz Nazir Tarar

ABSTRACT

About 97.5% of all water resource on earth is salt water in oceans and seas leaving 2.5% as freshwater. Only under 1% of this freshwater is theoretically available for direct human use in the form of over 40,000 km^3 annual runoff (AR). After considering ground realities, out of this AR, only about 33000 km^3 is geographically accessible. Currently diverted AR is about 12500 km^3 which could increase to about 13700 km^3 by 2025 principally by regulation through dams. Total annual appropriation at the end of 20th century was over 4700 km^3 which could go above 9800 km^3 by 2025 representing over 71% of the correspondingly estimated AR of 13700 km^3. Clearly, humanity is approaching the limit of freshwater supply in view of growing world population projected to approach about 8 billion by 2025. Even now, a large part of world's population is experiencing water stress which may further aggravate by 2025. Therefore, sustainable development of water is the dire need of mankind as it is essential even for its existence.

This paper overviews water and sustainable development in global and national contexts. In global context, sustainable water development is the key to: conservation of its quantity and quality; security; economic health; and societal well being. It also implies progressive socio-economic betterment without going beyond ecological carrying capacity and exceeding earth's twin capacities of natural resource generation and waste absorption. In national context, concurrent with future, the present priority requirement is sustainability of already developed very large surface and groundwater resources. Failing this, it will be a serious detriment to our stagnating economy largely based on agriculture. This could be achieved in the medium term (2025) through priority development of multi-purpose storages with aggregate capacity of about 18 MAF. Besides conserving some of 29 MAF surface water being escaped to sea, it will provide a large chunk of cheap hydropower to pull the country out of perpetual energy crisis. Additionally, effective management of groundwater will be inescapable to conserve quantity and quality of fresh aquifers, which are already under serious stress.

The paper draws conclusion both in global and national context to

provide further insights. In global context, the focus of future evaluation strategy should be: substituting current piecemeal and consumption oriented approach to systematic approach; increasing public awareness about the challenges the world is facing in relation to water; and keeping definition of future sustainability as open and as flexible through the use of adaptive management. In national context, the medium-term (2025) priority should be for sustainability of already developed surface and groundwater resources consistent with need for food, fibre and energy requirements of the burgeoning population. For surface water, development of multi-purpose storages should receive priority attention. In this regard, immediate launching of core construction of already engineered and approved Diamer Basha Dam Project is considered critical. This will infuse into the stagnating economy: 6.4 MAF of water storage for irrigated agriculture; and over 20700 GWh energy through 4500 MW installed power. Regarding groundwater, the focus should be on effective management through: protecting quality and quantity of key aquifers; conjunctive use of surface and groundwater; and policy reforms to regulate aquifer use on the basis of effective quality and quantity monitoring.

1 GLOBAL WATER RESOURCES AND THEIR UTILIZATION

1.1 OVERALL INVENTORY

Water resources of the Earth result from Global Hydrological Cycle (refer Annex-01). Over 70% of our Earth's surface is covered by water (we should really call our planet "Ocean" instead of "Earth"). Although water is seemingly abundant, the real issue is the amount of fresh water available, as revealed by the following facts:-

i. 97.5% of all water on Earth is salt water in oceans and seas, leaving only 2.5% as fresh water

ii. Nearly 69% of that fresh water is frozen in the icecaps of Antarctica and Greenland while about 30% lies in deep underground aquifers as groundwater (refer Annex-02).

iii. Only less than 1% of the world's fresh water is accessible for direct human uses. This is the water found in lakes, rivers, reservoirs and those underground sources that are shallow enough to be tapped at an affordable cost. Only this amount is regularly renewed by rain and snowfall and is, therefore, available on a sustainable basis.

1.2 HUMAN USE OF WATER RESOURCES

Since antiquity, irrigation, drainage, and impoundment have been the three types of water control with a major impact on landscapes and water flows. Since the dawn of irrigated agriculture at least 5000 years ago, controlling water to grow crops has been the primary motivation for human alteration of freshwater supplies. Today, principal demands for fresh water are for irrigation, household and municipal water use and industrial uses. Most supplies come from surface runoff, although mining of "fossil water" from underground aquifers is an important source in some areas. The pattern of water withdrawal over the past 300 years shows dramatic increases during 20th century.

A timeline of human water use was as below:-

i. 12,000 years ago: hunter-gatherers continually return to fertile river valleys.

ii. 7,000 years ago: water shortages spur humans to invent irrigation.

iii. 1,100 years ago: collapse of Mayan civilization due to drought.

iv. Mid 1800's: fecal contamination of surface water causes severe health problems (typhoid, cholera) in some major North

American cities, notably Chicago.

v. 1858: "Year of the Great Stink" in London, due to sewage and wastes in Thames.

vi. Late 1800s-early 1900: dams become popular as a water management tool.

vii. 1900s: Green revolution strengthens human dependency on irrigation for agriculture.

viii. World War II: water quality impacted by industrial and agricultural chemicals.

ix. 1972: Clean Water Act is passed and humans recognize need to protect it.

1.3 CONSUMPTIVE AND NON-CONSUMPTIVE WATER USE

Consumptive use refers to water that is not returned to streams after diversion. For the most part, this water enters the atmospheric pool of water via evaporation (from reservoirs in arid areas) and from plant transpiration (especially from "thirsty" crops such as cotton and alfalfa). Currently, irrigated agriculture is responsible for most consumptive water use.

Agriculture represents 65% of the total water used globally. In Asia, it accounts for 86% of total annual water withdrawals, compared with 49% in North and Central America and 38% in Europe. Rice growing, in particular, is a heavy consumer of water. It takes some 5000 liters of water to produce 1 kg of rice. Compared with other crops, rice production is less efficient in the way it uses water. Wheat, for example, consumes 4000 m^3/ha, while rice consumes 7650 m^3/ha.

A great deal of water use is non-consumptive and returns to surface runoff. In this process, however, it gets contaminated, whether used for agriculture, domestic consumption or industry. In turn, this deteriorates the quality of water. WHO estimates that more than 5 million people die each year from diseases caused by unsafe drinking water and lack of sanitation and water for hygiene. This has economic effects as well such as an outbreak of cholera in Latin America which killed hundreds of people, and cost hundreds of million dollars.

1.4 GLOBAL PER CAPITA WATER AVAILABILITY

It is now recognized that fresh water will be a critical limiting resource for many regions in the 21st Century. About one-third of the world's population lives in countries that are experiencing water stress. In Asia, water has always been regarded as an abundant resource but per capita availability declined by 40-60% between 1955 and 1990. On the other hand, most of Africa historically has been water-poor. Projections suggest that most Asian countries including Pakistan will have severe water problems by the year 2025 as reflected in Global Per Capita Water Availability' (refer Annex-03).

Above water scarcity will be the result of:-

i. Rapidly growing population, putting more pressure on our water supply (demand is increasing).

ii. Wasteful use of fresh water without regard to efficiency.

iii. Effective reduction in fresh water due to pollution and contamination.

1.5 FRESH WATER RESOURCES OF EARTH

What does the future hold for sustainable water resource development? We can best explore this question by looking carefully at the world's water resources.

Global annual hydrological cycle (refer Annex-01) is the source of water for Earth. However:-

i. Water cycle on Earth is essentially a closed system – we always have the same amount of water.

ii. The only parts of this cycle which can be appropriated by humans are the renewable fresh water held as surface water or shallow aquifers.

Available fresh water consists of:-

i. Terrestrial replenishable fresh water supply through precipitation.

ii. Estimated runoff to the sea in the annual range from 33,500 to 47, 000 km^3 (average of over 40,000 km^3).

iii. Evapotranspiration from the land.

iv. Non-replenishable fossil ground water.

1.6 HUMAN APPROPRIATION OF RUNOFF

Distribution of continental global runoff is highly uneven and corresponds poorly to regional distribution of the world population (refer Annex-04). Asia has 69% of world population but 36% of global runoff. South America has 5% of world population with 25% of runoff.

Much of the runoff is also inaccessible. Amazon River accounts for 15% of runoff out of which 95% is inaccessible. It is currently accessible to only 25 million peoples (0.4% of world's population). Zaire River (estimated run-off 1300 km^3) may be 50% inaccessible. Mostly untapped northern rivers have an average annual flow of 1815 km^3 and considered to be 95% inaccessible. Together, this amounts to

7774 km^3 or 19% of total average annual 40700 km^3 runoff, thus leaving about 32,900 km^3 as geographically accessible.

Temporal availability of about 28% of global runoff (11,100 km^3) is renewable ground water and base river flow. Remainder is flood water and requires regulation through dams. Presently, available storage capacity of large dams totals 5500 km^3, of which 3500 km^3 is used to regulate river runoff. Adding together base flow and surface runoff controlled by dams gives total stable flow. Corrected for spatially inaccessible flows yields a safe estimate of available runoff (AR) as 12,500 km^3/yr.

Out of 12500 km^3/year available runoff, the humanity is estimated to be using about 4705 km^3 out of which only 2560 km^3 (about 54%) is being consumed (refer Annex-05). Sector-wise break-up is as below:-

i. **Agricultural:** Estimated average withdrawals of 2880 km^3 (assuming water application rate of 12,000 m^3/ha and world irrigated area of 240 x 10^6 ha in 1990) out of which about 1870 km^3 (65%) are consumed.

ii. **Industrial**: Estimated at 975 km^3 with roughly 9% (90km^3) consumed and remainder discharged back into environment, often polluted.

iii. **Municipal:** Estimated at 300 km^3 per year out of which 50 km^3 (17%) is consumed.

iv. **Evaporation From Reservoirs:** Estimated 275 km^3 / year assumed as 5% of gross storage capacity of reservoirs (5500 km^3).

v. **Instream Flow Needs:** Estimated from pollution dilution and assuming that this suffices to meet instream needs. A common dilution term is 28.3 liters per second per 1000 population. Using the 1990 population yields a dilution requirement of 4700 km^3. If half of water received adequate treatment, the dilution requirement is reduced to 2350 km^3/year.

1.7 OPTIONS FOR INCREASING AVAILABLE RUNOFF

Principal options are to capture and store more flood runoff or desalinate sea water. Latter is too energy-intensive for the near future.

Worldwide, new dams (> 15 m ht) were constructed at rate of 885 per year during 1950-80, 500/yr during 1980-2000 and further estimated 350/yr. Assuming size of reservoirs is unchanged, new construction could add 1200 km^3 to accessible supply thus raising total AR to 13,700 km^3/yr by 2025. Assuming average per capita water demand stays unchanged, but adjusting the pollution dilution for additional population, the total human appropriation in 2025 could be 9830 km^3/yr, or about 71% of correspondingly estimated AR. Clearly we are approaching the limit of available fresh water supply.

1.8 IMPROVED WATER USE EFFECIENCY

Water Use and Consumption Estimates on Global Scale' (refer Annex-05) indicated that we are hardly using about half of the water being diverted for various purposes. For instance, the largest user agricultural sector consumes about 65% of the diversions.

Efficient management and modern technology can stretch even scarce water supplies much further. Israel, for example, supports its population with growing industrial base, and intensive irrigation with less than 500 cubic meters per person per year.

Water is often wasted because it is underpriced. Direct and indirect subsidies (especially for agricultural use) are still common in both developed and developing countries. Removing such subsidies and letting water prices rise can provide incentives for conservation and for the investments needed to spread more efficient technologies.

2 SUSTAINABLE DEVELOPMENT

2.1 HOLISTIC VIEW

World's resources are finite, and growth that is unmanaged and unsustained will lead to increased poverty and decline of the environment. We owe it to future generations to explore lifestyles and paths of development that effectively balance progress with awareness of its environmental impact. In order to preserve the future, we must appreciate the interconnectedness between humans and nature at all levels. Sustainable development practices can help us do this, and through education and building awareness, preserving the future is within everyone's reach.

More than one hundred definitions of sustainable development exist, but the most widely used one is from the World Commission on Environment and Development, presented in 1987 (schematically defined in Annex-06). It states that sustainable development is:

> *'The development that meets the needs of the present without compromising the ability of future generations to meet their own needs.'*

Sustainable development promotes the idea that social, environmental, and economic progresses are all attainable within the limits of our earth's natural resources. Sustainable development approaches everything in the world as being connected through space, time and quality of life.

Earth's connection to time is demonstrated in how we, today, are either benefitting or suffering from the choices of our grandparents and other ancestors. Their decisions about how to farm their land, for example, continue to impact the agricultural practices of today. Looking to the future, the economic choices we make and policies we endorse today will be the ones affecting our children and grandchildren as adults.

Sustainable development constantly seeks to achieve social and economic progress in ways that will not exhaust the earth's finite natural resources. The needs of the world today are real and immediate, yet it's necessary to develop ways to meet these needs that do not disregard the future. The capacity of our ecosystem is not limitless, meaning that future generations may not be able to meet their needs the way we are able to now.

Some of the more common examples of sustainable development practices are:

i. **Solar and Wind Energy:** Energy from these resources is limitless, meaning that we have the ability to eliminate dependence on non-renewable power sources by harnessing power from renewable resources.

ii. **Sustainable Construction:** Homes, offices and other structures that incorporate recycled and renewable resources will be more energy efficient and stand the test of time.

iii. **Crop Rotation:** Many farmers and gardeners are using this method as a chemical free way to reduce diseases in the soil and increase growth potential of their crops.

iv. **Water Fixtures:** Water conservation is critical to sustainable development, and more and more products are available that use less water in the home, such as showers, toilets, dishwashers and laundry systems.

2.2 WATER SUSTAINABILITY AND SECURITY

It is projected that by 2025 global population will grow to about 8 billion (refer Annex-07) and diverting about 70% of AR. On the other hand, billions of peoples will lack basic water services and millions die each year from water-related diseases. Water is, therefore, a basis of international conflict. What is involved in achieving water sustainability and water security? The following lists some of the criteria that should help us chart our direction:-

i. Basic human needs for water should be fully acknowledged as a top international priority.

ii. Water-related diseases, including Guinea worm, diarrhea, onchocerciasis, malaria and typhoid should be brought under control.

iii. Agricultural water should be efficiently used and allocated.

iv. Basic ecosystem water needs should be identified and met.

v. Serious water-related conflicts (both external and internal) should be resolved through formal negotiations.

Water conservation through better planning, management and technologies offers great promise. For instance, per capita water withdrawals in the U.S. almost doubled from 1950 to 1980. However, per capita water withdrawals began to decline in 1985, despite continued population growth. More efficient agricultural and industrial water use accounted for this trend.

3 SUSTAINABLE DEVELOPMENT OF WATER RESOURCES

3.1 NEED

Water resources management is one of the most important challenges the world faces today. It is difficult to think of a resource more essential to the health of human communities or their economies than water. Humans cannot live for more than several days without water, shorter than for any source of sustenance other than fresh air. In meeting their demand for water, societies extract vast quantities from rivers, lakes, wetlands, and underground aquifers to supply the requirements of cities, farms and industries.

There is also growing recognition that functionally intact and biologically complex freshwater ecosystems provide many economically valuable commodities and services to society (ecosystem services) beyond simply direct water supply. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals and production of fish and other foods and marketable goods. These ecosystem benefits are costly and often impossible to replace when aquatic systems are degraded.

Deliberations about water allocation should, therefore, always include provisions for maintaining the integrity of freshwater ecosystems, including the need to maintain minimum in-stream flows and to anticipate the impact of hydrologic modifications on downstream environments. Otherwise, we have few safeguards that will protect the systems that sustain us.

Besides being an integral part of the ecosystem, water is a social and economic good. Demand for water resources of sufficient quantity and quality for human consumption, sanitation, agricultural irrigation, and manufacturing will continue to intensify as populations increase and as global urbanization, industrialization, and commercial development accelerates. Water runs like a river through our lives, touching everything from our vigor and the fitness of natural ecosystems around us to farmers' fields and the production of goods we consume. It is critical that efforts intended to be sustainable fully consider the health and operation of aquatic ecosystems and that the environmental value of watersheds be recognized when making economic and social decisions on water allocation and use.

3.2 CONCERNS ABOUT WATER QUANTITY AND QUALITY

As already mentioned, freshwater comprises only 2.5% of global water resources (refer Annex-02). Out of this only about 1.2% is freshwater in the lakes and rivers that has served as the major source of water through most of human history. However, societies worldwide have not always appreciated this easily accessible freshwater and the need to protect it. Thus, water consumption has nearly doubled since 1950, and much of the world suffers greatly from inadequate access to potable water. About 20% of the Earth's population lacks access to safe drinking water. According to United Nations, more than 200 million people every year suffer from water-related diseases, and about 2.2 million of them—mostly the poor—die. Currently, there are substantial disparities between regional water resource availability and utilization as summarized in the concerns in Annex-08.

Demand for water resources is continuing to increase. This increase is being driven not only by a growing world population but also by the aspirations of that population for an ever increasing standard of living. At the same time, the capacity of the planet to meet this demand is in decline because of over-harvesting, inappropriate agricultural practices, and pollution, to name just a few. These impacts on Earth are occurring because humans are not in line with the way the natural world functions.

Currently a large proportion of the world's population is experiencing water stress which may become critical by 2025 (refer Annex-03). Rising population demands for water from irrigation, industrial and residential greatly outweigh greenhouse warming affects on world water supplies. Likewise, humans are using about 38% of the available freshwater, about half of which is wasted, thus leaving about 62% for all other life forms on Earth (refer Annex-05).

Average U.S. household uses about 50 gallons (225 litres) per person per day, a rate more than seven times per capita average in rest of the world and nearly triple Europe's level. On the other hand, World Health Organization says good health and cleanliness require a total daily supply of about 8 gallons (36 litres) per person per day.

Society is hitting the limits or hitting the wall of a funnel in its never-ending use of natural resources and production of waste. The situation of the people on Earth can be viewed as a funnel with ever diminishing room to maneuver. Life-support systems for our continued existence on the planet are in decline. At the same time, the global population and global demand for these resources are increasing, leading us to hit the wall of the funnel. Increasing water shortages or inequitable access to safe water can cause poverty and environmental degradation that can lead to global hunger, resulting in civil unrest and human conflict. And with conflict comes regional and national disputes, even war, that can best be averted by the sustainable use of these resources.

4 GLOBAL CONTEXT OF SUSTAINABE WATER DEVELOPMENT

4.1 APPROACH

Sustainable development is the centerpiece and key to water resource quantity and quality, as well as national security, economic health and societal well-being. The word sustainability implies the ability to support life, to comfort and to nourish. For all of mankind history, the Earth has sustained human beings by providing food, water, air, and shelter. Sustainable also means continuing without lessening. Development means improving or bringing to a more advanced state, such as the economy.

Thus, sustainable development can mean working to improve human's productive power without damaging or undermining society or the environment. That implies: progressive socio-economic betterment without growing beyond ecological carrying capacity; and achieving human well-being without exceeding the Earth's twin capacities for natural resource regeneration and waste absorption. By acting under the principles of sustainable development, our economic desires/demands become accountable both to an ecological imperative to protect the ecosphere and to a social equity imperative to create equal access to resources and minimize human suffering. These requirements are the foundation of sustainable development as represented by the three circle model (principle elements) of sustainability in Annex-09. These three elements interact with each other so continuously that we cannot make decisions, make policy, manufacture, consume, essentially do anything without considering the effects and costs upon all three simultaneously. Each circle (sustainability principle) is briefly defined as follows:

i. **Economic Vitality (Compatible with Nature):**

Development that protects and/or enhances natural resource quantities through improvements in management practices/policies, technology, efficiency and changes in life-style.

ii. **Ecologic Integrity (Natural Ecosystem Capacity)**

Understanding natural system processes of landscapes and watersheds to guide design of sound economic development strategies that preserve these natural systems.

iii. **Social Equity (Balancing the Playing Field):**

Guaranteeing equal access to jobs (income), education, natural resources and services for all people.

Carrying out activities that are sustainable require simultaneous, multi-dimensional thinking about the consequences of present actions in a cause and effect pattern on future public and environmental health through examination of the connections among environmental, economic and social concerns when we make choices for action.

4.2 FUTURE EVALUATION STRATEGY

Current piecemeal and consumption-oriented approaches to water policy cannot solve the problems confronting our increasingly complex world. Traditionally, we apply a sectorial approach to the evaluation of water. The only equitable solution to these problems, however, is a systematic approach that considers ecological integrity and the ecosystem services that natural resources can provide. By considering the ecosystem services that water resources offer we find it much easier to integrate the social and economic issues into our deliberations that would otherwise allude us if we were only concerned about the environmental aspects of water.

More than one-sixth of the world's population does not have access to safe water supplies. The potential conflicts from this disparity are frightening. The escalation of a water crisis in the world is due essentially to the unsustainable use and management of water resources and to the destruction of ecosystems such as forests, wetlands and soils that capture, filter, store, and release water.

Through our evaluation of water resource sustainability, we must not only increase public awareness about the challenges the world is facing in relation to water, but we must also change the way the water issue is perceived from being a driver of conflict to being a catalyst for collaboration. In doing so, we must not only view sustainability as a problem of science, engineering, or economics. On the other hand, it is also founded on values, ethics, and the equal contributions of different cultures. Additionally, all members of a community have a shared future as they are dependent on each other in ways that are both complex and profound. Thus, ideals of preservation and protection, on the one hand, and of economic vitality and opportunity, on the other, are not in conflict. Rather, in a sustainable future, they are linked together. Moreover, as we recognize our limited ability to see needs of the future, any attempt to define sustainability should remain as open and flexible as possible through the use of adaptive management.

5 NATIONAL CONTEXT OF WATER DEVELOPMENT SUSTAINABILITY

5.1 SURFACE WATER

5.1.1 Availability

Backbone of Pakistan's economy is irrigated agriculture through one of the world's largest contiguous irrigation system. Presently, Indus Basin Irrigation System (IBIS) serves 45 canals with a command area of 35 MA (14Mha) through an extensive primary, secondary and tertiary system. As a result of Indus Waters Treaty 1960, three Eastern Rivers (Sutlej, Beas, and Ravi) were assigned to India. Consequently, IBIS had to depend on three Western Rivers (Indus, Jhelum and Chenab) through a network of inter-river link canals and three storages with original live capacity of about 15.7 MAF. Estimated annual rim-station inflows of Western Rivers over the period of 1976-2008 averaged about 145 MAF.

5.1.2 Utilization

Before induction of storages as part of Indus Basin Project (IBP), the canal system was receiving run-of-river supplies with wide inter and intra seasonal variation in withdrawals. However, with the storage provided through Mangla, Chashma and Tarbela reservoirs under IBP, it was possible to significantly regulate the high flow as well as increase the Rabi supplies through seasonal carry-over from Kharif. Consequently, as compared to pre-Mangla (1960-67) period, the annual canal withdrawals over post-Tarbela (1976-2008) period showed an overall increase of 15.5%. Particularly, the increase in Rabi was 27.7% and 20% during the low flow period of early and late Kharif (refer Annex-10).

Average post-Tarbela (1977-80) IBIS canal head diversions are compared with recent trend (2005-13) in Annex-11. This shows that since 2004-05, IBIS is persistently suffering an average water shortages of about 11% (varying between 2.5 to 20.6%) as compared to post-Tarbela average. Consequently, the annual growth of agriculture sector is almost stagnant around the average of 2.5%. Against this, the mean annual growth should be at least 4% to cope with the food and fiber requirements of our burgeoning population. Basic reasons for this stunted agricultural growth are: progressively reducing capacity of the on-line storage reservoirs due to sedimentation (reduction from 15.7 to 11.4 MAF by 2012 as shown in

Annex-12); and inability to construct any major storage dam after commissioning of Tarbela in 1977 despite annual escapage of over 29 MAF un-utilized water into the sea (refer Annex-13) which represents about 21% of available river inflows.

5.2 GROUNDWATER

5.2.1 Availability

Indus Basin is underlain by an extensive unconfined aquifer covering about 40 million acres (MA) of surface area, of which about 15 MA are fresh and remaining 25 MA saline. The aquifer receives its direct recharge from natural precipitation, river flow and continued seepage from the unlined canals, distributaries and watercourses and application losses from the irrigated fields. The safe groundwater yield is estimated around 55 MAF, whereas the extraction for agriculture, domestic and industrial sectors is already approaching about 45 MAF. This virtually means that this resource is available for future in very limited quantity. Furthermore, the remaining potential is located in areas where groundwater quality is poor or in areas where it is economically not feasible to extract it for normal crop use such as hard rock areas of Balochistan.

5.2.2 Development

Large-scale extraction and use of groundwater for irrigated agriculture in the Indus Basin started during the 1960s with the launching of Salinity Control and Reclamation Projects (SCARPs). Under this public sector programme, 16,700 wells with an average capacity of about 3 cusecs were installed to control groundwater and salinity problems in an area of about 6.4 MA. The pumped groundwater was discharged into the canal system to increase irrigation supplies.

Following SCARPs and the provision of subsidized electricity and introduction of locally made diesel engines provided an impetus for a dramatic increase in the number of private tubewells. Currently, about 1.2 million small capacity private tubewells (averaging about 1 cusec) are working in Pakistan. Out of these, 800,000 are located in Punjab only. According to recent estimates, 13% of these tubewells are run by electricity whereas the rest 87% use diesel engines. Diesel engines are preferred by farmers because of their low installation cost and assured operation as compared to electric tubewells. Diesel tubewells are also more feasible for small and fragmented land holders.

Estimated number of users is over 2.5 million farmers, who exploit groundwater directly or hire the services of tubewells from their neighbors. Their behavioral patterns are highly variable and they understand little about any adverse interaction, which is likely to result due to unsystematic and erratic nature of groundwater exploitation.

Their major interest is to pump even more water to meet the crop water requirements. On average, every fourth farming family has a tubewell and a large proportion of non-owners purchase groundwater through local, fragmented groundwater markets. The groundwater is currently providing around half of the total crop water requirements with the flexibility of its availability on as and when needed basis. Thus, groundwater has also assumed critical importance in sustainability of irrigated agriculture.

More than 70% of the private tubewells are being used to irrigate lands in conjunction with the canal water whereas the rest provide irrigation based on groundwater alone. The area irrigated by groundwater alone has increased from 6.7 to 8.4 MA whereas the area irrigated by canal water alone has decreased from 19.5 to 17.0 MA. The production of major crops such as wheat, cotton, rice and sugarcane is only sustainable because of the supplemental use of groundwater for irrigation.

In the water short environment of the Indus Basin, accessibility to groundwater is a dividing line between poverty and welfare. The uncontrolled and relatively cheap access to groundwater proved significant not only for the livelihoods and food security of the poor, but also as a driving force for rural economies. In many water short areas of Pakistan, it transformed the concept of low and uncertain crop yields to a more secure and predictable crop production. Groundwater exploitation enabled farmers to attain 50-100% higher crop yields as compared to those fully dependent on canal water.

The flexibility provided by groundwater has strategically supported employment generation, rural development and poverty alleviation. The role groundwater irrigation has attained in maintaining agricultural boom is very unique and vital and will further expand in future due to mounting pressure to grow more food and increasing incidences of drought in the region. It is estimated that more than 70% of the farmers in the Punjab depend directly or indirectly on groundwater to meet their crop demands. This clearly indicates that without sustained groundwater availability not only Punjab but the whole country would face food shortages as Punjab produces more than 90% of the total grains.

5.2.3 Problems of Development

5.2.3.1 Overdraft

Unregulated and uncontrolled use of groundwater is diminishing the relative accessibility. Trend of continuous decline of the fresh groundwater table has been observed in many areas of the Indus Basin, which illustrates serious imbalance between abstraction and recharge (refer Annex-14). The supportive province-wise groundwater balance is also shown in Annex-15. Many wells have gone out of production, yet the water tables continue to decline and the quality deteriorates. Depletion of groundwater is more pronounced in non-canal command areas of Punjab and where surface water supplies are low and agriculture is heavily dependent on groundwater.

Excessive mining of aquifers in fresh groundwater areas has resulted in falling water tables and groundwater has become inaccessible in 5% and 15% of the irrigated areas of Punjab and Balochistan provinces, respectively. Although no recent estimates exist, it is anticipated that, under the business as-usual scenario, this area is expected to increase to 15% in Punjab and 20% in Balochistan by 2020.

With the increasing groundwater table depths (> 50 ft), farmers were left with no choice than to drill deeper wells. This transformation led to increased installation and operational costs due to high energy use. The construction cost of a deep electric tubewell (>65 ft) is five times as compared to a shallow tubewell (<20 ft). Further, maintenance of these deep tubewells is generally beyond the capacity of poor farmers. The electricity for pumping groundwater is heavily subsidized in Balochistan. The negative side of this subsidy is that only rich farmers having deep tubewells are the real beneficiaries and the poor are not getting any benefit of this state facility. This policy is not only creating unrest in the society but also exacerbating the problems of groundwater over-draft in Balochistan.

5.2.3.2 Deterioration of Quality

Quality of groundwater in Indus Plains varies widely, both spatially and with depth and is related to the pattern of groundwater movement in the aquifer. Though about 77% (10 MA) of the area in Punjab province has access to fresh groundwater, there are large numbers of saline groundwater pockets in the canal command areas. Saline waters are mostly encountered in central Doab areas. Cholistan area in southern Punjab is well known for highly brackish waters, which cannot be used for drinking purposes. In some parts of Punjab, there are also reports of high flouride content (7-12 mg/l) and high concentrations of arsenic (50 µg/l) in the groundwater. In the Sindh province, about 28% of the area has access to fresh groundwater. Large areas are underlain by poor quality of groundwater. In Sindh, the area of fresh groundwater is confined to a narrow strip along the Indus River. Excessive pumping of this layer is causing salt water intrusion into fresh groundwater areas. This situation has already resulted in abandoning of about 200 public tubewells located in the fresh groundwater zone of Sindh province.

5.2.3.3 Socio-economic and Environmental Impacts

Declining groundwater tables and land degradation as a result of poor quality groundwater use for irrigation has seriously affected the social fabric of Pakistani society. Drying up of Karez systems in Balochistan have increased the livelihood burden on women due to immigration of spouses for income supplementation. On the average, a woman must carry more than 200 liters of water every day over long distances, which creates an enormous burden on her time and physical capacities. Similar conditions also exist in the Cholistan area of Punjab where women have to walk miles to bring fresh drinking water from natural streams as groundwater is very deep and hazardous to health. Soil salinity also remains a hazard for the Indus Basin and threatens the livelihood of farmers, especially the small-scale ones.

5.2.3.4 Need For Sustainability

Until recently the management of groundwater in Pakistan did not receive much attention because the resource was in abundance and therefore the focus over 1970-2000 remained primarily on its development. The spectacular expansion of agriculture helped lift millions out of poverty. However, the situation began to turn serious when such unregulated exploitation brought many aquifers under severe stress and threatened the sustainability of this resource. The major reason for these negative developments was that the management of groundwater could not keep pace with its development. So, for sustainability of this precious resource strict groundwater management measures require focused attention.

5.3 NATIONAL ENERGY SCENARIO

5.3.1 Short Term Energy Demand

Currently (2014-15), even on suppressed basis, the national peak energy demand is around 18,000 MW. Against total installed capacity of 20,400 GWh, availability of dependable generation is 15,900 MW in summer and 13,400 MW in winter. Thus, a perpetual load-shedding between 2000-4000 MW is being experienced. This has been caused by a combination of constraints comprising: no dependable system spare capacity; de-rating of existing thermal units; non-availability of gas for thermal power stations; and seasonal reduction in hydropower capability due to drawdown of reservoirs.

Even assuming a stunted load growth of about 4% per year, peak energy demand over the five year period of 2014-18 is expected to go up from 18,000 to 21,100 MW. Against this, the ongoing run-off-river hydropower projects likely to be commissioned by WAPDA over this period would aggregate to 2507 MW comprising: 22 MW Rehabilitation of Jabban (2015); 106 MW Golen Gol (2016); 969 MW (Neelum-

Jhelum (2016); and 1410 MW Tarbela 4th Extension (2017). On the thermal side also, additional capacity of 2507 MW is expected comprising: 425 MW Nandipur (2014); 245 MW Rehabilitation of GENCOs (2015); 163 MW Grange Holding (2014); 134 MW Star Thermal (2016); 1200 MW imported coal; and 340 MW CHASHNUPP IC (2017). Even if all these additional installations of about 5000 MW materialize in the short term scenario of next 5 years (2014-18), the System could still be facing substantial load shedding.

5.3.2 Prevailing Thermal-Hydro Mix and Generation Costs

Prevailing thermal-hydro mix within the dependable / derated installed capacity of 15,900 MW is 65:35. Considering energy generation this mix is 70:30. Against this, the past (1990's) mix was 30:70. Due to reversal of thermal-hydro mix over the last two decades, the power tariffs have gone very high. Basic reason for this is excessive thermal generation costs varying between Rs. 6 / kWh for gas (if available) to Rs. 26 / kWh for diesel operated plants. On the other hand, overall generation cost of WAPDA's Hydropower System is estimated around Rs. 3.50 per kWh. It covers: operative hydropower stations (Rs.1.07); under Commissioning / Implementation Projects' (Rs. 4.67); and Ready for Implementation Projects' (Rs. 4.76). Therefore, sustainability of energy development at affordable tariffs is closely linked to development of hydropower with priority for large multi-purpose storages.

5.3.3 Projection of Medium Term Demand Upto 2025

It is gathered that the Planning Commission of Government of Pakistan (GoP) is now in the process of developing a medium term national development plan titled Vision 2025 Programme'. Regarding electricity, even on the basis of very low annual growth rate of 4%, the peak demand of 18,000 MW in 2013-14 could to go up to 28,000 MW by 2025.

5.3.4 Coping Strategy

It is understood that to cope with the above Medium Term Electricity Demand, GoP is focusing on power development as per following priorities:-

i. Bringing the old de-rated thermal plants of WAPDA to design capacity including switch over from costly fossil fuels to coal.

ii. Adding coal based thermal generation on account of short term gestation and low running costs as compared to oil based stations.

iii. Developing run-of-river hydropower facilities with somewhat shorter gestation period as compared to multi-purpose storage projects.

iv. Tapping of un-conventional source of wind for an aggregate capacity of about 2200 MW by the private sector through Alternate Energy Development Board (AEDB) of GoP.

Above strategy to cope with Medium Term Electricity Demand notably ignores synergic multi-purpose development of surface water needed not only for cheap renewable energy but direly needed storage water for sustenance of irrigated agriculture.

6 PROPOSED APPROACH TO NATIONAL SUSTAINABILITY OF WATER RESOURCES

It can be appreciated from the foregoing that current global and national sustainable water development strategies are somewhat at variance. While global strategy is generic and futuristic, the national scenario warrants priority actions for sustainability of already developed surface and ground water resources consistent with food, fibre and energy requirements of rapidly growing population.

6.1 SURFACE WATER

6.1.1 Compulsion of Constructing Large Dams

Regarding surface water, Pakistan has compulsion for construction of large dams due to the following reasons:-

i. Need for maximum conservation of unutilized water of over 29 MAF on the verge of becoming a Water Scarce Country' as per global per capita availability criteria (refer Annex-03).

ii. Rapidly increasing population with enhancing need of food and fiber to be provided by agriculture sector through timely / additional availability of water.

iii. Rapidly depleting on-line storages (since lost about 1/3rd of original live capacity of 15.7 MAF as shown in Annex-12).

iv. Optimal river regulation and integration of existing irrigation system.

v. Flood regulation, particularly for super events like 2010 and 2014, to avoid extensive loss of life and property in the Indus Plains.

6.1.2 Minimum Additional Storage Requirement By 2025

To sustain the agricultural economy as well as ensure national food autarky through increased agriculture outputs, the main reliance has to be placed on the Indus Basin Irrigation System (IBIS). Including replacement of lost capacity of on-line reservoirs, minimum additional storage requirement by 2025 is estimated around 18 MAF.

6.1.3 Dams Identified During 2005 For Priority Implementation

In 2005 the Federal Cabinet took policy initiative to construct five dams on priority basis. This was also conveyed to the nation through the Presidential Pronouncement. These five dams comprised: Kalabagh; Diamer Basha; Akhroi; Munda; and Kurram Tangi. As a sequel to the above policy decision of GoP, engineering studies were pursued by WAPDA, particularly of the large dams to store Indus River surplus flows.

For the above mentioned five dams, the current engineering status is as below:-

i. Kalabagh Dam with live storage of 6.1 MAF and installed capacity of 3600 MW, though ready for implementation since 1987, is in suspended animation due to lack of national consensus.

ii. Diamer Basha, after completion of engineering design, tenders and approval of PC-I in 2009, is under implementation through construction of Preliminary Works' and land acquisition. However, to develop live storage of 6.4 MAF and installed capacity of 4500 MW, launching of the core construction is awaiting commitment of the needed foreign financing.

iii. Feasibility Study of Akhori Dam has been completed and go ahead for tender design is awaited.

iv. After updation of feasibility and engineering design of Munda Dam Project, with 0.7 MAF live storage and installed capacity of 740 MW, procurement process for implementation is now under way.

6.1.4 Proposed Sequencing of Large Dams

Based on the current status of Engineering Preparedness' the three candidate large dams for sequential implementation through 2025 are: already approved Diamer Basha with live storage of 6.4 MAF; Kalabagh with live storage of 6.1 MAF subject to national consensus; and Akhori with live storage of 6.0 MAF. Coincidentally the aggregate live capacity of 18.5 MAF to come from these three dams would be adequate to meet the minimum additional storage requirement of 18.0 MAF by 2025.

Proposed Way Forward' for achieving this objective is: -

i. Priority launching of Diamer Basha Dam Project with adequate local / foreign funding commitments. Alternatively, core construction of Dam and Appurtenants' should be immediately started through national resources to attract foreign donors for other project components.

ii. Start of parallel efforts to achieve national consensus regarding need and sequencing of two additional storages for meeting 2025 requirements.

iii. Engaging IFIs (WB/ADB/USAID) in conceptually / financially supporting the needed reservoir infrastructure

6.2 GROUNDWATER

6.2.1 Conjunctive Use With Surface Water

In IBIS, groundwater is usually used in conjunction with surface water. While doing so, farmers tend to decrease the salinity of irrigation water in an attempt to avoid soil salinization. In most of the canal command areas, conjunctive use of surface water and groundwater is equally practiced in head and tail ends of the canal system. One of the key disadvantages of this unmanaged conjunctive use is that upstream areas are subjected to rising water tables and water-logging whereas tail-end users are aggravating their salinity problems due to the bad quality of the groundwater. Therefore effective conjunctive use should be encouraged that will allow a combination of surface and groundwater to farmers in such a way that equity in availability of water of acceptable quality is ensured all along the channel.

6.2.2 Improving Productivity Through Resource Conservation Technologies

Resource conservation technologies such as precision land levelling, zero tillage, bed and furrow planting have also shown considerable reduction in water application at the field level. The studies done by International Water Management Institute (IWMI) found that in Rechna Doab of Punjab sub-basin zero tillage and laser leveling technologies for wheat was considerably increased during 2000-2003 from around 15% to above 35%. This increased the area under zero tillage during 2003-04 exponentially with wheat sown on an area of about 1 MA.

6.2.3 Introduction of Policy Reforms

Due to the peculiarities of Pakistan's groundwater socio-ecology, a multi-dimensional policy approach is needed. In Balochistan province, for example, the policy of providing subsidies on electricity needs to be reviewed. Currently, the annual subsidy on agricultural tubewells is Rs. 14 billion (US$ 140 million). This subsidy is mainly provided to only 2.5% of the farmers who own deep electric tubewells. In Punjab province, more efforts are needed to review existing cropping patterns for areas where hydrological conditions suggest that additional groundwater resources are insufficient to support intensive agriculture.

Separate strategies should be developed for large commercial farmers and for small poor farmers who are totally dependent on groundwater for protecting their livelihoods. Cropped areas for different crops should be fixed on the basis of the country's food requirements and the availability of water resources. In areas such as Cholistan desert where groundwater resources are not yet tapped due to lack of resources of the local population, groundwater still presents the opportunity to secure the livelihoods of the large population living in this region.

6.2.4 Effective Management

It is disheartening to note that the groundwater resource which helped in boosting Pakistan's agriculture and reducing poverty in rural areas is now fast turning into a catastrophe. For effective groundwater management, farmers need to be taken into confidence to implement possible technical, scientific, institutional and political tools to protect key strategic aquifers with regard to quality and quantity. Policies should also be formulated for the economic transition of the population that currently depends on intensive irrigated agriculture to earn their living. This is essential to reduce pressure on groundwater resources and to create political space for direct management of the resource base.

Pakistan must learn that development of groundwater resources without proper planning and management strategy has paid back very badly. Therefore, Pakistan needs a serious debate about whether to pump their aquifers to the maximum and face the consequences thereafter, or be more proactive now, better manage abstraction and invest in recharge today. For effective groundwater management, Pakistan is required to introduce frameworks and instruments that are suitable to its needs. The frontline challenge is not just supply-side innovations but to put in place a range of corrective mechanisms before the problem becomes either insolvable or not worth solving.

7 CONCLUSIONS

7.1 GLOBAL CONTEXT

i. 97.5% of all water on earth is salt water in oceans and seas leaving about 2.5% as fresh water.

ii. Only under 1% of world's fresh water is accessible for direct human use and found in lakes, rivers, reservoirs and those underground sources that are shallow enough to be tapped at an affordable cost.

iii. Total estimated annual river run-off is about 40,700 km^3 out of which:-

a. Only 32,900 km^3 is geographically accessible.

b. Considering base flow and surface run-off controlled by dams currently estimated available run-off (AR) is 12,500 km^3 per year. <u>With increased regulation through dams AR could go upto 13,700 km^3 by 2025.</u>

iv. Total annual appropriation:-

a. At end of 20^{th} Century was 4705 km^3.

b. By 2025 it could go up to 9830 km^3 (over 70% of AR).

v. Clearly, humanity is approaching the limit of fresh water supply. On the other hand, only about half of the diverted water is being consumed. Therefore, efficient water management and modern technology can stretch even scarce water supply further. Similarly, water conservation through better planning, management and technologies offers great promise.

vi. Even now, a large proportion of world's population is experiencing water stress which may become critical by 2025.

vii. Sustainable development of water resources is the dire need of mankind as it is more essential even for existence of human communities.

viii. Deliberations for water allocation should always include provisions for maintaining integrity of freshwater systems including need of minimum instream ecological flows.

ix. Sustainable water resource development:-

a. Is key to conservation of its quantity and quality as well as security, economic health and societal well being.

b. Can improve human's productive power without damaging or undermining society or the environment.

c. Implies progressive socio-economic betterment without going beyond ecological carrying capacity within Earth's twin capacities of natural resource generation and waste absorption.

x. Following three principal elements provide the foundation of sustainability:-

a. Economic vitality compatible with nature

b. Ecological integrity of natural ecosystem capacity

c. Social equity to provide access to jobs, education, natural resources and services to all peoples.

xi. Focus of evaluation strategy should be that:-

a. Current piecemeal and consumption oriented approaches to water policy may be substituted by systematic approach that considers ecological integrity and ecosystem service which natural sources can provide.

b. Besides increasing public awareness about the challenges the world is facing in relation to water, we must also change the way water issue is being perceived from being a driver of conflict to being a catalyst for collaboration.

c. Recognizing our limited ability to see needs of the future, any attempt to define sustainability should remain as open and as flexible as possible through the use of adaptive management.

7.2 NATIONAL CONTEXT

i. While global approach to sustainable water resource management is somewhat generic, the national context requires focus on sustainability of already developed surface and groundwater resources consistent with food, fibre and energy requirements of rapidly growing population.

ii. Indus Basin Irrigation System (IBIS), the mainstay of national economy, is basically dependent on diversion of surface water from Indus River. Currently, it is facing an average shortage of about 11% over the post-Tarbela developed uses after completion of the Indus Basin Project. This is basically due to:-

a. Rapid siltation in live storage capacity of the storages at Tarbela, Mangla and Chashma (already reduced by about 30%).

b. No construction of any new mega storage after commissioning of Tarbela in 1977, while about 29maf surplus water is escaping to sea.

iii. Pakistan is facing an energy crisis for the past few years with perpetual load shedding in the range of 2000-4000 MW. This has been basically caused by heavy reliance on thermal generation costing upto 8 times WAPDA's Hydropower System. To overcome this crisis at affordable tariffs, it is imperative to harness vast hydropower potential through multi-purpose mega storages instead of the present focus on run-of-river development.

iv. Stunted growth of agriculture in the face of rapidly growing demand for food and fiber warrants not only sustenance of post-Tarbela canal diversion into IBIS, but further development. In this regard:

a. It is estimated that by 2025 additional storage of about 18 MAF will be needed.

b. The main focus should be for priority development of 5 multi-purpose already identified storages and principally approved by GoP in 2005.

c. Considering engineering preparedness, core construction may be immediately started on Diamer Basha Dam Project with live storage of 6.4 MAF and cheap annual energy generation of over 20,000 GWh through its installed capacity of 4500 MW.

v. Besides surface water, a very large scale extraction and use of groundwater for irrigated agriculture has already taken place. Consequently, about 45 MAF of fresh groundwater is being pumped at the farm gate thus providing over half of crop water requirements.

vi. Though sustainable groundwater yield is estimated about 55 MAF, the remaining potential is located in areas where the quality is poor.

vii. Unregulated and uncontrolled use of groundwater has diminished the relative accessibility. The trend of continuous decline of groundwater has been observed in many areas of the Indus Plains which illustrates serious imbalance between abstraction and recharge. Depletion of groundwater is more pronounced in non-command areas of Punjab where agriculture is heavily dependent on this source.

viii. As groundwater management in Pakistan has received no attention, many aquifers have come under severe stress thus threatening sustainability of this resource.

ix. Effective groundwater management is dire need of Pakistan to ascertain sustainability of this precious water resource through:-

a. Taking farmers into confidence to implement possible technical, scientific and political tools to protect key aquifers with regard to quality and quantity.

b. Effective conjunctive use of surface and groundwater to remove disparity between head and tail enders of canal distribution system.

c. Introduction of policy reforms to regulate aquifer usage for exploitation of groundwater on the basis of effective quantity and quality monitoring.

d. Putting in place a range of corrective mechanisms before problem becomes insolvable or not worth solving.

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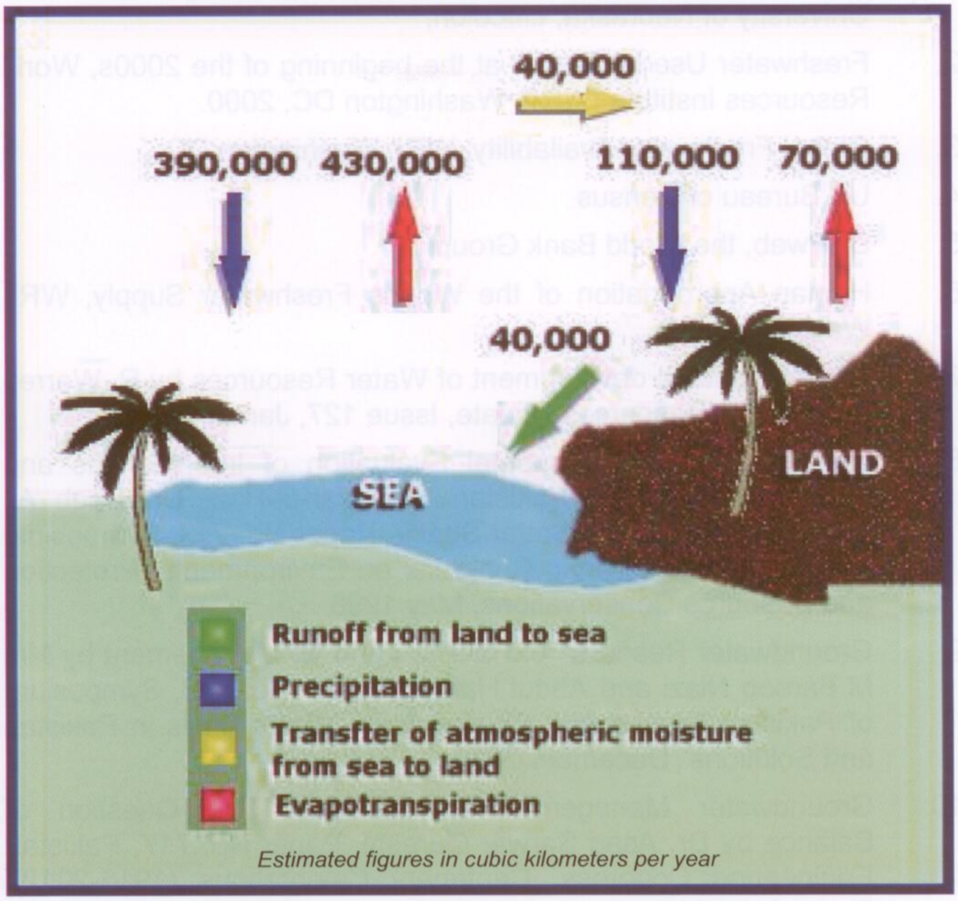
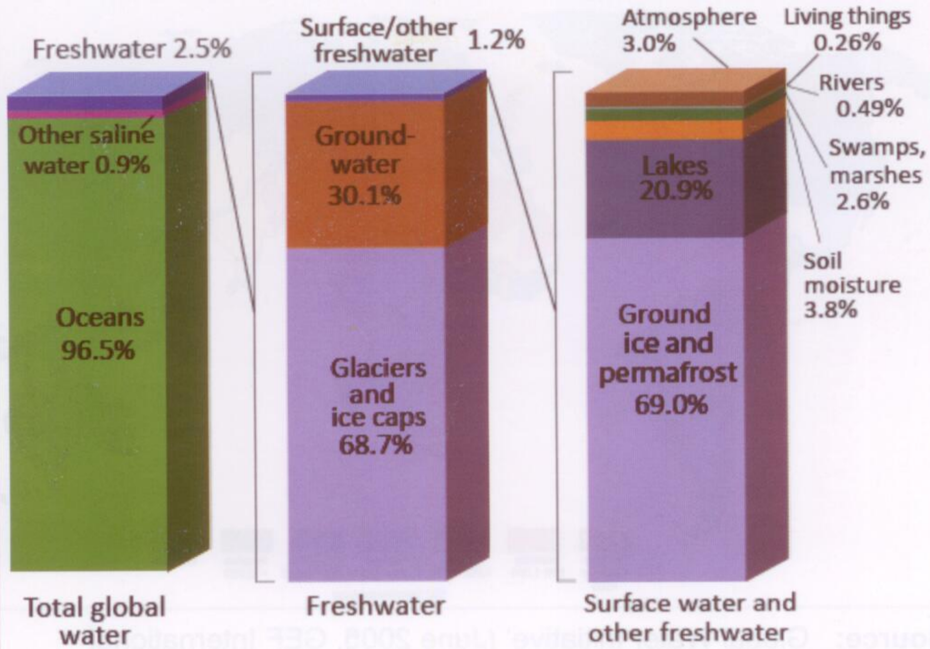
ANNEX-01

ANNUAL GLOBAL HYDROLOGICAL CYCLE



ANNEX-02

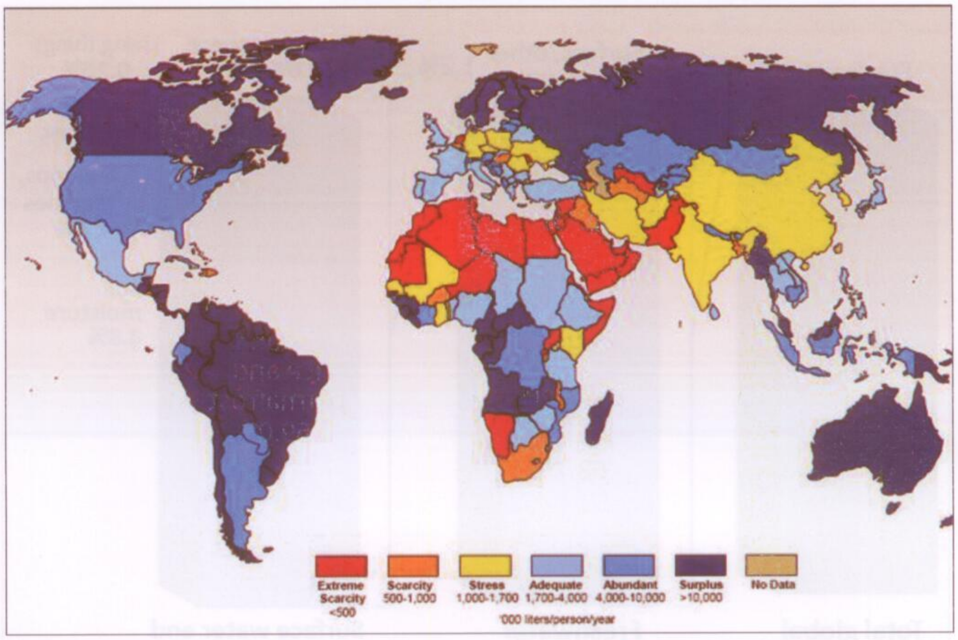
GLOBAL WATER DISTRIBUTION



Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.
NOTE: Numbers are rounded, so percent summations may not add to 100.

ANNEX-03

GLOBAL PER CAPITA WATER AVAILABILITY (2025)



Source: ‗Global Water Initiative‘ (June 2005), GEF International Waters Conference, The Coca-Cola Company

ANNEX-04

CONTINENTAL BREAKDOWN OF SHARE OF GLOBAL RUNOFF AND POPULATION

Region	River Runoff (km^3)		Global Population 2025	
	Total	Global Share (%)	No. (Billion)	Percent of Total
Europe	3,240	8.0	1.04	13.0
Asia	14,550	35.8	4.84	60.5
Africa	4,320	10.6	1.00	12.5
North & Central America	6,200	15.2	0.624	8.0
South America	10,420	25.6	0.44	5.5
Australia& Oceania	1,970	4.8	0.04	0.5
Total	**40,700**	**100.0**	**8.00**	**100.0**

ANNEX-05

WATER USE AND CONSUMPTION ESTIMATES ON A GLOBAL SCALE (2000)

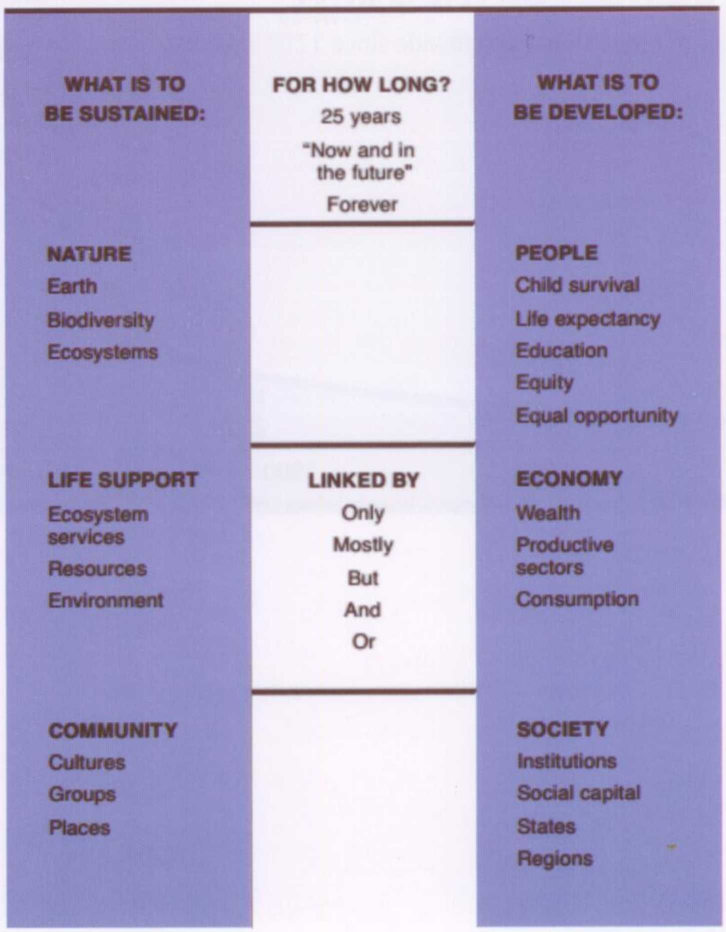
Sector	Diversion (km^3 /year)	Consumption (km^3 /year)	Percent of Diversion
Agriculture [a)]	2,880	1870	65
Industry	975	90	9
Municipalities	300	50	17
Reservoir Losses [b)]	275	275	100
Sub-total	**4,430**	**2,285**	**52**
Instream Flow Needs	275	275	100
Total:-			
i. Km^3	**4705**	**2560**	**54**
ii. % of AR (12,500 km^3)	**38**	**20**	

a) Assumes average diversion of 12,000 m^3/ha and consumption equal to 65%.

b) Assumes evaporation loss equal to 5% of gross reservoir storage capacity.

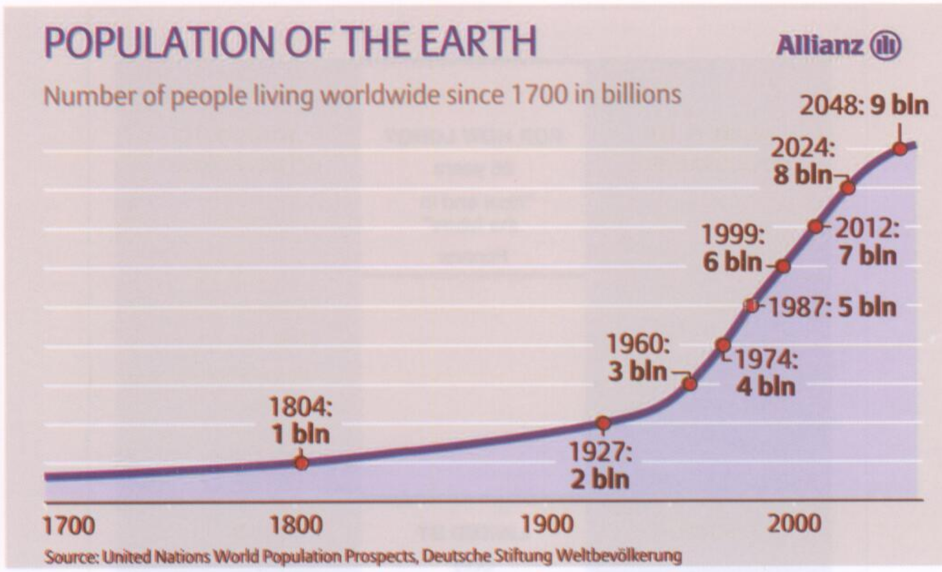
ANNEX-06

SCHEMATIC APPROACH TO SUSTAINABLE DEVELOPMENT



SOURCE: U.S. National Research Council, Policy Division, Board on Sustainable Development, *Our Common Journey: A Transition Toward Sustainability* (Washington, DC: National Academy Press, 1999).

ANNEX-07



POPULATION OF THE EARTH
Allianz
Number of people living worldwide since 1700 in billions
2048: 9 bln
2024: 8 bln
2012: 7 bln
1999: 6 bln
1987: 5 bln
1974: 4 bln
1960: 3 bln
1927: 2 bln
1804: 1 bln
1700
1800
1900
2000
Source: United Nations World Population Prospects, Deutsche Stiftung Weltbevölkerung

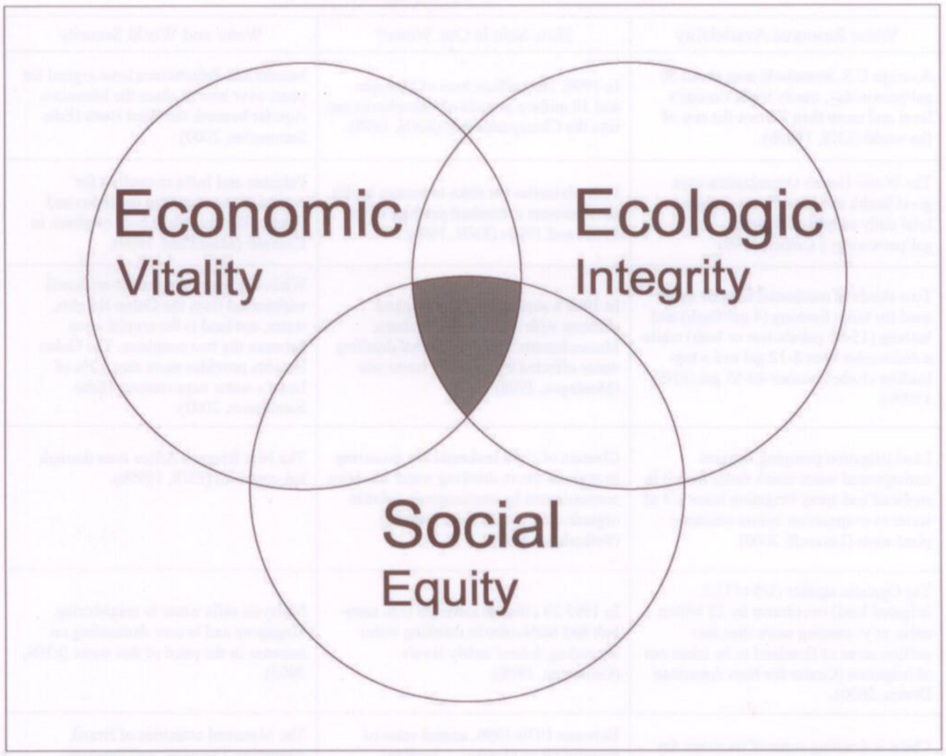
ANNEX-08

CONCERNS ABOUT WATER RESOURCES

Water Resource Availability	How Safe Is Our Water?	Water and World Security
Average U.S. household uses about 50 gal/person/day, nearly triple Europe's level and more than 7 times the rest of the world (ENS, 1999b).	In 1996, 263 million tons of Nitrogen and 18 million pounds of Phosphorus ran into the Chesapeake Bay (ENN, 1998).	Israelis and Palestinians have argued for years over how to share the Mountain Aquifer beneath the West Bank (Edie Summaries, 2000).
The World Health Organization says good health and cleanliness require a total daily supply of about 8 gal/person/day (Collier, 1999).	Fish advisories for risks to human health have become a standard practice of the 1980s and 1990s (ENN, 1999).	Pakistan and India in conflict for centuries over water in the Indus and Ganges Rivers, which both originate in Kashmir (Mustikhan, 1999).
Two-thirds of residential interior water used for toilet flushing (4 gal/flush) and bathing (15-50 gal/shower or bath) while a dishwasher uses 8-12 gal and a top-loading clothes washer 40-55 gal (ENS, 1999b).	In 1986 a study statistically linked children with leukemia in Woburn, Massachusetts to contaminated drinking water affected by a nearby waste site (Montague, 1998).	While the Syrians press for an Israeli withdrawal from the Golan Heights, water, not land is the crucial issue between the two countries. The Golan Heights provides more than 12% of Israel's water requirements (Edie Summaries, 2000).
Land irrigation pumping extracts underground water much faster than it is replaced and spray irrigation loses 1/3 of water to evaporation before reaching plant roots (Lazaroff, 2000).	Clusters of child leukemia are occurring in regions where drinking water has been contaminated by carcinogenic volatile organic compounds from industry (Sutherland, 1999).	The Nile River in Africa runs through ten countries (ENS, 1999b).
The Ogalalla aquifer (1/5 of U.S. irrigated land) overdrawn by 12 billion cubic m/yr causing more than two million acres of farmland to be taken out of irrigation (Center for New American Dream, 2000).	In 1995 29 cities & towns in U.S. corn-belt had herbicides in drinking water exceeding federal safely levels (Grossman, 1998).	Malaysia sells water to neighboring Singapore and is now demanding an increase in the price of this water (ENN, 2003).
China is draining some of its rivers dry and now mining ancient aquifers that take thousands of years to recover (Brown, 1999).	Between 1976-1996, annual rates of harmful algae blooms — leading indicator of health risks for marine animals and people — increased from 74 to 329 (Barker, 1997).	The Mercosul countries of Brazil, Argentina, Uruguay, and Paraguay launched a project for preservation of the Guarani Aquifer that serves all four countries (Muggiati, 2003)
Africa's Lake Chad has shrunk from a surface area of 25,000 sq km in 1960 to only 2,000 sq km today (GreenBiz.com, 2003).	Aging infrastructure, source water pollution and outdated treatment technology increase human health risks in 19 US cities (ENS, 2003)	Canada and the U.S. signed a treaty approximately 10 years ago that states no water can be removed from the Great Lakes basin (ENS, 1999a).
Mexico City sinking as residents pump water beneath them -- elevated train tracks, built flat in the 1960s, look like roller coasters now (Center for New American Dream, 2000).	Mass fish kills and disease outbreaks went from nearly unheard of before 1973 to almost 140 events in 1996 (Borenstein, 1998).	Mexico and the U.S. have a long-standing treaty for maintaining water flow in the Colorado River (Stevenson, 2003).
One-fifth of the world's freshwater fish -- 2,000 of the 10,000 species identified so far -- are endangered, vulnerable, or extinct (GreenBiz.com, 2003).	Stranding of whales, dolphins, and porpoises linked to poor oceanic environmental conditions jumped from nearly zero in 1972 to almost 1,300 in 1994 (Borenstein, 1998).	Conflict in the Missouri River among navigation, power generation, and environmental concerns (Quaid, 2003).
Globally the world has lost half of its wetlands, mostly in the last 50 years (Wilson and Yost, 2001).		Conflicts in water between northern and southern California (Hettena, 2003).
Two of every 3 persons could live in water-stressed conditions by the year 2025 (GreenBiz.com, 2003).		Maryland is in control of Virginia's water destiny (IATP, 2003).

ANNEX-09

SUSTAINABILITY MODEL



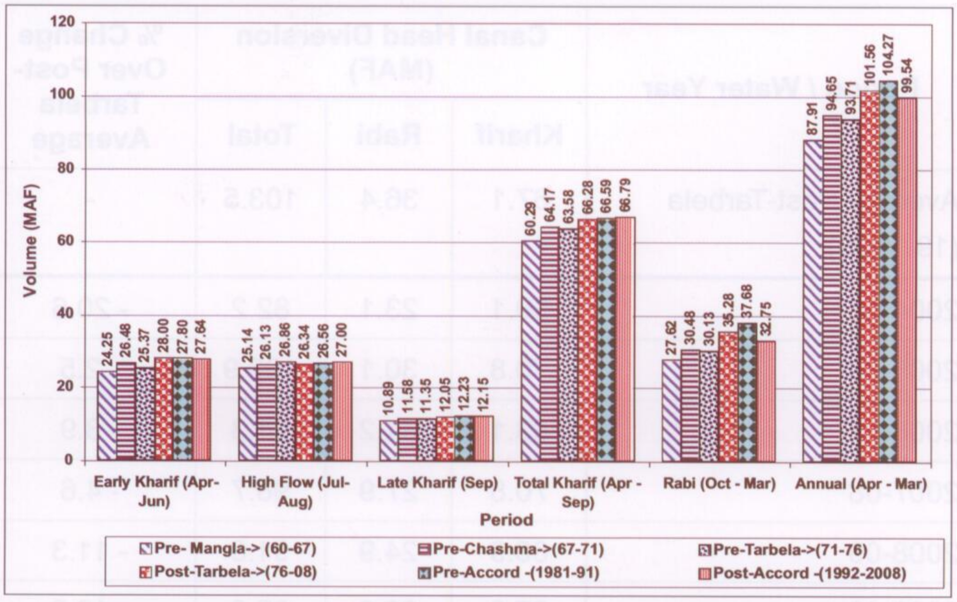
The conceptual model of sustainable development that illustrates the relationship among economic, ecologic, and social issues of concern in decision-making. The black overlap of the three circles represents the nexus of connection among issues.

ANNEX-10

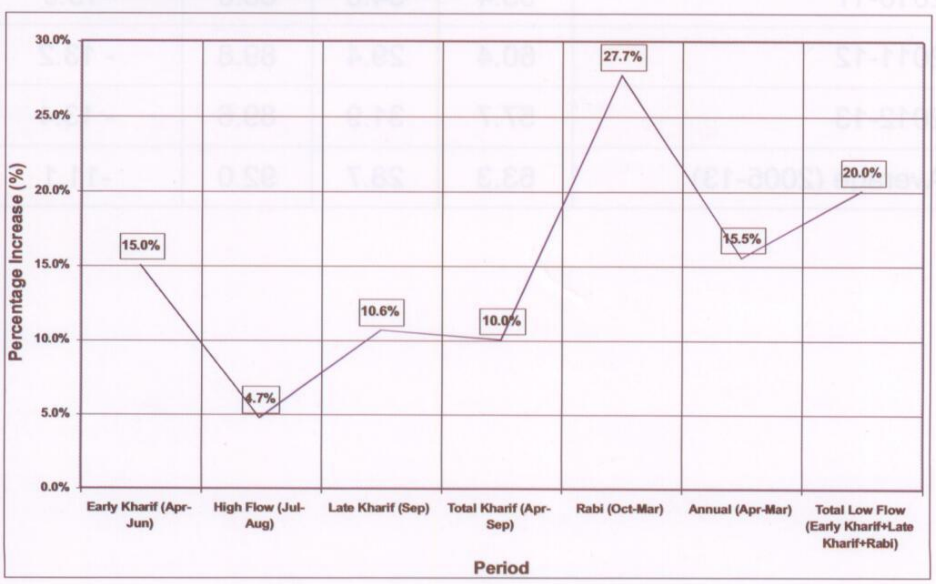
INDUS BASIN IRRIGATION SYSTEM

I. COMPARISON OF CANAL HEAD WITHDRAWALS DURING

COMPARISON OF CANAL HEAD WITHDRAWALS DURING DIFFERENT PERIODS



II. INCREASE OF AVERAGE CANAL WITHDRAWALS DURING 1976-2008 AGAINST 1960-67



ANNEX-11

INDUS BASIN IRRIGATION SYSTEM

ANNUAL CANAL HEAD DIVERSIONS DURING POST-TARBELA PERIOD

Period / Water Year	Canal Head Diversion (MAF)			% Change Over Post-Tarbela Average
	Kharif	Rabi	Total	
Average Post-Tarbela (1977-80)	67.1	36.4	103.5	-
2004-05	59.1	23.1	82.2	- 20.6
2005-06	70.8	30.1	100.9	- 2.5
2006-07	63.1	31.2	94.3	- 8.9
2007-08	70.8	27.9	98.7	- 4.6
2008-09	66.9	24.9	91.8	- 11.3
2009-10	67.3	25.0	92.3	- 10.8
2010-11	53.4	34.6	88.0	-15.0
2011-12	60.4	29.4	89.8	- 13.2
2012-13	57.7	31.9	89.6	- 13.4
Average (2005-13)	63.3	28.7	92.0	-11.1

ANNEX-12

STORAGE LOSS DUE TO SEDIMENTATION OF ON-LINE RESERVOIRS

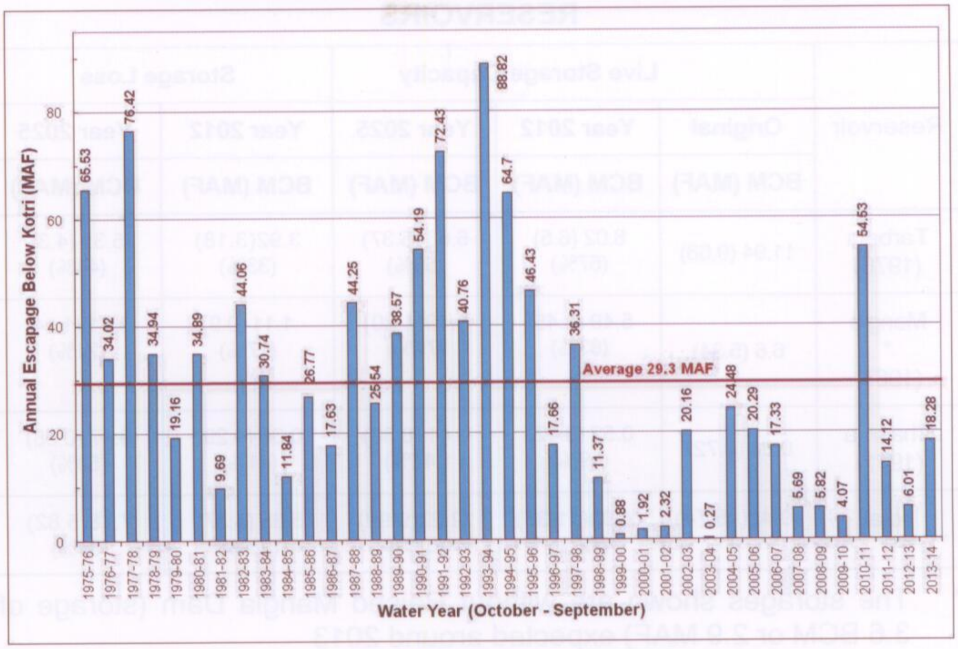
Reservoir	Live Storage Capacity			Storage Loss	
	Original	Year 2012	Year 2025	Year 2012	Year 2025
	BCM (MAF)	BCM (MAF)	BCM (MAF)	BCM (MAF)	BCM (MAF)
Tarbela (1976)	11.94 (9.68)	8.02 (6.5) (67%)	6.63 (5.37) (56%)	3.92(3.18) (33%)	5.31 (4.3) (44%)
Mangla * (1967)	6.6 (5.34)	5.49 (4.45) (83%)	5.19(4.20) (79%)	1.11 (0.9) (17%)	1.41 (1.14) (21%)
Chasma (1971)	0.88 (0.72)	0.52 (0.42) (59%)	0.41 (0.33) (.47%)	0.36 (0.29) (41%)	0.47 (0.38) (53%)
Total	19.42(15.74)	14.03(11.37) (72%)	12.23(9.92) (63%)	5.39 (4.37) (28%)	7.18(5.82) (37%)

* The storages shown are without Raised Mangla Dam (storage of 3.6 BCM or 2.9 MAF) expected around 2013

Source: Paper No. 744, Addressing Water and Power Needs of Pakistan Through Construction of Storage Dams by Muhammad Munir Ch., Zia-ul-Hasan, Dr. Allah Bakhsh Sufi, 72nd Annual Session of Pakistan Engineering Congress, December 2013

ANNEX-13

POST-TARBELA ESCAPAGES BELOW KOTRI

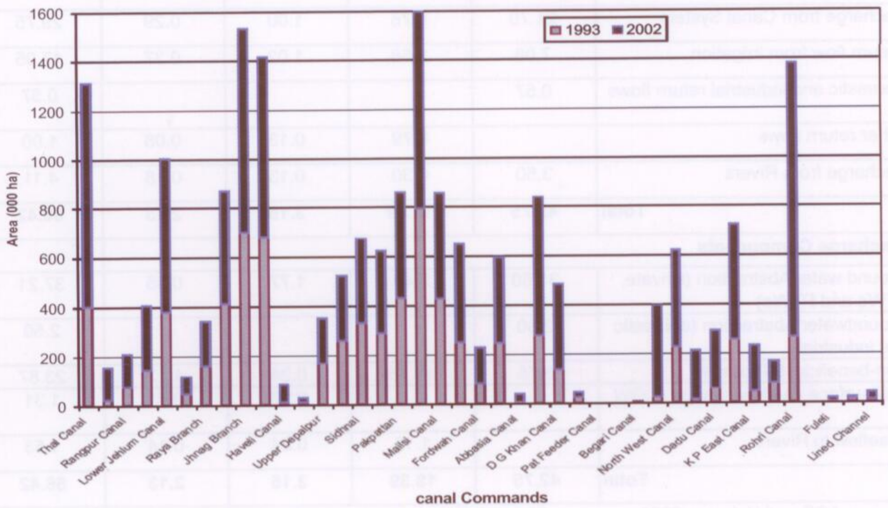


Source: Water Resource Management Directorate, WAPDA

ANNEX-14

CANAL COMMANDS OF PUNJAB AND SINDH PROVINCES

INCREASE IN AREA WITH A GROUNDWATER TABLE DEPTH OF 300 CM (10 FEET) OVER A PERIOD OF 10 YEARS (1993-2003)



ANNEX-15

ESTIMATED PROVINCE-WISE GROUNDWATER BALANCE

(MAF)

Parameters	Punjab	Sindh	KPK	Balochistan	Total
Recharge Component					
Rainfall Recharge	9.90	1.96	0.87	1.21	13.94
Recharge from Canal System	21.70	6.76	1.00	0.29	29.75
Return flow from irrigation	7.08	8.58	1.02	0.37	17.05
Domestic and industrial return flows	0.57				0.57
Other return flows		0.79	0.13	0.08	1.00
Recharge from Rivers	3.50	0.30	0.13	0.18	4.11
Total	**42.75**	**18.39**	**3.15**	**2.13**	**66.42**
Discharge Components					
Ground water Abstraction (Private, STWs and PTWs)	31.50	3.49	1.77	0.45	37.21
Groundwater Abstraction (domestic and industrial)	2.50				2.50
Non-beneficial ET losses	8.75	13.75	0.24	1.13	23.87
Sub-surface Outflow/change in GW			0.90	0.41	1.31
Baseflow to Rivers		1.15	0.24	0.14	1.53
Total	**42.75**	**18.39**	**3.15**	**2.13**	**66.42**

Source: ACE and Halcrow, 2001

SUSTAINABLE DEVELOPMENT OF WATER RESOURCES: THE DEEPENING CRISIS IN PAKISTAN

Asrar-ul-Haq[1] and Afaf Ayesha[2]

ABSTRACT

The paper presents the theme and framework of sustainable development in the context of water resources. It highlights the emerging water sector crisis in Pakistan and the challenges that the country is facing. The paper also recommends the strategies and interventions and the way forward for sustainable development of water resources.

Sustainable development refers to the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Water is at the heart of sustainable development and is critical for socio-economic uplift, healthy ecosystems and for human survival itself. Scarcity and misuse of freshwater poses a serious and growing threat to the mankind. It was in this backdrop that the Dublin Conference in 1992 set out recommendations for action at local, national and international level based on four guiding principles and the agreed Action Agenda.

The paper brings out the main factors which are resulting in water crisis in Pakistan. These include water scarcity, a high-risk environment, extremely inadequate storage capacity, large-scale degradation of resource base, over-exploitation of groundwater, lack of access to safe drinking water and sanitation and increasing incidence of flooding. In addition, climate change impacts, inadequate knowledge base, low water productivity and fragmented governance are also exacerbating the crisis. In order to address the above challenges, recommendations and way forward have been proposed in the context of the framework of sustainable development. The recommended strategies relate to improvements in surface water management, groundwater management, managing climate change impacts, institutional reforms and pollution control measures by adopting the integrated water resources management strategies.

1. SUSTAINABLE DEVELOPMENT IN CONTEXT

The concept of sustainable development has been evolving for more than 30 years. The 1972 United Nations (UN) Conference on the Human Environment in Stockholm contributed to this evolution by

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[2] Environmentalist, PIAIP Consultants/ NESPAK Foundation, Lahore - Pakistan

emphasizing that protection of the human environment is a crucial element in the development agenda. The next milestone in the evolution of sustainable development occurred at the 1992 UN Conference of Environment and Development in Rio de Janerio, also known as Earth Summit. The World Summit on Sustainable Development was held in Johannesburg in 2002 to review implementation progress of the recommendations of the previous conferences. (*Rogers, P .et al., 2008)*

Sustainable development was explicitly contextualized by the Brundtland Commission in the document —Our Common Future□ where it was defined as: ***development that meets the needs of the present without compromising the ability of future generations to meet their own needs***. (UN, 1987)

The Brundtland Commission focused on three pillars of human well being: economic, socio-political and ecological/environmental conditions. The basic concept endorses putting in place strong measures to spur economic and social development, particularly for people in developing countries, while ensuring that environmental integrity is sustained for future generations.

The main pillars and sectors associated with sustainable development are depicted in figure 1.

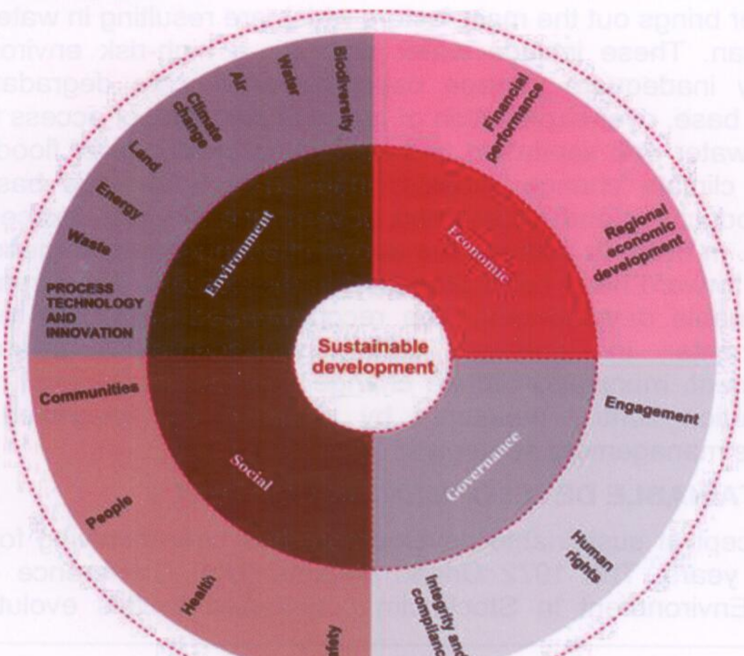

Fig. 1: Pillars and Sectors of Sustainable Development

2. WATER AND SUSTAINABLE DEVELOPMENT

Water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. It is vital for reducing the global burden of disease and improving the health, welfare and productivity of populations. It is central to the production and preservation of a host of benefits and services for people. Water is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society and the environment.

Water is a finite and irreplaceable resource that is fundamental to human well-being. It is only renewable if well managed. Today, more than 1.7 billion people live in river basins where depletion through use exceeds natural recharge, a trend that will see two-thirds of the world's population living in water-stressed countries by 2025. Water can pose a serious challenge to sustainable development but managed efficiently and equitably, water can play a key enabling role in strengthening the resilience of social, economic and environmental systems in the light of rapid and unpredictable changes.

The Millennium Development Goals (MDGs), agreed in 2000, aim to halve the proportion of people without sustainable access to safe drinking water and basic sanitation between 1990 and 2015. The Rio+20 Conference in 2012 was an opportunity to reflect on progress towards sustainable development over the previous 20 years. One of its main outcomes was an agreement to launch a process to develop a set of Sustainable Development Goals, which build on the Millennium Development Goals and converge with the post-2015 development agenda. The member states have agreed that human rights, equality and sustainability should form the core of the development agenda and be recognized as critical for true development (UN Water, 2015).

3. PRINCIPLES FOR SUSTAINABLE DEVELOPMENT OF WATER

Scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment. Human health and welfare, food security, industrial development and the ecosystems on which they depend, are all at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past.

Five hundred participants from a hundred countries attended the International Conference on Water and the Environment (ICWE) in Dublin, Ireland, on 26 to 31 January 1992. The Conference Report set out recommendations for action at local, national and international levels, based on four guiding principles (*https://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html*):

Principle No. 1 - Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment

Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2 - Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels

The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3 - Women play a central part in the provision, management and safeguarding of water

This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4 - Water has an economic value in all its competing uses and should be recognized as an economic good

Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

Based on the above four guiding principles, the Dublin Conference developed recommendations to enable countries to tackle water resources management challenges. The main points of the Action Agenda are presented in Box-1.

Box-1: Action Agenda for Sustainable Water Development

- *Alleviation of poverty and disease*
- *Protection against natural disasters*
- *Water conservation and reuse*
- *Sustainable urban development*
- *Agricultural production and rural water supply*
- *Protecting aquatic ecosystems*
- *Resolving water conflicts*
- *The enabling environment*
- *The knowledge base*
- Capacity building

4. MULTIPLE USES OF WATER

Water is one of the most vital natural resources for all life on Earth. Humans, plants, and animals are made up of mostly water. Common uses of water are depicted in Box-2 (Hildering, 2006).

Box-2: Multiple Water Uses

A. Social Uses

- Domestic Uses
- Food Production
- Cultural Uses

B. Economic Uses

- Industrial Uses
- Transport
- Hydropower

C. Ecological Uses

- ✓ Aquatic Ecosystems
- ✓ The Hydrological Cycle
- ✓ The World Ecosystem

5. WATER RESOURCES OF PAKISTAN

The water-resources of Pakistan include surface water, rainfall, and groundwater. The extent and availability of these resources is location-specific. The land and water resources of Pakistan are summarized in

Box-3 and brief description of water resources of Pakistan is also given below (GoP, 2004; WAPDA 2006):

Box-3: Land and Water Resources of Pakistan

Total Area	:	197 Million Acres
Cultivated Area	:	51 Million Acres
Irrigated Area	:	34.5 Million Acres
Average Annual Surface Flow	:	144 MAF
Average Annual Canal Withdrawals	:	103 MAF
Sustainable Annual Groundwater Availability	:	61 MAF
No. of Tubewells	:	1.0 Million
Total Length of Canals	:	58,500 Km
Reservoir Capacity (designed)	:	15.7 MAF
Reservoir Capacity (existing)	:	11.5 MAF
Additional Mangla Raising	:	2.8 MAF
Per capita Water Availability	:	less than 1000 m^3
Per capita Storage Capacity	:	less than 150 m^3

5.1 Surface Water-Resources

Surface water-resources of Pakistan are mainly based on the flows of the Indus River and its tributaries. The Indus River has a total length of 2900 kilometres (Km) and the drainage-area is about 966,000 sq. Km. Five major tributaries joining its eastern side are Jhelum, Chenab, Ravi, Beas and Sutlej; besides, three minor tributaries are the Soan, Harow, and Siran, which drain in mountainous areas. A number of small tributaries also join the Indus towards its western side. The biggest of such tributaries is River Kabul. The long term average flow of the western rivers is around 131 MAF while those of the eastern rivers is about 13 MAF.

Rivers in Pakistan have individual flow characteristics, but all of them generally start to rise in the spring and early summer, with the monsoon rains and snow melting on the mountains and have a combined peak discharge in July and August. The flows are minimum during winters i.e., during the period November to February, mean monthly flows are only about one tenth of those in summer. Besides the major rivers, there are numerous small rivers and streams, which are only seasonal with flow depending on rain fall and carry practically no water during the winter months.

5.2 Rainfall

About 70 per cent of the annual rainfall occurs in the months of June to September. This causes the loss of most of the run-off in the lower

Indus plains to the sea. The mean annual rainfall distribution in Pakistan has a broad regional variation. It ranges between 125 mm in Balochistan (South East) to 750 mm in the North West.

Rainfall is neither sufficient nor regular. The intensity of rainfall and the volume of downpour are much more than can be utilized readily. A large part of the rainfall, therefore, either floods the riverine areas and/or villages/cities near the rivers and causes consequential miseries and damages, or flows into the sea without any economic benefit to the country.

5.3 Groundwater Resources

Most of the groundwater resources of Pakistan exist in the Indus Plain, extending from Himalayan foothills to Arabian Sea, and are stored in alluvial deposits. The Plain is about 1,600 km long and covers an area of 21 Mha and is blessed with extensive unconfined aquifer, which is fast becoming the supplemental source of water for irrigation. The aquifer has been built due to direct recharge from natural precipitation, river flow, and the continued seepage from the conveyance-system of canals, distributaries, watercourses and application-losses in the irrigated lands during the last 90 years.

6. THE IMPENDING WATER SECTOR CRISIS IN PAKISTAN

Sustainable development and management of water resources in Pakistan is facing serious crisis, due to multi-faceted challenges as described below (World Bank 2005, Haq et al 2012, Ayesha, 2012):

i) **Rapid population growth** – The escalating population pressure, urbanization and unsustainable water consumption practices have placed immense stress on the quality as well as quantity of water resources in the country. The population was 80 million in 1980 and it is projected to increase 230 million by 2025. Simultaneously, the urbanization is rapid the percentage of population living in urban areas doubled over the past twenty years.

ii) **Impending water scarcity** – Pakistan is already one of the most water-stressed countries in the world, a situation which is going to degrade into outright water scarcity due to high population growth. The per capita availability which was 5300 m^3 per capita in 1951 has progressively reduced to around 1000 m^3 per capita now and would further reduce to 885 m^3 per capita by 2025, exhibiting conditions of extreme water scarcity.

iii) **A high risk water environment** – Pakistan's dependence on a single river system means it has little of the robustness that most countries enjoy by virtue of having a multiplicity of river basins and diversity of water resources. The scenario deteriorates further during droughts and floods.

iv) **Large seasonal fluctuations in water availability** – The water availability is highly seasonal and uneven over time and space. 80-85% of the river flows are received during summer season and only 15-20% during winter season. Of this, above 70% river flows occur during three monsoon months and the remaining 30% in the nine months.

v) **Water storage capacity is extremely inadequate** – When river flow is variable, then storage is required so that the supply of water can more closely match water demands. Relative to other arid countries, Pakistan has very little water storage capacity. Whereas the United States and Australia have over 5000 cubic meters of storage capacity per inhabitant, and China has 2200 cubic meters, Pakistan has only 150 cubic meters of storage capacity per capita. As a result of this constraint, the water availability during the crucial Rabi maturing and Kharif sowing periods seriously hampers the system capacity to meet the irrigation requirements which translates into lower yields.

vi) **Water pollution issues**– Water pollution is one of the most serious environmental hazard and it occurs because the water is increasingly contaminated form human and animal wastes, industrial effluents and toxic chemicals, etc. These pollutants are discharged untreated into water bodies from natural and anthropogenic sources. This is seriously impacting the quality of surface and groundwater. The water pollution is a major cause of deaths and diseases. The contaminated water is unsafe for drinking, recreational and agricultural purposes and it is also destroying the aquatic life and posing hazards to the human health.

vii) **Progressive degradation of the resource base** – There is abundant evidence of wide-scale degradation of the natural resource base on which the people of Pakistan depend. Salinity remains a problem, with some aspects partially controlled but others – including the fate of the approximately 15 million tons of salt which are accumulating in the Indus Basin every year and the ingress of saline water into over-pumped freshwater aquifers–remains the major threats.

viii) **Large population does not have access to safe drinking water and sanitation** – one in six people worldwide do not have access to the safe fresh water. Asia shows the highest number of people unserved by safe water supply and sanitation (80% of the population). The situation is similar in Pakistan. Water and sanitation related diseases are responsible for 60% of child mortality and diarrheal diseases are estimated to kill more than 460,000 children under five each year.

ix) **Groundwater is now being overexploited in many areas, and its quality is deteriorating** – Over the past forty years, the exploitation of groundwater, mostly by private farmers, has brought enormous economic and environmental benefits. Groundwater now accounts for almost half of all irrigation requirements. Now, although, there is clear evidence that groundwater is being over-exploited, yet tens of thousands of additional wells are being put into service every year, which is jeopardizing the sustainability of this precious resource. The progressive over-exploitation and the falling groundwater levels are resulting in higher construction and pumpage costs, degradation of water quality and also the threat of upconing of saline groundwater into fresh aquifers.

x) **Flooding and drainage problems are going to get worse** – The drainage problems are encountered due to flat topography and construction of roads and other infrastructure across the natural drainage lines. Similarly, the risk of flooding is increasing due to accretion of river beds, encroachments in the river flood plains and incidence of unprecedented floods as happened in 2010 and 2014.

xi) **Climate change-** The Indus Basin depends heavily on the glaciers of the western Himalayas which act as a reservoir, capturing snow and rain, holding the water and releasing it into the rivers which feed the plains. It is now clear that climate change is already affecting these western glaciers. While the science is still in its infancy, estimates are that there will be fifty year of glacial retreat, during which time river flows will increase. This – especially in combination with the predicted flashier rainfall – is likely to exacerbate the already serious problems of flooding and drainage. But then the glacial reservoir will be empty, and there are likely to be substantial decreases in river flows in the Indus Basin in one hundred years' time.

xii) **An inadequate knowledge base** – The Indus Basin is a single, massive, highly complex interconnected ecosystem, upon which man has left a huge footprint. The past twenty years should have been ones of massive investment in knowledge about this ecosystem. But the reverse has happened, and even the once-renowned Pakistan water planning capability has fallen into disarray.

xiii) **The system is not financially sustainable** – The irrigation system used not only to fully finance the O & M cost but it also used to generate sufficient surplus revenue. The situation has however changed with passage of time due to inflation and stagnation of water rates. The current income finances only 20 to 25% of the O&M cost of the irrigation infrastructure. This is one of the reasons for the declining health of the water resources infrastructure.

xiv) **Dwindling trust of the stakeholders**– Conceptually the simplest task for water managers in the Indus Basin is to move water in a predictable, timely manner to those who have a right to it. Because of building pressures on water resources due to population growth, system and supply constraints and socio-political implications, the water resources management is facing threats. This state of affairs is resulting in growing water shortages, particularly in the tail ends of the system. This is reflecting adversely on the trust of the stakeholders.

xv) **Water productivity is low** – Large parts of Pakistan have good soils, abundant sunshine, and excellent farmers. And yet crop yields, both per hectare and per cubic meter of water, are much lower than international benchmarks, and much lower even than in neighboring areas of India. In view of this and emerging water scarcity, there is urgent need to invest in productivity enhancement initiatives to sustain agricultural and economic growth.

xvi) **Fragmented governance** – There is absence of unitary command in water governance. A host of Ministries, Departments and Agencies are responsible for water management at the Federal and Provincial level. This state of affairs is further complicating effective governance and management of the water resources. The diffused responsibility is impinging on various facets of water management, i.e. irrigation, drinking water, pollution of water bodies and over-exploitation of groundwater, etc.

7. RECOMMENDATIONS AND WAY FORWARD

7.1 The Framework

In the wake of the water crisis looming large, urgent need for sustainable development and management of water resources in Pakistan cannot be over-emphasized. Towards this end, the principles and guidelines of sustainable development have to be adopted. These include conservation, sustainable use, infrastructure optimization, institutional restructuring, better governance, caring for the poor and unprivileged, sections of the society, value enhancement, capacity building, public participation and stewardship to enable the future generations to meet their needs.

7.2 Surface Water Management

The Indus Basin Irrigation System reflects a situation in which the primary resource constraint on agriculture production is water. Pakistan has very little water storage capacity and can barely store 30 days of water. When river flow is variable, then storage is required in order the supply of water can more closely match water demands. Growing shortfall in water availability compared to demand will continuously increase in future. Holistic policies for water resources development and management are therefore required to sustain growth in the context of resource limitation. Development of 15 to 20 MAF of additional water storage and interventions for improving water availability through water conservation are imperative.

Water has always played a key role in economic development. Investment in water management has been repaid through livelihood security and reductions in health risks, vulnerability and ultimately poverty. While most of the old challenges of water supply, sanitation and environmental sustainability remain, new challenges such as adaptation to climate change, rising food and energy prices, and ageing infrastructure are increasing the complexity and financial burden of water management.

Competition for water and shortcomings in managing it to meet the needs of society and the environment call for enhanced societal responses through improved management, better legislation and more effective and transparent allocation mechanisms. The specific interventions in this regard include additional storages, rehabilitation and upgradation of irrigation infrastructure, ensuring equitable supplies to all stakeholders, encouraging the participatory management approach by associating farmers in management at gross root, and taking steps for financial sustainability of the system. In addition conservation measures comprising lining of distributaries and water courses, improved farm lay-out, precision land levelling and modern irrigation technologies (drip, sprinkler, etc.) need to be adopted. A comprehensive and real time monitoring system also needs to be put in place along-with improved drainage and flood control interventions.

7.3 Groundwater Management

Groundwater has become a vital and major part of the overall water resources in the Indus Basin irrigation system. The groundwater use is however reaching to the sustainable limits. The fast growing cities and industries looking for large increases in water supply are adding to the challenge. An effective monitoring and management system that encourages the management sustainability of this water source is needed. An effective framework for groundwater management needs to be put in place. The experience in this regard suggests to follow a phased and incremental implementation strategy with initial focus on groundwater monitoring and gradual shift to groundwater management. The awareness raising campaign is also very important for sensitizing the stakeholders about groundwater issues, self-regulation, groundwater monitoring and management interventions. It is relevant to point out that the upcoming institution of Farmers Organizations can play an effective role for management of groundwater in their respective areas (Haq et al, 2012).

7.4 Integrated Water Resources Management (IWRM)

Strengthening IWRM and water management capacity is needed to deal with both the existing and emerging water challenges taking into account the issues like climatic changes, groundwater use, water quality, pollution, urbanization and industrialization, licensing access to water etc. A continuum for decision making in water resources management is to be prepared, identifying the fundamentals of IWRM implementation by addressing the resource condition and allocation issues at the basin level.

The distinct elements for progressing IWRM and to address the resource conditions and allocation issues are shown below (Donald, 2008):

Box-4: IWRM Fundamentals

- ❖ How much water (surface and groundwater) is available
- ❖ What are the risks / opportunities associated with these resources – climate change / pollution / new dams
- ❖ What is the quality of water
- ❖ Who is authorized to use it and under what conditions will this authorization be changed
- ❖ Who will have policy and decision making responsibility for an integrated approach for water management that will take into account all the competing issues and sectors

7.5 Institutional and Policy Reforms

Holistic institutional and policy reforms to improve the management and maintenance of the Indus Basin Irrigation System are required to ensure its long-term physical and financial sustainability, reforms to make inter and intra- province water allocation and distribution more transparent, service delivery reforms to improve the quality, efficiency and accountability through farmers participation in irrigation management at the gross root level and strategies to improve water use efficiency and the on-farm productivity (Haq et al, 2012).

7.6 Managing Climate Change Impacts

It is now clear that climate change is already affecting the western glaciers. While the science is still in its infancy, best estimates are that there will be fifty year of glacial retreat, during which time river flows will increase. This with the predicted flashier rainfall is likely to exacerbate the already serious problems of flooding and drainage. But then the glacial reservoir will be depleted, and there are likely to be substantial decreases in river flows in one hundred years time. The emerging impacts of climate changes would add a new dimension to the water challenges, which call for adequate knowledge base, strategic planning and proactive management initiatives (World Bank 2005).

A Task Force on Climate Change was set up by the Planning Commission of Pakistan in October 2008 with the view to take stock of country's situation and to recommend the national climate change strategies. The Task Force finalized its report in February 2010. The salient recommendations of the Task Force are summarized in Box-5.

Box- 5: National Climate Change Strategies/ Recommendations

- Providing incentives for adoption of more efficient irrigation techniques
- Development of local rain harvesting measures
- Enhancing public awareness to underscore the importance of conservation and sustainable use of water resources
- Protecting groundwater through management and technical measures like regulatory frameworks, water licensing, artificial recharge especially for threatened aquifers, and adopt integrated water resources management concepts
- Developing wastewater recycling and its reuse in agriculture, artificial wetlands and groundwater recharge
- Protecting and conserving water catchment' areas, and reservoirs from degradation, silting and irrigation system contamination
- Encourage active participation of farmers in water management along-with line-departments
- Development of contingency plans for short-term measures to adapt to water shortages that could help to mitigate drought
- Legislating and enforcing laws and regulations required for efficient water resources management, conservation and participatory management
- Legislating and enforcing laws related to industrial and domestic waste management
- Strengthening the present hydrological network to monitor river flows and flood warning systems
- Developing and extending technologies and techniques for domestic and drinking water
- Enhancing country's water storages capacities
- Ensuring the rehabilitation and up-gradation of existing irrigation infrastructure in the country, which can sustain the climate change related expected extreme weather events
- Developing infrastructure to harness the hill torrents potential

7.7 Addressing Water Quality Issues

The water quality challenges need to be addressed in an integrated manner by adopting pollution prevention strategies as presented below (Ayesha, 2012):

- The monitoring of water quality is required at the government level on regular basis. For this purpose, capacity building of staff, fully equipped laboratories, recurrent budgets, latest technologies, data-sharing and analysis, and management institutions should be strengthened.

- The development of new technologies for improving water quality is required. This may be required for the deployment, maintenance, and operation of systems to collect, transport, and treat human wastes, used water, stormwater, industrial wastes and agricultural runoff.
- Strict enforcement of water quality rules and regulations need to be ensured in order to prevent the discharge of untreated effluents from the industries and municipalities.
- The industries may be required to install wastewater treatment plants. The technologies need to be scaled up rapidly to deal with the tremendous amount of untreated wastes entering into water bodies daily; and water and wastewater utilities need financial, administrative, and technical assistance to implement these approaches.
- Appropriate solid waste management system should be put in place to prevent the dumping of solid waste into the water bodies and leachate generation.
- A sustainable pollution control strategy needs to be devised in order to reduce the wastewater volumes at sources. This approach may include the segregation of wastewater streams, process modification techniques and recycling and reuse of wastewater.
- The public education and awareness campaigns about the importance of water-quality needs to be launched. Media and non-governmental organizations (NGOs) can play a vital role in this aspect.

7.8 Providing Safe Drinking Water and Sanitation

In September 2009 the government approved the National Drinking Water Policy that aims at providing safe drinking water to the entire Pakistani population by 2025, including the poor and vulnerable, at an affordable cost. A main objective is a clearer separation between the functions of service provision and regulation. The right to water for drinking precedes all other uses, like industrial or agricultural water use. Women are recognized as main actors of domestic water supply, and their active participation in the sector is sought. Towards this end, low-cost indigenous and efficient systems may be installed, particularly in the saline groundwater areas. Public awareness, participation by the stakeholders and focused subsidies for ensuring continued operation of the schemes may be ensured.

The National Sanitation Policy (NSP), approved by the federal government in 2006, promotes the grassroots concept of community-led total sanitation (CLTS) in communities with less than 1,000 inhabitants. In larger communities, the NSP promotes a "component sharing model", under which sewage and wastewater treatment facilities are provided by the communities in case that local government-developed disposal is not available. For improving sanitation, technical support and targeted subsides may be provided involving NGOs, local governments and communities in the process.

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SURFACE WATER RESOURCES AND THEIR SUSTAINABLE DEVELOPMENT IN PAKISTAN

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ABSTRACT

1. Pressing Need for Water

Pakistan is a country of over 187 million people (2014), which is expected to grow to about 221 million by the year 2025. The increasing population will have a major impact on food and water requirements. The most pressing need thus over the next quarter in Pakistan will be development of surface water and provision of basic amenities.

Surface Water, the most precious resource of Pakistan, which with its diverse uses will continue to play a major role in reaching the broader development objectives of achieving food security, poverty alleviation and improvement of quality of life in Pakistan. The increasing pressures of population and industrialization are placing great demands on surface water with an ever increasing number and intensity of local conflicts over its availability and use.

2. Water & Power are Inter-linked

While agriculture remains Pakistan's largest force in extracting water, energy is the engine for Pakistan economy. In fact nothing moves forward without energy. Water and hydropower are so intimately linked that actions to increase access to one of them will inevitably have good effects on the other. If we are wise we must increase access to both, otherwise we may trap ourselves in a downward spiral. Pakistan is exposed to double whammy, suffer water shortages as well as power supply, which adversely affect both its agriculture and industry.

3. Cheap Hydel Power

Pakistan's food requirements as well as energy consumption are increasing day by day. Pakistan's progress is impossible without energy security. No form of energy production is cheaper than Hydel power. Affordable standard tools are available for water to be used for energy production.

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Dams offer a cost effective, reliable, technology, which is a mature and efficient source of potentially renewable energy.

4. Dams Carry Higher Priority than Motorways & Metro Bus Projects

Dams deliver substantial benefits in major sectors of Pakistan's economy and must be constructed at higher priority than Motorways & Metro Bus projects. However dams come with very high environmental, social displacement and ecological costs. Sustainable development has a meaning if it includes everything equally important. Wise plans demand sharing information with all, especially with those living downstream with environmental impacts. Water sector typically has more political clout than Hydel power.

5. One Storage Dam – Immediate Need of the Country

Under Integrated Management Sustainable Development of storage dams for irrigation and Hydel Power generation is the aim and objective of this paper as in Pakistan Water and Hydel Power are interdependent. Under the paralyzing economy of Pakistan, there is no better option than Kalabagh Dam which can rescue the Country from imminent risks and pave a path of progress towards greater heights in the near future.

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6. 1.0 INTRODUCTION

Pakistan is an arid country, with an average rainfall of 240 mm a year. Its agriculture depends heavily on irrigation as such its main agricultural output comes from irrigated lands. Average canal head withdrawals at the time of Independence were about 67 MAF. Canal head withdrawals have continued to increase with progressive improvements in the system. During the 10 year period ending in 1959-60 i.e., prior to the signing of the Indus Waters Treaty canal head withdrawals had increased to an average of 83 MAF an increase of about 24% over the 67 MAF withdrawn at the time of Independence. In the seven year period ending 1966-67, i.e., prior to the completion of Mangla Dam withdrawals had further increased to an average of 87.7 MAF. After the completion of Mangla and prior to the commissioning of Tarbela Dam in 1974-75 average canal withdrawals rose to 96.37 MAF. During the years 1976-77 to 2012-13, withdrawals have averaged 105 MAF. Thus since independence withdrawals have risen by 38.35 MAF. Details are given in Box-1 below:-

BOX-1

AVERAGE ANNUAL CANAL DIVERSIONS (MAF)

PROVINCE		PRE-MANGLA (1957-63)	POST-MANGLA (1967-76)	POST-TARBELA (1976-2012)
Balochistan	K	0.00	0.52	1.18
	R	0.00	0.08	0.80
	T	0.00	0.60	1.98
KPK	K	2.90	3.49	3.25
	R	1.53	1.92	2.18
	T	4.42	5.40	5.43
Punjab	K	30.03	31.65	34.03
	R	16.78	16.93	20.33
	T	46.80	48.85	54.36
Sindh	K	22.65	29.85	28.55
	R	9.93	11.94	15.03
	T	32.58	41.79	43.38
Total	K	55.58	65.51	67.01
	R	28.23	30.86	38.34
	T	83.81	96.37	105.35

This improvement is attributed to the storage reservoirs of Mangla, Chashma and Tarbela. While the bulk of storage water is utilized during Rabi season, supplies have also been available in the critical water short period of early Kharif, during the sowing and maturing periods of summer crops. Figures of Gross Storage Capacity & population are given in Box-2 below:-

BOX-2

GROSS STORAGE CAPACITY VS POPULATION

YEAR	GROSS STORAGE (MAF)					POPULATION (Million)
	MANGLA	RAISED MANGLA	TARBELA	CHASHMA	TOTAL	
1966	-	-	-	-	NIL	-
1967	5.88	-	-	-	5.88	-
1971	5.74	-	-	0.87	6.61	-
1974	5.60	-	11.62	0.80	18.02	66.09
1975	5.57	-	11.51	0.77	17.85	71.06
1980	5.39	-	10.99	0.65	17.02	81.88
1991	5.01	-	9.82	0.37	15.21	109.91
2000	4.69	-	8.87	0.15	13.72	137.78
2013	4.24	2.90	7.50	0.05	14.69	183.67
2020	4.03	2.90	6.73	-	13.63	205.52
2025	3.88	2.90	6.45	0.00	13.23	221.00

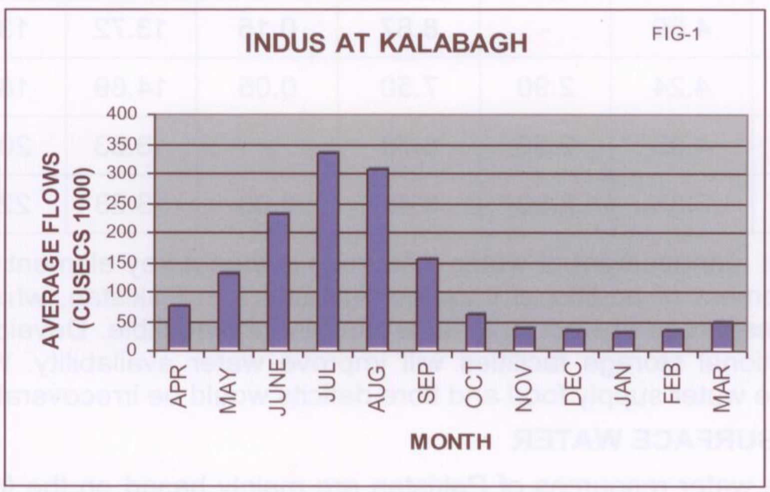
Efficient management of water resources is thus a key element for the development of additional irrigated agriculture in Pakistan, where the water resources are not only finite but also exhaustible. Development of additional storage facilities will improve water availability. Without requisite water supply food and fibre deficits would be irrecoverable.

2. SURFACE WATER

Surface water resources of Pakistan are mainly based on the flows of the Indus River and its tributaries. The discharges in the River Indus and its tributaries range from a few thousand cusecs in winter to hundreds of thousands cusecs during monsoons. Based on the Post-Tarbela period, the average annual inflow of the Western Rivers at the rim-stations amounts to 138.43 MAF. The flow varies from year to year. The maximum was 186 MAF in 1959-60 and the minimum 97.74 MAF in 2001-02. The flow varies re-markedly during the Kharif and Rabi seasons also. Kharif inflows average 113.43 MAF or nearly five times the Rabi inflows of 24.91 MAF. On the basis of the Rim Station measurements the average annual discharges of Western Rivers are given in Box-3. The Indus represents about 65 percent of the total mean flow.

BOX-3 ANNUAL AVERAGE DISCHARGE OF WESTERN RIVERS (MAF)	DISCHARGE				
	KHARIF	**RABI**	**TOTAL**	**MIN**	**MAX**
INDUS AT KALABAGH	74.70	15.08	89.78	63.19	120.09
JHELUM AT MANGLA	17.45	5.14	22.59	16.32	31.65
CHENAB AT MARALA	21.28	4.69	25.97	18.23	35.05
TOTAL (MAF)	113.43	24.91	138.34	97.74	186.79

Average monthly flows for post Tarbela period, for Indus, Chenab & Jhelum Rivers are shown in Fig 1 to 3.



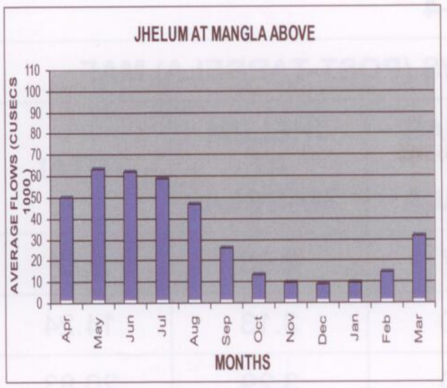


FIG-2

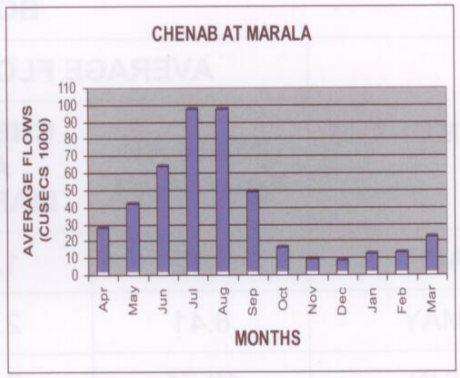


FIG-3

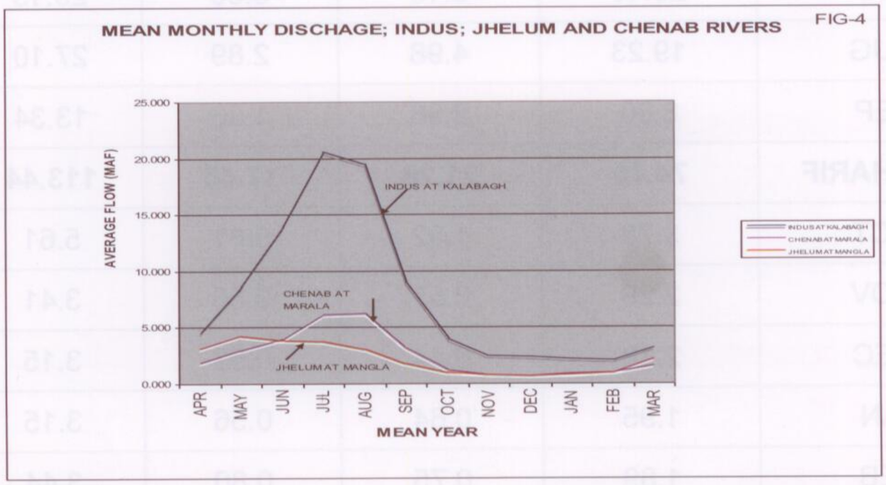


FIG-4

There is considerable month to month variation in discharges of the rivers. During winter months (Rabi season) the flows in the rivers are minimum. The discharge in the river Chenab ranges from a few thousand cusecs in winter to hundred of thousands cusecs during monsoon. Based on historic data of Post-Tarbela period, the average annual inflow of this river, at the rim-station, amounts to 25.97 MAF. The flow varies from month to month and year to year.

Hydrographs of the three rivers are illustrated in Fig-4. Average monthly discharges are given in Box-4. The Indus is more highly peaked than the other two Rivers about 67 MAF or 72 percent of the mean flow on the Indus, occurs in the four months June to September. Flows in the Indus also vary proportionately much less from year to year than do those in Jhelum & Chenab. The Post-Tarbela period range is from 75 to 120 percent below and above the mean.

BOX-4				
MONTHS	**AVERAGE FLOWS (POST-TARBELA) MAF**			
	INDUS AT KALABAGH	**CHENAB AT MARALA**	**JHELUM AT MANGLA**	**TOTAL**
APR	4.12	1.67	2.98	8.77
MAY	8.41	2.70	3.13	14.24
JUN	13.74	3.80	3.29	20.83
JUL	20.40	5.15	3.60	29.15
AUG	19.23	4.98	2.89	27.10
SEP	8.80	2.98	1.56	13.34
KHARIF	**74.70**	**21.28**	**17.45**	**113.44**
OCT	3.78	1.02	0.81	5.61
NOV	2.29	0.57	0.55	3.41
DEC	2.18	0.44	0.53	3.15
JAN	1.95	0.64	0.56	3.15
FEB	1.89	0.75	0.80	3.44
MAR	2.99	1.27	1.90	6.16
RABI	**15.08**	**4.69**	**5.15**	**24.91**
TOTAL	**89.78**	**25.97**	**22.60**	**138.35**

2.1. Surface Water Potential

In terms of the quantum of surface water resources the flows of the Western Rivers available to Pakistan are the most significant. The meager and highly variable flow of all other streams, offer only a limited potential for adding to the stock of water.

The annual surface water inflows at rim stations of the Indus, Jhelum & Chenab, the canal diversions and the outflows to the Sea, following the completion of Tarbela Dam are given in Table -1.

TABLE-1

RIM STATION INFLOWS, DIVERSION TO CANALS AND OUTFLOWS TO SEA – MAF

YEAR	RIM STATION INFLOW	DIVERSION TO CANALS	OUT FLOW TO SEA
1976-77	135.37	99.29	69.08
1977-78	127.46	105.18	30.39
1978-79	163.48	99.14	80.59
1979-80	131.99	107.58	29.81
1980-81	136.39	109.91	20.10
1981-82	140.61	104.37	33.79
1982-83	122.37	105.81	9.68
1983-84	149.95	103.03	45.91
1984-85	134.93	103.61	29.55
1985-86	117.69	98.84	10.98
1986-87	146.65	108.35	26.90
1987-88	141.07	111.63	17.53
1988-89	161.41	107.62	52.86
1989-90	131.32	104.59	17.22
1990-91	166.12	112.26	42.34
1991-92	172.10	112.48	53.29
1992-93	169.69	103.92	81.49
1993-94	127.46	110.59	29.11
1994-95	165.81	97.47	91.82
1995-96	158.86	105.36	62.76
1996-97	161.24	114.10	45.40

1997-98	142.25	106.16	20.79
1998-99	149.55	113.70	35.15
1999-00	129.56	109.71	8.83
2000-01	102.89	89.21	0.77
2001-02	97.16	82.63	1.93
2002-03	118.03	96.45	2.37
2003-04	137.93	106.11	20.19
2004-05	112.52	90.78	0.29
2005-06	145.13	109.44	24.54
2006-07	142.67	102.66	21.72
2007-08	126.08	107.47	15.84
2008-09	118.48	100.05	5.82
2009-10	120.30	101.93	4.07
2010-11	157.22	97.22	54.53
2011-12	118.66	100.98	14.12
2012-13	117.23	95.62	6.01
AVERAGE	138.35	103.66	30.20

This Table brings out that out of the average inflow of 138.35 MAF, 103.66 MAF or 75% is diverted annually into the Irrigation System and 30.20 MAF flows out to the Sea un-utilized.

Season wise the situation is that during Rabi all the natural river flows are captured, and the diversions are augmented from the storage release. The out flow to the Sea during this season is negligible. During Kharif, however, the river flows exceed the diversion by highly variably amounts and end up in the Sea.

The water out-flowing to the Sea (Table-I), amounting to 30.20 MAF thus represents a potential source for the future development of the water resources. A year-wise picture of escapages below Kotri Barrage is shown in Plate-1.

2.2 WATER AVAILABILITY FOR FURTHER DEVELOPMENT

a) INDIAN RIGHT ON WESTERN RIVERS

The consumptive uses for agriculture have been allowed under Article-III of the Indus Waters Treaty 1960 and further elaborated in Annex-C of the Treaty. Accordingly, India can develop a maximum irrigation cropped area, to the extent of 701,000 acres. So far India has reportedly developed a new area of 166,000 acres whereas 535,000 acres of new area can possibly be developed in small patches due to its topography.

Water requirement for possible 535,000 acres cropped area, in India on Western Rivers would be about 2 MAF, as shown below:-

ESTIMATED INDIAN WITHDRAWALS ON WESTERN RIVERS AS PERMITTED UNDER ARTICLE III OF 1960 WATER TREATY

i)	Maximum Permissible Irrigated Cropped Area	701,000 Acres
ii)	Area Already Developed by India	166,000 Acres (a)
iii)	Balance Area To Be Developed (i – ii)	535,000 Acres
iv)	Crop Water Requirement For Balance Area @ 3.68 Acre Feet/acre (b)	2.0 MAF

a. On the Basis of information obtained from Pakistan Commission for Indus Waters.

b. On the basis of crop Consumptive Use requirement of Chashma Right Bank Canal.

b) MINIMUM ESCAPAGE TO SEA DOWNSTREAM KOTRI

Water Apportionment Accord of the waters of the INDUS RIVER SYSTEM , between the four provinces of Pakistan was signed at Karachi on March 16, 1991. Para 7 of the Water Accord reads as under;-

"The need for certain minimum escapes to Sea, below Kotri, to Check Sea Intrusion was recognized. Sindh held the view, that the optimum level was 10 MAF, which was discussed at length, while other studies indicated lower/higher figures. It was, therefore, decided that further

studies would be undertaken to establish the minimal escapage needs downstream Kotri".

- As a part of the studies recognized in Para-7, the Government of Pakistan (M.O.W&P; Chief Engineering Adviser, Federal Flood Commission) arranged the following two studies through International consultants;-

i) (STUDY – I October 2005)

Study on Water Escapages Downstream Kotri Barrage to Check Seawater Intrusion .

ii) (STUDY-II November 2005)

Study on Water Escapages Downstream of Kotri Barrage to Address Environmental Concerns.

c) RECOMMENDATIONS BY INTERNATIONAL PANEL OF EXPERTS (IPOE)

Based on the review of the above studies carried out by joint ventures of local and foreign consultants IPOE identified the needs for water escapages below Kotri Barrage to:

- Check salinity & encroachment in the river aquifer and coastal zone;
- Provide coastal stability;
- Ensure a sustainable enviornment;
- Maintain fisheries;
- Prevent salinity accumulation; and
- Provide water for reverine forests, riverine agriculture, pollution control and drinking water supply.

To meet these requirements, the IPOE recommended the following releases (Box-5) downstream from Kotri Barrage.

BOX-5
KOTRI WATER RELEASES REQUIREMENT

PERIOD	WATER RELEASES REQUIREMENT (MAF)		
	Normal[1] Minimum	Average High[2] Flow Period	Sub-Total
Apr	0.300	-	0.300
May	0.300	-	0.300
Jun	0.300	-	0.300
Jul	0.300	2.500	2.800
Aug	0.300	2.500	2.800
Sep	0.300	-	0.300
K-total	1.800	5.00	6.800
Oct	0.300	-	0.300
Nov	0.300	-	0.300
Dec	0.300	-	0.300
Jan	0.300	-	0.300
Feb	0.300	-	0.300
Mar	0.300	-	0.300
R-total	1.800	-	1.800
Annual Total	3.600	5.000	8.600

[1] An escapage of 5,000 cfs throughout the year to check sea water intrusion, accommodate the need for fisheries and environmental sustainability and maintain the river channel. In a dry year, the above amounts can be proportionately reduced in relation to the reductions in the irrigation water supply.

[2] A total volume of 25 MAF in any 5-year period (an annual equivalent of 5 MAF) to be released in a concentrated way as flood flow (Kharif period), to be adjusted according to the storage in the reservoir (s) and the volume discharged in the four previous years. These flood flows recommended by the IPOE are required for;

- Deposition of Sediment on coast and delta area to stop the coastal erosion
- Keeping the river morphology in good condition
- Sustainable mangrove growth.

*: Indus flows below Kotri vary widely, seasonally as well as yearly. Its discharge drops sharply in winter. The above flows below Kotri can only be maintained through mega storage dams.

PARA-7 OF WAA STRESSES THE NEED FOR CERTAIN MINIMUM ESCAPAGES BELOW KOTRI, BUT WHERE FROM 8.6 MAF OF ESTIMATED WATER WILL COME, IS NOT GIVEN. IN FACT THE ACCORD DISTRIBUTES NOT ONLY THE PRESENT BUT ALSO THE FUTURE SUPPLY TO THE SYSTEM. THERE IS NO MENTION OF WATER REQUIRED BELOW KOTRI. ANY SUCH REQUIREMENTS HAVE TO BE MET FROM THE STORAGE AT KALABAGH DAM WHICH MUST BE CONSTRUCTED AT THE EARLIEST.

2.3 POTENTIAL FOR DEVELOPMENT (Table-1)

Total escapage below Kotri, over the past 38 year (1976-2014) has averaged 30.20 MAF. A part of these escapages, which are presently running to the Sea un-used shall be utilized to provide irrigation to new lands to meet Rabi and the early and late Kharif requirements.

BOX-6
WATER AVAILABILITY ON DOWN STREAM APPROACH
(1976-2003)

Sr. #		WAPDA
1	Post Tarbela (1976-77 to 2001-14) Escapage below Kotri (average)	30.20
2	**Possible reduction**	
2.1	Indian uses on Western rivers	2.0
2.2	Possible uses on Kabul river in Afghanistan	0.5
2.3	Kotri Outflow	8.65
2.4	Requirement of Projects under construction	7.8[1]
3	Total reductions	19.45
4	Net available for further development	10.75

[1] Including allocation of 2.50 for Greater Thal 1.2 for Kachhi and 1.1 MAF for Rainee and 0.1 MAF for Pat Feeder Canal & 2.9 for Raised Mangla.

3. SURFACE WATER DEVELOPMENT

Water has a pivotal position in all development activities for its enormous importance in food security, livelihood, environment, economics, power generation and in fact life itself. The water situation in our country is facing problems. The increasing, population pressure and industrialization, has placed a great demand of water. With the pressure of population growth, per capita surface water availability of Pakistan is reducing progressively. It can be seen from Box-7 that availability of water in Pakistan has alarmingly declined from 5250 cubic meters per capita in 1951 to about 1038 cubic meter in 2010. It will further reduce to 809 M^3 in 2025, and according to the Falkenmark indicator the reduced water availability will hamper the health and well being of humans.

BOX-7

PER CAPITA WATER AVAILABILITY

YEAR	POPULATION (Million)	PER CAPITA WATER AVAILABILITY (M^3)	DECREASING % AGE
1951	34	5250	100 %
1961	43	4159	79 %
1971	63	2838	54 %
1981	84	2129	41 %
1991	111	1611	31 %
2001	143	1250	24 %
2010	172	1038	20 %
2020	204	877	17 %
2025	221	809	15 %

Per capita water availability less than 1000 M^3 shows a water scarce country

Now see the increasing use of water (Box-8 below)

BOX-8

AVERAGE ANNUAL CANAL DIVERSIONS (MAF) IN FOUR PROVINCES OF PAKISTAN

	PERIODS	CANAL DIVERSIONS	INCREASING % AGE
1.	At Independence (1947)	67.0	(100 %)
2.	Prior to signing of the Indus Waters Treaty (1960)	83.0	(124 %)
3.	Prior to completion of Mangla Dam (1967)	87.7	(131 %)
4.	Prior to commissioning of Tarbela Dam (1975)	96.37	(144 %)
5.	After signing of Water Apportionment Accord i.e. present position (2012-13 position)	105.35	(157 %)
6.	Ultimate position as per Water Apportionment Accord (para-2)	117.35	(175 %)

As population growth is rising rapidly, stress on Pakistan's Water Resources is intensifying. All agree that reduced access to fresh water will lead to a cascading set of consequences including impaired food production, the loss of livelihood security and increased economic and geopolitical tensions and instabilities. Over time, these effects will have a profound impact on security throughout Pakistan. It is essential that concentrated efforts be made to conserve water, develop the available water resources to the optimum. It is, therefore, essential that this finite source is judiciously used and the scarce fresh water is not allowed to flow to the sea except that needed for ecological requirements.

3.1 CONSTRUCTION OF DAMS ON FIRST PRIORITY

The development of river water resources has remained stagnant after Completion of Tarbela Dam in 1976. There are now pressing reasons which necessitate the construction of dams ON FIRST PRIORITY without any further delay.

- **Seasonal Water Availability**

In Pakistan more than 75% water for storage is available only during three summer months starting from July to early September (Kharif). This water cannot unfortunately be used and escapes to sea. Our cropping pattern is such that the water availability is scarce for the Rabi and early Kharif crops. Accordingly there is an urgent need for reservoirs to store the available water and transfer the same from high flow to low flow period.

BOX-9

POST-TARBELA BELOW KOTRI (MAF)

YEAR	KHARIF	RABI	TOTAL	YEAR	KHARIF	RABI	TOTAL
1976-77	64.05	5.03	69.08	1995-96	61.05	1.71	62.76
1977-78	29.00	1.39	30.39	1996-97	44.72	0.68	45.40
1978-79	75.03	5.56	80.59	1997-98	16.98	3.81	20.79
1979-80	29.38	0.43	29.81	1998-99	32.50	2.65	35.15
1980-81	18.74	1.36	20.10	1999-2000	8.72	0.11	8.86
1981-82	33.53	0.26	33.79	2000-01	0.77	0.00	0.77
1982-83	9.43	0.25	9.68	2001-02	1.92	0.00	1.92
1983-84	43.81	2.09	45.91	2002-03	2.32	0.05	2.37
1984-85	28.64	0.91	29.55	2003-04	20.12	0.07	20.19
1985-86	10.93	0.04	10.98	2004-05	0.21	0.08	0.29
1986-87	26.72	0.18	26.90	2005-06	24.40	0.14	24.54
1987-88	17.45	0.08	17.53	2006-07	20.16	4.56	21.72
1988-89	44.17	8.69	52.86	2007-08	15.77	0.06	15.84
1989-90	16.85	0.37	17.22	2008-09	5.68	0.15	5.82
1990-91	38.19	4.14	42.34	2009-10	4.00	0.07	4.07
1991-92	50.05	3.24	53.29	2010-11	50.50	4.03	54.53
1992-93	69.19	12.30	81.49	2011-12	11.81	2.31	14.12
1993-94	28.47	0.64	29.11	2012-13	5.30	0.71	6.01
1994-95	88.18	3.65	91.83				
MEAN					**28.34**	**1.86**	**30.20**

The annual system average out flows to Sea, below Kotri in the Post-Tarbela period (1976-2013), is about 30.20 MAF (i.e. Kharif 28.34 and Rabi 1.86). From Box-9 it is clear that surplus water for storage is now available during about 70 days of Kharif season only. This aspect needs urgent attention at the national level for storage of water at the earliest possible.

- **Future Agricultural Development – 30 % Area lying uncultivated.**

With a vast resource of culturable land, it would be unfortunate if we fail to achieve self sufficiency, in food for ensuring continued economic growth. At present average irrigation diversions are about 105 MAF/year.

To meet the requirement of growing population and sustain development, there is a need to increase the agriculture significantly. The total culturable area (fit for Agriculture) in Pakistan is 76.6 million acres. The presently cultivated area including agriculture and barani is about 54.5 million acres (70% of the total). Additional area which can be brought under agriculture in Pakistan is 22.5 million acres (30% of the total). The agriculture demand will require larger water availability to feed the nation and sustain economic development.

- **DEPLETION OF ONLINE STORAGES**

The present live storage capacity of Tarbela, Mangla and Chashma reservoirs has reduced by about 5.71 MAF (2013) which is 31% of total (live) storage capacity. Box-10 shows the live storage and live storage lost due to sedimentation on the three reservoirs. If no reservoir is built by the year 2025, water shortages due to sedimentation will increase to 5.71 MAF i.e. 31% of the total live storage capacity. Accordingly there is an urgent need to replace the lost storage by constructing at least one large reservoir just to restore and sustain the 1976 position. For bringing additional lands under agriculture another storage would be required.

BOX-10

LIVE STORAGE LOSS OF RESERVOIRS

RESERVOIR	LIVE STORAGE CAPACITY (MAF)	LIVE STORAGE LOSS BY THE YEAR 2013 (MAF)	LIVE STORAGE LOSS BY YEAR 2025 (PROJECTED),(MAF)
TARBELA (1976)	9.692	3.111	4.093 (42 %)
CHASHMA (1971)	0.717	0.428	0.550 (77 %)
MANGLA (1967)	5.34 + 2.90 (2013)	0.845	1.065 (13 %)
TOTAL	15.74 + 2.90	4.384	5.709 (31 %)

Ref. WAPDA Annual Sedimentation Reports

- **WATER APPORTIONMENT ACCORD (1991) – STRESS ON CONSTRUCTION OF DAMS**

According to Water Apportionment Accord (para 2) Water, allocation of 117.35 MAF has been made. However, actual water diversion of only 105.4 MAF per year on average is possible at present. To utilize additional allocation of 11.95 MAF, there is need for development of reservoirs.

The drafters of the Water Accord must have taken into account (and rightly so) the inherent requirements of additional storages without which distribution of water that was not available does not make sense. The Water Accord in fact stresses the need for more storages so that the aspirations of the provinces could be practically implemented and our requirements of food and fibre are ensured.

a) ADDITIONAL ADVANTAGES OF DAMS - FLOOD MITIGATION

In Pakistan very often there are major floods which create havoc in terms of human lives, standing crops, road infrastructure, flood protection structures and loss of property worth billions of dollars. To reduce flood damages, to regulate river flows, and to avoid wastages of huge amounts of water, construction of dams/reservoirs is urgently required in the country.

b) ADDITIONAL ADVANTAGE OF DAMS - POLLUTION FREE CHEAP HYDROPOWER

In mid seventies, the hydel thermal proportion in WAPDA System was 70% and 30% respectively. Due to non-implementation of hydropower projects and installing only thermal power stations during the last two decades, the above ratio has reversed. The cost of Power supply from Independent Power Producers (IPPs) is very high whereas Mangla Power Station cost is Rs. 0.20/unit and Tarbela cost is Rs 0.30/unit. The access to energy has now become expensive. Therefore, in order to keep the 'prices' in reasonable limits and to keep our Industry competitive with world market we must install hydel power stations.

Pakistan has about 59000 MW identified hydropower potential (PLATE-II), out of which only 6600 MW of Hydel potential has been harnessed which is only about 10% of the total Hydel potential. Hydel power is an inexpensive, dependable, indigenous and environmentally friendly source of energy. It is essential that its share in overall electricity generation for sustainable economic development for Pakistan must be increased.

There is acute shortage of energy. We urgently need cheap electricity to supply to thousands of villages which are still devoid of this essential modern day need, for poverty alleviation and to sustain our agro based economy.

c) **ENERGY IS THE ENGINE OF ECONOMY**

Major advantages accruing from the dams and their additional benefits in 3 fields are listed below:-

DAM

WATER	ENERGY	FLOOD MITIGATION SAVING OF DAMAGES
1 Increased agriculture	1 Industrial Development	1 Damage to crops
2 All food crops	2 Increased work potential	2 Damage to land
3 All Kinds of trees & plants	3 Job Opportunities	3 Damage to flood bunds
4 Wood industry/Jobs	4 Export earnings	4 Damage to Barrage Structures
5 Animal wealth/meat production	5 Increased transport activities	5 Reduction in displaced persons
6 Fish production	6 Improvement of foreign relations	6 Reduction in rehabilitation effort
7 Increase ground recharge	7 Improvement of human life	7 Reduction in human & animal losses.
8 Environmental improvement	8 Increased economic activities	8 Increased geopolitical stability

In fact the advantages are countless in numerous sectors of economy.

d) Dams Carry Higher Priority than Motorways and Metro Bus Projects

- Dams deserve to be placed on 1st priority due to their Gigantic and innumerable advantages. The priority of Motorways and Metro-Bus Projects is far below dams. Pakistan has Grand Trunk Road as well as Railway lines connecting all cities from Peshawar in the North to Karachi in the South. These are serving our needs and constructing a 3rd alternative will damage their utility.
- Wisdom demands 1st priority for dams. Differences do occur in the construction of dams, but concerted efforts must continue to sort out such differences till the dams are completed.
- The Creator of this Universe says ماء منقالخ يشء لكل"ڸ" . We have created everything from water. Is this not enough for us to give 1st priority to dams for storage of water and leave Motorways & Metro-bus projects to the second priority?

3.2 FUTURE STORAGE DAMS

To meet our Water & Power needs, large storages are urgently required. On Indus we have three sites where storage of water is possible. Unfortunately there is no storage site on the Upper reaches of River Chenab and Jhelum available to Pakistan. Box-11 shows the status and Technical Issues of future dams on the River Indus.

BOX-11

STATUS & TECHNICAL ISSUES OF FUTURE DAMS

	PROPOSED DAM		
	KALABAGH	**BASHA**	**AKHORI**
Water Availability (MAF)/year	90	50	14
Live Storage (MAF)	6.10	6.4	6.00
Power Potential (MW)	3600	4500	600
Logistic Problems	Least	More	Less
Power Dispersal	Nearest	Very Difficult	Nearest
Constructability	Easy ECRD	Difficult RCC	Easy ECRD
Start of Construction	2016	2020	2025

Water Availability for Irrigation	Early	Late	Early
Seismicity	Less	More	Less
Environmental: - Persons Displaced - Roads Affected	 120,000 Minor	 24,000 KKH-Submerges 110 Km Up-gradation 320 Km	 49,300 97 Km
Land Submergence (Acres)	110,200	32000	59,200

Small size storages are also possible on tributaries of the Indus which can benefit local areas but cannot contribute to the integrated system.

i) Kalabagh Dam Project: Kalabagh is the lower most storage site on River Indus before it debouches onto the plains. The feasibility, detailed design and tender documents for this project are ready since 1988. This Project can be taken up for construction almost immediately. It would take about 6 years to build and could be completed by 2021.

ii) Basha Diamer Dam Project: Basha Diamer Dam is located 314 KM upstream of Tarbela dam on River Indus and 160 Km downstream of Gilgit. Its Studies are completed and it is ready for construction since 2010. Active construction can be started in the year 2020. It would take seven to eight years to complete.

iii) Akhori Dam Project. It is an off channel storage project taking surplus water from Tarbela reservoir. The Feasibility Studies of the scheme have been completed in August 2005. After the detailed investigations and completion of design and contract documents, the project may start in 2025 and likely to be completed in 2031. It may however, be mentioned that there is only a small hydel potential (600 MW) at this dam.

It would be worthwhile to take a dispassionate and deeper look at the mothballed, Kalabagh Dam Project, which has remained in political limbo since 1988. Now besides the recurrence of flooding, the annual recurring irrigation water crisis (during late Rabi and early Kharif) and shortage of electrical power call for REVISITING THE KALABAGH DAM which is designed for a live storage of 6.1 MAF and for the hydropower generation of 3600 MW.

4.0 KALABAGH DAM PROJECT – FIRST PRIORITY

4.1 STATUS AND TECHNICAL DATA (Box-11)

Kalabagh Dam Project site is located 210 Km downstream of Tarbela Dam and 26 Km upstream of Jinnah Barrage on the River Indus. Preliminary feasibility report of Kalabagh Dam Project was prepared by Tipton and Hill a firm of USA in the year 1956. Feasibility report of the project was drawn by M/s ACE Ltd; during 1975. Detailed designs and tender documents of this project were prepared during 1988 by Kalabagh Consultants a joint venture of HARZA of USA, Binnie & Partners of England, Preece Cardio & Rider of England, M/s NESPAK and ACE Ltd; from Pakistan.

The project envisages construction of 260 ft. high rock-fill dam. With its maximum retention level at 915 ft, it will create a reservoir with usable storage of 6.1 MAF. The project has two spillways on the right bank for disposal of flood water. In the event of the highest probable flood, these spillways will have a discharge capacity of over 2 million cusecs. On the left bank is the power house which will be connected to twelve conduits each 36 ft. in diameter, with ultimate generation capacity of 3600 MW. (Project Layout Plan on PLATE-III).

BOX-12
PRINCIPAL PROJECT DATA

Indus River at Site	
Catchment Area	110,500 sq. miles
Maximum observed flood	1,200,000 cfs
Reservoir	
Gross storage	7.9 MAF
Live storage	6.1 MAF
Dead storage	1.8 MAF
Retention level	915 ft. SPD
Minimum reservoir level	825 ft. SPD
Area at retention level	164 sq. mile
Main Dam	
Crest elevation	940 ft. SPD
Crest width	50 ft.
Maximum height (above river bed) beded bed)	260 ft.
Length (overall)	4375 Ft.
Overflow Spillway	
Sill level	860 ft. SPD
PMF discharge	1,070,000 cfs
Orifice Spillway	
Sill level	785 ft. SPD
PMF discharge	980,000 cfs
Installed Capacity	
Initial Capacity	3600 MW
COST	U.S. $ 6.10 Million (2012)

i) Construction of the urgently needed Kalabagh Dam remains hanging fire since 1988 for want of consensus among the 4 Provinces of Pakistan. In view of the chronic logjam over the Kalabagh Dam for several decades with the claimed resolutions of three Provincial Assemblies of Sindh, KPK, and Balochistan, albeit lukewarm in the later case, recently with no fresh resolution, it is of vital importance to search again for an out-of-the-box solution. To begin with we need to carefully look into the major concerns.

ii) Sindh fears that;

- The Kalabagh dam could allow the upstream provinces to withdraw water from the reservoir through High Level Outlets.
- Cultivation in Sindh riveraine area would be adversely affected.

4.2 HIGH LEVEL OUTLET WORKS

THE DESK STUDY (CARRIED OUT BY PROJECT CONSULTANTS) HAS CONFIRMED THAT;-

The High Level Outlet Works (HLOW) water releases would have to be conveyed through tunnels over long distances, because of the hilly terrain around the Kalabagh Reservoir. Serious geotechnical problems are to be encountered on some reaches of the tunnel routes.

The right HLOW involves large diameter tunneling through 15.5 miles of hill ranges –10 miles through Tattak and 5.5 miles through Khisor. The first 7 miles of tunneling would be in the Nagri formation consisting of interbedded sand stone and clay stone, with dips steepening from 4° to 40°. Highly disturbed geologic conditions would be encountered in the area of the Kalabagh fault system. The tunnel alignment would cross at least two major regional faults in this reach, the Dhinegot fault at mile 2.75 and the Ainwan fault at mile 4.5. The gouge zone in the former is about 150 to 300 ft. wide. The Ainwan fault is about 100 to 150 ft. wide with steep dips. Further away, the Kalabagh fault zone would be encountered at mile 7.5. This is a highly controlled zone, extending more than 700 ft. Tunnelling through such formations will be both difficult and very costly. The last 1.5 miles route would pass through lime stone, calcareous sandstone, rock salt and marl of the saline series.

The left HLOW tunnel route passes through comparatively better terrain. The first 6 miles or so are in the Nagri formation of Siwaliks consisting of interbedded sand stone and clay stone. Dips generally increase from 4° to 15° in the downstream direction along the tunnel alignment. The remaining route is in Chinjil, Kamlials and Murree formations. The Chinjil formation consists of about 70% clay stones.

The Kamlial and Murree formations mostly comprise sand stone interbedded with red shale and pseudoconglomerates.

The conveyance works will not only be excessively costly but also present serious problems of tunneling in disturbed zones. Beyond the hill ranges the right HLOW canal would run into numerous cross-drainage works including a mile and a half long aqueduct over Kurram River. The left HLOW would require a major crossing over or under Sanhi Nala near the dam, besides another one at Goran Nala. The order of magnitude of only tunneling cost would be more than 100,000 million rupees (1987).

The above description of ground realities leads to the following conclusion.

- **The High level outlet tunnels would have to pass through zones where the geological conditions are very unfavourable. It was concluded that it would be difficult to construct the tunnels, which would be vulnerable to future tectonic disturbance, and that the development is not feasible by normally accepted standards. Other possible ways of irrigating these high level areas may be preferable.**
- **Use of the outlets would incur a substantial energy penalty and over 1140 GWh/year would be lost on average.**
- **KALABAGH DAM PROJECT AS PER ITS DESIGN (1988) DOES NOT INCLUDE ANY CANAL OUTLETS.**

4.3 SINDH RIVERAINE AREA

The Sindh Riveraine Area (SRA) is owned by the Government and present cultivable land is let out on lease to farmers for crop cultivation. However, these leases are directly under the control of influential families, who have land adjacent to river embankments.

RIVERAINE AREA (KATCHA AREA) SINDH*

GUDDU --- SUKKUR ---- KOTRI TO SEA

- Width — 4 Miles to 14 Miles
- Length — 568 Miles

		AREA (Acres)	**%**
-	Forest	586,846	35
-	Cultivable	534,898	32
-	Un Cultivable Sand Bars, Under Water)	553,180	33
	TOTAL	**1674,924**	

- Private Tubewells in operation	5700 (1987)

*: Source: KDB Project Supplement Document Volume-IV)

Kalabagh Reservoir capacity (6.1 MAF) is too low as compared to the average annual inflow of the river (90 MAF) at Kalabagh and therefore it will not significantly affect the useful flood spills in the riveraine tract of Sindh.

- Assuming 20% loss in the river from Kalabagh to Kotri Barrage during flood season the equivalent of 6.1 MAF at Kalabagh is 4.88 MAF at Kotri. In the 38 post-Tarbela years, except 4 years, the escapage downstream Kotri Barrage, during Kharif is always more than 4.88 MAF (Box-8).
- The critical flood peak to inundate all the potential Sailaba cultivated area is about 300,000 cusecs which would occur during most of the years.

4.4 APPREHENSIONS AND REALITIES

A number of concerns on the proposed Kalabagh Dam Project have been shown by various quarters in the Provinces of KPK and Sindh. In the following paragraphs, these concerns are briefly discussed along with the factual position established through various studies.

	APPREHENSIONS	
KPK	Historic flooding of Peshawar Valley including Nowshera town would be aggravated in the event of recurrence of 1929 record flood.	Back water effect of Run-of-River from Kalabagh lake would end at Attock, about 35 km downstream of Nowshera. Storage at Tarbela Dam can also be used for flood mitigation. Recurrence of record flood of August, 1929 would not affect water level at Nowshera
	• Drainage of Mardan, Pabbi and Swabi plains would be adversely affected by the reservoir thus creating waterlogging and salinity. • Operation of Mardan	Lowest ground levels at Mardan Pubbi and Swabi area are 970, 960 and 1000 ft. (AMSL) respectively as compared to the maximum conservation level of 915' (AMSL)

	SCARP would be adversely affected	
	• Fertile cultivable land would be submerged. • Population Dislocation. • Resettlement of Affected Population.	• Kalabagh (Run-of-River) reservoir will extend 150 km (upto Attock), up the Indus river. • Compensation shall be paid to all the affectees for their properties like land, trees, buildings etc at market prices. • The affected families will be resettled in various towns.
SINDH	2. There would be no surplus water to fill Kalabagh reservoir. 3. The project would convert Sindh into a desert. 4. High level outlets would be used to divert water from the reservoir. 5. Cultivation in riveraine (Sailaba) areas would be adversely affected. 6. Sea Water intrusion in Indus estuary would accentuate. 7. Mangrove forests, which are already threatened, would be	• After allowing for obligatory abstraction as much as 29.26 MAF will be available for storage. • With KBD Project, Sindh, like other provinces, will get more water. • Kalabagh Project study did not propose any High Level Canals from the reservoir neither on the left nor on the right flank. • Flood peaks in excess of 300,000 cusecs would still be coming which can soak Sailaba area. • The main aquifer unit is already historically saline. Any reduction in river flow will be of no consequence to the main aquifer. • All the mangroves comprise salt tolerant Avasanis

	further affected adversely.	Marine species in the region. They sustain Sea water.
	8. Fish production and below Kotri would be adversely affected.	• No study has conclusively proved that sea water fish production would be affected by the construction of Kalabagh Dam Project.

5.0 KALABAGH DAM – VITAL FOR PAKISTAN

There is a growing shortage of water for agriculture because of the silting of the existing storages. Moreover, as much as 30 percent of the total cultivable area of 76.60 M. Acres in Pakistan remains uncultivated, mainly because of lack of irrigation. Hence, there is a consensus that the country needs more water reservoirs.

There are several possible dam sites that could be built, namely, Kalabagh, Diamer-Basha, Akhori, etc. In the case of Diamer-Bhasha dam, KKH would need 5 to 6 years for its up gradation from Abbotabad to Diamer in a length of about 320 Km to make it fit for heavy machinery transport and its raising by about 1000 ft. at Chalas/Basham. Akhori is in its initial phase of planning. Majority of experts are in favour of Kalabagh, the construction of which can be started straightaway. Kalabagh Dam is indispensable for better economic future of the Country. The issue is as to how this objective be achieved.

Lack of trust among the provinces especially between Punjab and Sindh is at the heart of the water issues in Pakistan. All disputes stem from this crisis of no-confidence. Sindh (the lower riparian in this case) feels that it will be deprived of its share of water from Kalabagh Dam Project by Punjab. It feels that because of the historical events its scepticism is justified. Punjab, on the other hand, questions the surpluses' which pass downstream Kotri unused and is insisting that major quantity of this escapage should be stored and put to use. Sindh on the other hand considers the escapage downstream Kotri as essential. The dispute on sharing the water shortages during the past five drought years has further accentuated this crisis of confidence. This lack of trust is the greatest issue in the context of water resources. Similarly, there is varying degree of opposition to Kalabagh Dam project in KPK & Balochistan.

In our country, the issue of building a mega storage dam has been converted into an emotionally charged issue, full of sound and fury. In any mature society, national issues are discussed in a rational manner, keeping in view the supreme interests of the country as a whole. It is proposed that the issue of construction of Kalabagh Dam Project must be discussed in the meetings of CCI in great details. That would surely be a much more desirable scenario for building the Kalabagh Dam. It is hoped that all the provinces will come out in favour of this project.

SUPERIORITY OF KALABAGH DAM

	Kalabagh Dam	Diamer Basha Dam
1	Very suitable location, close to the load centre	Very difficult location
2	High river flows – 90.0 MAF	Low flows – 50.5 MAF
3	Smaller height of Dam – 260 ft	Dam height – 893 ft
4	Longer life due to flushing through low level spillway crest	Shorter life due to high level spillway crest
5	Very easy access to the site	Difficult access to the DB Dam
6	Very economical transmission lines	Very difficult and long transmission lines through difficult mountainous corridors
7	Shallower bed rock	Very deep bed rock
8	Earthquake intensity – light	Earthquake intensity – heavy
9	Construction period - short (6 years)	Construction period - long (10 years)
10	Additional power generation at Tarbela (336 GWh)	No additional power generation
11	Low project cost – (US$ 6.12 billion)	High project cost (US$ 11.2 billion)

9 6.0 KALABAGH DAM – A GOLD MINE FOR PAKISTAN

- Kalabagh Dam Project stands ready for implementation. The list of its benefits is unending, much larger than a gold mine.
- Such suitable dam sites are not available to every country.

- Countries gain strength with the construction of dams (look at the cases of USA, China, India etc). Pakistan is wasting 30 MAF of water by not building dams. No doubt dams provide food and fiber, cheap and abundant power, rapid industrialization and boost of economy in all sectors. Rivers and dams are gifts of God. The Creator of this Universe warns us of fatal consequences if we discard His gifts in the following words.

  وَلَا تَكُونُوا كَالَّذِينَ نَسُوا اللَّهَ فَأَنسَاهُمْ أَنفُسَهُمْ ۚ أُولَٰئِكَ هُمُ
  الْفَاسِقُونَ ١٩

  (Don't become such people who forget the God Almighty, because God then makes them forget their ownselves). Who are the people who forget their own selves - those who do not understand their own benefits, their own interests, their own welfare and the needs of their kith and kin. Certainly we will destroy our own interest and the benefits of the coming generations in case we fail to build dams.

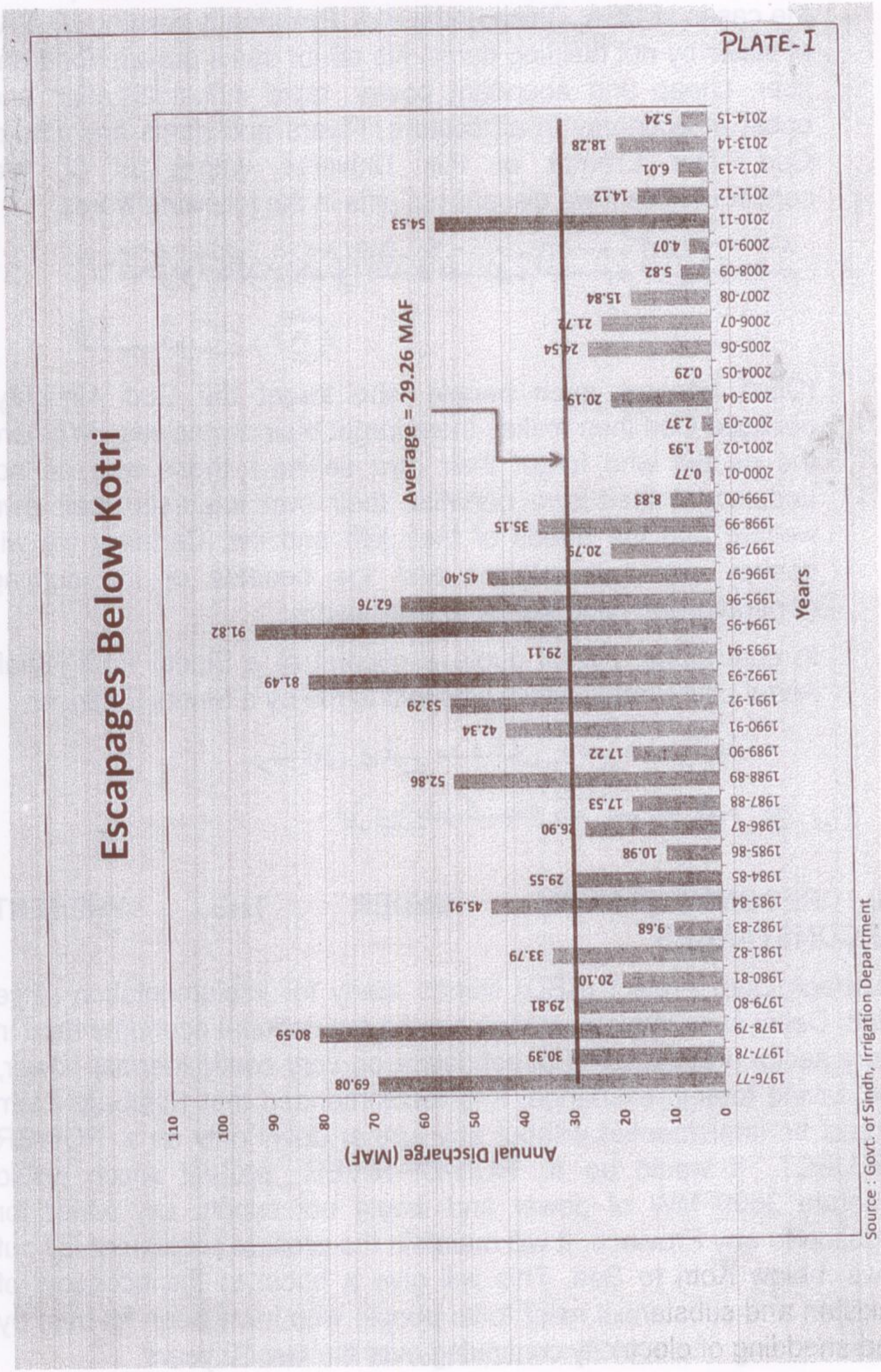
  In concluding, I shall quote a couplet of a Sindhi Poet (Shah Abdul Latif Bhatai) which was told to me by a Sindhi Engineer.

  رب رُسّے تے متھکُںّے نے ھ نہ رایھتہ
  ایڑیڑیسیک جنارک ینم جو کھم ایج راج

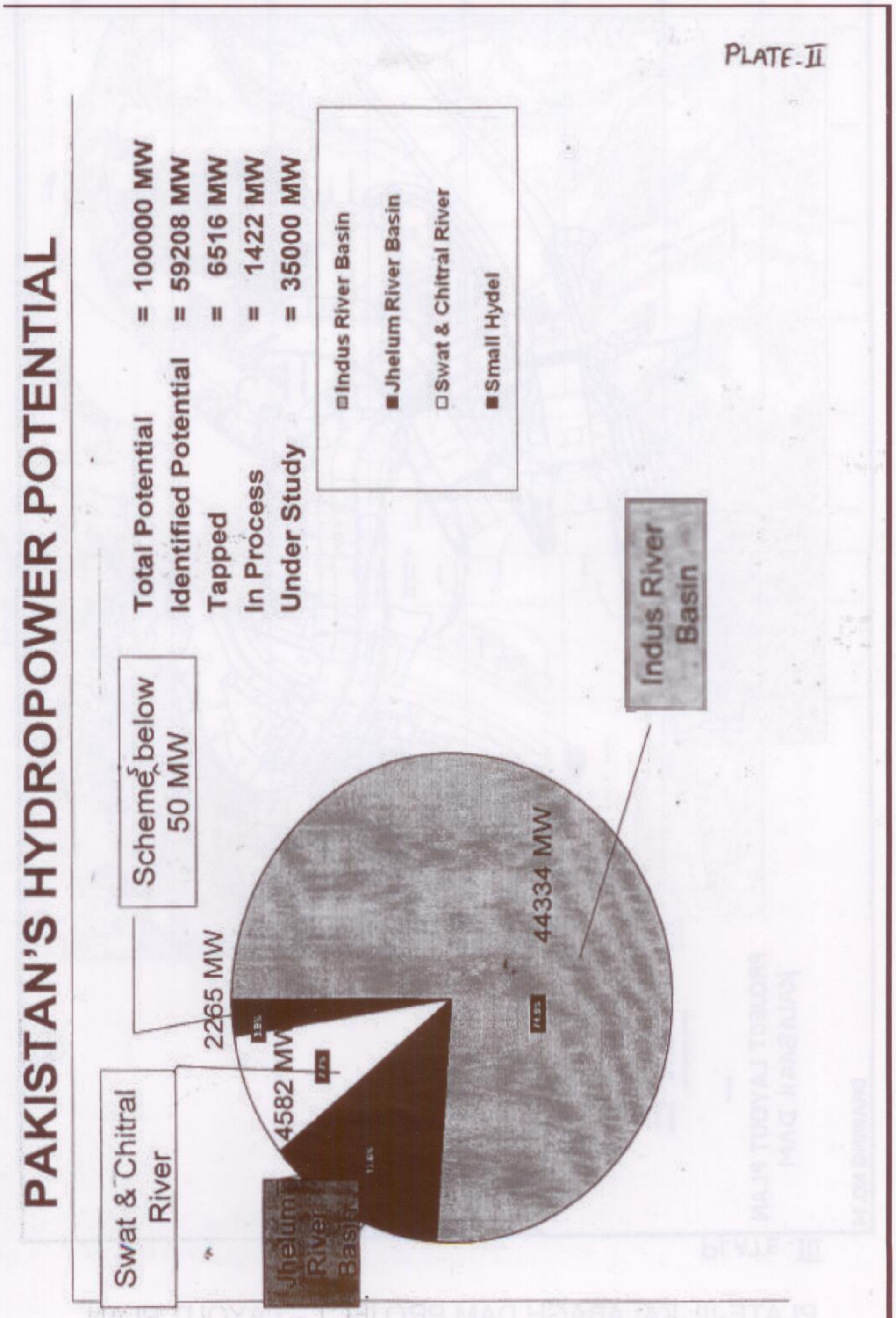
7.0 RECOMMENDATION UNDER THE PRESENT CIRCUMSTANCES

Kalabagh Dam Project (KBD) stands ready for implementation since 1988. Delay in its implementation has hit the national economy hard in every sector. For reducing dependence on very costly thermal power, and saving foreign exchange, it is recommended that Kalabagh Dam Project be implemented without any further delay only as a POWER PROJECT . It would be a RUN-OF-RIVER , project which would generate 3600 MW of power and would not supply any water for irrigation to any Province. It will maintain the present position of full out flows, below Kotri to Sea. This will give a boost to the economy of Pakistan and substantial relief to its people who have been hit hard by load-shedding of electricity continuing over the last 10 years.

11 PLATE-I: ESCAPAGES BELOW KOTRI



12 PLATE-II: PAKISTAN HYDROPOWER POTENTIAL



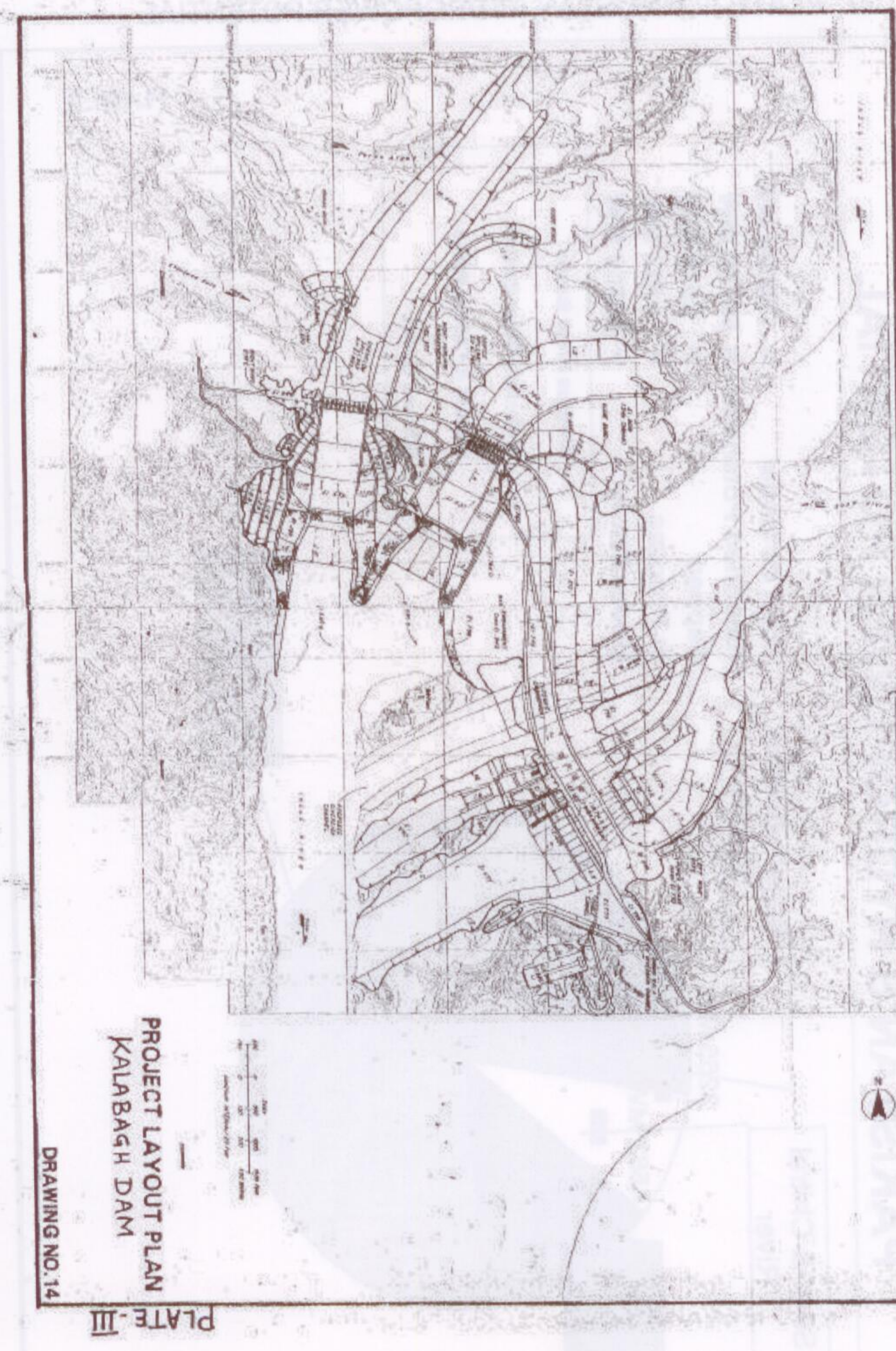


PLATE-III: KALABAGH DAM PROJECT – LAYOUT PLAN

WATER CRISIS AND FUTURE OPTIONS IN PAKSTAN

By

Dr. Muhammad Nawaz Bhutta

ABSTRACT

Pakistan is already one of the most water-stressed countries of the world, a situation which is going to deteriorate into outright water scarcity due to large and expanding population. Water for agriculture will progressively become scarcer due to persistent increases in the competing demand for drinking water, industry and environment. Salt balance in irrigated lands is negative. More salt is being added in the Indus Basin than the quantity of salt that is getting out of the Basin. With the passage of time the soil quality will further deteriorate and crop yields could be seriously affected. For maintaining a favourable salt balance in the root zone of crops, 20% water additional to the crop requirement is needed to flush the salts on continuous basis. Pakistan is fast losing storage capacity of Tarbela, Mangla and Chashma due to siltation. Climate changes, intensifying droughts and floods will have the combined effect of deepening the crisis. The snowfall will occur for a shorter duration and melting will continue for longer period. Snowmelt and supply of water will be available much earlier than the present (prior to Kharif sowing) and may be inadequate for Rabi sowing. Many small glaciers may disappear. With the rise in temperature as a result of climate change, crops will require more water due to excessive evaporation, cattle will consume more water and domestic water consumption would also increase.

Water is crucial for food production. Water scarcity will lead to food scarcity which is a radically different threat because it affects the poor so profoundly. It has been the cause of riots and revolutions. Imported food cannot be relied upon as the era of cheap food is over. It is easier to store water for drought years than store food for such events. Luckily we have water to store and we have sites to store water. Investing in water reservoirs is a key step towards ensuring food security. By far the most effective way of tapering flood peaks and minimizing flood damages and loss of life is flood control through storage reservoirs. To mitigate impact of droughts, it is necessary to build large dams having carry over capacity from wet years to dry years, to build small and medium size dams for local and regional uses and to recharge aquifer. Large dams not only increase the assurance of water availability but they can also generate large amount of electricity which is vital for development of industrial, agricultural and service sectors. Projects ranking highest in technical, economic and environmental viability should be preferred irrespective of any other consideration. The

benefits of existing storages are so well demonstrated that all the provinces keenly contest of every cusec of store water in the existing reservoirs.

To overcome water and power scarcity, and as a short term measure it is recommended that immediate construction work should be started on another large Dam concurrently with Diamir-Bhasha. Long term plan for storing additional 50 MAF (for meeting farmgate requirement of 40MAF by year 2050) water needs to be prepared and implemented starting with the top ranked project.

1 STATUS OF WATER AVAILABILITY

Pakistan is already among one of the most water-stressed countries of the world, a situation which is going to degrade into outright water scarcity due to large and expanding population and demand in other sectors.

Per capita availability of water is about 1200 m^3/year which is less than the threshold of 1700 m^3/year for a water stressed country. The water scarcity indicator is 1000 m^3/person/year which is likely to be reached in 2017. Another water stress indicator applies to river basins having a ratio of withdrawal to long term average annual runoff is above 0.4. In case of Indus Basin system, this ratio is about 0.77.

Per hectare availability of water in the country is less than the world average. The perception that Pakistan is using many times more water in agriculture than other countries is not right. The much talked about water use efficiency in agriculture is not relevant in arid conditions, as 20% excess water is needed to percolate below root zones for keeping a favourable salt balance.

Primary source of fresh water is rainfall, snow and glacier melt. It then transforms into river flows, groundwater and surface storage, evapotranspiration and river outflows into sea. Part of river flows is generated outside the country. Existing and proposed developments on western and eastern rivers outside Pakistan by Afghanistan and India have already impacted water availability and the trend is likely to continue to the disadvantage of Pakistan.

Annual average river inflow measured at rim stations of western rivers is 142 MAF. Khyber Pakhtunkhwa (KP) diverts 5 MAF above rim stations while eastern river runoff within Pakistan averages about 4 MAF. Thus total river flow of Indus Basin on an average is about 151 MAF. Rainfall contribution below rim stations is in addition.

Indus River System inflows vary from 97 MAF to 172 MAF (post storage period of 1967 to 2006). Inflows prior to Indus Water Treaty implementation ranged from 109 MAF to 188 MAF (30 year average for the period 1937 to 1967).

The river outflows for post Tarbela period vary from nil to 95 MAF. On the average annually 35 MAF river water escapes unutilized below Kotri.

There are 14 hill torrent areas with an average potential of 18.6 MAF. Out of this 60 to 70% can be used for the development of 5 million hectares of culturable wasteland lying in the hilly areas of Hazara, Bannu, D.I. Khan, D.G. Khan, Kacchi basin, Kirthar range, Karachi area, Sehwan area, Petaro and vast areas in Balochistan.

The combined contribution of the eastern rivers generated in Pakistan is estimated to vary between 1.5 and 9.67 MAF with an average of 3.99 MAF (based on data of 1976 – 1994). If data of later years is added (which includes four drought years) the average is likely to reduce. A reliable average contribution by eastern rivers can be taken as 3 MAF. This would compensate for the authorized uses by India on western rivers. The total contribution of eastern rivers including flows and spills from Indian storage reservoirs is about 8.4 MAF (based on 11 years data from 1993 to 2004). With the completion of India's Northern Transbasin Link Project spill flows will reduce.

The irrigated area of Indus Basin receives approximately 40 MAF of rainfall annually. Rainfall conservation potential outside irrigated area is approximately 20 MAF.

The groundwater is not an independent source. However it is contributing 40% crop water requirement. The safe yield of groundwater is 53.3 MAF (Punjab 40 MAF; Sindh 10 MAF; KP 2.4 MAF; Balochistan 0.9 MAF). The groundwater potential and use in AJK is very limited as compared to other provinces.

In Balochistan, non-Indus internally generated surface runoff is 12.7 MAF. Out of this 3 MAF is currently being utilized while 9.7 MAF remains unutilized.

2 THE WATER CRISIS

2.1 COMPETING DEMANDS

Water will progressively become scarcer due to persistent increases in the competing demands of various sectors. Municipal water requirement is expected to increase to 11 MAF by 2025 on the basis of 3% annual increase in demand. The industrial water demand is expected to grow at about the same rate to 5.2 MAF in year 2025.

Adequate water would also need to be committed for the conservation of fresh water lakes, delta and coastal eco systems. This is estimated as 2 MAF for the same period.

All these additional water requirements will have to be met out of the water already committed to agriculture which is barely able to sustain the existing population.

2.2 NEGATIVE SALT BALANCE

Salt balance in irrigated lands is negative i.e. more salt is being added in the Indus Basin than the quantity of salt that is getting out of the basin. With the passage of time the soil quality will progressively deteriorate and crop yields could be seriously affected. It's like a time bomb. Twenty percent water additional to the crop water requirement, is needed to percolate below the crop roots for maintaining a favorable salt balance. Where will this water come from?

2.3 RESERVOIR SILTATION

Siltation of water reservoirs at Tarbela, Mangla and Chashma has reduced their storage capacity by about 6 MAF (equal to the capacity of one large dam). Releases from these storages had immensely benefited overall agriculture production in the Indus Basin. We are fast losing this benefit. Due to sedimentation of these reservoirs this capability has now reduced from 21% to 19%.

2.4 UPSTREAM DEVELOPMENTS

Existing and future upstream developments by India and Afghanistan is also a matter of serious concern. Pakistan is fighting a losing battle on this front. Prospects that we will prevail on India and Afghanistan are not encouraging. Climate changes intensifying droughts and floods will have the combined affect of deepening the crisis.

2.5 ENERGY CRISIS

The water crisis coincides with series of other crises i.e. energy crisis and international recession that imperil economic growth. Water scarcity which can have the affect of endangering food security could become the biggest crisis of all as it hampers the health and wellbeing of people of Pakistan. Our future generations could be lost to the ravages of hunger.

2.6 WATER QUALITY DETERIORATION

Pakistan faces serious deterioration of surface and ground water quality because of unabated industrial, municipal, and agricultural pollution and lack of universal sanitation. In the absence of a regular surveillance or monitoring program and weak regulatory enforcement, several drains, irrigation canals, and rivers have become severely polluted. The indiscriminate discharge of untreated industrial wastewater, and municipal sewage is increasingly polluting irrigation systems, streams, rivers as well as other aquatic and marine ecosystems. Subsequently this is leading to severe contamination of groundwater (including drinking water), pollution of surface water in major rivers and seawater and harm to aquatic life. The associated adverse health and productivity impacts are significant, with the poor bearing the brunt. Polluted drinking water is the cause of a rising incidence of water-borne diseases such as diarrhea, dysentery, cholera, pneumonia, and hepatitis. As estimated, health costs of polluted water in the country run into Rs. 112 billion annually. According to other studies, water-related infectious and parasitic diseases account for almost 40 percent of all patients and 60 percent of infant mortality.

3 POPULATION DYNAMICS AND SUSTAINABILITY

There is a strong empirical link between population and sustainable development. Pakistan's current population is estimated to be 180 million and is projected to reach over 350 million by the year 2050, thus, further burdening the country's already fragile economy and putting mounting pressure upon its already scarce and depleting natural resources. This burgeoning and growing population poses the most serious challenge to any future water resources, economic and environmental sustainability.

4 IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Climate changes intensifying droughts and floods will have the combined affect of deepening crisis. Droughts will affect rainfed as well as irrigated agricultural production and depress water supply for domestic, industrial and agricultural purposes. As droughts would become longer and more frequent, small farmers will move to urban areas.

There is growing consensus that the impact of climate change may increase the frequency and magnitude of floods. Monsoons of 2005, 2006, 2007 and 2010 confirm this trend. Increased incidents of Glacier Lake Outburst Floods (GLOFS) are likely in north western regions.

Under warming conditions, the summer season will expand while winter will shrink. Resultantly the snowfall will occur for a shorter duration and melting will continue for a longer period bringing drastic changes in mass balance. Snow melt and supply of water will be available much earlier than the present (prior to Kharif sowing) and may be inadequate for Rabi sowing. Many small glaciers may disappear.

With the rise in temperature as a result of climate change, crops will require more water due to excessive evapotranspiration, cattle will consume more water and domestic water consumption would also increase. Higher temperatures are also likely to degrade water quality.

Overall scientific consensus is that globally, the Earth will be getting higher than average precipitation. A simple explanation is that whatever goes up, must come down . All climate model simulations show complex pattern of precipitation change, with some regions receiving less and other more precipitation than they do now. However geographic location of Pakistan places the country in heat surplus zone on the earth making it very high on the vulnerability scale on weather changes.

Predicting how rainfall patterns will shift in a few years and how it will affect aquifers and agricultural outputs has become an urgent task. This kind of local climate modeling requires a lot of data to process. Computing resources need to be pooled to adopt global climate models to local conditions. Collaboration can be worked out with international companies specializing in weather simulation modeling.

5 FUTURE WATER REQUIREMENT

Two comprehensive studies on Water Resources Development of Pakistan were undertaken during 2000-2002 with the assistance of the World Bank and the Asian Development Bank:

a. The water strategy study under Asian Development Bank

b. The water policy study under the World Bank.

Both of these in-depth studies had assumed a liberal and successful implementation of conservation programme of lining of irrigation channels and improvements in agriculture practices. Even then, by year 2020 additional water need at the field level would be 15 to 20 MAF. Considering a conservative 25% conveyance loss in the river and canal system, the additional storage capacity for immediate future works out to 20 to 25 MAF.

Since major water storage projects take a long time to plan, investigate and build, the water requirement for year 2020 is not a suitable threshold to plan for. It is at best a short term plan. We need to foresee our requirement for the year 2050.

A study carried out in the Technical Paper 240 for the symposium held in 2003 on water crisis for the Pakistan Engineering Congress has worked out additional water requirement for the year 2050 as 40 MAF at the farmgate or 50 MAF additional diversion. This projection is based on the assumption of 50% increase in the average crop yields.

6 FUTURE OPTIONS

6.1 HILL TORRENTS

Average annual surplus available for storage in Indus Basin is 38.5 MAF (WAPDA vision 2025) whereas there is a potential of 9.7 MAF in Balochistan. Approximately 12 MAF is available in the hill torrent regions of the country.

6.2 RECHARGING GROUNDWATER

Storing water underground will be equally useful particularly during drought years. This can be achieved by recharging aquifers through various means. All potential aquifers need to be identified on the basis of water quality and recharge capacity. Surplus flows during monsoon can then be directed towards these areas during floods for recharging groundwater.

6.3 THE RESERVOIR OPTION

The additional storage capacity to be created does not have to match with the annual average surplus in the system. It should rather take into consideration the cycle of dry and wet years to mitigate the impact of drought. This essentially means having much larger carry over capacity.

Four years moving means storage surplus on Indus has been worked out as 100 MAF and a 6 years moving means storage surplus on Indus is 122 MA F (Technical Paper 235 Pakistan Engineering Congress).

There are however only a few feasible sites on Indus and hardly any on Jhelum. Indus potential therefore needs to be fully developed. A long term additional water supply of 40 MAF at farmgate should be aimed at.

It is well recognized that large seasonal and annual variability of fresh water availability (a situation applicable to Pakistan) makes it necessary to store water. It is a common sense question. All of us do it for our domestic water supply security by building underground and overhead storage tanks. At national level unfortunately we forgot it. Successive governments have lulled into a false sense of complacency about water availability. But all around the world, governments realized this vital need and invested hugely in building water reservoirs in their river basins. Whereas the United States and Australia have 5000 cubic meter water capacity per inhabitant and China has 2200 cubic meter, Pakistan has only 150 cubic meters of capacity per capita.

We got ourselves involved in a totally unwarranted debate of whether or not the proposed dams will be filled every year. If we want the storages to carry over water from wet years to dry years (which of course should be the objective to mitigate droughts) than the question of whether the reservoir is filled every year to the extent of 100%, 80% or less becomes irrelevant. There are examples of river basins having carry-over facility extending beyond seasonal storages. The dams of Colorado and Murray-Darling river basins can hold 900 days of river runoff, Egypt's Aswan Dam can store upto 700 days, South Africa can store 500 days of flow in its Orange river while India between 120 to 220 days in its major rivers. By contrast Pakistan can barely store 30 days of water in its Indus Basin.

For satisfactory river control and regulation, internationally accepted practice is to have storage capacity of at least 40 % of river flows. When applied to Pakistan the desirable storage capacity works to about 64 MAF including areas lying outside Indus Basin. Our existing live storage capacity is about 20 MAF.

For various known and unknown reasons we failed to create this storage capacity. Our future generations will pay heavy price for inaction on our part with regards to construction of storage.

Environmental and social negative impacts of some of these projects have been played up beyond proportion. No dam was ever built anywhere in the world without such impacts. Most infrastructural developments involve these concerns. But these can be addressed by proper identification and mitigation measures with the involvement of people. If effectees are settled in the same vicinity with their consultation and are ensured livelihood better than the existing, there should be no reason for concern.

7 BENEFITS OF STORING WATER

7.1 FOOD SECURITY

Self sufficiency in food production ensures national sovereignty more than any other measures of economic independence. It is a mistaken assumption that imported food could be cheaper in certain situations. The era of cheap food is over --- most likely for good. Very few rich countries can depend on imported food.

Food security is a radically different threat because it affects the poor so profoundly. It has been the cause of riots and revolutions. The larger the affected population the more serious the problem. Water is crucial to food production. It is easier to store water for drought years than to store food for such events. Luckily we have water to store and we have sites to store water, although limited. Investing in water reservoirs is a key step towards ensuring food security.

The benefits of water releases from existing storages at Mangla and Tarbela are well demonstrated and clear. Representatives of four provinces bitterly contest for every cusec of water released. If storing water was against the interest of any province no one would be sitting on IRSA panel.

7.2 DRINKING WATER SUPPLY

Currently 60% of population has access to municipal water supply. The shortages and poor quality of water supply contributes significantly to the high infant mortality rate and sickness. In terms of quantity, domestic water needs (besides industry) will pose rising competition to the traditional irrigated sector. A strong commitment to the domestic water subsector is needed to ensure supply of safe and adequate drinking water to the entire population by year 2025.

Bulk of drinking water requirement is met by groundwater. But groundwater is depleting and its quality is deteriorating. The only way to replenish it and to improve its quality is by recharging it with fresh water which can be made available during monsoons provided we store the surplus flows. The stored water can then be diverted to the areas where recharge is required.

7.3 SUSTAINABLE USE OF GROUNDWATER

At present dependent upon groundwater is very heavy. The water table in almost entire basin is depleting and groundwater quality is deteriorating. This indicates that present use is not sustainable. The increase in storage will increase canal diversions and consequently dependence on groundwater will be reduced. This will reduce deterioration of groundwater and its use will be more sustainable.

7.4 SOIL SALINITY MANAGEMENT IN IRRIGATED AREAS

The salinity surveys indicate that salts in the root zone of crops have been increasing due increased use of groundwater which has much more salts than canal water. Increase canal supplies due to storage will help to leach down the salts from the root zone resultantly better yields.

7.5 FLOOD MANAGEMENT

Floods are one of the major national calamities in Pakistan. During last 60 years (upto 2007) Pakistan has suffered cumulative financial loss of Rs 385 billion (present worth of this amount is much higher) and loss of more than 7800 people (FFC Annual Report 2007).

By far the most effective way of tapering flood peaks and minimizing flood damages and loss of life is flood control through construction of storage reservoirs. These losses can be largely eliminated.

7.6 DROUGHT MITIGATION

National storage capacity needs to be augmented considerably in order to store water during high flow flood periods and use water during drought years.

Storage capacity that takes into consideration the historic drought cycles is based on the moving means of surpluses of the period matching the drought years. Creating carryover capacity in the surface storages will ensure that water shall be available for releasing during drought years.

Recharging and maintaining underground reservoir is equally effective in mitigating impact of drought.

7.7 ENVIRONMENTAL BENEFITS

Adequate and assured releases below Kotri are needed for maintaining delta and coastal eco system. This requirement is not being presently met as water releases from existing reservoirs are hardly sufficient to meet the requirement of agriculture. As the demand for agriculture increased, the canal diversions for irrigation also increased during the post-Terbela period. Had there been more reservoir capacity, there would have been no problem for adequate releases for meeting environmental needs.

Power generated from reservoir (hydropower projects) is clean energy as it eliminates the need to burn fossil fuel which pollute the environment resulting in the serious health problems. This element can be traded apart from the advantage of local pollution control.

7.8 CHEAP HYDRO-POWER

Large dams do not only increase the assurance of water availability, but they can generate large amounts of electricity. Currently about 30% of Pakistan energy is generated from hydro-power. Even though irrigation requirements are its priority, Tarbela's power benefits account for 60% of the overall economic benefit from the dam. Pakistan has utilized only about 12% of its estimated 55,000 MW of economically viable hydro-power potential, a proportion much lower than India and China (around 30%) and much lower than rich countries (around 75%). Being relatively cheap energy it will have the affect of reduced electricity tariff and continue supply of electricity.

7.9 ECONOMIC BENEFIT DURING CONSTRUCTION

Large dams and hydro-power projects involve mostly local construction resource content. They are labour intensive and thus generate substantial local economic multipliers. For a typical large dam/hydropower project, the local content is 80% against 20% for the thermal project.

8 WHO BENEFITS?

With the help of Chashma, Mangla and Tarbela Reservoirs seasonal carry over capacity from Kharif to Rabi was increased from 12% to 21%. The available supplies for canals in critical Rabi and Kharif sowing/maturing period are thus progressively reducing. Creation of more storages is an imperative need in the present situation. After the construction of Mangla, Tarbela and Chashma reservoirs, the provincial annual canal diversions have increased by about 16 percent. The increase in magnitude of canal flows of the four provinces is:

Province	Increase under Post Dam Conditions (MAF)	Percentage Increase
Punjab	4.43	9.13
Sindh	6.17	16.59
KP	1.50	32.19
Balochistan	1.18	190.32

The above figures indicate that Sindh Province got the highest share in magnitude as compared to all other provinces and in percentage it received more water as compared to Punjab Province under the post reservoir environments.

It is a misconceived perception that only a particular province will benefit or that the lower riparian will suffer as a result of construction of more storage. As a part of the 1991 Accord, the shares of any increase in water availability as a result of new storages are clearly allocated. The Accord provides a strong re-distributional component with the smaller provinces (Balochistan and KP) getting much larger share of the new water than they have of the existing allocations.

The shares of both Sindh and Punjab will be less than their share of existing water with Punjab a little less better off than Sindh.

With new storages coming online, KP will be able to provide gravity flow to 0.5 million acres in D.I. Khan and Bannu plains which otherwise need to be served with pumped supply at huge cost.

Releases for early Kharif in Sindh will not be a problem nor would retaining of early snow melt flow in Mangla be an issue.

It would become possible to provide perennial supplies in non-perennial areas. Investment in under-construction flood canals in Punjab, Balochistan and Sindh (Greater Thal, Kacchi and Rainee canals) would become more productive due to availability of assured supplies.

Additional supplies in Sindh could help provide leaching requirement in its saline, saline-sodic soils and help reclaim salt affected lands.

Creation of additional storage capacity helps to improve and in no case limits or reduces the existing uses among the co-sharers. Ever since Water Accord of 1991, inter-provincial sharing even in extreme shortages and drought periods have been remarkably well managed. Releases from Tarbela and Mangla were minutely monitored by provincial and federal governments.

9 WATER RESROUCES DEVELOPMENT OUTSIDE INDUS BASIN

Being less favored environment for agriculture due resources have not been committed outside Indus Basin. This is one of the causes of un-employment, feeling of deprivation and frustration among the unemployed youth.

Irrigation projects keep people employed on long term and permanent basis while serving the objective of food security. Following initiatives are proposed:

a. Development of small scale perennial irrigation schemes in Northern Areas, AJK, mountainous regions of KP, Punjab and Balochistan with potential of developing new irrigated lands of 1 million hectares.

b. Development of spate and Rod-Kohi or Sailaba farming in all the four provinces, FATA, Northern Areas & AJK with high potential area of spate irrigation of 2 million hectares.

c. Development of Baran & Khushkaba in KP , Punjab, Balochistan, FATA, Northern Areas and AJK with potential of development of dryland farming of 2 million hectares.

d. These 5 million hectares as noted in paras a,b & c would largely come from available culturable waste of 8.33 million hectares. This development can be part of a long term plan which covers the entire wasteland.

10 DEVELOPMENT OF FLOODWATER GENERATED WITHIN THE BASINS

- The non-Indus internally generated floodwater is 12.7 MAF.
- The current use of floodwater is 3.0 MAF per annum. The balance amount of water assessed 9.7 MAF should be stored in dams integrated with Sailaba farming and groundwater recharge by developing Spate irrigation. The stored water should be provided in droughts and dry spells to sustain Sailaba farming.
- Carry over dams are needed to sustain Sailaba farming and groundwater recharge.
- Development of floodwater will provide an immense opportunity and potential for generating new livelihoods and groundwater recharge measures in a province where un-employment is a major issue resulting in unrest and insecurity among the un-employed youth.
- The floodwater during wet years should be used to generate new groundwater aquifers in command areas of Spate irrigation and Sailaba farming. This is a cost effective way of managing

and developing new livelihood sources in Balochistan. The only effective way of recharging or building new aquifer is through watershed management and expanding irrigated agriculture in pockets of high recharge zones.

11 ACTION PLAN

The following action plan is proposed for the augmentation of water resources in Pakistan.

- As a short term measure, work on another large dam having hydropower potential should be started concurrently with Diamir Bhasha Dam Project.
- A long term plan for storing additional 50 MAF upto year 2050, needs to be prepared and a ranking system devised to prioritize projects for implementation.
- An awareness campaign about the needs and benefits of water reservoirs needs to be launched immediately.
- Rainwater harvesting and groundwater recharge plans be prepared and initiated.
- Steps to be taken to protect water from pollution due to sewage and industrial waste.
- Sprinklers and drip irrigation shall be introduced at feasible locations.

SUSTAINABILITY OF WATER FOR PAKISTAN

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Shahzad Ghafoor [3]

Abstract

Three-fourths of the Earth's surface is covered with water. Only 1% of the World's water is usable, about 97% is salty sea water and 2% is frozen in glaciers and ice caps. All life on earth depends on water. Population is increasing and hence water availability per person is reducing. In modern times a remarkable irrigation network was developed by the British in the Indus river basin and at the time of partition the dividing line of the sub-continent disregarded not only the topography but also the irrigation boundaries of the then existing canal supply system. This created great challenges for the water resources development work in Pakistan.

This document is intended to provide information on the current status of water resources of Pakistan and the challenges that lay ahead for a sustainable future in the irrigation and agriculture sectors. It is an endeavour to assist in understanding the difficulties and searching for the best options and solutions.

1. General

Water is blessing from God. It is the foundation of life and life without water is not possible. Water has some special properties to sustain life on earth. Had itbehaved like other liquids, earth would have been a solid planet of rocks and ice. The density of water at 4°C temperature keeps the ice floating above water and fish life continues beneath ice layer.On surface of the earth temperature varies a lot but sea water temperature varies only within a short range.Over 70% of our Earth's surface is covered by water. Although water is seemingly abundant, the amount of fresh water availableisonly 2.5% and remaining 97.5% is saline water. Out of available fresh water only 1% is accessible for human use and the remainder is frozen in polar ice caps, glaciers, soil moisture or as groundwater at great depths.

Each day the sun evaporates a trillion tons of water from the oceans and continents and pumps it as vapor into the atmosphere. Each day same amount of vapor condenses and falls as rain, snow or sheet replenishing its source. The availability of water in measured quantities in its various shapes is the order of God for sustainability of life on earth. We must manage its use in optimum quantities and must not

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waste even a drop.

2. Pakistan□s Water Resources

2.1 Rainfall

Pakistan is an arid country. The rainfall over most of the agricultural area of the Indus Plains averages only 9 inches per year. The Northern Areas,annuallyreceive 30 to 40 inches of rain with maximum of about 60 inches in Murree &Balakot areas.It decreases from the foothills of Himalayas to the south with 32 inches at Sialkot, 25 inches at Lahore, 6 inches at Multan and 3.5 inches at Nawabshah. Further south, it increases towards the coast with 7 inches at Hyderabad to 12 inches near the south west coast.

Balochistan is the driest part of Pakistan with an average annual rain of only about 6.5 inches (165 mm) and has to import by food grains produced in the Indus plains.

2.2 Snowfall

The bulk of snowfall, nourishing the glaciers in the Hindu Kush, Karakorum and Himalayas derives its moisture from westerly winds, during the winter. However, even in summer large quantity of precipitation falls as snow. Topography largely determines where snowfall occurs. Only a fraction of whole Upper Indus Basin probably less than 30% contributes an estimated more than 80% of the river's flow.

In essence, all the hydrological action takes place in the zones about 8,000 ft (2500 m)above mean sea level. Below 8,000 ft. there is generally little precipitation and high evaporation.

The main summer period of river flows commences as melting reaches the ablation zones. Monitoring of annual changes in snow and ice cover is therefore very important for Pakistan.

2.3 Glaciers

The upper Indus catchment has numerous glaciers. Those exceeding 6km have an aggregate length of 1,800 km, and represent only a third of the glaciers in the watershed. They are great natural storage reservoirs that feed and regulate the Indus and its tributaries. Because cloud cover restricts snow melt, the more it rains or snows, the more they conserve, but when the weather changes, the moving glaciers and the dynamic avalanches release the stored waters.

Large glaciers such as Siachen72km, Hispar62 km, Biafo60 km and
Braldo56 km and the extensive ice fields may be holding, in

aggregate, more than a billion acre feet (1.233 Billion m^3) of water which is 70 times the combined capacity of Tarbela and Mangla reservoirs.

2.4 Groundwater

Groundwater in Pakistan is an important resource for irrigation as well as domestic and industrial supplies. The Indus plain comprises alluvium predominantly silts and sands to depths exceeding 1,000 feet in Punjab and Upper Sindh tapering down to some 200 ft in lower Sindh.

Groundwater under the Indus irrigation system is plentiful, however quality is a constraint. Development of this resource, mainly by private tube wells (now about 1.021 Million) accounts for a gross annual abstraction of about 45 MAF.

Kirthar and Suleiman mountain ranges separate Balochistan from the Indus Basin. Covering an area of about 3,47,000km^2, it happens to be the largest province of Pakistan. Population of Balochistan was recorded as 1.3 million during 1961. It has risen to 9.7 million by 2014.

Balochistan is an arid province. The higher altitude plateau of Quetta and the areas towards north receive upto 15 inches (350-400 mm) of annual precipitation, some of which occurs as snow.Most of the rainfall run-off is lost through evaporation or percolation into inaccessible rock zones and Kharan desert. The southern plains representing about two thirds of the province area, receive 100-150 mm of annual precipitation. Most of this run-off generates flash floods rapidly flowing into Arabian Sea. Wide annual variations in precipitation are a special feature of the precipitation pattern, especially in the low rainfall areas.

Soils in about 70 % of the province particularly towards south and west are of the desert' type. These possess extremely low organic matter and are highly susceptible to erosion. Kharan basin has 120,175 km^{2}catchmentarea but most of the run-off water disappears into the desert sands. However, soils in the plateau and highland areas towards north and east are relatively fertile and also possess groundwater in disjointed basins.

3. Status of Water Availability

The flow of the Indus River system is derived from snow and glacier melt and rainfall primarily outside the Indus Plains. The total inflow of Chenab, Jhelum and Indus River at the Rim Station is 145 MAF. Availability of this water is not uniform through the year. Winter season flows are less than 20% of the total inflows. Transfer of surplus water from Kharif to the lean period of Rabi is necessary (Fig-1).

The quantity of inflow of the Indus River system to the Indus Plains is measured at three rim stations: Indus at Kalabagh, Jhelum at Mangla and Chenab at Marala. These stations include most of the tributary inflows the most significant exception being the Swat and Kabul Canals, thus the measurements at these three stations closely approximating the total surface water inflow.

Freshwater scarcity is commonly described as a function of available water resources and human population. The Faulkenmark indicator proposed by Swedish hydrologist MalinFaulkenmark is perhaps the most widely used measure of water stress. It is defined as the fraction of the total annual runoff available for human use.

The index values 1,700 m^3 and 1000 m^3 per capita per year are used as the thresholds between water stressed and water scarce areas, respectively (Faulkenmark 1989). Above 1700 m^3 there is no stress and below 1000 m^3 index the problems due to water scarcity are severe or extreme. Current population of Pakistan is 188 million. Considering 145 MAF as average annual rim station inflows into the Indus Basin available for human use the**current water availability in Pakistan is 951 m^3 per capita** and hence we are in a situation of water scarcity.

Although the widely used Faulkenmark indices of water stress and scarcity are extremely helpful to clarify the relationship between water use and human population growth, they cannot by themselves tell the whole story. These indices do not distinguish whether fresh water in any given country is available at the time when it is most needed (e.g. for crop irrigation) or in the places where it is most needed (e.g. various regions in a country). For a more complete picture regional availability alongwith physical indicators should be taken into consideration when evaluating the conditions of water availability.

The benefit of 145 MAF surface flow of Indus Basin is not directly available to most areas of Balochistan. The population of Indus Basin is 178.38 million therefore per capita water availability would be 1003 m^3which is still a water stress situation. For Balochistan the population is 9.7 million.Surface flows are 10.79 MAF are often generated as flash floods and cannot sustain any irrigation system unless stored. Currently the water available through storage dams and flood dispersal structures is only 2.22 MAF. As such the water availability in Balochistan is only 282 m^3 per capita per annum.Balochistan province is therefore under a situation of severe scarcity of water.

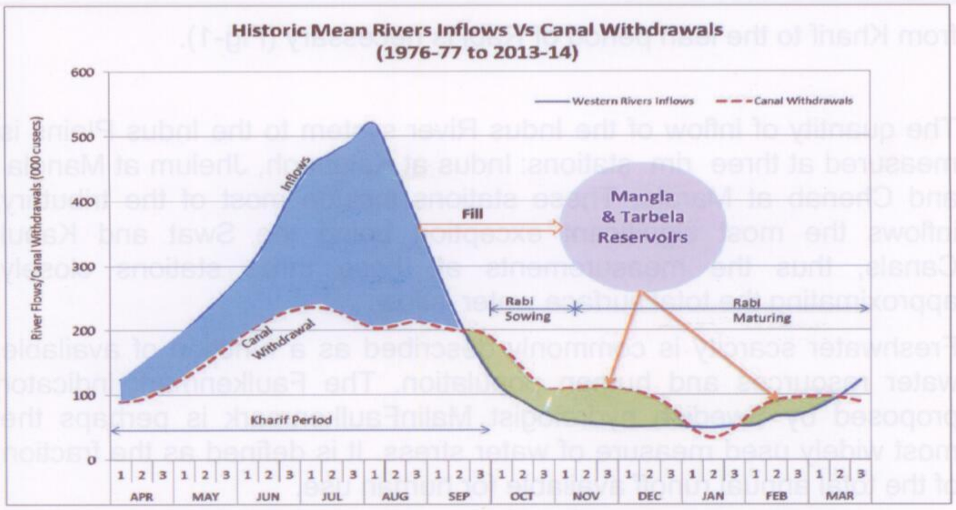

Fig-1: Historic Mean River Inflows Vs Canal Withdrawals

The Dublin Conference in 1991 concluded that since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems (ICWE, 1992).

Water availability should not be solely defined by total runoff because it ignores the fraction of the runoff required to maintain the environment. The environmental demand should be subtracted from the total runoff.

With no check on population explosion, the per capita water availability is destined to reduce sharply. It is essential to take up measures both on supply side and demand side. Whereas the water supplies should be ensured to be available at right times and right places, the demands should be rationalized by water conservation measures and by optimization of crop water requirements.

High efficiency irrigation system helps to reduce water demands. For Pakistan, the Drip Irrigation is better than Sprinkler Irrigation which is energy intensive and high technology. Drip irrigation requires much less energy and it can be started with locally available technology.

The currently practiced crop water supplies are based on traditional thinking and need to be modified on scientific basis. There is ample scope to reduce crop water requirements and manage our system for timely supplies to produce more food and fibre per unit of water.

4. Problems of Irrigated Agriculture

a) Irrigation is central to Pakistan's economy. Around 90% of agricultural output is entirely dependent on irrigation water. Pakistan's major problems are waterlogging and salinity, over-exploitation of fresh groundwater, low efficiency in delivery and use, inequitable distribution; unreliable delivery and insufficient cost recovery.

b) The Indus Basin has flat topography, poor natural drainage, porous soils, and a semi-arid climate with high evaporation. In such an environment, irrigation without adequate drainage has inevitably led to rising water tables and eventual salinity. Presently, about 30% of irrigated area is waterlogged, 13% highly waterlogged, while soil salinity is estimated to cause about 25%loss of potential production of major crops. Drainage thus requires rigorous efforts for additional projects and the neededinvestments.

c) Groundwater use has been a major factor in raising agricultural production. Because of uncontrolled development of groundwater, there is a danger of excessive lowering of water tables and intrusion of saline water into fresh-water aquifers.

d) Due to age, overuse, and poor maintenance, the efficiency of delivery of the canal system has gone low, ranging from 35-40% from canal head to the root zone. Some irrigation systemsintheworld (Gezira in the Sudan, for instance) have efficiency ratesof70%. Much Surface water in Pakistan is currently lost in the conveyance system that could be profitably used by farmers.

e) The Indus irrigation system is supply based, and so unable to accommodate changing water demands during the crop season. Inefficient water delivery and water use also mean that, in reality, water does not reach users toward the tail end of the system.

f) Pakistan's extensive irrigation and drainage systems have been deteriorating because of deferred maintenance and utilization beyond design capacities. The gap between O&M expenditure and recoveries through water charges is high (4+ %) and increasing.

g) Direct rainfall contributes less than 15 % of the water supplied to crops. The major source of water for irrigation is the Indus Basin Irrigation system.

h) Flat topography and lack of well-defined natural drainage in the Indus Plain create a surface drainage problem which has been compounded by the construction of roads, railways, flood embankments, and irrigation system that obstruct flows.

i) Water distribution, contrary to the system's objective, is not equitable. Significant areas lack drainage and excessive seepage results in waterlogging and salination.

5. Global Warming & Climate Change

There is scientific consensus that global warming is occurring as a result of human activity. The largest contributor for global warming is the increase in atmospheric CO_2particularly from fossil fuel combustion, cement production and deforestation. Fig-2 shows the Greenhouse Effect that causes warming of the earth's surface and its lower atmosphere.

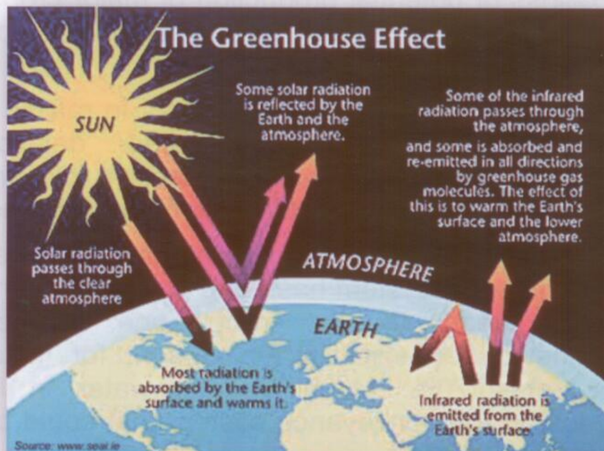

Fig-2: The Greenhouse Effect

The Intergovernmental Panel for Climate Change (IPCC) has confirmed that during last century there has been a rise of about 1.5^0 C in the global temperatures. They have indicated that during the 21st century the global surface temperature may rise a further 1.7^o C to 4.8^{o}Cdepending on the lowest or highest emissions scenario. (Fig-3& Fig-4)

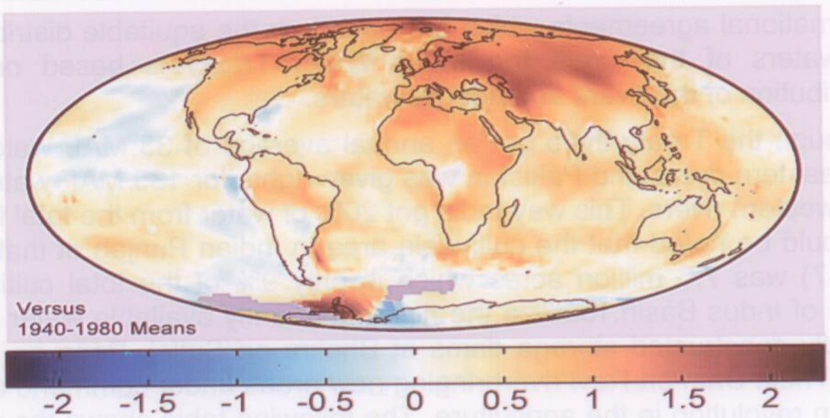

Fig-3: 1999-2008 Mean Temperatures

The effects of an increase in global temperature include a rise in sea levels and a change in the amount and pattern of precipitation and probable expansion of subtropical deserts. Warming is expected to be strongest in the Arctic with significant retreat of glaciers.

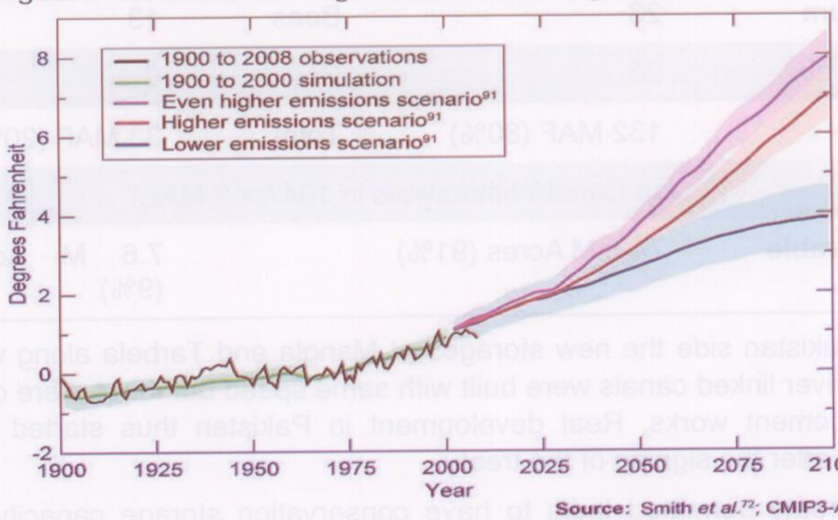

Fig-4: Observed and Projected Global Temperature Changes

6. Surface Water Challenges

The Indus Water Treaty is unique in one respect. Unlike many of the international agreements which are based on the equitable distribution of waters of the rivers the Indus Water Treaty is based on the distribution of the rivers and not the waters.

Through the Treaty India got an annual average of 33 MAF waters of the eastern rivers and Pakistan was given rights for 135 MAF waters of the western rivers. This way India got 20% of water from the total flows. It would be noted that the cultivable area in Indian Punjab at that time (1947) was 7.6 million acres which is only 9% of the total cultivable area of Indus Basin.Toutilize the now abundantly available water India rapidly constructed storage dams at Bhakra on Sutlej, Pong on Beas and Thein Dam on Ravi riverbringing new areas under command and a green revolution in the agriculture. The following table shows the water distribution under the Treaty.

River	Pakistan	River	India
Indus	89 MAF	Sutlej	14 MAF
Jhelum	23	Beas	13
Chenab	23	Ravi	6
Total	132 MAF (80%)	Total	33 MAF (20%)
(Indian Canal Withdrawals in 1947 = 9 MAF)			
Cultivable Area	74.8 M Acres (91%)		7.6 M Acres (9%)

On Pakistan side the new storages at Mangla and Tarbela along with inter-river linked canals were built with same speed but these were only replacement works. Real development in Pakistan thus started ten years after the signing of the treaty.

The treaty permitted India to have conservation storage capacity of 2.85 MAF on the western rivers. India was also allowed to draw water from the western rivers for irrigation of the then existing 642,000 acres and an additional entitlement to irrigate 701,000 acres. India has so far not made full use of its rights to draw this quantity of water from the western rivers.When India builds new projects,Pakistan would loose another 3.5 MAF of waters from the western rivers.

The World Bank report of 1966 by P. Lieftinck studied the development options of water and power resources of Pakistan and recommended the following storage program:

Name of Dam	Construction Plan	Present Status
Mangla	1967	Completed
Tarbela	1975	Completed
Sehwan	1982	(Awaits approval by Govt. Sindh)
Raised Mangla	1986	Completed
Chotiari	1986	Completed
Kalabagh	1992	(Awaits consensus)
Swat (Mohmand Dam)	2002	Under Study
Low Gariala(Akhori Dam)	2011	Feasibility ready
Skardu	after 2020	Under Study

Only Mangla and Tarbela Dams were built as planned. Raised Mangla was completed 25 years after the program date. On Kalabagh Dam there were objections from KPK and Sindh provinces which remain unsettled. We have miserably failed to build water reservoirs and protect our water resources on rivers, Indus, Jhelum and Chenab.Pakistan is primarily an agrarian country, water becomes the most important of all the natural resources to be secured and managed. We cannot blame India for our own lethargy and mismanagements.

India maintains a huge military machine in Occupied Kashmir. The deployment is tasked to deal with freedom fighters. But where its work goes almost unnoticed is the security it provides to Indian engineers, who are planning and working day and night to build dams on rivers that take water to Pakistan.

India has built dams Nimoo Bazgo, Dumkhar and Chutak on river Indus. In case of any of these dams collapse or large quantity of water is deliberately released, it will cause submergenceofSkardu city and Airport.

On Chenab river India has built 17 dams and planning to build atleast10 more. Although, most of these are non-consumptive hydropower projects but not without a potential of stopping flows into Pakistan for several days.

There is therefore a permanent threat from operational consequence of cumulative live storage which can store about one month's worth of low-season flow on the Chenab. This cumulative live storage can be used by India to impact major reductions on water availability in Pakistan during the critical sowing season. It is notable that by building dams on rivers in Kashmir, India has achieved military, economic and political supremacy vis-à-vis Pakistan.

The Treaty has missed to include provision for environmental waters. For example what happens to the state of Bahawalpur where the rivers Sutlej and Ravi are dry and what happens to the environment of Lahore because of no flows in Ravi.

India's Hadiyara drain flows near Lahore and brings the industrial waste to Pakistan and pollutes Ravi. Baramulla's waste is also polluting Jhelum river. The Indian officials complain that Pakistan's Kasur drain is causing the same damage on their side.

The interests of the two countries are so closely linked, that they can be protected only by establishing closer ties. A failure to do so will bring only more episodes of discord, over river water, over dams, over toxic dumping in drains and over illegal border crossings.

Global warming over a period of time is going to deplete the flow of water in the Indus (the major supplier) which depends mostly on glacial runoffs.As in other Himalayan regions like in Nepal, the rivers carry very heavy sediments that result in silting the dams and barrages thus reducing the availability of water for cultivation.

The canals that feed the irrigated lands are not lined resulting in seepage and loss of water.

There is mismanagement in use of water by using antiquated techniques and heavy cropping of water intensive varieties of farm products. Optimum crop rotations have not been done extensively as it should have been done to save water.

With the construction of barrages diverting water into irrigation canals the discharge of fresh water into the Arabian sea has reduced considerably which has resulted in the sea water pushing further into the estuaries and beyond, making water in those areas unfit for cultivation.

Between 1933 (Sukkur barrage) and 1962 (Guddu barrage) the canal water diversion capacity increased to 217,300 cusecs. As a consequence the downstream Kotri average annual flows reduced by about 40MAF.This situation was further exacerbated by the construction of storage reservoirs at Bhakra, Pong, Thein, Mangla & Tarbela and the downstream Kotri flows were further reduced. The situation in 2014 is shown in Fig-5 below.

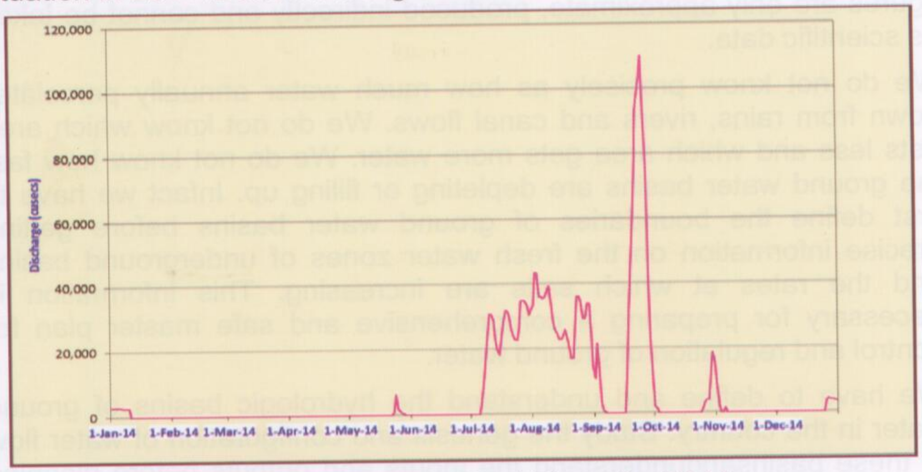

Fig-5: Downstream Kotri Flows for 2014

When the treaty (signed in 1960) was being negotiated, a future possibility of water scarcity was not priority or a leading concern for the negotiators. Hence, we find that there is no provision per se that provides a mechanism to both the countries if climate-based water scarcity occurs. Who determines whether the reduced amount of water flowing into the rivers of Pakistan from the Indian side is because of obstructions or on account of climatic water scarcity. The general framework of international law calls on the upper riparian state to the necessary measures to minimize water scarcity.

In Europe and elsewhere, water scarcity has promoted trans-boundary water cooperation instead of inciting war over this issue. The UN Convention on Uses of International Water Courses 1997 obliges states to conserve, manage and protect international water courses.

Water scarcity issue with Afghanistan signs of a serious conflict has arisen regarding the shared waters but the potential is always there. Therefore, as a matter of preventative diplomacy or may be as a confidence building measure both countries should establish a joint multi-disciplinary scientific fact-finding working group to build a mutually agreed-upon hydrological knowledge base on the Kabul river basin.

7. Groundwater Challenges

Water resource statistics of Pakistan indicate that 45 MAF of ground water is being annually harvested by public and private tubewells. It is generally believed that annually an equal amount of fresh surface water percolates down and recharges the ground water basin. Both figures are only approximate, produced indirectly and cannot be taken as scientific data.

We do not know precisely as how much water annually percolates down from rains, rivers and canal flows. We do not know which area gets less and which area gets more water. We do not know how fast the ground water basins are depleting or filling up. Infact we have to first define the boundaries of ground water basins before getting precise information on the fresh water zones of underground basins and the rates at which salts are increasing. This information is necessary for preparing a comprehensive and safe master plan for control and regulation of ground water.

We have to define and understand the hydrologic basins of ground water in the country. Study the genesis and configuration of water flow in these basinsandunderstand the inputs and outputs before planning projects in response to the local needs.

The existing ground water in Pakistan has formed by inputs of nature and the farmer. Nature has been supplying water for percolation right through the geologic history. Farmer has been adding and extracting water for the last about one century only. Therefore sustainability of any future project will depend upon the equilibrium between these three factors. The equilibrium can be ensured only when scientifically collected data on water and salt movement through the soil becomes available and the future projects address the needs of equilibrium.

Over the past 20 years groundwater use has been a major factor in raising agricultural production. Groundwater tube wells not only supply additional water but have provided flexibility to match surface water supplies to crop water requirements. Because of uncontrolled (and rapid) private sector development of groundwater (6% annual growth) there is a danger of excessive lowering of water tables and intrusion of saline water into fresh-water aquifers. Control and regulation of ground water mining is urgently required.

In most areas the development has reached the equilibrium point between mining and recharge with very little potential for further development. Specific studies are required to define this potential more accurately.

There is also some potential for recovery of irrigation losses in saline groundwater areas by means of interceptor drains, scavenger wells and other special means.

In certain areas lining of canals and water courses has been taken up to enhance water conveyance efficiency and reduce seepage losses but this has negative impact on water recharge for the groundwater reservoirs.

8. Impact of Global Warming on Indus Basin River Flows

Climate Change is impacting the glaciers the World over. The countries with a large number and size of glaciers feel concerned about this fact and are making investments to observe and study these glaciers in order to understand and predict their future.

Most of the studies suggest that rise in global temperatures would accelerate melting of glaciers. This may result in higher flows in the rivers for some decades until the volume of glacial ice is substantially reduced and then a period of progressively reducing flows will take over. Indus Basin rivers flow data of past thirty years shows a somewhat declining trend. Why so is not yet fully understood.

According to an article from the United Nations Environmental Programme Website (Sep 2012);

Issues related to Himalayan glaciers have become a major focus of public concern and scientific debate. In spite of recent attempts to address the knowledge gaps on the state of Himalayan glaciers, the findings still show inconsistencies. Kenneth Hewitt was the first to challenge the excessive melting of Karakorum glacier.

Analyses by Bolch and others (2012) and Gardelleet.el. (2012) and Hewitt et. el. have shown gains in the glaciers of the central Karakoram region.

Scherler and others (2011) report that 50 % of observed heavily debris-covered glaciers in the westerly's-influenced Karakoram region show stable conditions;

Widely quoted findings from the entire region show that glacier retreats are observed mostly in the east, while in the west, the glaciers' responses are complex, especially around the Karakoram region. Since the1990s, expansion of some larger glaciers has been observed in the central Karakoram; and some have advanced and thickened. The current behaviour of Karakoram glaciers prevents drawing conclusions about how the glaciers will continue to respond in the Karakoram region in the future.

The World Bank in their report titled, Pakistan: Country Water Resources Assistance Strategy, Water Economy: Running Dry, Nov 2005 have given the following opinion;

The Indus basin depends heavily on the glaciers of the western Himalayas which act as a reservoir, capturing snow and rain, holding the water and then releasing it into the rivers. It is now clear that climate change is already affecting these western glaciers in a dramatic fashion.Best estimates are that there will be for few decades' retreat, during which time river flows will increase. This especially in combination with the predicted flashier rainfall is likely to exacerbate the problems of flooding and draining, especially in the lower parts of the basin.

The Friends of Democratic Pakistan (FoDP) in their report of Feb 2013 have identified the following actions in this area;

- The mapping of all existing glaciers in the Indus catchment area should be given high priority.
- Mass balance measurement programme should be done on more glaciers having easy access.
- Measure ice thickness on some and calculate the ice volume of all the glaciers
- With improved data calculate the glacier melt water volumes both in space and time.

It emerges from the foregoing that Pakistan should be pro-active in the studies of glaciers as well as for other impacts of climate change like more frequent droughts and floods.

9. Storage Reservoirs

As a part of Indus Basin Settlement Plan, three reservoirs were built by 1976 at Mangla, Chashma and Tarbela for storage and regulation of Indus and Jhelum river flows. These reservoirs provided a live storage capacity of 15.75 MAF which the engineers knew was destined to deplete with time due to sediment deposition. It was planned right in the 1960's, that Pakistan should be progressively building additional reservoirs to compensate for sedimentation losses and to meet additional storage needs of development. PieterLieftinck in the World Bank's report on Development of Pakistan's Water Resources had recommended to build a large size reservoir every decade for the foreseeable future. As such, during last four decades Pakistan should have added about 24 MAF of storage capacity. Unfortunately Pakistan has failed in this regard.

It is satisfying that about eleven (11) medium and small size projects have been built at Baran, Rawal, Tanda, Simly,Khanpur, Hub, Mirani, Sabakzai, Gomal, SatparaandDarawatsites. Rawal and Simlydams solely supply water for drinking purpose. The combined capacity of all other projects is 2.1 MAF. These projects are located outside the integrated irrigation system of Pakistan, however they can provide water to meet the local needs. More such dams should be built to keep balance in development of less fortunate regions of the country.

Nationwide it is necessary to enhance storage capacity of irrigation water supply to meet the future demands of food and fibre of the expanding population. The Rawal and Simly Dams provide drinking water.There are limited storage sites and all of them should be developed. On Indus there are only four sites namely Kalabagh, Basha and Skardu on main stem and Yogo on its Shyok tributary. The sites of Kalabagh and Skarduhave environmental problems of special significance. While solutions are being explored, no time should be wasted in the implementation of projects at Basha and Shyok sites.

Designs and tender documents are ready for Basha Dam but there are difficulties in the procurement of foreign funds. When built Basha Dam will be a large storage and power machine.It is prudent that Pakistan should start civil works of this project with its own resources while continuing efforts for foreign funds.

Shyok dam replaces the earlier proposal of Yogo Dam which has large environmental issues. Shyok dam located 3 km upstream of Khaplucan store 5.6MAF of water with very low environmental impact.

Skardu dam with a storage capacity of more than 20 MAF as was envisaged in sixties cannot be builtnow for this large capacity because of unaffordable and unacceptable environmental impacts. A lower dam with about 2to3 MAF capacity should however be studied and built. The dams at Shyok and Skardu would be beneficial in reducing the sediment load at downstream sites. Particularly at Bunji Dam (nearGilgit) the sediment problems would be substantially reduced for the foreseeablefutureand resultantly life of Bunji dam and its power units would be greatly enhanced. The future storage sites are shown in the following table;

Name of Dam	River	Dam Height (Ft)	Live Storage Capacity (MAF)	Remarks
Shyok	Indus	450	5.6	Least environmental impacts
Skardu	Indus	200	2	Re-study to save Skardu
Diamer Basha	Indus	892	6.4	Ready to build
Kalabagh	Indus	260	6.1	Awaits

Kalabagh is most suitable site for storage on consideration of hydrology and power evacuation. The inflows at Kalabagh are more than any other upstream site and its location is closest to the national power grid systems requiring minimum transmission lines. Major objections are its environmental impacts which can be resolved by serious interaction and consultations with the stake holders. The best option would be to build the Projectaccording to the Planning Report of June 1988.

KPK reservations on this report can be addressed by reviewing the maximum conservation level. The concerns of Sindh can be alleviated by discussing and agreeing on reservoir operation rules. Once it is accepted that Kalabagh may have a storage of about 6 MAF, the next crucial point is how and when to store water and how to release it for maximizing its benefits to the irrigated areas, the riverine areas (Kacho) and the Indus delta areas. Engineering tools are available to design the size and number of minimum and maximum applications of water for Kacho areas and the Indus Delta. Operation procedures can also be designed for strict and assured implementation. The federal government should constitute a Kalabagh Consensus Commission and assign the task to resolve the issues and provide solutions within a specified period of time.

The hydrology of Indus river shows that a very large flood occurs every five to ten years. The reservoir at Kalabagh can help to chamfer the flood peak and later utilize the stored water for environmental flows. A carryover dam if built at Kalabagh site can be normally operated as a run of the river project with conservation level at the minimum pool level given in the 1988 project report. Thus it will generally be producing electricity at this low head. During every super flood its carry over capacity can be utilized to reduce the flood peak and alleviate flood damages in Punjab and Sindh. In the subsequent times at well-designed intervals this stored water can be sent down in stages to meet the environmental needs of Indus delta.

10. Conclusions

10.1 Total average annual inflow at rim stations into the Indus Basin is 145 MAF. It is supplemented by 25 MAF of rainfall in the Indus Basin.

10.2 Population shall continue to increase but available surface water may not. Rather as a consequence of global warming and after a brief period of higher flows the river flows are most likely to decrease reducing the water availability to its extreme values.

10.3 Balochistan which is hydrologicallycutoff from the Indus Basin gets 10.8 MAF water by way of average annual rainfall of 6.5inches. The run-off is mostly in the form of flash floods. The estimated total river flows in Makran coastal areas are about 1 MAF.

10.4 Demand of food grains shall increase with time. The nation would need additional 5 million tons of wheat by 2025.

10.5 Water availability particularly for Rabi crops is reducing food security.National survival demands that storage dams at Kalabagh, Basha, Skardu, Shyok and Munda should all be built in earnest.

10.6 The existing infrastructure of Irrigation system is in urgent need of rehabilitation and up-gradation.

10.7 The level of groundwater extraction has reached its peak and is in a state of equilibrium with recharge. A management and regulating authority is urgently required to save it from an undesirable depletion as well as deterioration.

10.8 Global warming is not a myth; it is a fact and our glaciers are certainly going to melt faster in the coming decades. Monitoring and research are imperative.

11. Recommendations

11.1 Water availability per capita is reducing with time. Climate change poses further threats by way of glacier melting, frequent events of higher magnitude floods and longer duration droughts. Monitoring and research in these fields and preparation of adaptation programs should be taken up more seriously.

11.2 Transfer of water from ample summer flows to the winter lean period flows is essential. Build storage dams on Indus, Neelum and Swat rivers to meet the future needs.

11.3 Storage dams and recharge dams can improve the water availability situation in Balochistan. These should be built on priority and drip irrigation should be promoted.

11.4 Small and medium size dams should be built in areas outside the integrated irrigation system to meet the local needs. Drip irrigation projects should be implemented in their command areas.

11.5 Hill torrents areas have large potential of improving water availability. Delay action dams, water disposal and irrigation systems as well as drainage of surplus flows to the Indus should be implemented. In this regard D.G Khan area hill torrents should be takenup on priority.

11.6 Sindh has flat topography. Surface drainage projects along with improvements of existing drainage infrastructure are urgently needed.

11.7 Within Pakistan, Punjab being one of the upper riparian provinceshould include enough measures to satisfy Sindh, a lower riparian province, to deliver its share as per Water Apportionment Accord of 1991. Similarly Sindh being upper riparian for Balochistan, the required measures should be put in place to ensureBalochistan to get its due share as per Accord 1991.

11.8 Improve the ineffective water governance.The CCI has more or less fallen into disuse over the years with no one showing much interest in its operation since the 1970s.

11.9 Constitute Kalabagh Consensus Commission with authority to interact with all provinces and stakeholders to agree and prepare a revised plan of Kalabagh Dam for its timely implementation.

11.10 The management and Control of ground water should be taken up as a project, with a start and end point to be subsequently handed over to the operating organizations in the provinces.

11.11 Create conducive environment for effective water conservation practices;

11.12 Management of population explosion is urgently required in view of the free fall of per capita water availability of water.

11.13 Considering the ever increasing scarcity of water and with climatic changes, the supply and demand side water management are imposed options to be given due attention for action.

11.14 With all our short-comings, we still are very lucky nation to have the IndusWaterTreaty of 1960 and the Water Apportionment Accord of 1991. We should divert all our energies to make sure that these agreements are implemented in original letter and spirit.

11.15 We should modify the design criterion of equitable water distribution systems to be based on actual ground conditions and crop water requirements to bring more areas under irrigation.

11.16 The most important task should be to make rigorous studies for the preparation, prioritization and scheduling of all above recommendations and devise workable financial plans for their implementation.

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GROUNDWATER ENVIRONMENT AND EVALUATION OF LONG-TERM SUSTAINABILITY OF THE AQUIFER UNDER LAHORE

Dr. Muhammad Basharat[1]

The Lahore city, capital of Punjab, Pakistan, has expanded almost double area-wise in the last 12 to 15 years. The total area of the Lahore District is 1772 km^2 and the estimated population is 8.83 million,while 84% of the population resides in Metropolitan city area. Annual groundwater withdrawal is about 1161 MCM. Currently, the recharge to groundwater is estimated as 1013 MCM (including inflows from boundaries), in comparison to abstraction of 1161 MCM. Thus, recharge/inflows to the aquifer are less by about 15% as compared to the groundwater abstraction.There is continuous reduction in recharge, which is mainly caused by desiccation of the Ravi River and land use change to urbanization. Unregulated abstraction, without any recharging efforts and surface supplies have led to an annual watertable depletion rate of 0.57 to 1.35 m. Maximum depth to watertable reached to 45m in 2011.In addition, the quality of shallow groundwater layer has also deteriorated over the years.

The sustainability of the aquifer and the associated water supply in the Lahore district is evaluated under the project Enhancing the groundwater management capacity in Asian cities through the development and application of groundwater sustainability index in the context of global change supported by Asia Pacific Network and executed by Asian Institute of Technology (AIT), Bangkok, Thailand, using the methodology of Deriver-Pressure-State-Impact-Response (DPSIR). In total, nine Asian countries (one city each) participated in the project.The groundwater sustainability infrastructure index (GSII) was calculated and ranked into five classes: GSII for highly sustainable rank being > 900 and for non-sustainable rank being < 300. The GSII for the Lahore District is 706, i.e. it falls just at the bottom of sustainable range. This suggests that overall situation of groundwater sustainability infrastructure' in Lahore cannot be rated as very commendable. Therefore, significant devotions are needed to achieve the goal of groundwater sustainability'. In addition to the allocation of surface supplies to the city, the major chunk of improvement in sustainability can be achieved by addressing two out of five

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components of the GSII. These are Policy and Legislation' and Stakeholder's Participation'.

1. INTRODUCTION

Lahore is the capital of the Pakistani province of Punjab (Figure1) and the second largest and metropolitan city in the country. With its proximity to district of Kasur in the South and Sheikhupura district in the North-west, the district area is 1,772 km^2 and its urban area comprises largely of converted agricultural lands. Lahore has expanded almost double area-wise in the last 15 to 20 years. According to the 1998 population census, there were 6318745 persons, and the population density was 3566 persons per km^2. Among this urban population was 82.44% and rural population was 17.56%. During 2007-08, physical access to drinking water within the dwelling was available to 98% and improved sources for drinking water were used by 99% of the residents (Punjab Development Statistics, 2012). The estimated population of Lahore district (including rural population) is 8.83 million as on 31-12-2011 (Government of Punjab, 2011),while 84% of the population resides in Metropolitan city area (Government of Pakistan, 2011).

Lahore is also the second largest financial hub of Pakistan and has industrial areas including KotLakhpat and the new Sundar Industrial Estate (near Raiwind). The local economy is also enhanced by Lahore's historic and cultural importance. Being the capital of the largest province in Pakistan brings the city one of the largest development budgets in the country. It is also the most advanced in terms of infrastructure, having extensive and relatively well developed road links to all major cities in Punjab and Khyber Pakhtunkhwa (KP), a rail link with India and the province's biggest international airport. In case, the relations between India and Pakistan get improved, and the consequently the trade is accelerated, it will be the biggest trade route, through the Attari-Waga border crossing.

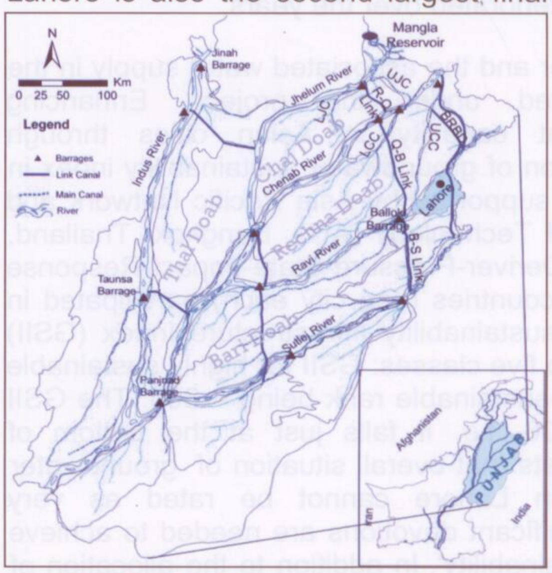


Figure 1: Lahore city and district boundary on the map of Pakistan.

1.1. CLIMATE

The climate of the Lahore region is characterized by large seasonal variations in temperature and rainfall. Mean annual reference crop evapotranspiration (ET_O) at Lahore is 1649mm. Mean annual temperature is about 24.3°C ranging from 33.9°C in June to 12.8°C in January (Pakistan Meteorological Department, 2006). The hottest month is June, where average highs routinely exceed 40 °C, highest temperature observed is 48.3°C, recorded on May 30, 1944, and the lowest recorded is –1°C, observed on January 13, 1967. The wettest month is July, with heavy rainfalls and evening thunderstorms with the possibility of cloudbursts. Thirty years normal (1971-2000) annual rainfall at Lahore is 712 mm. About 75% of the annual total falls between June and September(Basharat and Rizvi, 2011),

1.2. SURFACE WATER REGIME

The general altitude of the area is 208 to 213 m, above mean sea level (amsl). The area slopes towards the south and south-west, at an average gradient of 1 in 3000. The upper most part of the Bari Doab is now Indian Territory, after partition, but being the integral part to the Lower and Central Bari Doab provides natural route for the regional groundwater flow. The irrigation system is present in the area since 1879, with the construction of the first weir-controlled perennial irrigation channel; the Upper Bari Doab Canal (Pakistan National Committee of ICID, 1991), off-taking from the river Ravi at Madhopur (now in India).

But, after the Indus Water Treaty (IWT) of 1960 between India and Pakistan, India stopped the flows of eastern rivers (Sutlej, Beas and Ravi). In order to relieve this shortage, Bambawala-Ravi-Badian-Depalpur (BRBD) link canal was constructed (4000 cusecs), which is fed by Upper Chenab Canal off-taking from Marala Barrage, is now providing canal water to the command area of Upper Bari Doab Canal (now called Central Bari Doab Canal, CBDC) and Upper Depalpur canal. The irrigation distribution system consists of Lahore Branch (403 cusecs (cfs)), KhairaDisty (141 cfs), Butcher Khanadisty (244 cfs) irrigates agricultural lands of Lahore district. The adjoining Kasur districtis also fed by Main Branch Lower (1591 cfs) directly off-taking from BRBD Canal.In addition to BRBD Canal on the East, Ravi River on the north-west was once the major recharge source (very occasional flows, nowadays). Discharging boundaries are Beas drainage channel on the south and again the Ravi River in the west. However, these discharging boundaries only function in the form of surface runoff during heavy rainfalls; no groundwater discharge is possible due to excessive groundwater depletion in the area.

1.3. HYDRO-GEOLOGIC CONDITIONS OF THE AREA

The area is a part of a flat alluvial plain known as the Indus Plain. The soil profile comprises lean clay and silky clay,it extends generally from 4.5 to 11.5 meter below the natural surface level (NSL).Study of the lithologic logs of 149 test holes (600´ to 1000´ depth) and 28 test tubewells (102´ to 356´ depth), carried out in 1954 (Greenman et al. 1967), indicates that Bari Doab consists of consolidated sand, silt and silty clay, with variable amounts of Kankers. The sands are fine to medium grained and sub-angular to sub-rounded, very fine sand is common; the medium sand is proportionately higher in lower strata of Bari doab. Except for a few local lenses, a few feet thick, beds of hard rock, compact clay are rare in the area. Sheikh (1971) reported specific yield values ranging from 22 to 35%, with an average of 26.3%. In spite of the heterogeneous composition, the aquifer is highly transmissive in which groundwater occurs under watertable conditions. However, the lithology of the alluvium shows the heterogeneous character in vertical (depth wise) and transverse directions and random distribution of clay zones (Greenman et al., 1967). During the hydrogeological investigations conducted in 1954 in Bari Doab, 19 test holes were located in the north-eastern part of the Doab. Of these, only three test holes namely BR 1A, BR 6 and BR 7 (falling in Lahore district, Figure 2) reached Precambrian basement rock at 1252, 1021 and 928 feet, respectively (WAPDA, 1980).

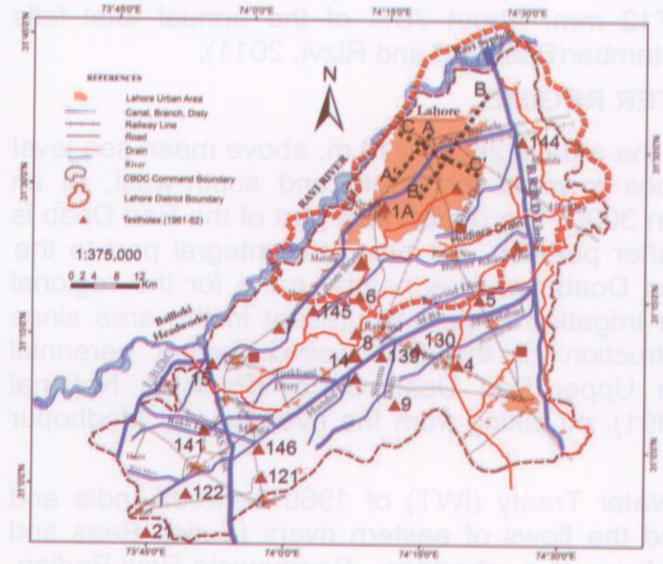


Figure 2: Location of the test holes and test wells (1961-62), and geologic x-sections.

1.4. GROUNDWATER FLOW AND QUALITY

On regional scale, the groundwater flow is mostly parallel to river network i.e. in north-east to south-west direction. However, due to local variations in natural surface elevations, discharge and recharge patterns, depth to watertable vary considerably in the area. Particularly this is true for the area under Lahore i.e. as mentioned earlier the maximum depth to watertable has gone beyond 45 m depth, due to heavily concentrated pumping by tubewells installed by WASA of LDA and private housing societies for piped supply to the local population, and individual pumping for houses and business. In addition, some particular industries have high consumption of groundwater, e.g. the beverage industry.

In general, the groundwater lying at deeper depths is of good quality as compared to the shallow groundwater. The deep groundwater quality data of 1961-62 has revealed that a strip of about 10 km wide between Pattoki and Chunian starting from Raiwind and ending at about the middle of Okara and Sahiwal has the highly saline groundwater. The deep groundwater in Raiwind area is highly saline (up to 9000 ppm) up to depths of 110 m. In the wake of induced groundwater hydraulic gradient, from Raiwind to Lahore (due to excessive pumping in Lahore), it is likely that saline groundwater may start intruding towards fresh groundwater, however, this may still take another about 50 years, to emerge a serious saline intrusion issue. It is because, regional groundwater flow velocities are low: of the order of 1 to 2 km/100-years, due to mild surface and groundwater gradient (Basharat and Tariq, 2013).

2. METHODOLOGY

The Deriver-Pressure-State-Impact-Response (DPSIR) framework, developed by Organization for Economic Co-operation and Development (OECD, 1994), is a causal framework for describing the interactions between society and the environment.Pandey et al. (2010) explains specifically with respect to groundwater environments that ***Drivers*** refer to fundamental processes in society which drive activities having a direct impact on the groundwater environment. ***Pressures*** are referred as direct stresses brought by expansion in anthropogenic system and associated interventions in the natural environment. ***State***describes the condition and tendencies in the groundwater environment and its trend, induced mainly by human activities. ***Impacts*** deal with effects on the anthropogenic system and on the environment itself due to changes in the state of natural environment, and contribute to the vulnerability of both natural and social system.However, the vulnerability to change varies between different systems depending on their geographic, economic, and social conditions; exposure to change, and capacity to mitigate or adapt to the change. Finally, ***Response***consists of actions of the anthropogenic system to modify/substitute the drivers, to reduce/prevent pressure, to restore/influence state and mitigate/reduce the impact. **Responses** address issues of vulnerability of both people and the environment, and provide opportunities for enhancing human well-being by means of sustainable use of groundwater resources.The Groundwater Sustainability Infrastructures Index (GSII) of the Lahore District is calculated based on its five components and 24 indicators, as explained below.

A set of indicatorsthat reflect the underlying groundwater environment were selected based on extensive literature review regarding the population, aquifer and water supply system in the city. The indicators were structured and analyzed under DPSIR framework developed by OECD. A few indicators were added/deleted based on the local groundwater environment and water supply management setup, in each of the selected cities, after discussion during the two 2-days workshops held in AIT, Bangkok, in January and July, 2014, with the support from the Asia Pacific Network (APN), through project **CBA2013-06NSY-Shrestha.**The discussions lead to make the framework applicable to cities with diversity of hydrogeological and management settings. The groundwater environment and the societal setup of the water use and governance in Lahore city is discussed here under, with reference to DPSIR (Figure 3).

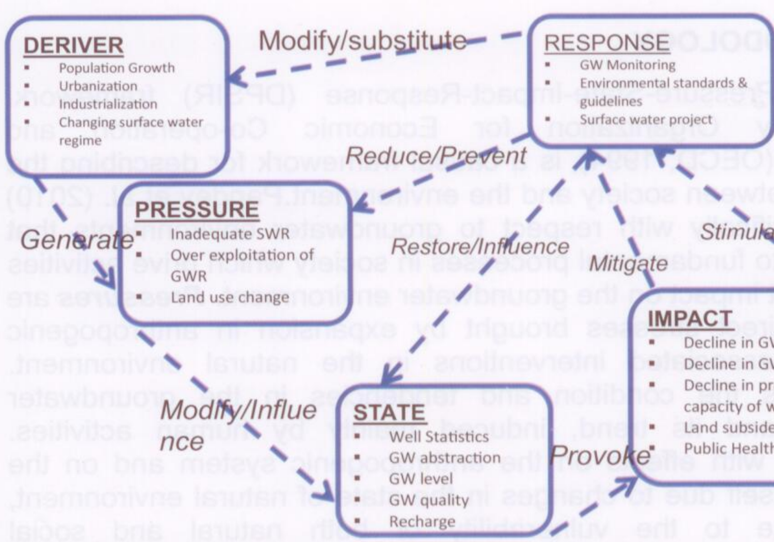


Figure 3:DPSIR framework, modified after Pandey et al. (2010), for Lahore.

2.1. GSII COMPONENTS AND INDICATORS

The final sustainability index representing the groundwater environment is composed of five components, further comprising of 24 indicators in total. The five components are discussed as under.

2.1.1 Monitoring of Stress on Groundwater [MSGw]

Data collection and monitoring with satisfactory space and time coverage enable a long-term understanding of groundwater availability and anthropogenic effects on the groundwater resources. Monitoring data if used in parallel with mapping and modeling reflect a complete picture of the aquifer conditions needed for a proper and full assessment of the resource and benefit the decision-making process for protecting groundwater environment. Current status of groundwater resource availability, density of observation wells, frequency of groundwater observations, total groundwater abstraction as percentage of recharge, groundwater quality parameters monitored, concentration of most frequently observed and significant parameters, and rate of land subsidence monitoring in the study area is discussed and appropriate rating, based on actual values according to the rating criteria finalized.

2.1.2 Knowledge Management [KM]

Knowledge management through evaluation, analysis and usage of available data and information and its compilation, integration and dissemination to the stakeholders helps facilitate groundwater resources evaluation, planning, and management. The sharing of knowledge helps build trust among the stakeholders to achieve the goal of groundwater sustainability.

2.1.3 Policy and Legislation [P&L]

The interventions implemented through Policy and Legislation (P&L) are considered as a part of whole groundwater management plans. The P&L are aimed at ensuring that distributions, rate, magnitude and duration of groundwater extractions and quality of groundwater resources are within the limits that are technically, socially, environmentally and politically acceptable.

2.1.4 Stakeholders Participation [StP]

The stakeholders like groundwater developers, private and public users, conservationists, water managers, administrators and policy-makers, etc. have wide-ranging positions about groundwater use, as a result of their different interests and objectives. StP at all stages, i.e. development, approval and implementation of the groundwater management plans, is important for sustainable use of groundwater resources.

2.1.5 Institutions and Capacity [InC]

Institution and capacity refers to provision for authority to look after groundwater development and management, legal framework and control mechanism, and adequate capacity (availability of human resources, information and education) to carry out its duty. The institutions empowered with sufficient resources (for daily business and research activities), adequate policies, and laws and means to apply and enforce them – is necessary to conduct groundwater management activities.

2.2 COMPUTATION OF GROUNDWATER SUSTAINABILITY INFRASTRUCTURE INDEX (GSII)

The sustainability value for each component is calculated based on aggregated score of the indicators representing the component. The selected indicators encompass both qualitative and quantitative measures, depending upon their respective importance, a weight (W) ranging from 1 – 5 was assigned to each of the indicators. Each indicator was evaluated for the study area, based on secondary data or the fresh survey or subjective judgment. The values so found were assigned rating (R, from 1 – 10) and multiplied with weightage of respective indicator, the total score was obtained by summation of products of W and R. This was taken as the Groundwater Sustainability Infrastructure Index (GSII), that has been classified into ranges i.e.: **highly sustainable**, if the index values > 800; **sustainable** if index ranges from 600 to 800; **medium sustainable** if index falls between 400-600; **less sustainable** when the value ranges from 200 to 400; and **non-sustainable** when the GSII is less than 200.

3. RESULTS AND DISCUSSIONS

3.1. DRIVER

Population growth, conversion of agricultural land use to urbanization and increase in industries are main drivers exerting pressures on the groerndwat environment, as explained below.

3.1.1. Population growth

Urban growth in Lahore continues to ascend. Urban population was 3.54, 6.32 and 8.83 million, in 1981, 1998 and 2011, respectively (Table 1). That is urban population increased to more than double within a period of thirty years. With its explosive growth which is under way at more than 2% per year, this trend is projected to continue for several decades, because the government does not have any planning to impede this urban growth rate by providing standard education and modern living facilities in small cities and rural areas.

3.1.2. Urbanization:

Conversion of fertile agricultural lands to populous urban areas with either asphalt roads or concrete floors is being undertaken without any proper policy. Urban area was 7.8% in 1980, 54.3% in 2000 and 70.5% in 2010 (Table 1), thus a 2% growth rate per year in urbanization. It is because much of the population shift involves movement towards the metropolitan city, from the villages, small towns and other cities in the province, in search of quality education, jobs and lavish life style.

Table 1: Summary of DPSIR indicators in 1981, 1998 and 2011.

	Indicators	1981	1998	2011
Driver	Population growth within the district (area: 1772 km^2)	Population: $3.54x10^6$ Population density~1998 (persons/km^2) Annual growth rate[1]	$6.32x10^6$ ~3566 (1998-1981)3.4%	$8.83x10^6$ (estimated) ~4983 (2011-1998) 2.57%
	Urbanization within the district	Urban area[2] (in 1980):137.9 (km^2) (7.8%) Urban population[3]:$2.95x10^6$	(in 2000): 961.6 km^2 (54.3%) $5.14x10^6$	(in 2010) 1249.7 km^2 (70.5%) $7.20x10^6$
	No. of registered industries[4]		In 2000: 1399[5]	In 2013: 3007[6]
Pressure	Inadequate surface water resources	Ravi inflows[7] 1922-1960: 7.0 MAF	1976-1999: 5.5 MAF	2000-2011: 1.2 MAF
		Surface water allocated since inception of irrigation system to agriculture lands in peri-urban areas is no longer available, due to land use change to urbanization.		
	Land cover change	Cultivated area[5] (in 1980):1634 km^2	(in 2000): 810.4 km^2	(in 2010): 522.3 km^2

[1]Exponential growth rate calculated using r = (1/t) x ln(Pt/P0); where Pt = population after t' years from the base period, P0 = base year population.

[2] Zaman and Baloch (2011)

[3]Pakistan Bureau of Statistics, Statistics Division, Government of Pakistan, G-9/1, Islamabd.

[4]An establishment is said to be registered under Section 2 (J) of Factories Act 1934, (Amended in 1973) if ten or more workers are working on any day of the preceding twelve months and in any part of which manufacturing process is being carried on with or without the aid of power.

[5] Bureau of Statistics (2005)

[6] Bureau of Statistics (2012),

[7] Basharat et al. (2014)

	Indicators	1981	1998	2011
	Over-extraction of GW resources	Extraction[1]: 1987; 1451 MLD (or 530 MCM/year)	2000; 1815 MLD (or 663 MCM/year)	2010; 3181 MLD (or 1161 MCM/year)
State	Well Statistics [2](only WASA wells)	Numbers: 1987; 200	2000; 316	2010; 467
	GW extraction	Extraction[10]: 1987; 1451 MLD (or 530 MCM/year)	2000; 1815 MLD (or 663 MCM/year)	2010; 3181 MLD (or 1161 MCM/year)
		Thirty years normal (1971-2000) rainfall in Lahore is 712 mm/year = 1262 MCM over an area of 1772 km^2		
	Depth to groundwater	1987: 7.6 – 19.8 m	2000: 10.7 – 32.0 m	2010: 12.2 – 44.2 m
	GW quality	Upper layer of groundwater is being rapidly polluted with disposal of untreated industrial effluents as well as leakage form sewerage system. Comparison of TDS in groundwater samples with the previous studies shows that the quality of groundwater is deteriorating with time. TDS and As contents are also less in deep wells.		
	Recharge	Groundwater recharge is decreasing due to Ravi River desiccation, ending of canal irrigation of the fields (now converted to urban area) and rainfall recharge reduction due to land use change to urbanization. As a whole there is drastic reduction in recharge. Currently, the recharge to groundwater is estimated as 1013 MCM (including flows from boundaries), in comparison to groundwater abstraction of 1161 MCM on annual basis. Thus, recharge/inflow to the aquifer is less by about 15% as compared to the groundwater abstraction.		
Impact	Decline in GW level (m/year)	1973-1980: 0.60	1980-2000: 0.65	2000-2011: 0.79
	Decline in GW quality	Deterioration of groundwater quality is being constantly faced; therefore, WASA and private groundwater users have increased bore depths from 150 to 230 m, in the past few years.		

[1] Basharat and Rizvi (2011)

[2]Represents only about 55% groundwater pumping.

	Indicators	1981	1998	2011
	Decline in production capacity of wells (l/s)	Six tubewells out of 15 were reported as having reduction in specific capacity of more than 50 % (NESPAK and Binnie& Partners, 1987). Wells yields reduce, depending upon groundwater depletion; therefore, tubewells boring depths are successively increased to get the desired discharge.		
	Land subsidence	No monitoring and no land subsidence has been noticed till now		
	Public health	Groundwater quality is under increasing threat due to domestic and industrial disposal into surface drains, which ultimately enters into Ravi, at various points. This effluent ultimately contributes to groundwater recharge, thus, posing a permanent threat to the public.		
Response	Groundwater monitoring	Proper groundwater monitoring was started in 1960. Continuous, once a month monitoring is carried out by WASA in urban areas, and twice a year, in irrigated areas by Irrigation Department. But, the data sharing is tedious.		
	Environmental standard and guideline	The provisions of these laws, to protect environment, had never been implemented due to deficiencies in legalities, non-application of fines, lack of public and official ignorance of environmental issues, and also political commitments etc. The sectorial legislations have totally failed to pay their even limited role in environmental protection.		
	Plan for construction of a lake on Ravi river	About three years earlier, Government of Punjab announced construction of a lake on the Ravi River, in order to raise and maintain rapidly decreasing groundwater level of the City.But, now it has been dismissed in favour of a new scheme Ravi River Development Front', which is a new city along Ravi, including a 36 kilometre long concrete channel for the Ravi River. With this idea of river course development, no major attention has been paid to depleting groundwater under the city, except creating ponding conditions in the river after its channelization.		

3.1.3. Industrialization

Lahore is the second largest financial hub of Pakistan and has industrial areas including KotLakhpat and the new Sundar Industrial Estate (near Raiwind). There were 1399 registered industries in Lahore in year 2000, which increased to 3007 in 2013 (Table 1). A major industrial trend in Lahore has shifted in recent decades from manufacturing to service industries.

3.1.4. Changing surface water regime:

The biggest setback due to the loss of water use of one of the three eastern rivers (Ravi) is being faced by the Lahore, depriving from major sources of recharge to the aquifer. Construction of Thein Dam in 2000 on Ravi is having a pronounced impact on attenuating floods and that is why no substantial floods have been observed at Balloki barrage since 1997. After 2000, only a maximum discharge of 30-40 thousands cusecs was observed in the Ravi River. In future, except such small flood events, no regular flows of appreciable amount are expected in the reach except that of Marala Ravi (MR) link releases from Marala Barrage.

3.2. PRESSURE

Pressures are referred to as direct stress brought by expansion in anthropogenic system and associated interventions in the natural environment. Pressure on Lahore's groundwater environment is increasing due to over-exploitation, absence of any surface water allocation and rapid land use change.

3.2.1. Inadequate surface water resources:

Ravi River was once associated as an identity of Lahore. After the partition of the area between India and Pakistan, the annual flows into Ravi decreased gradually from 7.0 MAF before IWT (1922-61) to 5.52 MAF, before the Thein Dam, and finally to about 1.2 MAF, after the Thein Dam (Figure 4). The reality is that the Ravi no longer flows by Lahore; rather it has become an effluent disposal drain (Figure 5). Thus, instead of recharging contribution to groundwater, it has now been forced to pollute the aquifer.

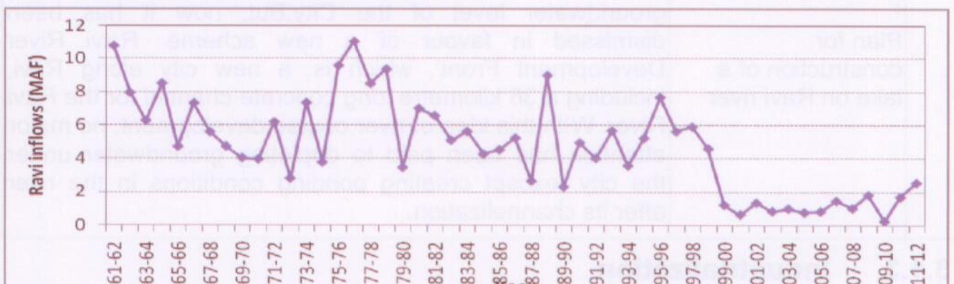


Figure 4: Gradual desiccation of Ravi River, after the completion of Thein Dam.

Figure 5: Ravi River without freshwater, but sewerage and solid waste flowing.

3.2.2. Over exploitation of groundwater resources:

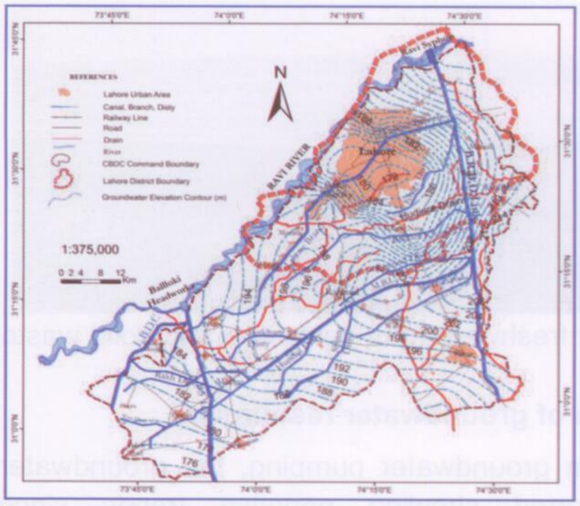
With successive increase in groundwater pumping, the groundwater balance of the city started showing negative trends since 1970's.Basharat and Rizvi (2011) developed groundwater elevation contours (Figure 6) that show a big depression (about 36m deep, within a radius of about 25 km) under the Lahore city, this is successively caused by intensive pumping from, and lack of recharge to the aquifer. The groundwater from the surroundings is flowing towards urban areas of Lahore. The area around Raiwind, with high salinity groundwater (about 9000 ppm), is lying at higher elevation and currently behaving as a groundwater divide.Thus, with further groundwater depletion in Lahore city, there are likely chances of saline intrusion, from the saline groundwater in Raiwind area.

3.2.3. Land use change

Surface water allocated to agriculture lands in peri-urban areas, since inception of irrigation system, is no longer available, due to land use change to urbanization. Thus, consistent reduction in recharge to groundwater from Ravi flows and land use change are adding major contribution towards negative water balance of the underlying aquifer.

3.3. STATE

State describes the condition and tendencies in the groundwater environment and the overall trend as a result of pressure brought by drivers. This section analyses state of groundwater environment from the perspective of number of wells, groundwater extraction volume, groundwater levels and quality and annual recharge/inflow into the aquifers under the Lahore.



3.3.1. Well Statistics

Depth to watertable prior to irrigation system was about 5-6 meters in the present urban area. The total pumpage including private wells was 164 cfs. Historical data about abstraction and number of tubewells installed by WASA only and depth to watertable for the Lahore city is given in Table 2. In addition to these reported wells by the government, there are privately owned agricultural tubewells, above 5000 in number. These are used for irrigating crop lands during canal water shortage.

Figure 6: Groundwater elevation contours (2009), in the CBDC (Basharat and Rizvi, 2011).

Table 2: Historical ground water development in Lahore city.

Description/year	1987	2000	2010
Depth to Watertable (m)	7.6 – 19.8	10.6 – 32.0	13.7 – 44.5
No. of Tubewells	200	316	467
Total Abstraction (mgd)	320	400	696
Population (million)	3.5 millions	4.83 millions	7.4

3.3.2. Groundwater abstraction:

In 2010, there were about 467 tubewells operated by WASA. Including all other consumers i.e. cantonment board area, private housing societies, industries and individual groundwater users, total groundwater withdrawal was about 1300 cfs (Basharat and Rizvi, 2011). With this groundwater withdrawal, annually pumped groundwater volume is 1161 MCM (0.94 MAF). WASA is supplying about 333 lpcd water (Iftikhar, 2007) to the area served. Using this water consumption rate and population of 8.83 million in Lahore District; total annual water consumption comes out to be 1093 MCM (0.885 MAF). Thus, including industrial consumption, the annual pumping volume of 1161 MCM (0.94 MAF) seems to be a reasonable estimation for the pumping from the aquifer.

3.3.3. Temporal impact on groundwater quality:

Earlier, almost all of the municipal waste of Lahore city was dumped into the River Ravi. However, nowadays LDA has allocated three scientifically designed solid waste disposal sites. Even now, Ravi River is being polluted with remarkable industrial and municipal wastewater, via untreated effluent disposal (Naqvi et al., 2012). The flow in the River Ravi is highly variable which has reduced up to 1,357.7 MCM (1.1 MAF) per annum, consequently, at the upstream of Balloki head, the river has mostly discharge of wastewater. As the enough data about the extent of groundwater quality deterioration of the upper shallow layer is not available, the same has been indirectly highlighted with the help of surface drainage discharge and its deteriorating quality as explained below:

(i) Ravi River Pollution: There are 15 main drains in Lahore and Sheikhupura (discharge capacity of about 70 cumecs), which are discharging municipal and industrial wastewater directly into River Ravi without any treatment. At various locations dumping of solid waste directly into the drains is causing reduction of their capacities and source of pollution and environmental hazard (Aftab, 2005). Due to Ravi River desiccation and untreated discharge of municipal and industrial waste into the river, it is now observed more as a drain, particularly during non-monsoon season. The Industrial areas adding wastewater in river Ravi are: *Kalashahkaku; Gulberg industrial area; KotLakhpat; and New Sundar Industrial Estate.*

It is very occasional that India spills excess flows downstream, during floods, and the river is washed away of its year round pollution. However, this extra flood water also helps the pollution to travel down in to the aquifer by providing extra solvent and head needed for solute transport to join the aquifer for ever. Hassan et al. (2013) highlighted that the untreated drainage disposal into Ravi River is deteriorating the quality of river water as well as the underlying groundwater; the severity of the situation is maximum at Shahdra Bridge. Quality of drain water entering the river is also deteriorating with passage of time (Table 3).

Table 3: Pollution load entering the Ravi River (Hassan et al., 2013).

Sr. No.	Drain	Environmental Protection Department (EPD)		Irrigation Research Institute (IRI)	
		Discharge (cfs) (2008)	TDS (ppm) (2008)	TDS (ppm) (May, 2011)	TDS (ppm) (March, 2012)
1	MehmoodBooti	20.8	312	775	1117
2	Shad Bagh	139.0	520	663	1067
3	Farrukh Abad	219.0	1000	1088	1627
4	Budha Ravi	42.0	690	1006	1100
5	Main outfall	193.0	560	627	1154
6	Gulshan-e-Ravi	246.5	660	897	1035
7	BabuSabu	270.7	660	760	1135
8	Hudiara	535.7	1020	1197	1506

(ii) Hudiara Drain: The Hudiara drain has a total length of 98.6 km of which 44.2 km lies in India and the remaining 54.4 km in Pakistan territory (Afzal et al., 2000); it joins the River Ravi at about 5km downstream of ThokarNiazbeg. It enters Pakistan loaded with pollution from India. The drain carries mainly industrial and agricultural waste from both India and Pakistan. Hudiara drain carries about 5 cumecs (177 cfs) of discharge and it flows round the year (Basharat and Rizvi, 2011), carrying untreated sewage and chemical waste water of 104 industries. There are around 100 industries located adjacent to the Hudiara drain on the Indian side, so it is already quite toxic when it enters Pakistan. Heavy metals such as Pb, Cu, Ni and Zn have been detected in Hudiara drain (DLR, 2007).

3.3.4. Recharge:

With the background of rapidly increasing abstractions, falling groundwater levels and future reduction in river recharge, two different groundwater model of the aquifer under Lahore were developed by NESPAK and Binnie& Partners (1988) and Alam (1994).According to the simulations, Ravi River was receiving seepage from the aquifer over most of its length in 1960. By 1987, the river was a principal source of recharge and was feeding the aquifer. Alam (1994) estimated the abstractions for the years 2000, 2010 and 2020 as 26.4, 36.4 and 38.3 cumecs (932.3, 1285.4 and 1705.6 cusecs), respectively;and the cone of depression was simulated to drop to 29.8, 35.8, 41.8 and 57 m in the years 2000, 2005, 2010 and 2020, respectively. Later through a post audit study (Alam et al., 2012) of his predictions using actual data of groundwater levels by WASA, it was observed that the prediction for year 2010 was almost accurate regarding maximum groundwater depletion (44 m in 2009).

NESPAK and Binnie& Partners (1988) with a model area of 1110 km^2, indicated a mean direct rainfall recharge to the aquifer on long-term average basis i.e.: Rural areas = 38 mm/year; suburban area = 22 mm/year; and urban area = 16 mm/year. Further, irrigation and rainfall recharge were taken as 40 and 38 mm/year, therefore, total recharge rate in irrigated areas was 78 mm/year. Thus, the recharge from the area outside of the model developed by NESPAK and Binnie& Partners (1988) is 1.64m^3/sec (57.93 cusecs). After adding the recharge for the NESPAK model area (1110 km^2) and the remaining irrigated area of Lahore district, the total recharge (including the inflow from boundaries) is 32.13 m^3/sec, which is equivalent to 1013.3 MCM per year. Thus, currently groundwater abstraction is about 15% larger than groundwater recharge including groundwater inflows from the surrounding areas.

3.4. IMPACT

Impacts are changes in environmental functions affecting social, economic and environmental dimensions, which are caused by changes in the State of the system i.e. decline in groundwater levels and quality, decline in production capacity of wells, land subsidence and the impact on public health.

3.4.1. Decline in groundwater level

Basharat and Rizvi (2011) analysed DTW data of a few observation wells, in and around the urban area of Lahore. The depth to watertable near the Bhobattianchowk on Raiwind road increased from 9.2m in 1993, to 10.4m in 2003. But near to River Ravi adjacent to ThokarNiazbeg, the depth to watertable increased by 10.8 m during 1999 to 2009, this had been due to desiccation of Ravi River, particularly after the construction of Thein Dam in India. Similarly, in Mughalpura (city centre) the drop in watertable was 3.5m, over a period of six years. On the other hand, in the surrounding agricultural areas there is not any long-term aquifer depletion trend. The subsequent development of groundwater levels at selected representative tubewells in Lahore by WASA for the years 2003-11 is shown in Figure 7. The decline of groundwater levels (during the last 8 years) in Lahore city, ranged from 4.61m (Gulistan Colony) to 10.85 m (Khizer Abad Mosque), which is equivalent to an annual groundwater depletion of rate of 0.57 to 1.35 m. The maximum depth to watertable reached to 45 in 2011.

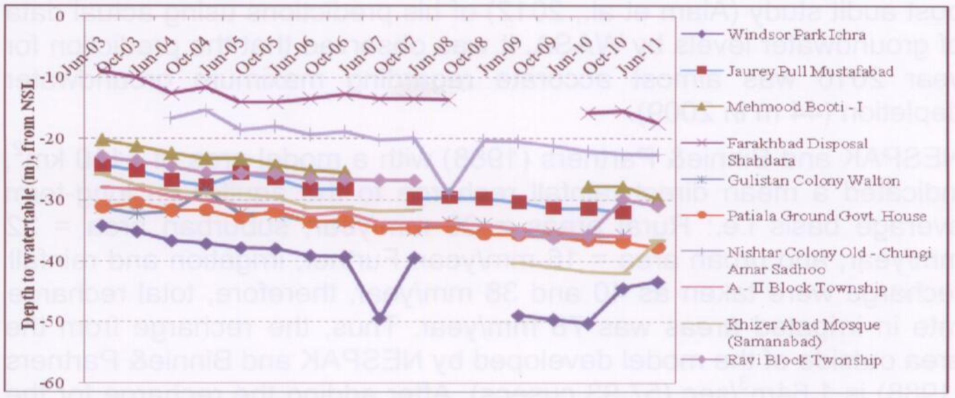


Figure 7: Groundwater trends in Lahore city (2003 – 2011).

3.4.2. Decline in groundwater quality:

According to an interim report by Pakistan Institute of Nuclear Science and Technology (PINSTECH) of Pakistan Atomic Energy Commission (PAEC) and WASA (2005), 43 samples were collected in the first set from deep wells having screen normally from 80 to 200 m and shallow pumps up to 40m depth. In the second sampling campaign about 100 samples were collected. Comparison of TDS in groundwater samples of the study with the previous studies shows that the quality of groundwater is deteriorating with passage of time(Table 4). The report also compares quality of groundwater by comparing Arsenic levels with WHO‘s highest desirable level (HDL) and maximum permissible level (MPL), as reproduced Figure 8.It is evident that As contamination is present in the groundwater, with considerable quantities above the WHO standards. However, the deeper wells have less As contamination as compared to the shallower wells. PAEC and WASA (2005) narrates that the concentration of nitrate in shallow and deep groundwater varies from 10 to 188, and 9 to 41 mg/l, respectively. Increase in nitrate concentration was reported for both the shallow and deep groundwater sources, and the concentrations are beyond the WHO limit of 50 mg/l in majority sources, with less nitrate concentration deep wells. It means the nitrate is derived from presently active surface sources.The quality of shallow water has deteriorated over the years and therefore, the deep aquifer is under the threat of pollution from the top shallow groundwater.

Table 4: Comparison of groundwater quality over time (PAEC and WASA, 2005).

TDS (mg/l)	NESPAK (1990) (88 samples)	PINSTECH (2000) (> 200 samples)	PINNSTECH (2005) (152 samples)
< 500	16%	12%	19%
501-1000	63%	40%	40%
1001-1500	17%	37%	21%
> 1500	4%	11%	20%

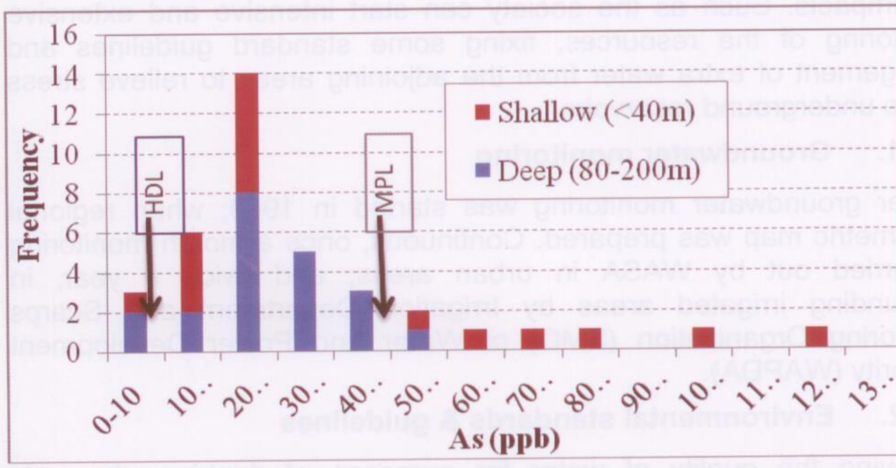


Figure 8: Frequency histogram of Arsenic in groundwater (PAEC and WASA, 2005).

3.4.3. Decline in production capacity of wells

In highly depleted areas, successive deepening of wells is required in order to pump good quality groundwater and maintain required discharge of the well.

3.4.4. Land subsidence

No single information is available, because no monitoring is being carried out for the subsidence phenomenon. No publication/study is available regarding the aspect in the Lahore city, even that groundwater depletion is at alarming rate and maximum depth to groundwater of 45m has been reached.

3.4.5. Public Health

Groundwater is sole source of water supply in the city. However, its quality is under increasing threat due to domestic and industrial disposal into surface drains, which ultimately enters into Ravi, at various points. This effluent ultimately contributes to groundwater recharge, and these surface flows are used for irrigation, further downstream. Therefore, the degradation of surface and groundwater quality is deemed to have badly impacting the human health.

3.5. RESPONSE

Responses are the policy actions which are directly or indirectly triggered by the perception of impacts and which attempt to prevent, eliminate, compensate or reduce their consequences. Responses can come from different levels of the society or the governments. These Responses can in turn influence trends in the Drivers, Pressures, State and Impacts. Such as the society can start intensive and extensive monitoring of the resources, fixing some standard guidelines and arrangement of extra water from the adjoining areas to relieve stress on the underground reservoirs.

3.5.1. Groundwater monitoring

Proper groundwater monitoring was started in 1960; when regional piezometric map was prepared. Continuous, once a month monitoring is carried out by WASA in urban areas, and twice a year, in surrounding irrigated areas by Irrigation Department and Scarps Monitoring Organization (SMO) of Water and Power Development Authority (WAPDA).

3.5.2. Environmental standards & guidelines

Improving the quality of water for purposes of drinking, domestic consumption, personal hygiene and certain medical situations has always been among the top priority goals of the Government of Pakistan. The *Guidelines and Criteria for Quality Drinking-Water* published by World Health Organisation (WHO) (1996, 2004) have made it possible to review, evaluate and further improve the quality of water in Pakistan against these standards. Through a combination of lectures, discussions, intense work sessions, and utilization of reading literature provided by WHO and Ministry of Health, quality standards for drinking water in Pakistan were finalized (Government of Pakistan, 2008). Pakistan Environmental Protection Agency has been establishment under section (5) of Pakistan Environmental Protection Act, 1997. The Agency may undertake inquiries or investigation into environmental issues, either of its own accord or upon complaint from any person or organization.

3.5.3. Surface water project

The Government of Punjab dismissed the construction of a lake on the River Ravi, in order to raise and maintain rapidly decreasing groundwater level of the City, in favor of Ravi River Development Front', which is a new city along Ravi, at Shahdara. This new city will be located along both banks of Ravi River, and entails building a 36 km long concrete channel for the Ravi River and developing a new city on its banks with green belts, parks and recreation areas. Under this project, a number of high quality residential schemes and colonies, educational institutes including colleges and universities, markets, trade centres, high rise plazas will be developed, on the acquired land of District Lahore and Sheikhupura, situated at both sides of the River Ravi. The project is likely to be completed in four to five years as per the desire of the Punjab Chief Minister. Also, the Ravi River will be cleaned as part of the project. There would be provision for waste water treatment according to NEQS. In the form of master planning (to be developed) and creation of lined channels and lake, provision of extra surface supply is also being thought. About 100 cusecs surface water was requested from irrigation department to be allocated for Lahore, from the BRBD canal. However, it was agreed to provide only 25 cfs canal water.

With this idea of river course development, no major attention comparable to the groundwater depletion issue of the city has been paid, except pounding of water within the river channel. This kind of business activity, without a major allocation of river water (at least 0.5 MAF) from Indus Basin Irrigation System, for water supply and additional recharge to the aquifer, is not expected to improve aquifer situation. Because, the additional amount of groundwater to be pumped for the residents of the new river city would be more than the additional recharge from the river channel. However, to save depleting resource of underground water, the LDA has initiated rainwater harvesting system, under which 39 points for collecting rainwater, at various appropriate locations, will be established and used to recharge the underground aquifer. In this regard two recharge wells have been announced for construction, on pilot basis.

4. RESULTS OF „GSII APLICATION IN LAHORE

The situation of groundwater sustainability infrastructures' in Lahore District is summarized in Table 5 and discussed hereafter through an evaluation of the GSII, its five components and 22 indicators. The indicators are discussed both qualitatively (by describing the situation) and quantitatively (by indicator values). Afterwards, the component scores were computed (using indicator values), on decimal scale and discussed in terms of their contribution in overall GSII. The situation of each component in terms of achievement of groundwater sustainability was classified into four classes in a scale of 0 – 1 (0 being the worst and 1 the best): very poor (0.00), poor (0.25), acceptable (0.50), good (0.75) and excellent (1.0).

4.1. MONITORING OF STRESS ON GROUNDWATER

The aggregated score of the component based on decimal score i.e. out of a total score of 1.0 is 0.90 (Table 5), i.e. it can be rated as good to excellent'.Per capita groundwater resource availability in the form of recharge and regional inflows from surrounding areas is 114.8 m^3/year. Total groundwater withdrawal is of the order of 1300 cfs, leading to annually pumped groundwater volume of 1161 MCM (0.94 MAF).In contrary, annual recharge and groundwater inflow from surrounding areas is 1013.3 MCM. Thus abstractions are about 15% higher than groundwater water resource availability in the current scenario where a deep groundwater has developed under the urban area and its continuously expanding with passage of time.

Keeping in view the severity of the situation, Hydrology Cell of WASA observes water level fluctuations at about 115 wells (1987 report) on monthly basis, which is equivalent to 13 observation wells per 100 km^2. It includes: Static water level; dynamic water level; and discharge of tubewells where ever possible. The agricultural area in the surroundings is also being monitored bi-annually by the DLR of Punjab Irrigation Department as well as SMO of WAPDA. There is one observation after every five km, which is equivalent to four observation wells per100 km^2.

Groundwater quality data and studies are available, especially of the toxic elements and heavy metals. Data for groundwater quality monitoring of usual parameters is also collected for routine tests, e.g. general nutrients, organic matters, major ions, trace elements, microbial etc. Thus groundwater quality monitoring is sufficient to warrant any toxic elements. However, there is lack of prompt action, in case any abnormal values are found, e.g. Arsenic above the standards for drinking water quality. Over 70% of the samples (Ca, Mg, TDS, NO3-N, SO4, Mn, Mg) comply with the UN Standards for drinking water quality. However, no monitoring is being carried out for the subsidence phenomenon. No publication/study is available regarding the aspect in the Lahore city, even that groundwater depletion is at alarming rate. However, the aquifer strata mostly consists of fine, medium and coarse sand particles, except few lenses of clay. Therefore, chances of subsidence are mild.

Table 5: Groundwater sustainability infrastructure indicators, components and indicator values.

Component	Indicator No.	Indicator Name	Parameter Values calculated from the actual data	Weight (W) assigned (1 to 5)	Rating (R) to be assigned to each indicator based on actual value (lowest 1 and highest 10)	Ratings (R) [1-10]	WxR	Component score
Monitoring of stress on groundwater	1	Per capita groundwater resources availability (m^3/year)	Per capita ground water recharge: 115	5.0	>200=10; 100-200=7;40-100=5;<40 =2	7	35	0.90
	2	Density of groundwater observation wells (nos/100 km^2)	13 Observation wells / 100 km^2	5.0	>10 per100Km2=10;6 per100Km2=8; 4per100Km2=6;3 per100Km2=5	10	50	
	3	Frequency of groundwater observation	once per month	5.0	once/month=10; once/three months =8; once/six months =5; No monitoring =1	10	50	
	4	Groundwater quality parameters monitored (physical, chemical & microbial)	Yes	5.0	general, nutrients, organic matters, major ions, trace elements, pesticides, microbial= 10; general, nutrients, organic matters, major ions, trace elements=7;general, nutrients,3; none=1	10	50	
	5	Concentration of most frequently observed & significant pollution parameter [for e.g. (NO_3-N) (%age of sample that comply with WHO standard)]	Over 70% of the samples (Ca, Mg, TDS, NO_3-N, SO_4, Mn, Mg) comply the UN standards for drinking water quality	5.0	<70%=5; 70-80%=7; 80-90%=8 and >90%=10	7	35	
	6	Rate of land subsidence (mm/year)	Not detected	5.0	Not detected =10; D (< 1mm/yr =8; 1-3mm/yr =6; 3-5mm/yr. =4; > 5mm/yr. =1)	10	50	
Knowledge Management	7	Basic hydrogeological map of aquifers layers (minimum information is mapping of aquifer layers and their permeability/ hydraulic conductivity)	Aquifer parameters values and cross-sections available in detail	4.0	> 1:50,000=10; < 1:50,000 =6; none=2	10	40	0.90
	8	Zonation of groundwater potential areas (groundwater use point of view)	Exists	4.0	Yes =10; No =1	10	40	

Component	Indicator No.	Indicator Name	Parameter Values calculated from the actual data	Weight (W) assigned (1 to 5)	Rating (R) to be assigned to each indicator based on actual value (lowest 1 and highest 10)	Ratings (R) [1-10]	WxR	Component score
	9	Delineation of groundwater critical zones (groundwater protection point of view)	Exists	4.0	Yes =10; No =1	10	40	
	10	Existence of an unit for groundwater data compilation, storage, & management	A dedicated Directorate exists in WASA	4.0	unit exists (Rate in 3-10, subjectively); doesn't exist =1	8	32	
	11	Access to groundwater-related data/information	Data is available, after frequent requests	4.0	Access with cost =3-6; access freely 7-10, no data available =2	7	28	
Policy & Legislation	12	Groundwater management policy/action plan	So, so	4.0	Exists =10; Doesn't exist =1	1	4	
	13	Groundwater licensing (no. of license issued as % of total pumping wells)	Nil	4.0	<70-75%=5; 75-80%=7; 80-90%=8 and >90%=10	5	20	0.33
	14	Economic instruments in place (e.g. Groundwater abstraction and use charge)	7% consumers on volume based billing	4.0	Exists =10; Non-existence =4	4	16	
Stakeholders' Participation	15	Level of awareness (% of people aware about groundwater situation)	75 to 80 %	3.0	<70-75%=5; 75-80%=7; 80-90%=8 and >90%=10	7	21	
	16	Availability of community groundwater management organizations	Fair, e.g. ChangaPani	3.0	Excellent=10; very good=8; good=6; fair=5; poor=3	5	15	
	17	Gender inclusiveness in groundwater development and management (i.e., % of women participation in groundwater related organizations)	fair	3.0	Excellent=10; very good=8; good=6; fair=5; poor=3	5	15	0.58
	18	Recognition of 'stakeholder's participation' in policy/law	in the process	3.0	Yes =10; In the process =6; No =1	6	18	

Component	Indicator No.	Indicator Name	Parameter Values calculated from the actual data	Weight (W) assigned (1 to 5)	Rating (R) to be assigned to each indicator based on actual value (lowest 1 and highest 10)	Ratings (R) [1-10]	WxR	Component score
Institutions & Capacity	19	Groundwater overseeing authority at national level (for e.g. Ministry)	Research organizations at Federal and Provincial levels. But, no authority for control and regulation	4.0	Yes =10; No =1	1	4	0.58
	20	Groundwater overseeing authority at sub-national/local level	in the process	4.0	Yes =10; No =1	6	24	
	21	Availability of physical infrastructures (for e.g office, instruments etc)	Physical infrastructure in very good state	4.0	Excellent=10; very good=8; good=6; fair=5; poor=3	8	32	
	22	Technical staffs involved in groundwater development and management (as % of total staffs in the relevant institution)	About 40% and 60%, with and without sewerage management staff, respectively	4.0	Excellent=10; very good=8; good=6; fair=5; poor=3	8	32	
						Over all GSII Index	651	

4.2. KNOWLEDGE MANAGEMENT

This component is evaluated based on the rating of its five indicators. The aggregated score of this component is 0.90 (Table 5), i.e. current status of this infrastructure can also be rated as excellent'.There is lot of information available regarding aquifer characteristics, also in the form of geologic sections, borehole logs etc. (e.g. Greenman et al. (1967), NESPAK and Binnie& Partners (1987). Similarly, groundwater depth and quality information for the deeper portion is available on the basis of 1960's investigations. Thus, deep groundwater quality is well established for different areas in the district. However, impact on shallow groundwater quality due to anthropogenic activities, both in urban and rural area has not been investigated afresh. Also, groundwater critical zones e.g. saline groundwater area near Raiwind is already well established, and the same had been pointed out in many such studies.

The data regarding hydrogeology of the urban area being served by WASA is being collected and maintained by Director (Hydrology), WASA, LDA. Knowledge generations about groundwater environment were started just after the inception of irrigation system in the area. A partial list of the knowledge/information generated in the study area is available in references. There could be many other unnoticed studies carried out in academic institutions in Pakistan. Therefore, the volume of knowledge generation can be considered as relatively good.

Some of available data and study reports are available in different libraries, especially from the CEWRE Library in UET Lahore, and/or several other government offices, private consultants or from some individuals. It is inferred that available data/information/knowledge are highly scattered non-coordinated. Information sharing is normally thought to be awkward on the grounds that top boss of the concerned agency might not be happy to lend the information, particularly, if the health of information/data is questionable or if the information is sensitive regarding public interest.

4.3. POLICY AND LEGISLATION

Despite several recommendations by international and national agencies/experts in the past, groundwater management policy and plans which meant regulatory interventions are not yet even evolved and coming into effect. As a result, provision of licensing and regulation of groundwater extraction does not exist in reality. However, pollution control is the responsibility of the Federal and Provincial Environmental Protection Agencies (EPAs). In spite of the existence of these agencies, control is almost absent in the study area. Overall score of this component is 0.33, i.e. at poor to acceptable level.

The economic instruments for groundwater extraction, regulation and quality protection are yet to be in place in the study area, even there is no practice of groundwater licensing. There is no central regulatory authority that can impose such economic instruments as binding, e.g. for WASA, private housing societies, industries etc. The biggest stakeholder in the aquifer is WASA, and only 7% area served by WASA is billed on volume basis. Presently WASA is unable to recover even its service charges, therefore, a total change in mechanism of the organization is required.The LDA has initiated the water and sanitation master plan for Lahore District that provides a 25-year roadmap for establishing physical infrastructure (with costing and institutional arrangement) for provision of water supply, sewerage, and storm water drainage and wastewater treatment.

4.4. STAKEHOLDERS' PARTICIPATION

The trend in the country had been that provision of all the utilities is considered to be the responsibility of the government, with little readiness/willingness for participation, from the departments and public, respectively. Public (75-80%) of the masses are quite aware that excessive groundwater extraction has cause depletion of groundwater levels and that has led to deepening of turbine pumps'. But, they are not made aware by any government agency, perhaps the government agencies are having lack of commitment with their obligations or because of lack of knowledge and importance of information dissemination. Many government organizations hold symposiums/seminars, but these are attended mostly by concerned departments and coverage is given by the media. However, there is lack of groundwater expert meetings and awareness raising programs, especially on electronic media. The media is mostly engaged by political and terrorism discussions.However, now the trend is changing, because of stress by the donor agencies for public participation. Overall score of this component on decimal scale is 0.58.

4.5. INSTITUTIONS AND CAPACITY

There are a number of institutions available in Pakistan, which by some means can impact positively or otherwise by their role in water management at basin/regional/local scale. The responsibilities of these are bit clear, however, not with enough boundaries, and the departments are not properly held responsible. The main reason is lack of political will and commitment. The provincial governments got carried out many studies from consultants and prepared draft groundwater management and regulation policies/plans. However, not a single concrete step has been taken towards the groundwater regulation. There is no specific authority for the control of groundwater over-exploitation.

There are about 7000 total employs in WASA Lahore. About 40% are involved in GW development and management, and another 20% for Sewerage. So, in total about 60% staff is involved in groundwater development and management. The staff employed by private societies and other organizations serving the residential area under their respective jurisdiction is in addition to the aforementioned.During 2007-08, physical access to drinking water within the dwelling was available to 98% and improved sources for drinking water were used by 99% of the residents (Punjab Development Statistics, 2012).Individual score of this component is 0.58.

4.6. GROUNDWATER SUSTAINABILITY INFRASTRUCTURE INDEX

The GSII for the Lahore District is 651(Table 5), which falls in sustainable range. However, it is on the boundary of lower and middle quartile of this range. Although, groundwater sustainability infrastructure' in Lahore can be rated as satisfactory, but significant attentions are needed to strengthen the long-term groundwater sustainability' in the area, and subsequently achieve the goal of groundwater sustainability'.The scores for the individual components (Figure 9) are: monitoring stress on groundwater' is 0.90; knowledge management' is 0.90; policy and legislation' is 0.33; stakeholders' participation' is 0.58; and institutions and capacity' is 0.58. Thus, it is inferred that the water supply system is lacking in sustainability regarding the three components i.e. Policy and Legislation', Stakeholders' Participation' and Institutions and Capacity'.

4.7. CONCLUSIONS AND RECOMMENDATION

Based on the diverse data analysis, it is very simple to conclude that the city infrastructure is expanding and population and water demand are increasing. On the other hand, recharge to the aquifer (the sole source of water supply) is decreasing, both in quantity and quality, due to onset of urban development, since 1980s onwards. Thus, per capita water availability from the safe yield of the aquifer system is decreasing. The main conclusions regarding the groundwater water environment are as under:

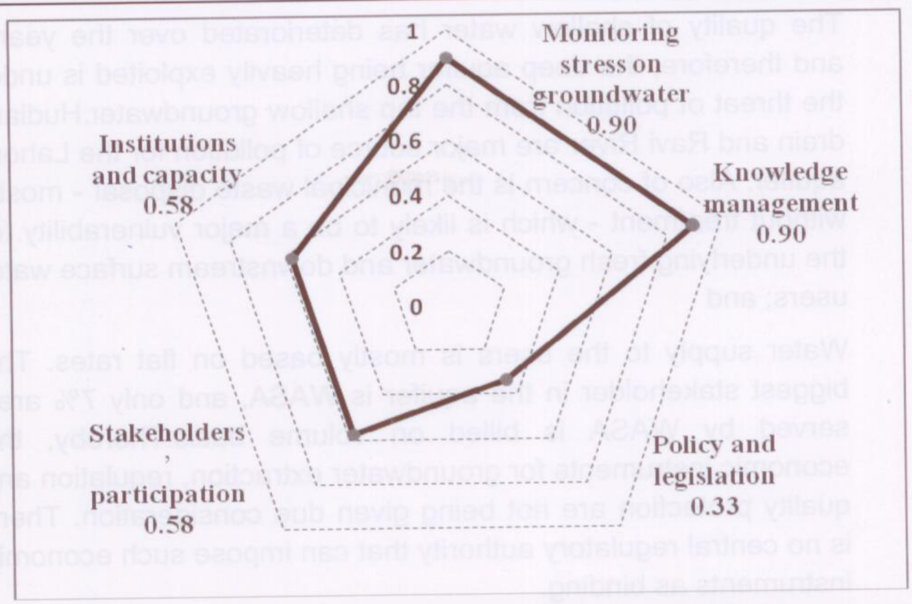


Figure 9: Values of the components of GSII index, on fractional scale, ranging from 0 to 1.

4.7.1. Conclusions

- There is a continuous expansion in total population and urban area, because much of the population shift involves movement towards the metropolitan city, from the villages, small towns and other cities in the province, in search of quality education, jobs and lavish life style;
- Currently, the recharge to groundwater is estimated as 1013 MCM (including inflows from boundaries), in comparison to groundwater abstraction of 1161 MCM on annual basis. Thus, recharge is less by about 15% as compared to the abstraction.
- On an average, groundwater depletion varies from 0.57 to 1.35 m/year. Keeping in view the groundwater level decline in the city, WASA regularly monitors groundwater levels in its wells.However, continuous monitoring of groundwater abstraction is not yet started, despite the fact that annual extraction has already exceeded recharge, since 1980s. WASA caters for about 55% of urban extractions and has estimates of pumping based on pumping hours' data. However, water extractions by private societies, individuals and industry are totally un-noticed and un-monitored.

- The quality of shallow water has deteriorated over the years, and therefore, the deep aquifer being heavily exploited is under the threat of pollution from the top shallow groundwater.Hudiara drain and Ravi River are major source of pollution for the Lahore aquifer. Also of concern is the municipal waste disposal - mostly without treatment - which is likely to be a major vulnerability for the underlying fresh groundwater and downstream surface water users; and

- Water supply to the users is mostly based on flat rates. The biggest stakeholder in the aquifer is WASA, and only 7% area served by WASA is billed on volume basis.Thereby, the economic instruments for groundwater extraction, regulation and quality protection are not being given due consideration. There is no central regulatory authority that can impose such economic instruments as binding.

4.7.2. Recommendations

Following are the recommendations for reducing the gap between recharge and abstraction:

- Three components i.e. Policy & Legislation', Stakeholders' Participation' and Institutions and their Capacity building' needs to be focus as much as possible for successive reduction of the gap between abstraction and recharge.

- Each and every use of existing groundwater above 0.20 cusecs should be registered and each new user should getting permit before installation of pumping equipment, should be charged with groundwater development surcharge;

- Building bye-laws should be amended to get maximum possible rainwater harvesting and its recharge to the aquifer by declaring it as mandatory for certain set and dimension of buildings, along with certain incentives;

- Waste water disposed by all entrepreneurs should be monitored, with the option to treat it at source, or otherwise pay extra charges for untreated load, for its collective treatment;

- In order to avoid pollution of the aquifer, sewerage being disposed into Ravi should be conveyed into a lined channel along both banks of the river;

- At least two small weirs may be constructed, one at Shahdra and the other about 20 km below Shahdra, for enhanced recharge to groundwater, with good quality river water, especially during floods.
- Surface water needs to be allocated (at least 0.5 MAF) from Indus Basin Irrigation System, for water supply and additional recharge to the aquifer to improve groundwater situation.
- Groundwater modeling approach is recommended to study and suggest appropriate management interventions under current and expected future conditions.

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HIGH EFFICIENCY IRRIGATION SYSTEMS "A TRANSFORMATION IN THE CONVENTIONAL IRRIGATION PRACTICES IN THE PUNJAB"

Chaudhary Mohammad Ashraff[1], Dr. Muhammad Asif[2], and Hafiz Qaisar Yasin[3]

ABSTRACT

Irrigated agriculture is the backbone of agricultural development in Pakistan, especially in the Punjab occupying 75% of irrigated area. An efficient and judicious use of available irrigation supplies becomes utmost important amidvarious emerging challenging including the water scarcity. The government has taken a mega initiative for large scale promotion of high efficiency irrigation systems (drip & sprinkler) under Punjab Irrigated-Agriculture Productivity Improvement Project. The performance evaluation of drip irrigation for vegetables production has shown enormous results including upto 55% of water saving, 66% of fertilizer reduction and water productivity enhancement to the tune of 480% aa compared to conventional irrigation methods as observed at 16 sites in Toba Tek Singh district. The wide scale adoption of the technology may result in enormous benefits in term of enhancing crop and water productivity leading to sustainable irrigated agriculture development.

1. RATIONALE

Agriculture is the key to economic development in Pakistan and its growth is mainly attributed to the availability of water being an important input. Water is considered to be the lifeline of agriculture activitiesas more than 80 percent of the cultivated area is irrigated (PES, 2013) producing food for over 180 million people. It is pertinent to point out that 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

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agricultural lands. The Punjab with 75 percent (34.83 million acres) of country's total irrigated area (46.60 million acres) is severely thrashed by this situation (PDS, 2013).Despite critical significance of irrigated agriculture to national development, it could not perform sustainably because of lack of mechanization as well as water scarcity and inefficient use of available resources amid various other emerging challenges.

During last decade in order to address the aforementioned water sector challenges, the Punjab Government has embarked upon various irrigated agriculture improvement initiatives to enhance its performance at the grassroots level. It includes water conservation and efficiency enhancement measures such as irrigation infrastructure rehabilitation and canal lining, improvement of watercourses, LASER land leveling, and promotion of better irrigation technologies & practices (PIPIP, 2012).These interventions have significantly contributed in enhancing the conveyance, application and water use efficiencies at the farm level along with increasing crop yields, which is evident from the impact evaluation study by the Planning Commission of Pakistan on watercourse improvement, which affirms that annual saving of water is 123 acre feet per watercourse and increase in crop yield is up to 15 percent besides several other tangible and intangible benefits (PIES-NPIW, 2011).

2. PUNJAB IRRIGATED-AGRICULTURE PRODUCTIVITY IMPROVEMENT PROJECT (PIPIP)

The Punjab government with the World Bank assistance has started implementation of Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) at a total cost of Rs. 36.00 billion (US$ = 423.54 million) to be implemented over a period of five years (2012-13 to 2016-17). It envisages execution of complete package of on farm water management (OFWM) interventions including installation of high efficiency irrigation systems (HEIS) on 120,000 acres, improvement of 5,500 watercourses in barrage commanded areas, completion of lining on 1,500 already improved watercourses, rehabilitation of 2,000 irrigation schemes outside the canal commands, and provision of 3,000 LASER units to the farmers/service providers as well as to provide the research backup support for maximizing productivity of irrigation water. The project aims at improvement of water productivity leading to greater agricultural output per unit of water used.

3. HIGH EFFICIENCY IRRIGATION SYSTEMS

High Efficiency Irrigation Systems (HEIS) are new and challenging technologies being introduced first time on large scale in Pakistan under the PIPIP. This is a reformatory initiative in irrigated agriculture of the country that would bring a paradigm shift in crop production as modernization has taken place in every agricultural operation all over the World and Pakistan can remain no exception. The farmers primarily employ traditional irrigation practices due to lack of knowledge and non-availability of necessary services for requisite modern irrigation technologies and practices.

Amid HEIS, drip 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. It 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.

4. WORLD OVERVIEW OF HEIS

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. Since 1960's, the micro irrigation is being practiced in Australia, Israel, Mexico, New Zealand, South Africa, and USA to irrigate vegetables, orchards and micro irrigated area grew slowly but steadily across the World, especially in the arid and semi-arid countries. The last two decades (1990 to 2010), however, witnessed a quantum leap in expansion of micro irrigation technology. According to the International Commission on Irrigation and Drainage (ICID),the nations like USA, Russia, France, and Brazil have adopted micro irrigation on more than 50 percent of their irrigated area. In Asia, Iran, China and India have adopted this technology on about 8 percent of irrigated area (**Figure-1**). Contrarily, Pakistan has installed these technologies on only 30,000 acres, out of which about 25,000 acres (above 85%) are in Punjab.

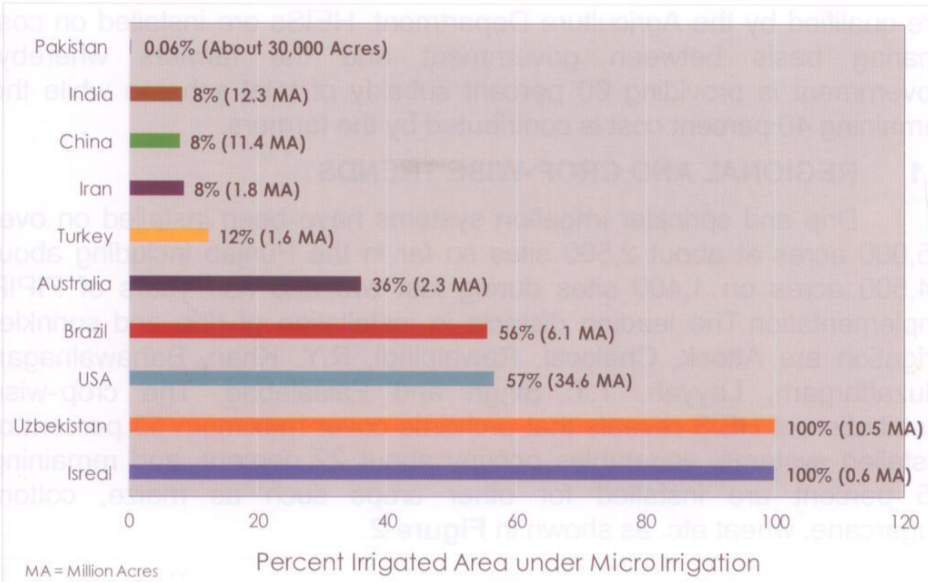

Figure-1: Country-wise Micro Irrigation Adoption

5. HEIS INSTALLATION IN THE PUNJAB

Only a few schemes were undertaken in the past for introduction of HEISs in the country that too on a very limited scale. The PSDP[1]funded —Water Conservation and Productivity Enhancement through High Efficiency (Pressurized) Irrigation Systemsll was one of the same started during 2008-09 to demonstrate and promote these technologies on acres in the Punjab over a period of four years (2008-09 to 2011-12) at a total cost of Rs. 6.917 billion. Due to some administrative, technical, and financial constraints, installation of drip and sprinkler irrigation systems could, however, be completed on only about 9,000 acres in the Punjab and project was abandoned in December 2011. Afterwards, Government of the Punjab at its own initiative undertook successful implementation of provincial ADP[2] funded —Pilot Project for Promotion of Cotton Cultivation in Thal Region with Drip Irrigationll on 2,000 acres from 2011-2012. Successively, the Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) has been designed envisaging installation of HEISs on 120,000 acres for province wide demonstration to promote these new interventions.

Under the PIPIP, drip and sprinkler irrigation systems are being executed on turnkey basis through supply and service companies (SSCs)

[1]Public Sector Development Program

[5]Annual Development Plan

pre-qualified by the Agriculture Department. HEISs are installed on cost sharing basis between government and the farmers whereby, government is providing 60 percent subsidy of total scheme while the remaining 40 percent cost is contributed by the farmers.

5.1 REGIONAL AND CROP-WISE TRENDS

Drip and sprinkler irrigation systems have been installed on over 25,000 acres at about 2,500 sites so far in the Punjab including about 14,500 acres on 1,400 sites during last two and half years of PIPIP implementation.The leading districts in installation of drip and sprinkler irrigation are Attock, Chakwal, Rawalpindi, R.Y. Khan, Bahawalnagar, Muzaffargarh, Layyah, T.T. Singh and Faisalabad. The crop-wise distribution of HEIS reveals that orchards cover maximum 53 percent of installed systems, vegetables occupy about 22 percent, and remaining 25 percent are installed for other crops such as maize, cotton, sugarcane, wheat etc. as shown in **Figure-2**.

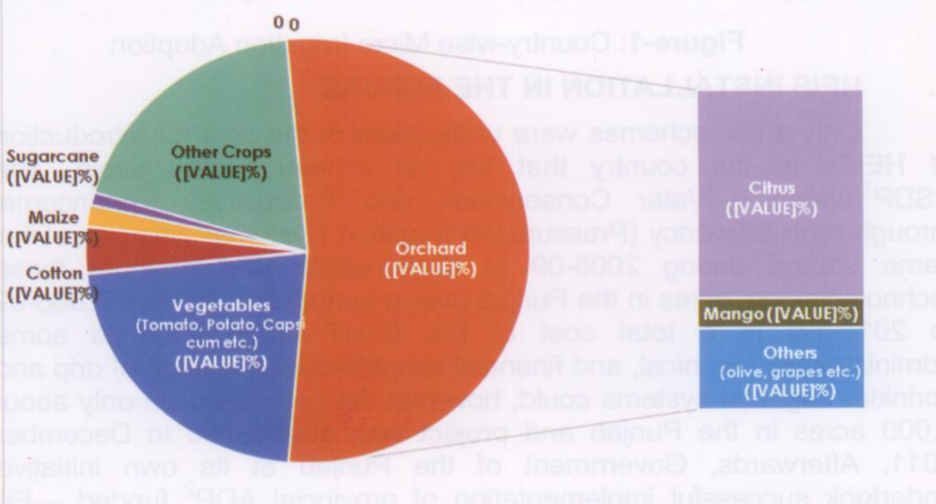

Figure-2: Crop-wise HEIS Installations in Punjab

The region-wise distribution shows that Rawalpindi is the leading region with 38 percent of total HEIS installed on 5,495 acres (2,224 hectares) followed by 35 percent in Multan (5,015 acres/ 2,030 hectares) and 27 percent in Lahore region (3,990 acres/ 1,615 hectares) as shown in **Figure-3**.

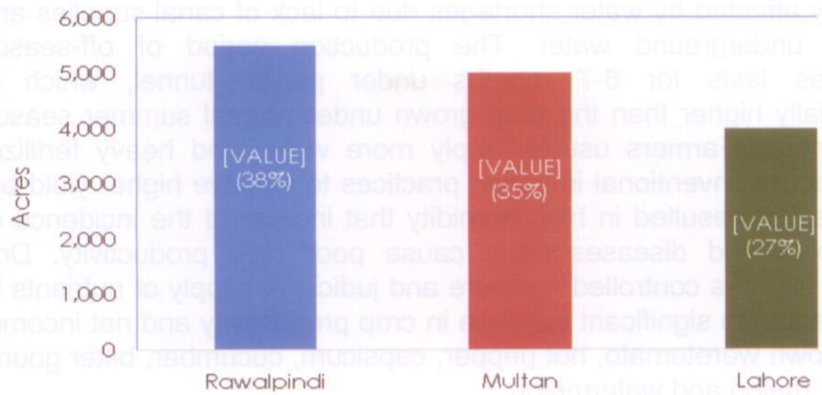

Figure-3: Region-wise HEIS Installations in Punjab

5.2 HEIS IMPACTS

The research conducted on HEISs around the globe has shown huge impact in term of precious and costly input savings including water and fertilizers, enhancing crop yields, improving produce quality besides many other tangible and intangible benefits.Based on the systems installed so far in Pakistan's Punjab, it is concluded that the technology has shown enormous impact in terms of water saving, most significantly reduction in fertilizer use, and crop productivity enhancement as well as resulting in crop diversification, value addition, increase in employment etc. These impacts are summarized as below.

- Saving of water upto 50 percent
- Enfacement in crop yield more than 100 percent
- Reduction in fertilizer use by 60 percent
- Maturity of orchard one-two year earlier
- Early picking of vegetables by 10-15 days
- Crop diversification (from grains to horticulture)
- Employmentgeneration at local level
- Value addition from improved quality of fruits and vegetables

5.3 IMPACT EVALUATION FOR VEGETABLES

More specifically, comparative performance of drip irrigation system against conventional methods such as flood and furrow was evaluated for vegetables grown under tunnel at 16 sites in Toba Tek Singh district for two years i.e. 2012-13 and 2013-14 by the OFWM staff in terms of enhancing crop and water productivity vis-à-vis input savings. It has been observed that production of vegetable in T.T. Singh is adversely affected by water shortages due to lack of canal supplies and brackish underground water. The production period of off-season vegetables lasts for 6-7 months under plastic tunnel, which is substantially higher than the crop grown under normal summer season (4-5 months). Farmers usually apply more water and heavy fertilizer doses under conventional irrigation practices to achieve higher yield but the same has resulted in high humidity that increased the incidence of insect, pest and diseases often cause poor crop productivity. Drip irrigation ensures controlled moisture and judicious supply of nutrients to plants leading to significant increase in crop productivity and net income. Crops grown weretomato, hot pepper, capsicum, cucumber, bitter gourd, pumpkin, melon and watermelon.

Results of studies carried out on different vegetables grown under tunnel for last two years revealed significant increase in crop yield along with considerable saving in costly inputs (water & fertilizer), and overall substantial reduction in cost of production. The comparison of water used for producing vegetables showed that 3,332 m^3/acre of water applied to capsicum under furrow as compared to 1,709 m^3m^3/acreunder drip irrigation leading to about 50% (1,623 m^3) saving of water. Similarly, water saving per acre under drip irrigation was 55% (2,382 m^3)for cucumber, 37% (1,188 m^3) for tomato, 30% (636 m^3) for bitter gourd and 24% (421 m^3) for green pepper (**Figure-4**).

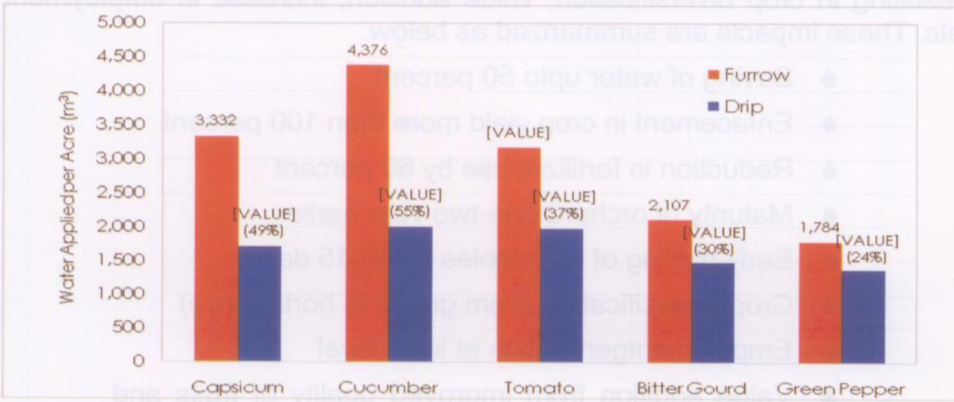

Figure-4: Water Saving under Drip Irrigation for Vegetables in Toba Tek Singh

The net profit in terms of per cubic meter(m^3) of water used wasalso evaluated under furrow and drip irrigation for different vegetables, which shows 268%, 480%, 226%, 193%, and 215% increase for capsicum, cucumber, tomato, bitter gourd, and green pepper, respectively as sown in **Figure-5**.

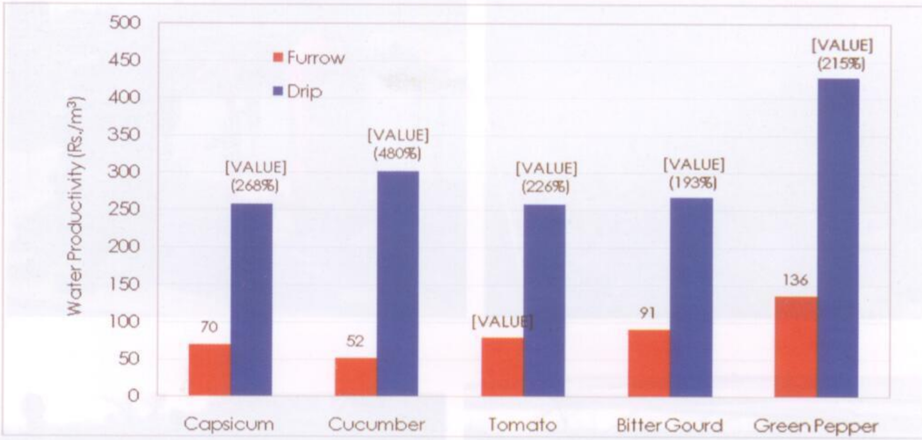

Figure-5: Increase in Water Productivity under Drip Irrigation for Vegetables

The most significant impact thedrip irrigation exhibited was saving ofmost costly input i.e. fertilizer to a great extent as compared to conventional (flood& furrow)irrigation, which is mainly due to precise application of fertilizer more closely to the plant root zone.The per acre fertilizer saving was Rs.33,157 (57%) under drip as compared to conventional method and Rs. 35,617 (52%) for cucumber, Rs. 32,910 (66%) for tomato, Rs. 28,037 (50%) for bitter gourd and Rs. 25,697 (49%) for green pepper (**Figure-6**).

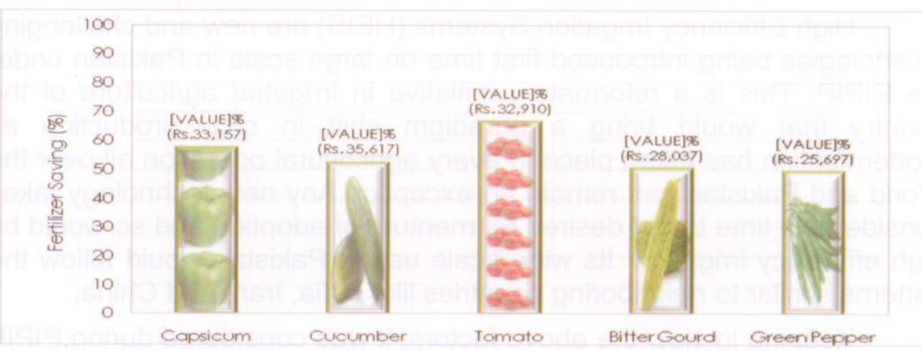

Figure-6: Fertilizer Saving under Drip Irrigation for Vegetables

A considerable reduction in pesticide use ranging from 11-19% was also observed under drip irrigation system as the crop root zone is maintained at optimal soil moisture levels reducing root diseases as well as incidence of insects/pest attack.

Figure-6: Glimpses of HEIS Installed Sites in Toba Tek Singh

6. HEIS TECHNOLOGY ADOPTION CHALLENGES

High Efficiency Irrigation Systems (HEIS) are new and challenging technologies being introduced first time on large scale in Pakistan under the PIPIP. This is a reformatory initiative in irrigated agriculture of the country that would bring a paradigm shift in crop production as modernization has taken place in every agricultural operation all over the World and Pakistan can remain no exception.Any new technology takes considerable time to get desired momentum of adoption and so would be high efficiency irrigation. Its wide scale use in Pakistan would follow the patterns similar to neighboring countries like India, Iran, and China.

Keeping in view the above factors, it was considered during PIPIP planning that pace of HEIS adoption would initially remain slow in the Punjab as well primarily owing to following reasons.

- HEIS is new technology in Pakistan
- Involves complete paradigm shift to move from inexact to exact agricultural practices
- High initial cost of HEIS equipment
- Inadequate (negligible) capacity of supply & service companies (SSCs) in terms of manpower and

inventory to cater even whatever demand is available

- Lack of technical knowhow amongst all stakeholders
- Escalating operating expenses due to energy shortage and cost is major hindering sustainability of the technology

A multipronged approach was needed to address all these issues. Since launching of the PIPIP, strenuous efforts have been made to accelerate the adoption of these technologies under awareness creation and capacity building program. The progress of HEIS component during financial year 2014-15 is in significantly better shape than 2013-14, which was considerably better than 2012-13.

7. CONCLUSION

HEIS technology, especially drip irrigation has exhibited huge impacts in terms of water saving, reduction in fertilizer use, enhancing water and crop productivity besides other tangibles and intangible benefits. It isstill at the nascent stage in Pakistan and requires continuity of government policies and financial support to build confidence amid stakeholders. Moreover, its adoption/promotionrequire extensive mass awareness and capacity building involving a complete paradigm shift from archaic traditional flood irrigation method and associated agricultural practices to the more efficient modern irrigation technology. The pace of adoption of HEIS technologies is picking up and it is expected that their province wide demonstration will further accelerate its promotion, which is highly essential for sustainability of irrigated agriculture in the country.

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Sustainable Efficient Irrigation Method for Rice and Wheat Crops

By

Zamir Ahmed Soomro*, Muhammad Dilshad, Khuram Ejaz****

Abstract: A study was conducted at R&D Centre PCRWR Sial More Regional office Lahore during year 2005-06, 2006-07and 2007-08. The soil texture of the trial field was Loam, Sandy Loam. Three treatments with three replications were evaluated in terms of water saving, yield and water use efficiency over conventional method of irrigation. The treatments were; T_1: 40 centibar stress, T_2: 60 centibar stress and T_3: 80 centibar stress with same cultural practices and crop inputs except irrigation applied. Furrows were irrigated at the designed water stress according to the tensiometere reading, while farmer applied traditional irrigation practices to conventional field. Results indicate that Bed and furrow irrigation method with treatment T_1 40 cb stress saved irrigation water up to 36% and 31% for rice and wheat crop respectively. Maximum yield of 3664 kg/ha and 3561kg/ha was achieved in bed and furrow irrigation method with treatment T_1 40 cb stress for rice and wheat crop respectively. Maximum water use efficiency was achieved in bed and furrow irrigation method with treatment T_1 40 cb as 0.52 kg/m^3 and 1.47 kg/m^3 for rice and wheat crop respectively. The Benefit to Cost ratio based on water applied and water saved was carried out. Based on water saved the Benefit Cost (B.C) ratio of 2.2 for rice and 2.7 for wheat with treatment T_1 indicates that bed and furrow irrigation method with 40 cb. stress of water is economically feasible for growing rice and wheat crops.

1. Introduction

Despite the impressive gains in global food production over the last half century, an estimated 790 million people, approximately one out of five in developing world, remain hungry (FAO, 1999). Many of the chronically hungry are poor farm families, who have neither the means to produce the food they need nor sufficient income to purchase it. For them, access to irrigation water, or the means to use the water they have more productively, is a key to increasing their crop production, their incomes, and their household food security.

Effective irrigation systems; must provide adequate water for high crop yields and also minimize point and non-point source pollution of surface and groundwater resources. Pollution problems may arise from deep percolation and runoff of excess irrigation water containing fertilizers and pesticides (Bouwer 1987). Efficient surface irrigation method such as bed and furrow irrigation system helps to save water (Kahlown et. al.1998) and thus avoid the pollution problems. Therefore, the water saved in bed and furrow irrigation can be used to increase the cropping intensity and also for leaching the salts in salt affected soils.

Rice is an important food as well as a cash crop of Pakistan, which occupies 11 per-cent of the country's cropped area. Punjab is the biggest producer of rice in the country and contributes 48 percent to the national production while the provinces of Sindh, Balochistan and NWFP, 41, 8 and 3 percent respectively. During 2000-01, the area planted under rice crop in the Punjab was 4.021 million acres which increased by 1 percent from last year's 3.977 million acres. Total delta of irrigation is more than 150 cm and 40 cm under farmers' traditional irrigation practices for Rice and Wheat crop respectively. Out of which a large quantity of water is lost through deep percolation.

Based on the water use efficiency, the bed and furrow method is the most efficient surface water application method. This method is being used for different crops and has been reported as the most efficient surface irrigation method. A study with different bed and furrow configurations revealed that bed and furrow 30 cm each was the most efficient configuration with maximum water use efficiency (WUE). Further; to evaluate when and how much irrigation water is required for growing rice and wheat crops on bed and furrow with following objectives;

1.1 Objectives

The specific objectives of the study were as follows:

- Determine the performance of bed and furrow under various water stress conditions and compute water use efficiency.
- IMPROVE WATER PRODUCTIVITY OF RICE AND WHEAT USING PROPER IRRIGATION SCHEDULING.

2. METHODOLOGY

2.1 SITE SELECTION

The study was conducted at R & D Centre PCRWR Sial More Regional Office Lahore during the year 2005-06, 2006-07and 2007-08. The soil of the trial field was Loam, Sandy Loam and free of salinity/alkalinity. The soil texture and initial salinity status of the selected field is reported in Table-1.

Table-1: Soil Texture

(a) Soil Texture

Sand %	Silt %	Clay %	Textural Class
52	30	18	Loam, Sandy Loam

(b) Salinity

ECe (dSm^{-1})	pH
1.27	7.9

2.2 Layout and Treatments

In the study, all the cultural practices and inputs were applied as equal in all experimental plots; however the irrigation was applied at different depletion (soil moisture stress) level. For measuring soil tension, tensiometers were installed in all plots. Following three treatments were randomized having three replications of each treatment for both of rice and wheat crops. The layout of experimental plots is given in figure -1

- T-1 40 centibar stress
- T-2 60 centibar stress
- T-3 80 centibar stress
- T-4 Conventional/Basin Flooding

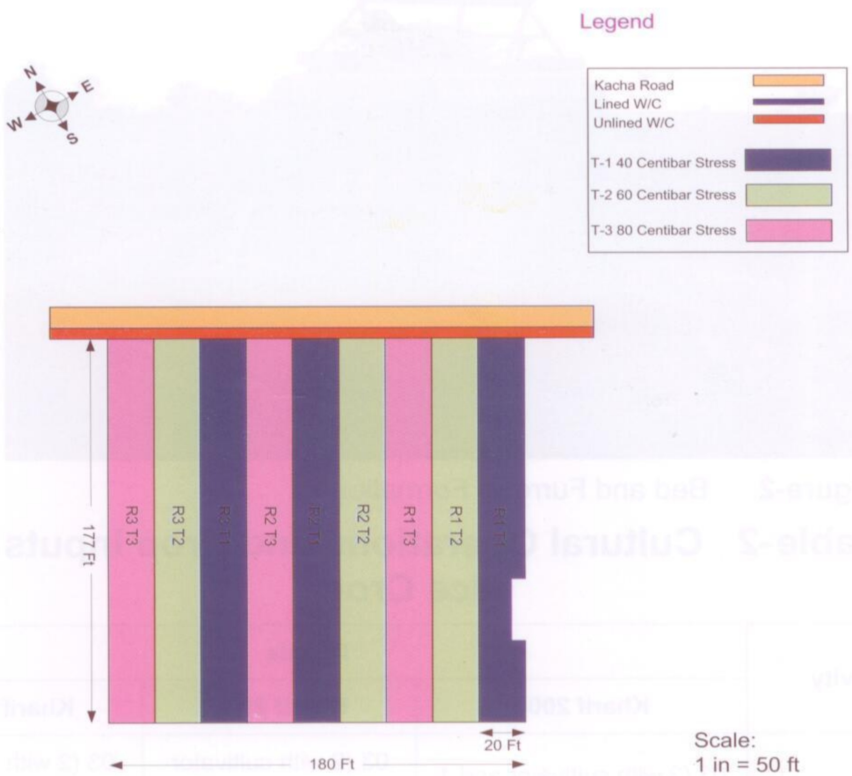

FIGURE 1: LAYOUT OF STUDY

2.3 CULTURAL PRACTICES AND CROP INPUTS

Selected field was LASER leveled and bed and furrow shaper was used for making beds and furrows (30 cm each) Figure-2. Nine plots of equal size were selected for the study. The tensiometeres were installed at head, middle and tail in each treatment at the depth of 15 cm. Rice nursery (Super Basmati) was transplanted at experimental site maintaining the plant to plant distance of 22 cm. The applied cultural practices and crop inputs are given below in Table-2.

Similarly for wheat crop seed bed was prepared and wheat variety, Inquelab-91 was sown at experimental site. To isolate the impact of irrigation all cultural practices and crop inputs such as fertilizer, chemical and seed rate were kept constant except method of irrigation in each treatment. The applied cultural practices and crop inputs are given below in Table-3.

Figure-2 Bed and Furrows Formation

Table-2 Cultural Operations and Crop Inputs of Rice Crop

Activity	Details		
	Kharif 2005	Kharif 2006	Kharif 2007
Ploughing	03 (2 with cultivator and 1 with disc plough)	03 (2 with cultivator and 1 with disc plough)	03 (2 with cultivator and 1 with disc plough)
Planking	02 No	02 No	02 No
Date of Transplanting	2nd week of July 2005	2nd week of July 2006	2nd week of July 2007
Plant and Row spacing	22cm x 22cm	22cm x 22cm	22cm x 22cm
Fertilizer Rate	Nitrogen (N) 79 kg/ha	Nitrogen 79 kg/ha	Nitrogen 79 kg/ha
	Phosphorus(P) 57 kg/ha	Phosphorus 57kg/ha	Phosphorus 57kg/ha
	Potassium (K) 0	Potassium (K) 0	Potassium (K) 0
Variety	Super Basmati	Super Basmati	Super Basmati
Weeding	1 Nos. (manual)	1 Nos. (manual)	1 Nos. (manual)

Table-3 Cultural Operations and Crop Inputs of Wheat Crop

Activety	Detail		
	Rabi 2005-06	**Rabi 2006-07**	**Rabi 2007-08**
Ploughing	03 No (2 with cultivator and 1 with disc plough)	03 No (2 with cultivator and 1 with disc plough)	03 No (2 with cultivator and 1 with disc plough)
Planking	02 No	02 No	02 No
Date of Sowing	3rd week of November 2005	2nd week of November 2006	2nd week of November 2007
Seed rate	124 kg/ha	124 kg/ha	124 kg/ha
Fertilizer Rate	Nitrogen (N) 74 kg/ha	Nitrogen (N) 74 kg/ha	Nitrogen (N) 74 kg/ha
	Phosphorus (P) 69 kg/ha	Phosphorus(P) 69kg/ha	Phosphorus (P) 69kg/ha
	Potassium (K) 0 kg/ha	Potassium (K) 0 kg/ha	Potassium (K) 0 kg/ha
Variety	Inqelab-91	Inqelab-91	Inqelab-91
Weeding	1 Nos. (manual)	1 Nos. (manual)	1 Nos. (manual)

2.4 Ground Water Quality

Tubewell irrigation supply is available at farm. The quality of groundwater used to irrigate rice and wheat crop is given in Table-4. The given quality is within irrigation water quality limits.

Table-4 Groundwater Quality Used for Irrigation

EC (dS m-1)	TDS (ppm)	SAR	RSC (meq/l)
0.73	518	0.88	0.60

2.5 IRRIGATION APPLICATION

The irrigation scheduling and application frequency was designed on the basis of tensiometers. For the treatment T_1 irrigation was applied when the tensiometer reads soil moisture tension (stress) in the crop root zone as 40 cb. Similarly in treatments T_2 and T_3 irrigations were applied when the tensiometer reads soil moisture tension (stress) in the crop root zone as 60 cb. and 80 cb. respectively. Frequent irrigations were applied in the treatment which was designed at 40 cb. stress i.e. near to field capacity level. Comparatively less number of irrigations were applied with more quantity to the treatments T_2 and T_3 respectively. Farmer irrigates conventional field according to his traditional irrigation practices. Each of irrigation applied to each treatment was measured carefully with the help of Cut Throat Flume (C.T.F) installed in the field channel.

2.6 Rainfall

A rain gauge was installed at experimental site. Rainfall data were recorded regularly and irrigation scheduling was done accordingly. The monthly rainfall for each study period during year 2005-06, 2006-07 and 2007-08 is presented in Table-5.

Table-5 Rainfall distribution

Year 2005-06			
Kharif 2005		**Rabi 2005-06**	
Month	**Rainfall (mm)**	**Month**	**Rainfall (mm)**
July-05	72	Jan-06	43
Aug-05	45	Feb-06	19
Sep-05	97	Mar-06	79
Oct-05	04	--	--
Total	**218**	**Total**	**141**
Year 2006-07			
Kharif 2006		**Rabi 2006-07**	
July-06	85	Dec-06	55
Aug-06	104	Feb-07	76
Sep-06	88	Mar-07	50
Oct-06	28	--	--

Total	305	Total	181
Year 2007-08			
Kharif 2007		**Rabi 2007-08**	
July-07	124	Dec-07	03
Aug-07	08	Jan-08	47
Sep-07	48	Feb-08	20
--	--	Apr-08	31
Total	**180**	**Total**	**101**

2.7 CROP YIELD

The yield was estimated on whole plot basis. The crop in three replications of each treatment was harvested separately and the average of these yields was used to estimate output on hectare basis.

3 RESULTS AND DISCUSSIONS

The performance of bed and furrow irrigation method to reduce water use for Rice and Wheat crops in terms of water saving yield and water use efficiency are discussed below.

3.1 Plant Population

The optimum plant population is very important to get a good yield and to establish, the plant to plant distance was kept 22 cm. It was observed on the basis of average of kharif 2005, 2006 and 2007 data for rice crop maximum 23 numbers of plants /m^2 were recorded in bed and furrow irrigation method with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress and T_3 80 cb stress with 21 numbers of plants /m^2. Plant density remained low as 18 numbers of plants /m^2 in conventional method of irrigation because farmer transplanted rice nursery without maintaining row and plant spacing Table-6. In case of wheat crop maximum 210 numbers of plants /m^2 were recorded in bed and furrow irrigation method with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with 207 numbers of plants /m^2. Whereas minimum 197 number of plants/ m^2 were found in conventional method of irrigation Table-7.

3.2 Tillering

Crop yield mainly depends upon the number of spikes bearing tiller, per unit area. Tillering had partial consensus with trend observed in case of plant population.

For rice crop number of tillers/plant remained 488 to 515 in bed and furrow method of irrigation. However maximum 515 numbers of tillers/m^2 were recorded in bed and furrow method of irrigation with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with 496 numbers of tillers/m^2. Whereas minimum 452 number of tillers/plant were found in conventional method of irrigation Table-6.

Incase of wheat crop number of tillers/m^2 remained 415 to 419 in bed and furrow method of irrigation. However maximum 419 numbers of tillers/m^2 were recorded in bed and furrow method of irrigation with treatment T_1 40 cb. stress, followed by treatment T_2 60 cb stress with 416 numbers of tillers/m^2. Whereas minimum 404 number of tillers/m^2 were observed in conventional method of irrigation Table-7.

3.3 PLANT HEIGHT (CM)

Although plant height has no direct concern with crop return (yield) yet higher values of this genetic growth character indicate more favorable growing and nourishing conditions. For rice crop maximum plant height of 108 cm was recorded in bed and furrow irrigation method with treatment T_1 40 cb. stress followed by T_2 60 cb stress and conventional method of irrigation with the plant height of 106 cm. Whereas minimum 105 cm of plant height was observed in treatment T_3 80 cb stress Table-6.

Incase of wheat crop the maximum plant height of 93 cm was recorded in bed and furrow irrigation method with treatment T_1 40 cb. Stress followed by treatment T_2 60 cb and T_3 80 cb, stress with the plant height of 90 cm. However minimum 88 cm of plant height was observed in conventional method of irrigation Table-7.

3.4 NO OF GRAINS/SPIKE

Crop irrigated with bed and furrow irrigation method utilizes the fertilizer doze more effectively as light irrigations are being applied. Incase of flood irrigation most of the fertilizer doze leach beyond the root zone which ultimately affect the grain size.

For rice crop maximum 153 number of grains/spike were obtained in bed and furrow method of irrigation with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with 146 number of grains/spike. Conventional method of irrigation remained at the lowest with 134 number of grains/spike Table-6.

Incase of wheat crop maximum 49 number of grains/spike were obtained in bed and furrow method of irrigation with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with 47 number of grains/spike. Minimum 43 number of grains/spike were observed in conventional method of irrigation Table-7.

3.5 Yield

Crop yield is an important criterion to evaluate bed and furrow irrigation method. Field inputs have the main impact on crop yield. The crop yield is affected by a number of factors among which irrigation is a major factor. Alternate wetting and drying during the yield formation and ripening periods may cause grain to check. The crop should be harvested before the grain is completely dry since crakes are more readily formed when grain is quite hard (Doorenbos and Kassam, 1979). This phenomenon ultimately affects the crop yield and quality. Moreover, irrigation application time, amount and its quality give its impact on crop yield.

For rice crop the maximum yield of 3664 kg/ha was obtained in bed and furrow method of irrigation with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with the yield of 3394 kg/ha. Minimum yield of 2971 kg/ha was obtained in conventional method of irrigation Table-6.

In case of wheat crop the maximum yield of 3561 kg/ha was obtained in treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with the yield of 3317 kg/ha. Whereas minimum yield of 3101 kg/ha was obtained in conventional method of irrigation Table-7.

Figure-3 Wheat and Rice on Beds

Table-6 Main Plant Characteristics and Yield Components of Rice Crop

Treatment	Plants per m^2	Tillers per m^2	Grains per Spike	Plant Height (cm)	yield (kg/ha)
Kharif 2005					
T-1 (40 cb stress)	23	451	156	101	3353
T-2 (60 cb stress)	21	414	144	99	3023
T-3 (80 cb stress)	20	402	136	98	2691
Conventional Plot	16	316	121	99	2014
Kharif 2006					
T-1(40 cb stress)	22	541	149	112	3663
T-2 (60 cb stress)	21	533	148	111	3505
T-3 (80 cb stress)	22	529	141	109	3312
Conventional Plot	18	497	136	109	3116
Kharif 2007					
T-1 (40 cb stress)	23	552	153	110	3975
T-2 (60 cb stress)	22	540	146	109	3655
T-3 (80 cb stress)	22	534	139	107	3391
Conventional Plot	20	542	145	109	3784

Average					
T-1 (40 cb stress)	23	515	153	108	3664
T-2 (60 cb stress)	21	496	146	106	3394
T-3 (80 cb stress)	21	488	139	105	3131
Conventional Plot	18	452	134	106	2971

Table-7 Main Plant Characteristics and Yield Components of Wheat Crop

Treatment	Plants per m^2	Tillers per m^2	Grain per Spike	Plant Height (cm)	yield (kg/ha)
Rabi 2005-06					
T-1 (40 cb stress)	141	498	39	89	3144
T-2 (60 cb stress)	139	501	37	87	2924
T-3 (80 cb stress)	139	499	36	87	2706
Conventional Plot	137	493	34	86	2867
Rabi 2006-07					
T-1 (40 cb stress)	251	393	56	106	3689
T-2 (60 cb stress)	247	387	55	102	3496
T-3 (80 cb stress)	249	391	52	100	3375
Conventional Plot	223	362	49	99	3013
Rabi 2007-08					
T-1 (40 cb stress)	237	365	51	84	3850
T-2 (60 cb stress)	235	361	49	82	3531
T-3 (80 cb stress)	231	354	46	82	3223
Conventional Plot	232	356	45	79	3670

Average					
T-1 (40 cb stress)	210	419	49	93	3561
T-2 (60 cb stress)	207	416	47	90	3317
T-3 (80 cb stress)	206	415	45	90	3101
Conventional Plot	197	404	43	88	3183

3.6 Weeds Infestation

Weeds reduce crop yield by 15 to 20 per cent, but in some cases, losses may go as high as 50 per cent. A manual weeding was provided to control weeds, number of weeds/m^2 were recorded before and after weeding. For rice crop 22 to 24 percent more weeds were observed in bed and furrow method of irrigation as compared to conventional field. Weeds intensity remained low in conventional field due to continuous standing water Table-8. In case of wheat crop 5 to 19 percent more weeds were observed in bed and furrow treatments as compared to conventional field. A manual weeding was provided to control weeds. The number of weeds/m^2 was recorded before and after weeding Table-9.

Table-8 Weeds Infestation of Rice Crop

Treatment	11.1 WEEDS DENSITY	
	Number of weeds /m^2 (Before weeding)	Number of weeds /m^2 (After weeding)
Kharif 2005		
T-1 (40 centibar stress)	43	18
T-2 (60 centibar stress)	46	20
T-3 (80 centibar stress)	46	22
Conventional	34	17
Kharif 2006		
T-1 (40 centibar stress)	42	26

T-2 (60 centibar stress)	41	23
T-3 (80 centibar stress)	39	22
Conventional	36	19
Kharif 2007		
T-1 (40 centibar stress)	53	24
T-2 (60 centibar stress)	51	21
T-3 (80 centibar stress)	49	19
Conventional	41	17
Average		
T-1 (40 centibar stress)	46	23
T-2 (60 centibar stress)	46	21
T-3 (80 centibar stress)	45	21
Conventional	37	18

Table-9 Weeds Infestation of Wheat Crop

Treatment	11.2 WEEDS DENSITY	
	Number of weeds /m^2 (Before weeding)	Number of weeds /m^2 (After weeding)
Rabi 2005-06		
T-1 (40 centibar stress)	17	9

T-2 (60 centibar stress)	19	11
T-3 (80 centibar stress)	18	10
Conventional	16	6
Rabi 2006-07		
T-1 (40 centibar stress)	25	14
T-2 (60 centibar stress)	23	12
T-3 (80 centibar stress)	22	11
Conventional	20	9
Rabi 2007-08		
T-1 (40 centibar stress)	32	16
T-2 (60 centibar stress)	29	14
T-3 (80 centibar stress)	25	13
Conventional	26	11
Average		
T-1 (40 centibar stress)	25	13
T-2 (60 centibar stress)	24	12
T-3 (80 centibar stress)	22	11
Conventional	21	9

3.7 Irrigation Application

Although rice is an aquatic plant and grows well under submerged conditions, deep and prolonged submersion of paddy rice adversely affects plant growth (FAO Paper-33). Crop had to irrigate after short intervals during initial stage. In case of wheat crop 1st irrigation was applied after about 22 days of germination. Timely application of this irrigation is necessary for primary roots development and tillering. Each of irrigation volume was measured with the help of Cut Throat Flume (C.T.F) installed in the field channel.

For rice crop water saving in bed and furrow method of irrigation was ranged as 31 to 36 percent. However maximum water saving of 36 percent was achieved in bed and furrow method of irrigation with treatment T_3 80 cb stress followed by treatment T_2 60 cb stress with the water saving of 34 percent as compared to conventional method of irrigation Table-10.

In case of wheat crop water saving in bed and furrow method of irrigation was ranged as 27 to 31 percent. However maximum water saving of 31 percent was achieved in bed and furrow method of irrigation with treatment T_3 80 cb stress followed by T_2 60 cb stress with the water saving of 29 percent as compared to conventional method of irrigation Table-11.

3.8 Water Use Efficiency

Water use efficiency is defined as the crop yield production per cubic meter of applied water. It is a simple estimate, which tells how efficiently water was used by the crop.

For rice crop the maximum water use efficiency of 0.52 Kg/m^3 was achieved in bed and furrow method of irrigation with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with water use efficiency of 0.50 Kg/m^3. Conventional method of irrigation remained at lowest with the water use efficiency of 0.29Kg/m^3 due to more consumption of irrigation water Table-12.

In case of wheat crop the maximum water use efficiency of 1.47 Kg/m^3 was achieved in bed and furrow method of irrigation with treatment T_1 40 cb. stress followed by treatment T_2 60 cb stress with water use efficiency of 1.42 Kg/m^3. Conventional method of irrigation remained at lowest with the water use efficiency of 0.96 Kg/m^3 due to more consumption of irrigation water Table-13.

Table-10 Volume of Water Applied, Crop Yield, Water Use Efficiency and Water Saving of Rice Crop

Treatments	Volume (m3/ha)	Yield (kg/ha)	WUE (kg/m3)	Saving (%)
Rice (Kharif 2005)				
T1-40 Centibar	6840	3353	0.49	30
T2-60 Centibar	6540	3023	0.46	33
T3-80 Centibar	6340	2691	0.42	35
Control	9760	2014	0.21	-
Rice (Kharif 2006)				
T1-40 Centibar	6947	3663	0.53	31
T2-60 Centibar	6812	3505	0.51	33
T3-80 Centibar	6510	3312	0.51	36
Control	10125	3116	0.31	-
Rice (Kharif 2007)				
T1-40 Centibar	7234	3975	0.55	33
T2-60 Centibar	7028	3655	0.52	35
T3-80 Centibar	6920	3391	0.49	36
Control	10812	3784	0.35	-
Average				
T1-40 Centibar	7007	3664	0.52	31
T2-60 Centibar	6793	3394	0.50	34
T3-80 Centibar	6590	3131	0.47	36
Control	10232	2971	0.29	-

Table-11 Volume of Water Applied, Crop Yield, Water Use Efficiency and Water Saving of Wheat Crop

Treatments	Volume (m^3/ha)	Yield (kg/ha)	WUE (kg/m^3)	Saving (%)
Wheat (Rabi 2005-06)				
T1-40 Centibar	2230	3144	1.41	29
T2-60 Centibar	2150	2924	1.36	31
T3-80 Centibar	2080	2706	1.30	34
Control	3128	2867	0.92	-
Wheat (Rabi 2006-07)				
T1-40 Centibar	2411	3689	1.53	25
T2-60 Centibar	2346	3496	1.49	27
T3-80 Centibar	2296	3375	1.47	28
Control	3210	3013	0.94	-
Wheat (Rabi 2007-08)				
T1-40 Centibar	2602	3850	1.48	27
T2-60 Centibar	2504	3531	1.41	30
T3-80 Centibar	2423	3223	1.33	32
Control	3563	3670	1.03	-
Average				
T1-40 Centibar	2414	3561	1.47	27
T2-60 Centibar	2333	3317	1.42	29
T3-80 Centibar	2266	3101	1.37	31
Control	3300	3183	0.96	-

3.9 Economic Analysis

The Benefit to Cost (B.C) ratio was carried out to evaluate bed and furrow Irrigation method to reduce water use for rice and wheat crop. The cost of water used in this analysis was Rs.1.03 /m^3, Rs.1.12 /m^3 and Rs.1.17 /m^3 for years 2005-06, 2006-07 and 2007-08 respectively. This cost was calculated on basis of Rs 1248/Ac.ft, Rs 1358/Ac.ft and

Rs 1418/Ac.ft (1 acre-foot= 1212.32 m^3), the prevailing water rates for years 2005-06, 2006-07and 2007-08 respectively.

3.10 Benefit Cost Analysis

The Benefit Cost analysis is a measure for project usefulness. Benefit Cost ratios have been estimated based on benefits occurred through water applied/saved by using bed and furrow irrigation methods and cost incurred.

Table-12 & 13 shows that on average basis maximum B.C Ratio for rice crop of 2.2 and 2.7 for wheat crop was achieved in bed and furrow method with treatment T_1 40 cb. stress. Higher benefit cost ratio for bed and furrows with 40 cb stress was on account of significant reduction in irrigation cost and slightly better yields.

Table-12 Benefit-Cost Analysis (based on water applied)

Method of Irrigation	Production cost (Rs./m^3)	Gross Income (Rs./m^3)	Net Income (Rs./m^3)	B.C. Ratio
Kharif 2005				
T1-40 Centibar	1.63	7.1	5.47	2.36
T2-60 Centibar	1.65	6.6	4.95	2.00
T3-80 Centibar	1.67	6.1	4.43	1.68
Control	1.38	3.0	1.62	-
Kharif 2006				
T1-40 Centibar	1.77	7.75	5.98	1.66
T2-60 Centibar	1.79	7.45	5.66	1.47
T3-80 Centibar	1.82	7.45	5.63	1.43
Control	1.50	4.53	3.03	-
Kharif 2007				
T1-40 Centibar	1.79	13.5	11.7	2.57
T2-60 Centibar	1.81	12.7	10.9	2.10
T3-80 Centibar	1.82	12.0	10.2	1.70
Control	1.52	8.6	7.1	-
Average				
T1-40 Centibar	1.73	9.5	7.7	2.2
T2-60 Centibar	1.75	8.9	7.2	1.9
T3-80 Centibar	1.77	8.5	6.8	1.6
Control	1.47	5.4	3.9	-

Table-13 Benefit-Cost Analysis (based on water applied)

Method of Irrigation	Production cost (Rs./m^3)	Gross Income (Rs./m^3)	Net Income (Rs./m^3)	B.C. Ratio
Wheat (Rabi 2005-06)				
T1-40 Centibar	1.95	14.1	12.2	2.15
T2-60 Centibar	2.00	13.6	11.6	1.8
T3-80 Centibar	2.00	13.0	11.0	1.5
Control	1.50	9.5	8.0	-
Wheat (Rabi 2006-07)				
T1-40 Centibar	2.00	16.3	14.3	2.95
T2-60 Centibar	2.10	15.8	13.7	2.52
T3-80 Centibar	2.12	15.6	13.5	2.40
Control	1.63	10.0	8.4	-
Wheat (Rabi 2007-08)				
T1-40 Centibar	2.07	23.1	21.0	3.14
T2-60 Centibar	2.11	22.0	19.9	2.56
T3-80 Centibar	2.14	20.8	18.6	1.92
Control	1.64	16.1	14.5	-
Average				
T1-40 Centibar	2.01	17.8	15.8	2.7
T2-60 Centibar	2.07	17.1	15.1	2.3
T3-80 Centibar	2.09	16.5	14.4	1.9
Control	1.59	11.9	10.3	-

Conclusions and Recommendations

4.1 CONCLUSIONS

Field trials on bed and furrow irrigation to reduce water use for rice and wheat crop led to the following conclusion and recommendations for research extension works and end user farmers:

a) For Rice crop

- Maximum water saving of 36 % was achieved in bed and furrow irrigation method with treatment T_3 80 cb. stress.
- Maximum yield of 3664 Kg/ha was achieved in bed and furrow irrigation method with treatment T_1 40 cb. stress.
- Maximum water use efficiency of 0.52 kg/m^3 was achieved in bed and furrow irrigation method with treatment T_1 40 cb. stress.
- Maximum B.C Ratio of 2.2 was achieved in bed and furrow irrigation method with treatment T_1 40 cb. stress.

b) For Wheat crop

- Maximum water saving of 31 % was achieved in bed and furrow irrigation method with treatment T_3 80 cb. stress.
- Maximum yield of 3561 Kg/ha was achieved in bed and furrow irrigation method with treatment T_1 40 cb. stress.
- Maximum water use efficiency of 1.47 kg/m^3 was achieved in bed and furrow irrigation method with treatment T_1 40 cb. stress.
- Maximum B.C Ratio of 2.7 was achieved in bed and furrow irrigation method with treatment T_1 40 cb. stress.

4.2 RECOMMENDATIONS

- Bed and furrow irrigation method with 40 cb. stress of water should be used for rice and wheat crop to save irrigation water without any loss in yield.
- To reduce the cost of land preparation and increase net benefits, Bed and furrows for rice and wheat crop should be prepared with bed and furrow shaper instead of manually.

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EVALUATION OF DIFFERENT TECHNIQUES FOR THE SAFE USAGE OF MANCHAR DRAINAGE EFFLUENT FOR GROWING OF CROPS

by

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ABSTRACT

Pakistan is predominantly an agricultural country with major economic reliance on the agriculture sector. Almost 80% of the agricultural production comes from the irrigated agriculture and the remaining 20% from the un-commanded rain-fed area. Although the country possesses one of the largest irrigation systems of the world, but it is still insufficient to cover the whole cultivable area and to meet with the crop water requirements of the area under canal command. To supplement the inadequate canal water supplies, redressal efforts largely focus the use of drainage water, which is generally of inferior quality and unfit for irrigation purpose.

In-spite of the extensive irrigation system in the country, the existing canal supplies are insufficient to cope with the present crop water requirements. These conditions compel the farmers to use groundwater as an alternative to meet the irrigation requirement of the crops. As regards water quality, in Pakistan about 50% of the groundwater reserves are fit for irrigation whereas the remaining 50% need careful application. In Sindh Province about 28% area has usable groundwater. The third alternative lies in the utilization of drainage effluent for growing of salt tolerant crops, grasses and trees. It will not involve much cost compared to other irrigation water sources and secondly drainage disposal problem will be reduced. Hence, attempt

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was made by utilizing saline effluent of Manchar Lake Drain in RBOD area for sustaining agriculture.

The research on Manchar Lake Drain was carried out in the area of RBOD in collaboration with LIM project WAPDA Hyderabad. The application of amendments in combination with canal and saline drain water were tested to sustain the use of saline drainage effluent for Agriculture. The findings of this research study helped a lot in depicting salt tolerance behaviour of crops, trees and grasses under varying soil and water conditions.

Application of drainage water was harmful for rice crop and reduced paddy yield, but with the amendment it is helpful for growing any type of crop. Maximum paddy yield was increased by 13% when it was compared with drainage water without any amendment.

It was observed that 28 and 21% yield of wheat increased when the drain water was applied with gypsum and H_2SO_4 respectively as compared to control (drain water without any amendment).

1. Introduction

The Indus plain is the most prosperous agricultural region of Pakistan, with an area of about 21 mha which is made up of fertile alluvium thousand of feet thick, transported and deposits by pre-historic river system. Major crops grown during Kharif season include Cotton, Rice, Sugarcane, Kharif fodder and during Rabi season Wheat, Rabi fodder, Rape seed/Mustard and Sunflower etc. The main problem is the inefficient use of the water. As time passes the water is becoming scarce and its demand is increasing in every sector of life. This causes a great deal of competitive use of water for agriculture, industry, domestic use and forestry etc. The ever increasing demand of water requires exploring the possible and safe ways of the use of saline groundwater and drainage effluent as the vertical and horizontal drainage measures opted to control waterlogging on the national level are generating a huge volume of saline water. Reasonable crop production is possible even with saline irrigation water provided appropriate precautionary management is exercised and environmental conditions are favourable.

The drain effluent having TDS between 1920 and 2560 ppm could be used safely for cultivation of wheat and cotton on normal soils with 15 percent of canal water for leaching (Drainage and Reclamation Institute of Pakistan, 1988) and another experiment on the cyclic use of canal and brackish groundwater for cotton production and found that the number of bolls per plant was improved when brackish groundwater was applied following the seedling establishment and first irrigation with canal water than when brackish groundwater was applied following the seedling establishment and first irrigation with canal water than when brackish groundwater was given continuously and in blending with canal water in 1:1 ratio throughout the growth period (Aslam,1990). The comparison of various brackish water management strategies for sustained crop production under rice-wheat rotation, the management strategies included the management of tubewell water with H_2SO_4 or gypsum, or cyclic or blended use of canal and tubewell water. Prior to rice planting green manuring crop sesbania was incorporated into the soil in all the treatments except one treatment where only tubewell water was applied. It was observed that the tillers count and the yield of both the rice and wheat were highest with treatment where canal water was applied. It was statistically similar to the treatment where tubewell water was amended with H_2SO_4 and there was less development in soil salinity after control with the same treatment indicating more scope for the amelioration of tubewell water with H_2SO_4 (Hussain *et al*. 1992).

The study was carried out study in slightly saline, silty clay loam soil and the tubewell water was used for irrigation purpose and had EC, SAR, and RSC, 9.2 dS m^{-1}, 20.2 (m molc $L^{-1})^{1/2}$ and 0.0 mmol L^{-1}, respectively. They found decrease in EC_e and SAR of soil with the passage of time in the upper depth. However, wheat and paddy yields were affected with drainage water. They have recommended that poor quality tubewell water can be applied to wheat crop during Rabi while the salinity buildup can be nullified by applying canal water to rice crop during Kharif season (Sidhu *et al*., 1996). The crop irrigation with drainage water increased EC_e and SAR of soil to some extent but they found higher crop yields when this water was amended with gypsum @ 25% of crop water requirement or FYM @25 tons ha^{-1}. They recommended that if need prevails for the use of brackish water, the soil must be amended either with gypsum or organic matter (Chaudhry *et al*., 2000). With the construction of SCARPs and conjunctive use of water resulted in the increase of crop yields and improvement in the socio-economic status of the farmers. They recommended that conjunctive/cyclic use can be adopted for bringing more area under cultivation for meeting the food and fiber requirements of the increasing population of the country (Chaudhry and Bhutta, 2002).

This water is used for irrigation purposes or disposed off into the sea through expensive disposal system. Therefore, it seems appropriate to test the saline agriculture technologies involving the use of saline drainage water for making productive use of normal and salt affected land. In this regard, International Waterlogging and Salinity Research Institute (IWASRI), designed a research study in which Manchar Lake Drain's saline effluent was used for Agriculture in RBOD area ,

The gross command area of Indus Right Bank Canals is 4.45 million acres with annual canal withdrawals of 14.17 million acre feet (MAF) from Guddu and Sukkur barrages (WAPDA, 1995). The command area is relatively flat and in general slopes away towards south as well as towards west from the river upto Nara Valley. However further in the west, the land rises again towards the Khirther Hills. The Nara Valley forms the natural drainage line forming boundary between Indus alluvium in the east and piedmont deposits in the west. In this depression lies the Main Nara Valley Drain (MNVD) constructed at the same time as Sukkur Barrage, in 1932. MNVD connects the two natural depressions i.e. Hamal lake to the North and Manchar Lake to the South and was aimed at carrying flood flows from Hamal Lake to Manchar Lake as well as escape flows from the Rice canal.

2. Objectives

The main objective of this study was to use the saline drainage effluent of Manchar Lake for growing salt tolerant crop cultivars with proper management. This will help in mitigating crop water shortage, utilizing abandoned land for cultivation and will reduce drainage disposal requirement.

The specific objectives of this paper are as under:

(1) Use of saline effluent for growing crops, and management techniques, for increasing area under crops.

(2) Impact of varying saline effluent water quality levels on soil salinity/sodicity build-up and crop production.

(3) Reduce drainage effluent disposal requirement.

3. Methodology

The research was taken out during the year 2012-13, actual field activities like site selection, collection of initial field data (soil sampling, water sampling layout design etc.), and contract with the farmers were initiated from July, 2011 and planting of crops were taken up from the season Kharif-2012 on farmer's fields in the vicinity of Manchar Lake Drain in RBOD area. The main research component was Re-use of saline water for agriculture in Manchar Lake Drain in RBOD area for sustaining agriculture and to enhance the irrigation supplies to meet with the shortage of irrigation water . Feasibility of the use of saline effluent was evaluated by applying different physical, biological and chemical techniques differently in the experiment. The location map of the research study (Manchar Lake) is shown in Figure1.

3.1 Site Selection Criteria:

The following criteria were followed for the selection of field sites: Normal productive land with ensured canal supplies for crops. Salinity//Sodicity hit abandoned land for trees.

(i) Farmer's interest, co-operation and willingness for the use of saline drainage water for saline agriculture and improvement of waste land.

(ii) Availability of drainage water as and when required for crops.

(iii) Easy access to the site.

(iv) Good demonstration value of the site for the anticipated beneficiary, adjoining farmers.

3.2 Site Selection

The site was selected in the vicinity of Manchar lake Drain near Sehwan Sharif (RBOD) at Sehwan-Dadu road, 8 KM from Sehwan Sharif. The treatments being evaluated are as under.

Treatments:

A. Irrigation Source:

(i) Canal Water

(ii) Drainage Water

B. Drainage Water Treatment:

(i) Control

(ii) Gypsum @ 10 tons ha^{-1}

(iii) Sulphuric Acid (H_2SO_4) @ 0.5 tons ha^{-1}

C. Crop Rotations:

(i) Rice-Wheat

(ii) Kharif Fodder-Wheat

(iii) Cotton-Wheat

Initial physical – chemical characteristics of soil is shown in Table1.

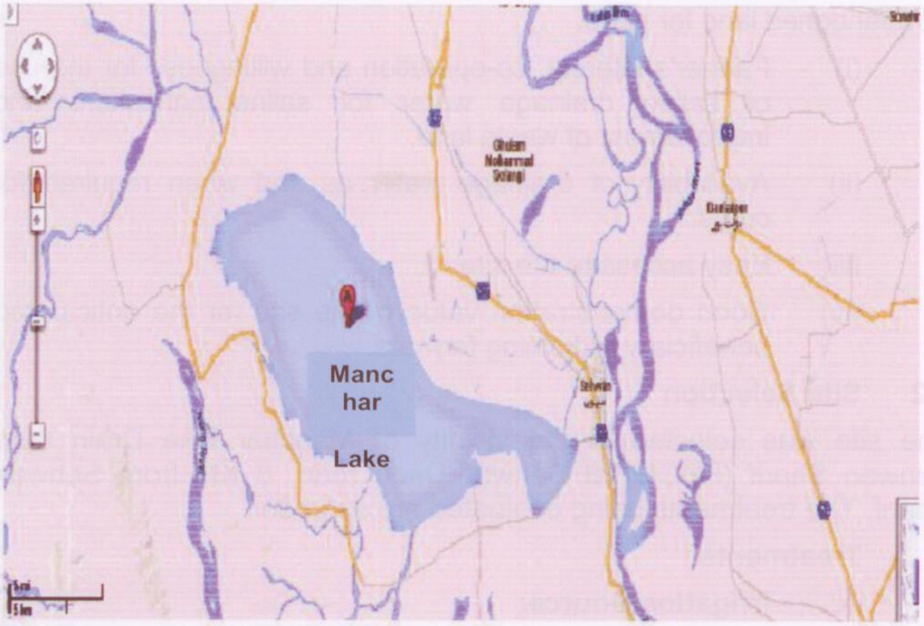

Figure 1 Locations Map of Manchar Lake Area

Table 1 Initial Physical-Chemical Characteristics of Soils

A-Physical

Depth (cm)	Sand%	Silt%	Clay%	Textural Class
0-15	19.6	66.0	14.4	Silt Loam
15-30	23.6	58.0	18.4	Silt Loam
30-60	25.6	58.0	16.4	Silt Loam
60-90	25.6	58.0	16.4	Silt Loam

B-Chemical

Depth (Cm)	pH	EC_e(dS m^{-1})	SAR $(mmol\ L^{-1})^{1/2}$
0-15	7.9	2.4	2.2
15-30	8.0	2.0	2.83
30-60	8.0	2.3	4.20
60-90	7.9	6.5	5.74

The experiment was conducted on salt tolerant crop cultivars for crops, the soil samples were taken before sowing and at harvesting of each crop to monitor changes in soil salinity/sodicity. Since Kharif and Rabi crops were rotated in the same field, therefore, soil samples collected at harvesting of each Kharif and Rabi crop were considered as samples at sowing of Rabi crop. Similarly, samples taken at Rabi crop harvesting were envisaged as salinity status before Kharif crop. The study was so executed that it had a research cum demonstration orientation. The study area was 1.5 ha at selected site located on Manchar Drain. Effect of different irrigation and soil amendments, crop cultivars and trees species on soil properties was studied in various experiments. The initial physical and chemical characteristic of the experimental field's soil under crops, and drainage water quality applied to experiment is given separately. The details regarding the treatments applied, crop rotations and the inputs/cultural operations applied to experiment is given as under. The initial soil analysis of the experimental sites is shown in Table1 where as the average water quality of the selected drains is shown in Table 2.

Table 2 Average Water Quality of Drain Water Used for Irrigation

Season	TDS (ppm)	SAR $(mmol\ L^{-1})^{1/2}$	pH	RSC $(meq\ L^{-1})$
Kharif – 2012	1592	7.46	7.80	0
Rabi – 2012-13	1320	7.37	7.60	0
Kharif – 2013	1872	7.49	7.60	0
Rabi – 2013-14	2128	7.83	7.70	0

3.3 Cultural Operations and Inputs

Common and basic cultural operations regarding sowing time, seeding rate, crop variety, use of fertilizers/amendments, tillage practices, plant protection measures and hoeing/weeding for the crop experiments regarding three crop rotations at the same location are given in Table 3. These operations were common and uniform to all the treatments without any discrimination.

3.4 Irrigation and Gypsum Application

Crops were irrigated with canal or drainage water as per treatment schedule. Samples of drainage water, used for irrigation, were collected and analyzed at crop sowing, in addition to routine quarterly ground water quality monitoring, for Na^+, $Ca^{++}+Mg^{++}$ and $CO_3^- + HCO_3^-$ contents to calculate the gypsum requirement of water by using the Eaton(1950) formula:

$$\text{Gypsum requirement (me L}^{-1}\text{) of water} = A + B + C$$

where

$A = Na^+ (me\ L^{-1}) \times 0.43 - (Ca + Mg)$

$B = \{CO_3 + HCO_3 (me\ L^{-1})\} \times 0.7$

$C = 0.5$ (a constant value)

Gypsum @ 50% CWR was applied to the respective treatment on the basis of water analysis at sowing assuming that wheat will receive three, cotton four and rice twenty five irrigations of brackish water during the growth period. Short fall or excess in gypsum for amending brackish water, in case of more or less number of irrigations under the real climatic conditions, were adjusted in the application for the next season. Soaking and first crop irrigations were applied with canal water for seed germination and initial crop establishment. The subsequent irrigations, each of about 7.5 cm, were applied as per treatment schedule. Number of irrigations applied to each crop under this sub-experiment is shown in Table 3.

3.5 RECORDED

- Baseline soil analyses for texture and salinity/sodicity under crops.
- Periodic water quality analysis of the drainage water used for irrigation.
- Monitoring of soil salinity/sodicity before and after cropping.
- No. of irrigations applied to crops.
- Crop germination, plant growth and crop yields.
- Watertable fluctuation on weekly basis.
- Rainfall and other relevant meteorological data.

Table 3 Number of Irrigations Applied to each Crop

Location	Wheat	Rice	Sun Flower	Kharif Fodder (Sorghum):
Canal Water I_1	4	25	2	4
Drain Water I_2	4	25	2	4
Cyclic Application I_3	2+2 = 4	13+12 = 25	1+1 = 2	2+2 = 4

4 RESULTS AND DISCUSSION

Field activities were taken up for the season Kharif 2012. The main research component i.e. use of saline water for Agriculture in RBOD area. The main objective of the study was to try chemical interventions with drainage effluent to avoid the deleterious effects of saline water on soil and crops. Different soil and crop management interventions on normal soil, for crops were adopted. The impacts of different interventions with the irrigation of drainage effluent of Manchar Drain are discussed as below.

The quality of drainage water used for irrigation is given in Table 4 where as its impact on different treatments at different depths of soil, infiltration rate, soil salinity and crop yield is also being monitored and the data collected so far is discussed as under.

Table 4 Quality of Manchar Drain Water Used for Irrigation

Month	dS/m	TDS (ppm)	SAR (mmol$_c$ L^{-1})$^{1/2}$
May, 2012	2.94	1880	5.71
June, 2012	2.66	1700	6.21
July, 2012	2.59	1656	6.84
August, 2012	2.30	1470	7.53
September, 2012	1.96	1256	7.82
October, 2012	1.79	1148	6.4
November, 2012	1.70	1088	5.35
December, 2012	1.64	1048	7.2
January, 2013	2.18	1396	8.17
February, 2013	3.00	1920	8.72
March, 2013	2.95	1886	6.25
April, 2013	2.84	1820	6.05

11.2.14.1 Soil Salinity/Sodicity

(a) Soil Salinity (EC$_e$ dS m^{-1})

Soil Samples were collected at the beginning of experiment, followed by harvesting of each crop and so on. The Soil Samples were collected by the help of augur at a depth of 0-15, 15-30, 30-60 and 60-90 cm of soil depth. The samples were tested in soil and water laboratory of Lower Indus Water Management Research Institute, Hyderabad (LIM), Campus for determination of EC_e and SAR. The results obtained are given in Table 3 as discussed below. Soil EC_e ranged from 2.30 to 5.70 in 0-90 cm in T_1, T_2, T_3, T_4, T_5 and T_6 treatment in A portion where drain water with amendments was applied and EC_e ranged from 2.8 to 6.5 in (B) portion where drain water without amendments was applied in cotton crop during pre-Rabi 2013. The decrease was observed in EC_e of soil 6 to 34% where irrigation was applied with drain water with all amendments as compared to EC_e of soil with drain water applied without amendments during pre-Rabbi 2012-13 as shown in Table 5. The graphical presentation of EC_e of soil with drain water with amendments and drain water without amendment for different crops are shown in Figures 2, 3 and 4.

Table 5 Effect of Different Treatments on EC_e of Soil

($dS\ m^{-1}$)

Treatments	Soil Depth (cm)	Pre-Rabi 2012-13		% ECe Dec. from Control
		Drain Water (A)	Drain Water (B) Control	
T1	0-15	2.5	2.8	11
Rice (Gypsum)	15-30	2.4	3	20
	30-60	2.5	3.2	22
	60-90	3	3.7	19
T2	0-15	2.3	-do-	18
Rice (H_2SO_4)	15-30	2.5		17
	30-60	2.7		16
	60-90	3.4		8
T3	0-15	4.2	4.9	14
Cotton (Gypsum)	15-30	4.8	5.3	9

Treatments	Soil Depth (cm)	Pre-Rabi 2012-13		% ECe Dec. from Control
		Drain Water (A)	Drain Water (B) Control	
	30-60	5	5.8	14
	60-90	5.3	6.3	16
T4 Cotton (H_2SO_4)	0-15	4.1	-do-	14
	15-30	4.5		15
	39-60	4.9		16
	60-90	5.2		17
T5 Janter (Gypsum)	0-15	3	4.45	33
	15-30	3.5	5.5	34
	30-60	4.2	6.3	33
	60-90	4.5	6.5	31
T6 Janter (H_2SO_4)	0-15	4.2	-do-	6
	15-30	4.8		13
	30-60	5.1		19
	60-90	5.7		12

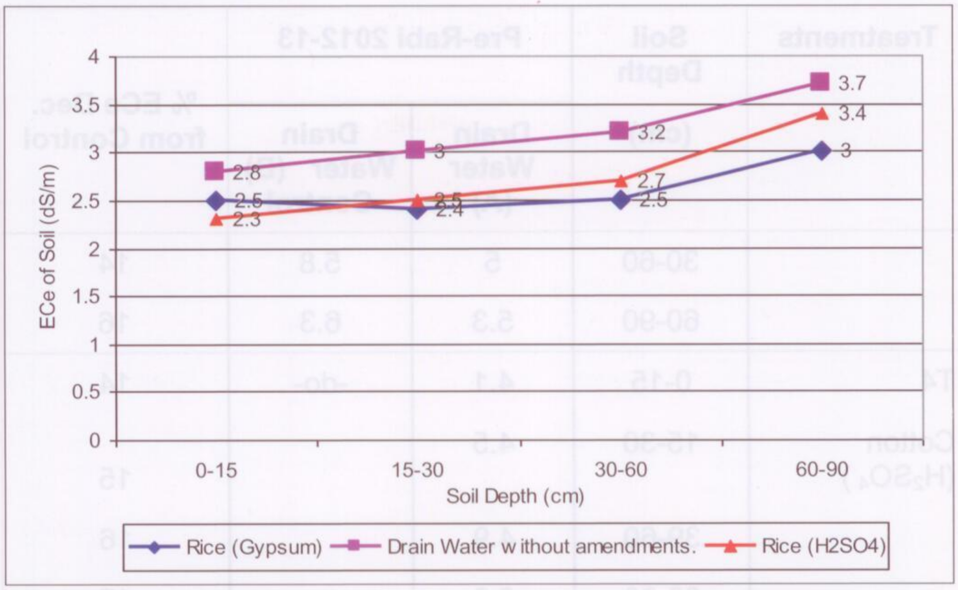

Figure 2 Soil EC_e by Using Drain Water with Different Treatments for Rice Crop

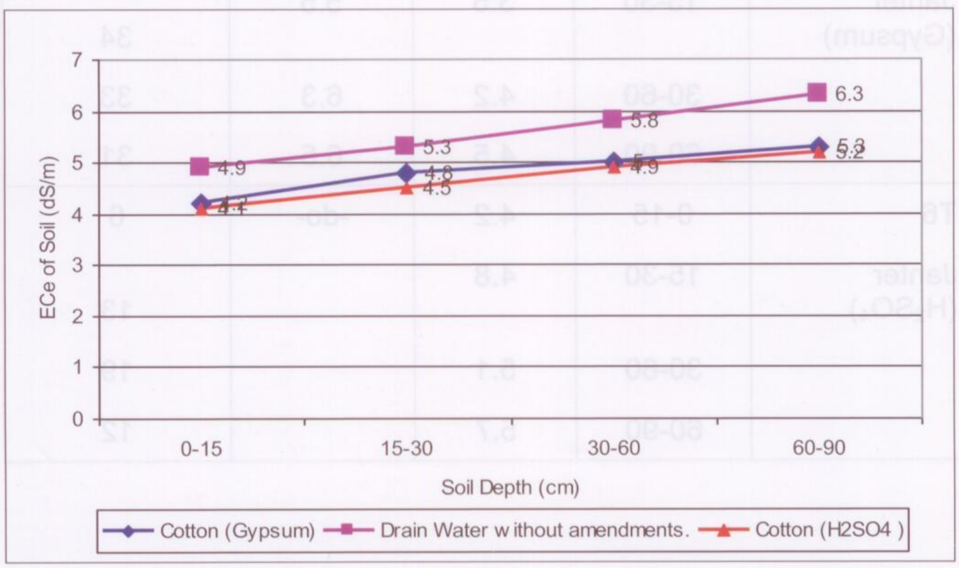

Figure 3 Soil EC_e by Using Drain Water with Different Treatments for Cotton Crop

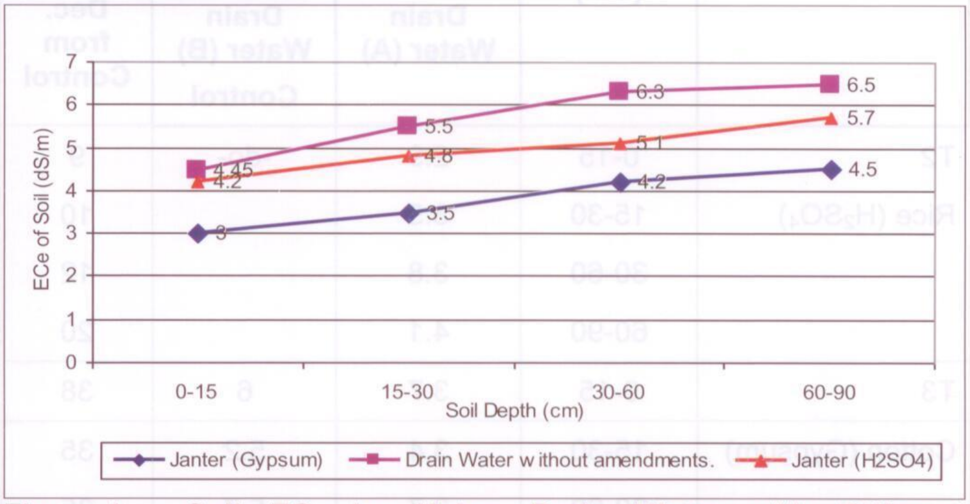

Figure 4 Soil EC_e by Using Drain Water with Different Treatments for Janter Crop

(b) Soil Sodicity (SAR $mmol_e\ L^{-1})^{1/2}$

The SAR of soil ranged from 2.60 to 5.59 where drain water with amendments was applied and SAR ranged from 2.50 to 6.40 where drain water without amendments was applied during the Pre-Rabi 2012-13. Maximum increase in SAR 6.80 was observed in T_5 where drain water was applied without amendments in Jantar Fodder and it is shown in Table 6. Decrease/Increase in SAR for different crops are shown in Figures 5, 6 and 7.

Table 6 Effect of Different Treatments on SAR of Soil

$(mmol\ L^{-1})^{1/2}$

Treatments	Depth (Cm)	Pre-Rabi 2012-13		% SAR Dec. from Control
		Drain Water (A)	Drain Water (B) Control	
T1	0-15	2.6	3.2	19
Rice (Gypsum)	15-30	3.4	3.9	13
	30-60	3.5	4.3	19
	60-90	4.3	5.1	16

Treatments	Depth (Cm)	Pre-Rabi 2012-13		% SAR Dec. from Control
		Drain Water (A)	Drain Water (B) Control	
T2	0-15	2.9	-do-	9
Rice (H_2SO_4)	15-30	3.5		10
	30-60	3.8		12
	60-90	4.1		20
T3	0-15	3.7	6	38
Cotton (Gypsum)	15-30	3.4	5.2	35
	30-60	3.7	5.7	35
	60-90	4.5	6.5	31
T4	0-15	3.5	-do-	42
Cotton (H_2SO_4)	15-30	4.1		21
	30-60	5.4		5
	60-90	5.9		9
T5	0-15	3.4	5.2	35
Janter (Gypsum)	15-30	3.4	6.1	44
	30-60	5.3	6.3	16
	60-90	5.7	6.3	10
T6	0-15	4.5	-do-	13
Janter (H_2SO_4)	15-30	4.8		21
	30-60	5.1		19
	60-90	5.3		16

Note: Drain Water (A) = Drain water with amendments.
Drain Water (B) = Drain water without amendments.

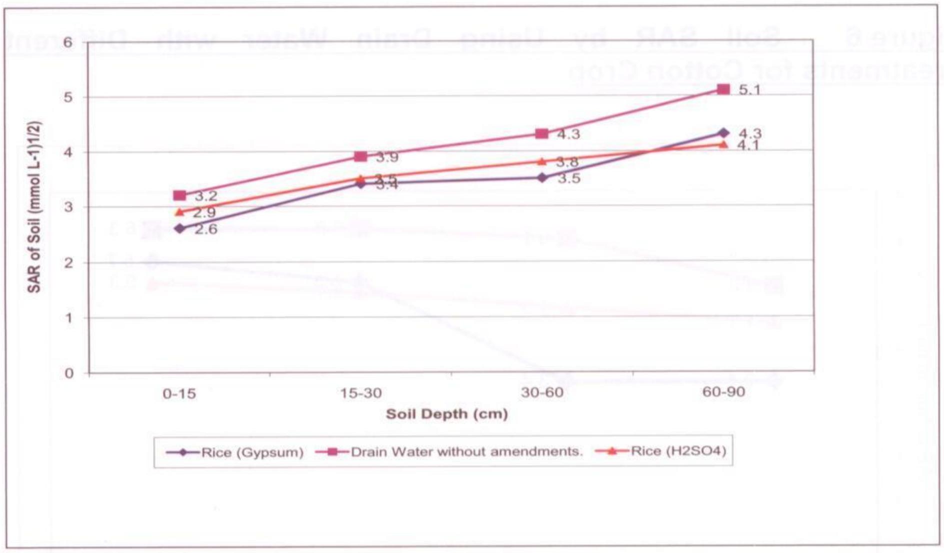

Figure 5 Soil SAR by Using Drain Water with Different Treatments for Rice Crop

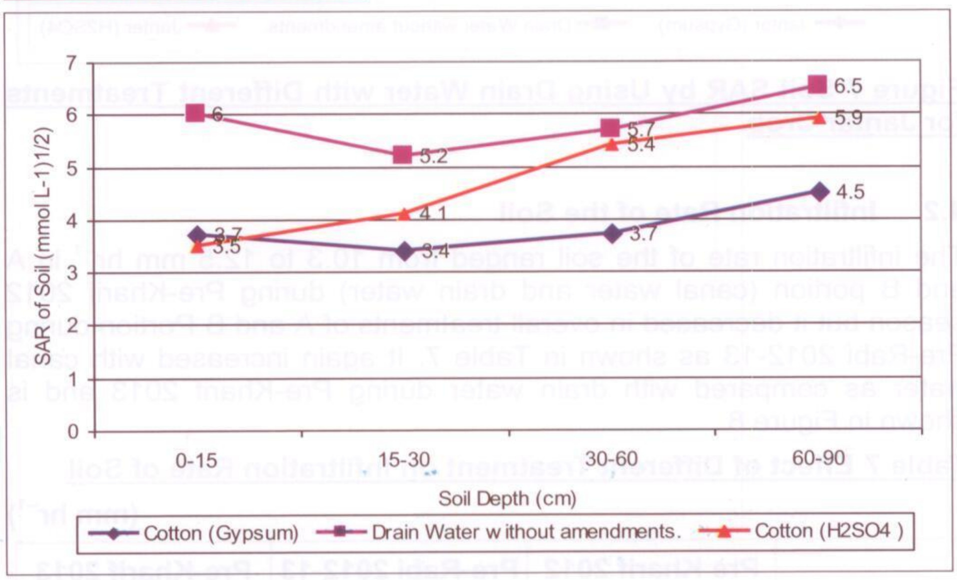

Figure 6 Soil SAR by Using Drain Water with Different Treatments for Cotton Crop

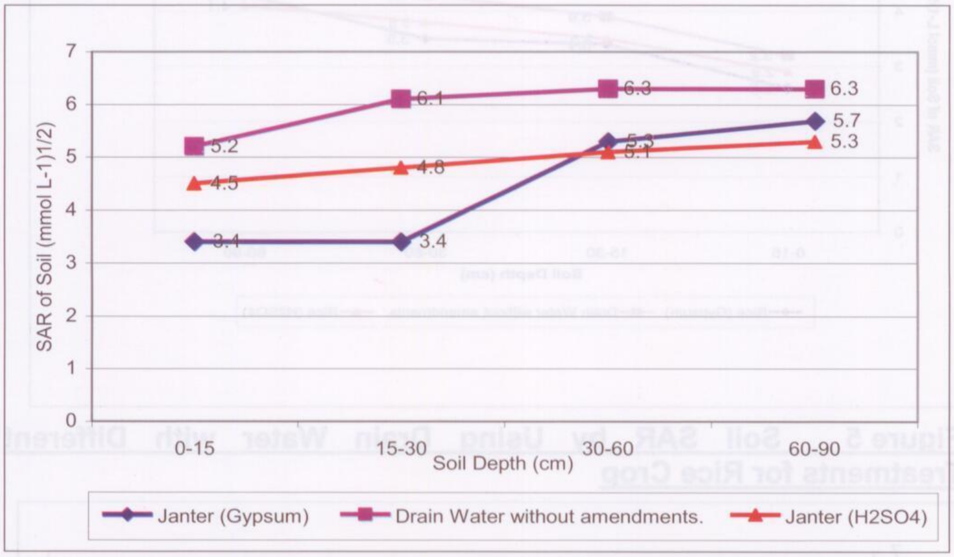

Figure 7 Soil SAR by Using Drain Water with Different Treatments for Jantar Crop

4.2 Infiltration Rate of the Soil

The infiltration rate of the soil ranged from 10.3 to 12.5 mm hr^{-1} in A and B portion (canal water and drain water) during Pre-Kharif 2012 season but it decreased in overall treatments of A and B Portion during Pre-Rabi 2012-13 as shown in Table 7. It again increased with canal water as compared with drain water during Pre-Kharif 2013 and is shown in Figure 8.

Table 7 Effect of Different Treatment on Infiltration Rate of Soil

(mm hr^{-1})

Treatments	Pre Kharif 2012		Pre-Rabi 2012-13		Pre-Kharif 2013	
	Canal Water (A)	Drain Water (B)	Canal Water (A)	Drain Water (B)	Canal Water (A)	Drain Water (B)
T1	11.3	11.0	8.8	8.3	11.0	8.3
T2	12.5	12.0	9.3	8.3	12.0	7.5

T3	10.8	10.3	9.3	8.5	10.5	8.5
T4	115	11.0	9.8	9.0	11.5	8.7
T5	12.5	12.3	11.3	10.5	12.8	10.0
T6	12.3	11.8	9.5	8.8	11.8	8.0

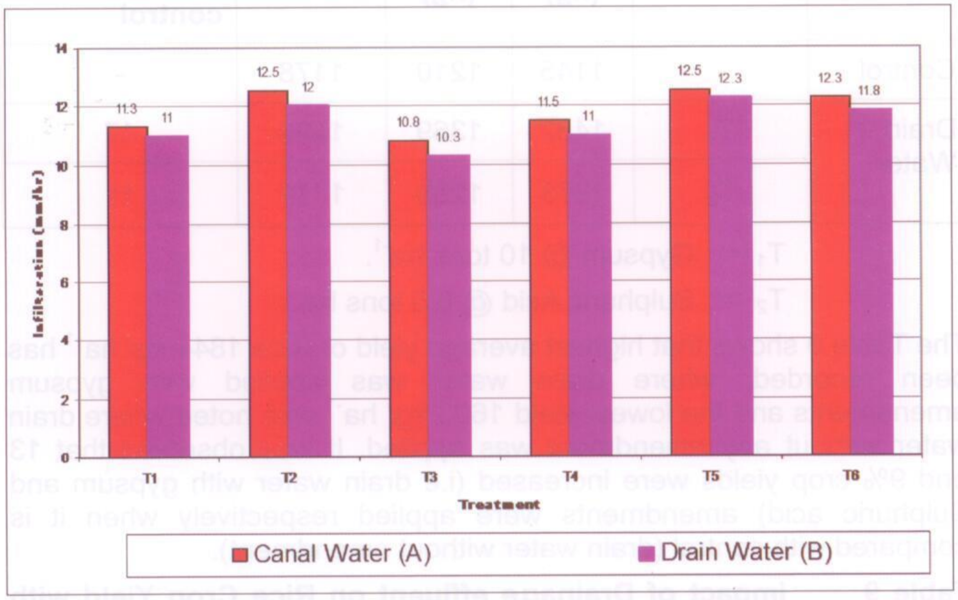

Figure 8 Infiltration of Soil Comparison with Canal Water and Drain Water During Pre Kharif 2012.

4.5 Impact of Drainage Water on Crop Yield with Chemical Amendments.

The data reveals that maximum average yield of Cotton 1425 kg/h^{-1} was obtained with drain water along with amendment of gypsum and whereas minimum 1178 kg/h^{-1} was recorded where drain water without using any amendment was applied. In this way 17 and 11% more cotton yield was obtained with drain water by using gypsum and H_2SO_4 respectively when it was compared with control (drain water without any amendment) as shown in Table 8.

Table 8 Impact of Drainage effluent on Cotton Crop Yield with Chemical Amendments.

COTTON					
	Treatment	*2012-13* (kg)	2013-14 (kg)	Average (kg)	% Yield Increased as compared to control
Control	-	1145	1210	1178	-
Drain Water	T_1	1482	1369	1425	17
	T_2	1378	1259	1318	11

T_1 = Gypsum @ 10 tons ha^{-1}.

T_2 = Sulphuric Acid @ 0.5 tons ha^{-1}.

The Table 9 shows that highest average yield of Rice 1844 kg/ ha^{-1} has been recorded, where drain water was applied with gypsum amendments and the lowest yield 1603 kg/ ha^{-1} was noted where drain water without any amendment was applied. It was observed that 13 and 9% crop yields were increased (i.e drain water with gypsum and Sulphuric acid) amendments were applied respectively when it is compared with control (drain water without amendment).

Table 9 Impact of Drainage effluent on Rice Crop Yield with Chemical Amendments.

RICE					
Irrigation	Treatment	*2012-13* (kg)	2013-14 (kg)	Average (kg)	% Yield Increased as Compared to Control
Control	-	1575	1630	1603	-
Drain Water	T_1	1894.28	1794.5	1844	13
	T_2	1776.5	1726	1751	9

T_1 = Gypsum @ 10 tons ha^{-1}.

T_2 = Sulphuric Acid @ 0.5 tons ha^{-1}.

The data in Table 10 indicates that the highest yield of Jantar Fodder 19772 kg/ha^{-1} was obtained where drain irrigation with gypsum amendment was applied. Lowest yield 16405 kg/ha^{-1} was recorded where drainage water without any amendment was applied. It was observed that Janter fodder yield was more as 17 and 13% respectively where drain water with gypsum and H_2SO4 were applied when it was compared with control (without any amendment).

Table 10 Impact of Drainage effluent on Jantar Fodder Yield with Chemical Amendments.

Jantar					
Irrigation	**Treatment**	***2012-13 (kg)***	**2013-14 (kg)**	**Average (kg)**	**% Yield Increased as Compared to Control**
Control	-	15460	17350	16405	-
Drain Water	T_1	19354	20190.5	19772	17
	T_2	18631.5	18885	18758	13

T_1 = Gypsum @ 10 tons ha^{-1}.

T_2 = Sulphuric Acid @ 0.5 tons ha^{-1}.

The data indicates that the highest yield of wheat crop 2168 kg/ha^{-1} was obtained where drain water was applied with gypsum amendment. Lowest yield 1570 kg/ha^{-1} was recorded where drainage water was applied without amendment. Further it was observed that 28 and 21% yield of wheat increased when the drain water was applied with gypsum and H_2SO_4 was applied respectively as compared to control (drain water without any amendment) as shown in Table 11.

Table 11 Impact of Different Irrigations water on Crop Yield

Wheat					
Irrigation	**Treatment**	***2012-13 (kg)***	**2013-14 (kg)**	**Average (kg)**	**% Yield Increased as Compared to Control**
Control		1560	1580	1570	-
Drain Water	T_1	1477.8	2858	2168	28
	T_2	1195.2	2748.2	1972	21

T_1 = Gypsum @ 10 tons ha^{-1}.

T_2 = Sulphuric Acid @ 0.5 tons ha^{-1}.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

- The permeability of the soil decreased with the use of drainage effluent; however addition of amendment exerted ameliorative effect on physical condition of soil. Exclusive use of drainage water reduced the penetration of water in the soil profile.
- Application of drainage water was harmful for Rice crop and reduced paddy yield, but with the amendment it is helpful for growing any type of crop. Maximum yield was increased by 13% when it was compared with drainage water without any amendment.
- It was observed that 28 and 21% yield of wheat increased when the drain water was applied with gypsum and H_2SO_4 respectively as compared to control (drain water without any amendment).
- Cotton yield was increased by 17 and 11% more with drain water by using gypsum and H_2SO_4 respectively when it was compared with control (drain water without any amendment).
-
- Water quality of Manchar Lake Drain was marginally saline ranging its TDS from 1048 to 1920 (ppm) and SAR from 5.71 to 8.72 $(mmol\ L^{-1})^{1/2}$

5.2 Recommendations

- It is recommended that chemical treatments may be adopted to avoid the adverse effect of Manchar Lake drain on physical and chemical properties of soil.

MESSAGE TO THE FARMERS

Saline/Drain water for cultivation of agricultural crops should be used with proper amendments like Gypsum and Sulphuric Acid (H_2SO_4) after testing the soil and water quality, in the laboratory.

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PLATES

(GLIMPSIS OF RESEARCH ACTIVITIES)

Plate 1. A view of adding amendments.

Plate 2. A View of Collection of Soil Samples

Plate 3. A View of Preparation of Layout Design

Plate 4. A View of Infiltration Test Through Double Ring Infiltrometer

Plate 5. A View of Pumping of Drainage Water for Irrigation

Plate 6. Another View of Pumping Drainage Water for Irrigation to the Crop Experiments

Plate 7. A View of the Experimental Rice Grown with the Use of Drainage Water Amended with Sulphuric Acid

Plate 8. A View of the Experimental Cotton Crop Grown with the Use of Drainage Water Amended with Sulphuric Acid

Plate 9. A View of Sesbania-Jantar Crop with the Use of Canal Water

Plate 10. A View of Sesbania-Jantar Crop with the Use of Saline Drainage Water

Plate 11. A View of Installed Piezometer at the Experimental Site to Determine Watertable Depth.

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Plate 13. A View of Wheat Crop Experiment under Kharif Fodder-Wheat Crop Rotation

INTEGRATED WATER RESOURCES MANAGEMENT - CASE STUDY OF ALBORZ PROJECT, IRAN

Dr. Mansoor A. Hashmi[1]

1. INTRODUCTION

The Government of Iran (GOI) undertook construction of Alborz Dam in Year 2004 and completed it in March 2008. In order to ensure that the Alborz Dam benefited communities without any adverse impacts, GOI requested a World Bank Loan to support the Alborz Integrated Land and Water Management Project (AILWMP) in Mazandaran Province, Iran with the purpose of piloting a basin wide Integrated Water Resources Management (IWRM), approach in Alborz Basin. The Project aimed at demonstrating the benefits of IWRM at the river basin level by:

- Sustainably increasing agricultural productivity through the improved irrigation and drainage system and participatory management mechanism
- Reducing soil erosion and sediment yields into the Alborz Dam through improved upper watershed management and
- Protecting the water environment downstream of Babol River and other water bodies through improved hydrological/water quality monitoring, reservoir operation and pest management

Alborz Project included five components, of which the first related to upper watershed management and second related to improvement in irrigation and agriculture in the downstream areas of Alborz Dam. The third related to development of IWRM support system and the fourth addressed Environmental and Social Management (ESMP) activities. The fifth related to overall project management and coordination.

2. COMPONENTS OF IWRM AND ENVIRONMENT & SOCIAL MANAGEMENT PLAN (ESMP)

IWRM comprised three sub-components; Setting up of Basin Water Council (BWC), establishing Basin Water Fund (BWF) and development of Integrated Water Resources Management (IWRM) Support System. The Environmental Management focused on implementation of Environmental and Social Management Plan (ESMP) in compliance with seven WB safeguard policies triggered by

[1] Vice President NESPAK, Team Leader Alborz Project

AIWLMP. In a Quality Based Selection (QBS) procurement process, NESPAK was selected to implement IWRM & ESMP components during the 7 year project period from 2006-2013.

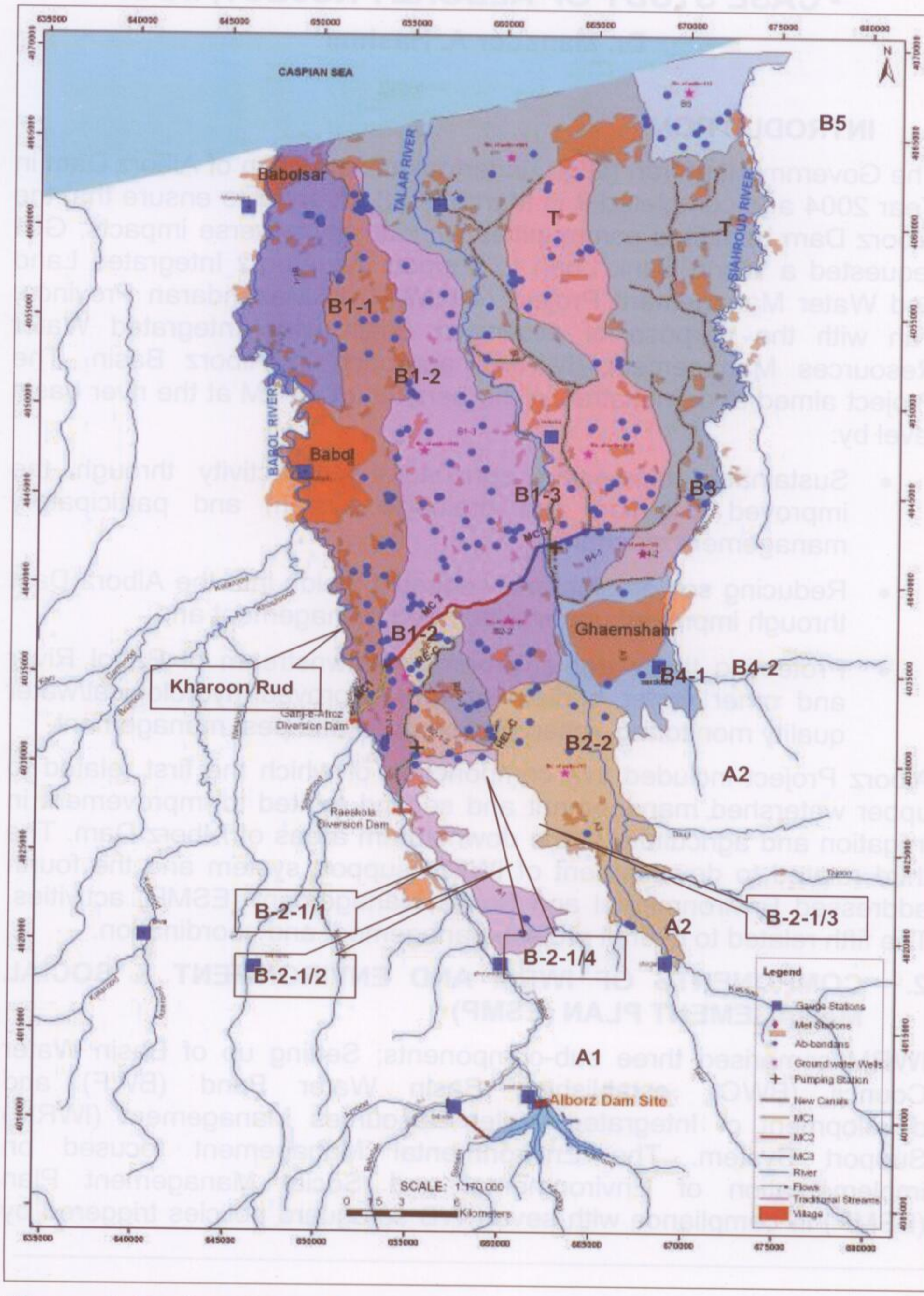

Figure 1: Project Area Map

The Consultants task was to setup a decision support framework to aid the management of land and water resources usage by multiple stakeholders. The framework required an information system that would generate indicators for continuous monitoring of water quantity, quality and reliability and associated environmental and social impacts that arise out of the prospects of increased irrigated agriculture. This was to be achieved by the development of latest computerized decision support systems based on basin wide surface and sub-surface water modeling using simulation and optimization models for reservoir operation, and to further enhance the use of these models by the development of real time data acquisition and operation for accurately managing the water demand in the system for various uses. The development of a knowledge database for water and environment based on GIS was also undertaken.

The implementation of ESMP required technical studies and monitoring activities in eight sub areas; namely, forest and wildlife, water quality and quantity, river ecology, EIA of projects funded by basin water fund, pest management, dam safety, resettlement, and protection of cultural heritage sites.

3. PROJECT AREA CHARACTERISTICS

The project area below the Alborz Dam is bounded by Babol River on the west, Shiaroud River on the east while Talar river flows in the middle. All three rivers terminate at Caspian sea. There are two diversion dams below Alborz dam on Babol River, the Raeiskola Diversion Dam and Ganj Afroz Diversion Dam. Just upstream of these diversion dams, there are tributary inflows. The total average annual surface flows of Babol round at stations Ghoran Talar are 221 & 521 mcm respectively while for Talar these are 248 mcm at Shergah and 298 mcm at Kiakola. The flows in the rivers are unregulated, except for the regulation to be provided by Alborz Dam and through proposed Raeiskola and Ganj Afroz weirs. The Project Area is shown in Fig. 1.

A lot of run-off generated in Babol river during winter and springtime (October-April) is lost to the Caspian sea. The irrigated areas between Alborz mountain and Caspian sea are currently irrigated traditionally but often suffer from water shortages in summer. The soils are excellent for rice cultivation. The maximum volume of water that would be stored in the reservoir is 150 mcm. The filling of the reservoir would be done mostly during winter and spring. The stored water would be released during summer to meet the irrigation shortages in the areas between Alborz dam and sea. The water potential and usage are to be integrated with Talar and Siah river basins in addition to Babol river due to hydrological connections. However, to prevent soil salinization, an effective drainage system was also required.

The cultivated area lies within the three river basins which is interspersed by numerous lakes *ab-bandans*. Irrigation is done through canals, wells and *ab-bandans*. The net cultivated area is 51,765 ha, of which 18,590 ha are located in the new area to be developed and 33,175 ha are located in the existing irrigated area.

4. DEVELOPMENT OF IWRM SUPPORT SYSTEM

Consultant's first task in the establishment of IWRM support system included: Basin wide water balance simulatory modeling; development of optimized surface and groundwater water use policies; development of basin wide water knowledge database; and defining water rights and volumetric pricing system.

Selection of Model and Results

After a thorough review of available models in the world and those being used in Iran, the consultants selected MIKE Basin backed by in-house Excel based model. Historic 30-year daily time series inflow discharge data at dam side was used to simulate operation of Alborz Dam. System network schematic diagram is shown in Figure 2. Water level variation in Alborz Dam is shown in Figure 3. Canal diversions in two canals downstream is shown in Figure 4 & 5. Groundwater pumping requirements are shown in Figure 6.

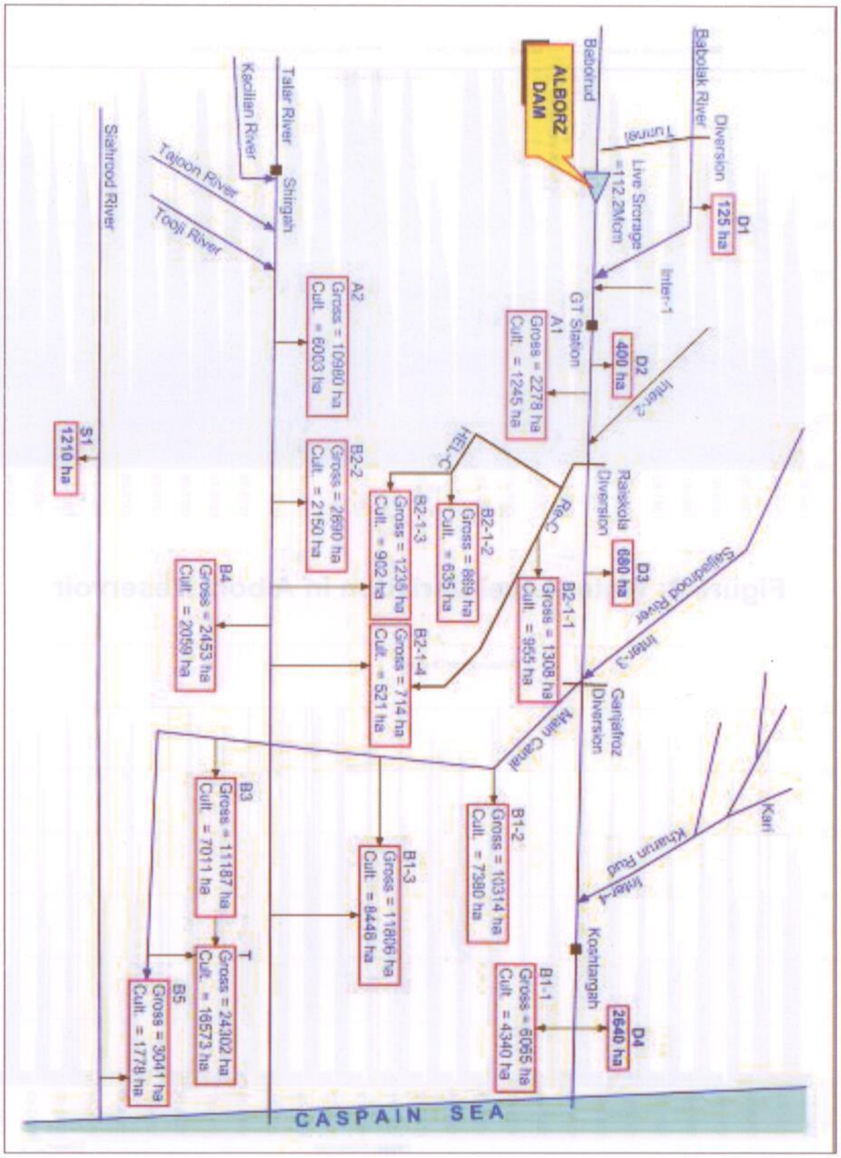

Figure 2: System Network Schematic Diagram

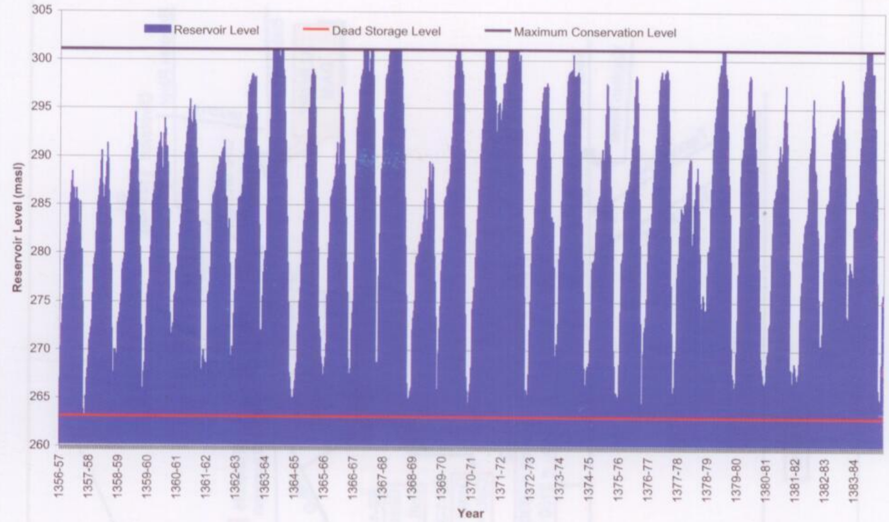

Figure 3: Water Level Variation in Alborz Reservoir

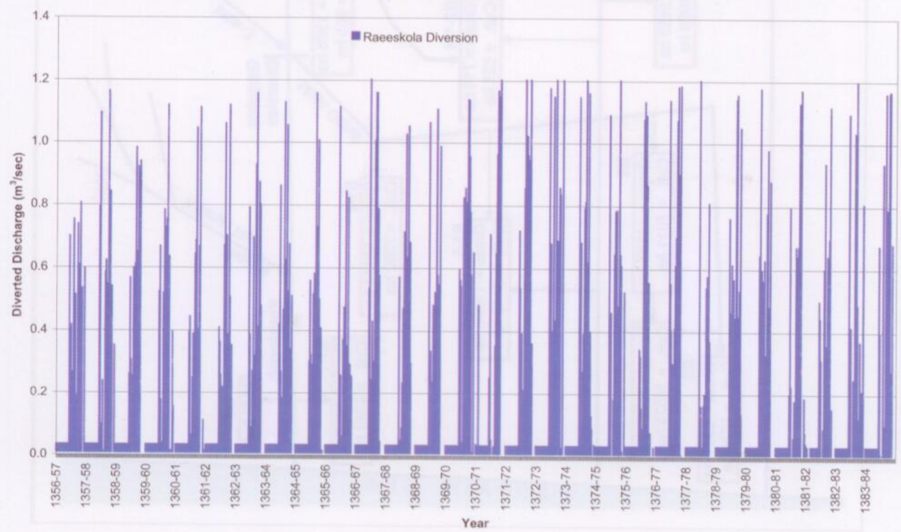

Figure 4: Raes kola Main Canal Diversion Time Series

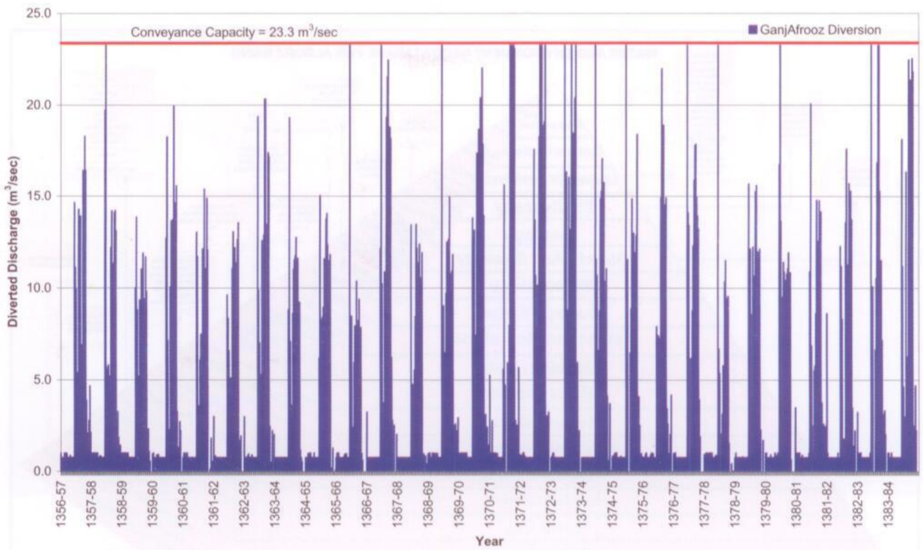

Figure 5: GanjAfrooz Main Conveyance Canal Diversion Time Series

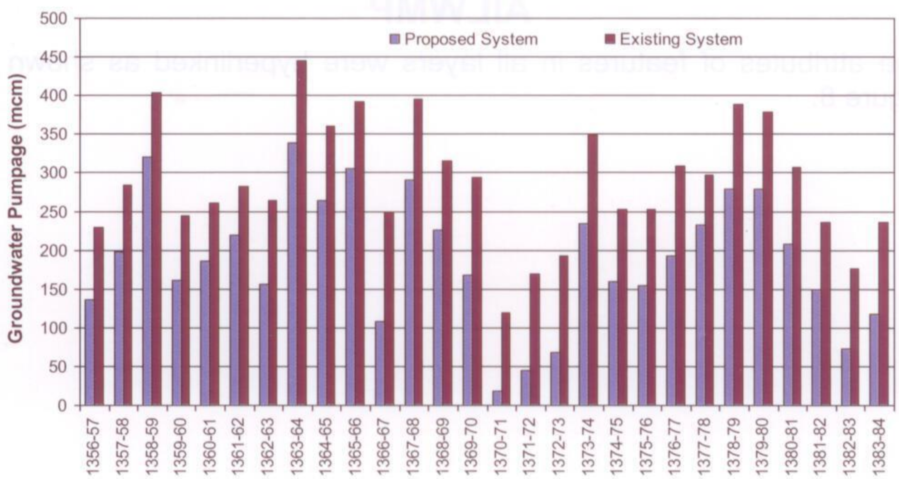

Figure 6: Groundwater Pumping Requirements

Water and Environment Database

High resolution satellite data with 0.6 metre ground resolution was made the basis of GIS database. Following GIS layers were developed: project boundary, satellite image, land use, infrastructure, rivers/streams, sub-catchment boundaries, etc. The GIS data layers are shown in Figure 7.

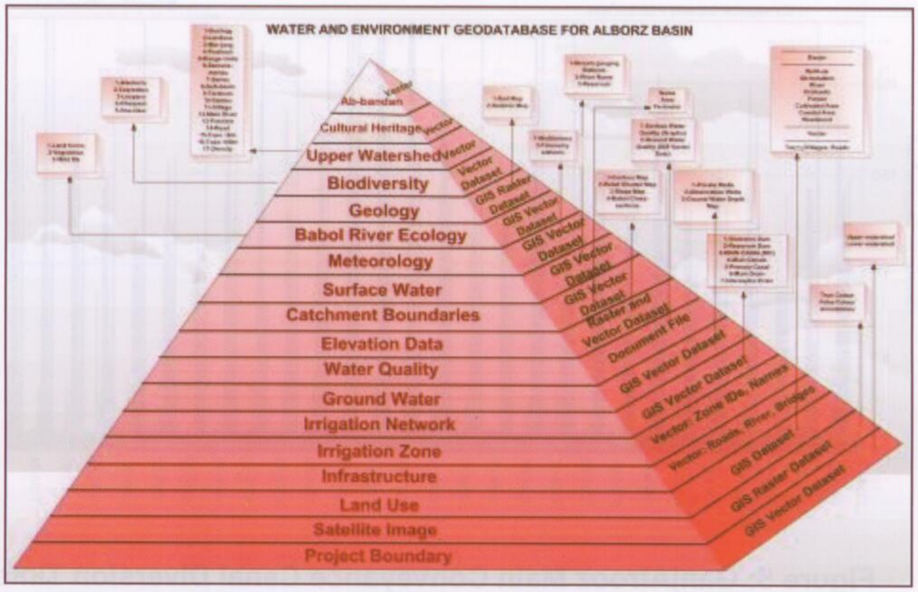

Figure 7: Organization of Geodatabase for AILWMP

The attributes of features in all layers were hyperlinked as shown in Figure 8.

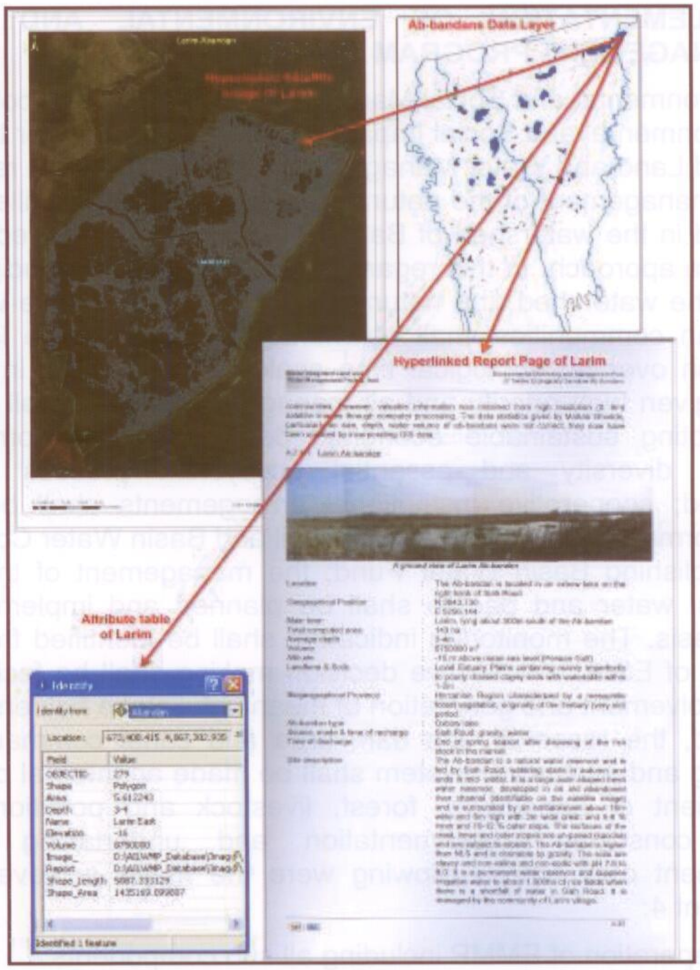

Figure 8: Satellite Image, Report page and attributes of Ab-bandans

5. DEVELOPMENT OF BASIN WATER AND SOIL COMMITTEE AND BASIN WATER FUND

The Basin Water and Soil Committee (BWC) was formed with 32 members consisting of Executive Committee headed by Secretary to Governor, Mazandaran Province and Heads of all Federal and Provincial Departments with representation from private sector.

The functioning of the BSWC was linked with project activities under Component 3 & 4. Subcommittees were formed to look after various kind of activities, such as water quality monitoring, forest degradation, pest management, ecology monitoring etc. Procedures for funding of projects out of Basin Water Fund were developed.

6. IMPLEMENTATION OF ENVIRONMENTAL AND SOCIAL MANAGEMENT PROGRAM (ESMP)

The Environmental and Social Management Plan (ESMP), contained in the Environmental and Social Impact Assessment (ESIA) for the Alborz Integrated Land and Water Management Project (AILWMP) recognized that the management of the natural resources of Alborz Valley located along and in the watershed of Babol River have to be based upon an ecosystem approach. In this regard, the following main principles were applied; the watershed, the natural resources, the soil, the water and the human communities shall be managed across whole landscape and region over an ecological time scale; human needs in the area shall be given high priority and all management efforts shall converge on promoting sustainable economic development of communities; Biological diversity and essential ecosystem process shall be maintained; cooperative institutional arrangements shall be utilized through formation of Basin Water Council and Basin Water Committees and establishing Basin Water Fund; the management of the natural resources, water and people shall be planned and implemented on holistic basis. The monitoring indicators shall be identified from within the ambit of ESIA; a collective decision making shall be facilitated by public involvement and generation of meaningful stake holders in upper watershed, the reservoir, the dam area and canal command areas; monitoring and evaluation system shall be made an integral part of the management of agriculture, forest, livestock and pollution control, through conscious experimentation and undertaking adaptive management over time. Following were the major achievements of Component 4:

- Preparation of EMMP including all sub components
- Capacity building of governmental, non governmental and community based stakeholders
- Procurement of required equipment
- Public participation and information disclosure.

The eight sub-components of this task are discussed below:

Forestry and Wildlife

The AILWMP focused on environmental and social monitoring and management in the forest and rangeland of Upper Watershed (UW) above the Alborz Dam on the Babol River, and in the Lower Watershed (LW), primarily agricultural lands below the dam. The UW lies in the hyrcanian vegetation zone (hyrcanian biom) having elevation ranges from 55 to 3300 m (amsl). Mostly the area is forested and contains high biodiversity. Therefore, there is a great potential for biodiversity conservation and protected area management through an effective monitoring system.

A detailed Master Plan *(December 2007)* was developed based on nine (9) thematic reports including Biodiversity Conservation and Eco-tourism reports. Master Plan proposed certain measures for biodiversity conservation and protection related to wildlife conservation. During the preparation of the Master Plan little information was collected for wildlife activities within the UW, therefore, systematic field surveys and review and systhesis of secondary data were done in order to fill the baseline gaps and thereafter, some measures were pointed to be monitored for observing the changes in the biodiversity. IWREMS Consultants' upgraded the biodiversity monitoring scheme by obtaining additional data on wildlife and prepare an upgraded monitoring program. The study has proposed monitoring and implementation of forest, rangeland and In-situ and Ex-situ conservation of biodiversity.

Water Quality and Quantity Monitoring

Agricultural, municipal and industrial effluents are the main sources of pollution of water bodies in the Project Area. Water quality in upper and middle watershed is good and is considered suitable for irrigation use. However in the lower watershed quality of water is degraded due to contamination by general agricultural run-off and many point sources of industrial and commercial outfalls near the urban areas especially along Babol River. The quality of water in ab-bandans varies with their use for irrigation and aquaculture and is susceptible to human activity. The quality of groundwater is also degraded from middle to lower watershed.

The establishment of baseline conditions of water quality has been done on the basis of existing water quality data available with the three (3) government agencies in the area. Monthly water quality data on physical and chemical parameters was collected but data on biological parameters irregular and the reliability of the data was questionable. All the data was analyzed for spatial and temporal variations and formed the basis of selection of monitoring stations in the Project Area.

Ab-bandans and River Ecology Monitoring

River Ecology Monitoring and Mitigation was the focus of this study and included (a) a baseline river morphology and ecology survey, (b) development and implementation of a river ecology monitoring plan (c) assessment of the impact and suitability of the proposed 1 m^3/ sec minimum river base flow and (d) study and monitoring of fish species, and specifically sturgeon migration and impacts of barriers on spawning and reproduction of all species. Eventually an Environment Management and Monitoring Plan was developed.

Pest Management Plan (PMP)

The Consultants updated the PMP part of implementation of Integrated Pest Management (IPM). For the up gradation of the PMP, the Consultants held many meetings with the scientists of various concerned institutions situated in Mazandran province and Tehran. The major additions as reported in this study were land use and cropping pattern to be adopted in Improvement and Development areas of the Project, pest monitoring, control measures for pests, pest control methods such as cultural, use of pheromones/ biochemicals, host-plant resistance, bio-technology, pesticides, monitoring of pesticides in water and agri-products, Farmer Field School (FFS), implementation, equipment for detection laboratories etc. In addition, a Pilot Study was carried out on use of *Bacillus thuringiensis* on Rice Stem Borer for biological control.

Dam Safety Studies

In compliance with the WB safeguard policy (OP 4.37) on dam safety, following studies were carried out;

Probable Maximum Flood

A deterministic approach utilizing the maximization of historic storms as opposed to statistical approach was used to arrive at PMF value which was revised from 1400 cubic metre per sec to 3812 cubic metre per sec. Restrictions were placed on reservoir filling at the probable occurrence of maximum storm in order to accommodate PMF.

Dam Break Analysis

Dam break analyses were carried out using HEC RAS to identify areas of inundation due to dam failure; the results of the study were used to develop an emergency evacuation and warning plan.

Reservoir Slope Stability Analysis

Slope studies were carried out using the saturated rock strength under condition of impounding and rapid draw-down with emphasis on those which were close to the dam body and appurtenant structures. It was found that Left Abutment was unstable and its slopes were revised.

Fault Rupture Hazard Study

Fault Rupture studies were carried out due to the proximity of a fault to the dam site

Dynamic Analysis of the Embankment Body

To investigate stress and strain behavior within the dam during an earthquake, dynamic analyses of embankment body were carried out.

Construction Quality Review

Construction quality review was periodically done through instrumentation data to monitor seepage in the dam body.

Resettlement Activities

Resettlement policy frameworks (RPF), land acquisition and significant compensation for the dam site were done, and identification of project affectees, compensation package, social preparation and valuation of affectees for the main canal were carried out. The resettlement plan (RP) was prepared and six monthly resettlement monitoring reports were issued. A Grievance Cell was established to address complaints.

Cultural Heritage Property

Following steps were taken ensure the safety and protection of any physical cultural heritage:

- A close contact with the cultural heritage department and authorities
- All the reports, on the subject, produced by the cultural heritage department were collected and examined and reported in quarterly and annual reports.
- GIS technology was used to produce large scale maps, showing all existing and known movements, cemeteries and recognized physical cultural sites. Regular monitoring of the area was carried out for checking the implementation of the ESMMP.

7. TRAINING

Transfer of technology and training of local experts and departments personnel was a key objective of the Project. Given the very diverse nature of tasks, a very large and comprehensive program was developed more than 50 training courses were conducted. Not only the personnel have to be trained in specific tasks respective to their fields, but the new approach of integrated management was also applied and taught with the help of newly created institutions, such as the establishment of Basin Water Council and Basin Water Fund.

The training program relating to project objectives and tasks consists of the following:

1. Seminars
2. Workshops
3. On Job Training
4. International short term training

5. International trainers visits
6. Foreign study tours
7. Informal discussion with farmers when they visit any of the offices
8. Using the existing electronic and print media of the Government to reach out to communities
9. Making use of schools and colleges and other such institutions to create awareness.

8. CONCLUSION

IWRM and associated ESMP is a valid approach to address the competitive needs of sustainable development and environment and social planning. This method is yet to be applied in Indus Basin, perhaps due to its large size and complexity aggravated further by transboundary issues in four countries. A Pilot sub-basin approach may be used to evaluate the benefits of this approach.

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4. *Basin Water Plan with Scenario Analysis - WUA Level*
5. *Basin Water Plan with Scenario Analysis - Irrigation Zone Level*
6. *Operational Model Report - WUA Level*
7. *Operational Model Report - Irrigation Zone Level*
8. *Water and Environment GIS Database Report*
9. *Water Volumetric Pricing System Study*
10. *Biodiversity Monitoring Scheme for Upper Watershed*
11. *Water Quality Monitoring Plan of AILWM Project Area*
12. *Ab - Bandans and River Ecology Monitoring*
13. *Environmental Guidelines Manual Submission and Selection of Sub-Projects in Compliance with Safeguard Policies (Community Demand Driven)*
14. *Pest Management Plan*
15. *Dam Assessment Report*
16. *Half Yearly Resettlement Monitoring Reports*
17. *Cultural Heritage Survey Report*

SEEPAGE AND ECONOMICS OF CANAL LINING IN LBDC-WORKSHEET MODEL APPLICATION

By

Engr. Ijaz Javed[1] Engr. Asim Saeed Malik[2]

and Engr. Hafeez ur-Rehman[3]

ABSTRACT

The Indus River and its tributaries are the main source of surface water in the Indus Basin of Pakistan. Annual canal water supplies are 40 percent short of crop water requirements. Therefore, the canal water is insufficient to meet crop water requirements and it is supplemented by groundwater. The present scenario of groundwater use is not sustainable and therefore, certain measures are needed to be taken. There are mainly three engineering ways for meeting the demand of water: i) canal lining; ii) increase storage capacity; and iii) groundwater extraction by tubewells.

This study is aimed to carry out economic analysis and to evaluate the economics of alternates of Lower Bari Doab Canal (LBDC) canal lining. The LBDC having discharge of 278.70 m^3/sec flows with 201.372 km length is located between the rivers Ravi and Sutlej covers a gross command area of 0.728 million hectares. The primary data & secondary data of LBDC selected sites were collected through field measurements, focused individual/group and from Irrigation and Power Department (I & P) to understand the existing potential of lined channel and assessment of current cost and benefits. A spreadsheet model has been developed in a truly original way which provides an opportunity of overview of inter-related variables/parameters and used for data cleaning, consistency check and sensitivity analysis in accordance with the economic viability

Pre and post lining seepage investigations of two concrete and four brick lined channels in LBDC through inflow-outflow methods were

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carried out as essential ingredients towards economic evaluation of canal lining. The result indicated low seepage rate in concrete lining, ranging from 0.09 to 0.12 m/d and succeeded in higher seepage reducing loss rate (69 percent) as compare to unlined channels. On the other hand, brick lining showed moderate degree of seepage reduction (49 percent) of the actual seepage. The result showed that the predicted annual water saving at root-zone was within the range of 169 to 428 acre-feet, which means that an additional amount of 1305 acre-feet irrigation water has been made available at the tertiary irrigation level.

The study proposed that economic justification of selected sites of canal lining may not be clear-cut even while applying multiple scenarios of discount rate and expected life. The results showed that the economic profitability is not very attractive and justifiable. Canal lining is cost-effective only when the useful life of the improved canal exceeds eight years. The cost comparison of canal lining with tubewell shows a payback period of less than four years. The cost of the canal lining might be justified in consideration of reduce storage and reduction of pumping costs where pumping is necessary. Cost per unit of water developed through groundwater abstraction is much higher than the water saved through canal lining. On the other hand, results indicated that storage reservoir as an alternate of canal lining is the most economical option and thus huge investment can be saved even as capital cost in addition to operational and maintenance cost.

1. INTRODUCTION

The Indus River and its tributaries are the main source of surface water in the Indus Basin of Pakistan. On average it brings about 142 MAF (million acre feet) of water annually. Almost 73% of the inflow which is 104 MAF is diverted for irrigation, 35 MAF flows to the sea and three MAF are the transmission losses in rivers. The canal network of the Indus basin irrigation system (IBIS) comprises 12676 km of main (primary) canals, 38884 km of secondary (distributary/minors) canals and 122268 watercourses.

Seepage from canals is one of the sources to accretion groundwater table. Lining is considered as an engineering solution to reduce seepage losses from irrigation canals and amount of water saved considered as a major component of benefits of lining. Canal lining also aims to gain hydraulic performance, and operational and maintenance improvements. For the last 60 years under various projects lining of main canals, distributaries and minors have been undertaken. The statistics of **Figure** 1 indicates that in Pakistan 5382 km out of 51845 km of canals & secondary canals are lined uptill now which is only 10% of the total length and 90 percent are still unlined.

Out of total lining, in KPK 68 % PCC (pre-cast concrete), 32 % PCC/stone and brick lining was used whereas in Punjab 49 % brick/PCC/stone, 40 % concrete and the rest was a combination of stone/PCC lining. On the other hand, in Sind 75 % concrete lining, 25 % brick/PCC/stone types were used. In Baluchistan, it was 50 % concrete and 50 % brick/PCC/stone lining.

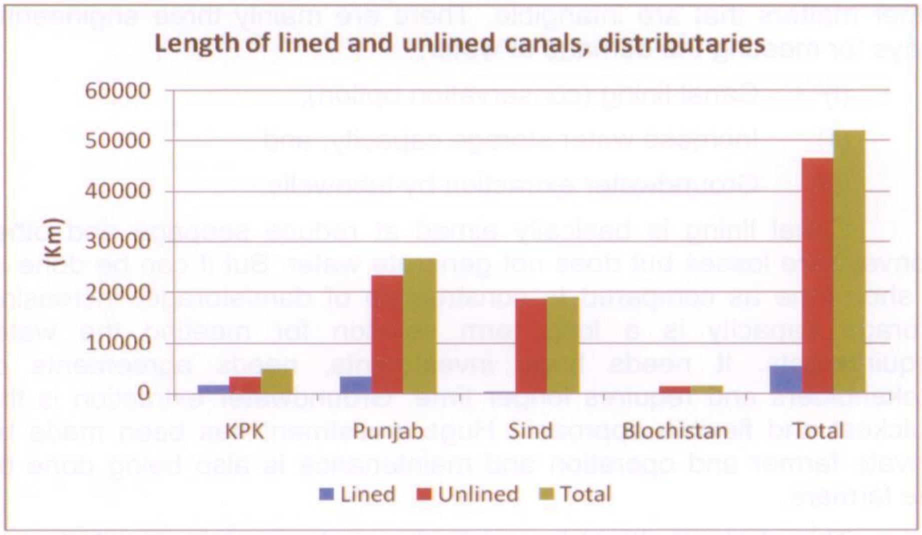

Figure 1 Length of lined and unlined Canals and Disributaries

Annual canal water supplies are 40 percent short of crop water requirements. Therefore, the canal water is insufficient to meet crop water requirements and it is supplemented by groundwater. It is estimated that more than one million private and public tubewells pump 50-55 MAF of groundwater annually. As a result of excessive extraction, problems such as over drafting of the aquifer and saltwater intrusion have emerged in many parts of the basin.

The Lower Bari Doab Canal (LBDC) Command System is located between 29° 53' 0" to 31° 13' 6" latitudes North and 71° 34' 49" to 73° 51' 56"longitudes East between the rivers Ravi and Sutlej and bounded by river Ravi in North and Sukh Beas Drainage channel in the South. The LBDC off-takes from the Ravi River at Balloki barrage and covers a gross command area of 0.728 million hectares with a culturable command area (CCA) of 0.676 million hectares along the left bank of the Ravi River. LBDC gross command area lying. LBDC having design discharge of 278.70 m^3/sec flows for some 201.372 km the length. The canal water supplies average to an annual figure of 4.86 MAF (4934 MCM) plus share of flow supplies during the flood period. Total annual groundwater abstraction of 2.2 MAF is used to supplement surface water. Average annual rainfall varies from about

366 mm to 249 mm contributing to an annual average of about 1.06 MAF.

Water resources development planning involves many choices among feasible alternatives depending upon many physical and environmental conditions. The choice has to be made properly on economic grounds influenced by both economic terms as well as by other matters that are intangible. There are mainly three engineering ways for meeting the demand of water:

(i) Canal lining (conservation option);

(ii) Increase water storage capacity; and

(iii) Groundwater extraction by tubewells.

Canal lining is basically aimed at reduce seepage and other conveyance losses but does not generate water. But it can be done in a short time as compared to construction of dam/storage. Increasing storage capacity is a long term solution for meeting the water requirements. It needs huge investments, needs agreements of stakeholders and requires longer time. Groundwater extraction is the quickest and flexible approach. Huge investment has been made by private farmer and operation and maintenance is also being done by the farmers.

This study is aimed to review the past experience and attempt field measurements of lined and unlined secondary canals. The objectives of the study are to: (a) to carry out economic analysis of canal lining in LBDC; (b) to evaluate the economics of canal lining with the development of additional surface water storages and groundwater usage

2. REVIEW OF LITERATURE

2.1 Seepage loss for lined and unlined channels

Dukker *et al*. (1994) measured the seepage losses from Lower Gugera Branch Canal Punjab, Pakistan (unlined) using the inflow-outflow technique and found a wide range of variation in seepage rate due to errors and uncertainties in measurements. Their results vary from 0.04 m/d to 0.62 m/d; they concluded that the actual seepage losses could deviate largely from the observed values. Bodla *et al.* (1998) indicated that average seepage rate of unlined canals was 0.06 m/d and after lining it reduced to 0.01 m/d seepage investigation under FESS project canal lining shows that on the whole in the project area.

Bhutta and Ahmad (2006) analyzed seepage investigations on lined and unlined distributaries under various studies conducted in Pakistan. In case of unlined distributaries the average seepage losses were 0.27 m/day (8.6 cfs/msf) ranging from 0.04 m/day to 0.50 m/day.

The average seepage loss from lined distributaries was 0.10 m/day (3.5 cfs/msf). Bhutta and Nazir (2006) reviewed the seepage losses from lined & unlined canals of Pakistan. The average seepage loss from unlined canals was 0.31 m/day whereas; average seepage loss from lined canals was calculated as 0.12 m/day. The comparison of average seepage rate of lined and unlined canals showed that on average only 44 percent seepage losses can be saved by lining of main and branch canals.

2.2 Groundwater Extraction

It is estimated that in Pakistan more than one million private and public tubewells pump 50-55 MAF of groundwater annually for irrigation. The total groundwater abstraction from these tubewells is estimated at $51x10^9m^3$ against a recharge of $40 x10^9 m^3$ (World Bank, 2007). Of this, about $33 x10^9m^3$ is extracted through private tubewells whereas the rest ($18x10^9m^3$) comes from large-capacity public tubewells.

Khan (2008) estimated the water cost for different modes of water extraction i.e. for electric and diesel operated tubewells in the LBDC. The cost is worked out as Rs.1005/- and Rs.1290/- per acre-ft of water (Rs.1239/- and Rs.1590/m^3) for electric and diesel operated tubewells, respectively. Sufi *et al.* (2009) worked out the cost as Rs.1005/- and Rs.1290/- per acre foot of water for centrifugal pump and diesel tubewells respectively.

2.3 Value of water saved by canal lining

Shahid, *et. al.* (1992) in a study of "Evaluation of SCARP Transition Pilot Project", estimated that the value of marginal product of water was to the extent of Rs.36 per acre-inch irrigation. The value of marginal product of water was estimated as Rs.36 per acre-inch (or Rs.432 per acre-foot. These figures were updated at the prices of 1997-98 and this became Rs.60 per acre-inch (or 720 per acre foot).

Ahmad and Kutche (1992) concluded that the value of marginal product of water in Agro-Climatic Zone of Indus Basin at Root-Zone was ranging from Rs.310 to Rs.4830 per acre foot in different months. Bodla et al. 1998 used the Rs 585/- as marginal value of water which adopted by Semedema (1996). Shahid (2009) estimated cost of saved water per acre-ft as Rs.3722/- and Rs.4555/- for LCC West and Eastern Sadiqia perennial canals respectively.

2.4 Canal lining life

The IWASRI Research for the FESS project reveals that the life of the canal lining depends on many factors starting from design to construction and maintenance during its operational period. The effective life of canal lining is much shorter than is assumed, which in turn affects the economics of the canal lining.

WAPDA (1983) have been taken into account four different scenarios of expected life of canal lining i.e., 15, 20, 25 and 30 years for estimating the economic analysis of canal lining in the Projects. Zaidi (1995) reported that the useful physical life of P.C.C. lining was around 30-40 years and it was 20-25 years with brick lining.

2.5 ECONOMIC ANALYSIS OF CANAL LINING

Walling and IPRI (1988) carried out a study title A Method for evaluating the Economics of Canal and Watercourse Lining ; in this the construction & maintenance costs have been compared with the value of water saved through the seepage reduction resulting from lining. The general conclusion was that additional expenditure on the lining programme with current construction and maintenance practices could be economically justifiable in terms of benefits from seepage reduction. NESPAK (1992) indicated in a PC-1 performa of FESS that the project has been estimated to be economically feasible where the magnitudes of benefits cost ratio and economic internal rate of return was to be extent of 1.5:1 and 18.8 percent respectively.

3. METHODOLOGY

Variables play an important role in economic analysis. A variable is a magnitude of interest can be defined and measured. Variables that are used in economics are income, expenditure, saving, interest, profit, investment, consumption, cost and so on. The Sequence of process for the conduct of study is shown in **Figure** 2 and described in the following sections.

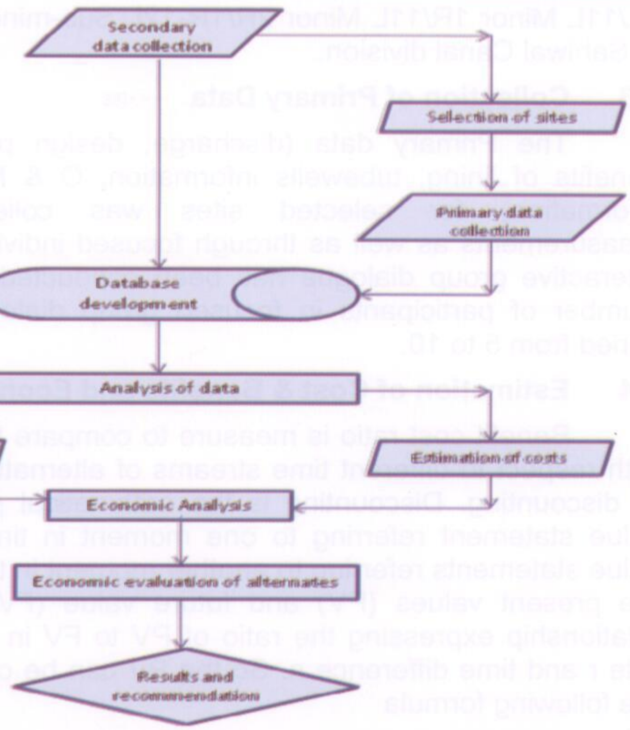

Figure 2 Flow Chart of Methodology for Conduct of Study

3.1 Collection of Secondary data

Secondary data from Irrigation and Power Department has been collected for Balloki Canal Division and Sahiwal Canal Division. Secondary data include: Gross command area, culturable command area (CCA), number of Distributaries, minors & watercourses, irrigation scheduling, design discharge, location, type of channels, type of lining, length of lined/unlined channels, cost of lined channels, cross section details and year of completion.

3.2 Selection of Sites

Sites were selected for primary data collection to understand the existing potential of lined channel and assessment of current cost and benefits. Due to certain additional constraints i.e., limited resources, hard to approach sites, available secondary data and study duration; the selection of sites has been restricted to four distributaries/minors (two lined and two unlined) in Balloki canal division and six distributaries/minors (three lined and three unlined) in Sahiwal Canal Division of LBDC Irrigation System. The selected four unlined/lined distributaries/minors namely Halla distributary & Deosyal minor and Hussain Garh Minor & Hussain Garh Sub-Minor in Balloki Canal Division while six lined/unlined i.e. 4R/9L Minor, 1L/2L-9L Sub-minor

1L/11L Minor 1R/11L Minor 2R/1R-12L Sub-minor 4R/12L Minor were in Sahiwal Canal division.

3.3 Collection of Primary Data

The Primary data (discharge, design parameters, x-section, benefits of lining, tubewells information, O & M cost and agro-scio information) for selected sites was collected through field measurements as well as through focused individual/group dialogues. Interactive group dialogue has been conducted at all selected sites. Number of participants in focused group dialogue at different sites varied from 5 to 10.

3.4 Estimation of Cost & Benefits and Economic Analysis

Benefit cost ratio is measure to compare the benefits and costs with respect to different time streams of alternative projects by means of discounting. Discounting is the arithmetical process of converting value statement referring to one moment in time to their equivalent value statements referring to another moment in time. Normally it refers the present values (PV) and future value (FV). It uses the above relationship expressing the ratio of PV to FV in terms of the discount rate r and time difference n. So the PV can be calculate directly using the following formula

$$PV/FV\ (\text{year } n) = \frac{1}{(1+r)^n}$$

The significance of PVs is that they are all expressed as value seen from the same moment, so they are in a common unit and can be added together. But we need to discount a series of numerically equal FVs in successive future years. Instead of writing down series of FVs and discount each one separately the following formula can be used for tabulating the sum of PV/FV.

$$PV/RV = \frac{1}{r}\left\{1 - \frac{1}{(1+r)^n}\right\}$$

Where RV is the repeated value, 1/r for long discounting period's trends

The most basic are the net present value or NPV and the benefit-cost ratio or B/C. The starting-point for both is to list the costs and the benefits by year, and to discount both series. This gives two numbers, the total discounted cost, C, and the total discounted benefits, B. Then the NPV is the difference between them, B-C, and the benefit-cost ratio is the ratio between them, B/C. The project costs concentrated in early years and its benefits spread mainly over later years, the increasing discount rate, while reducing the numerical value of both total discounted benefits faster than it reduces the discounted cost. Thus an increasing discount rate leads to a decreasing NPV and a decreasing B/C ratio. There is evidently some particular discount rate which will make the total discounted benefits equal to the total discounted cost, so that for that discount rate the NPV will be zero and the B/C ratio will be one. This particular discount rate is called the internal rate of return (IRR). If the analysis is an economic one it is the economic IRR or EIRR or ERR. So EIRR is the discount rate at which the net present value of an investment becomes zero.

NPV = 0; or PV of future cash flows − Initial Investment = 0; or

− Initial Investment + {CF1 $(1+r)^{-1}$+ CF2 $(1+r)^{-2}$ +CF3 $(1+r)^{-3}$..... CFn $(1+r)^{-n}$} = 0

Where,

r is the internal rate of return;
CF_1 is the period one net cash inflow;
CF_2 is the period two net cash inflow,
CF_3 is the period three net cash inflow, and so on ...

A general rule of thumb is that the EIRR value cannot be derived analytically. Instead, EIRR must be found by using mathematical trial-and-error to derive the appropriate discount rate.

The benefit cost ratio provides estimates regarding benefits generated by investing one rupee in a particular project activity.

The formula used in estimating the benefit-cost ratio is as under:

$$BCR = \left[\sum_{t=1}^{n} Bt\right] / \left[\sum_{r=1}^{n} \frac{Ct}{(1+r)^t}\right] = \frac{Total\,discounted\,benefit}{Total\,discounted\,cost}$$

Where B_1 = Increased benefit for Ist year

C_1 = Incremental costs for Ist year

t = Expected operational life of the project excluding civil

Works/construction work completion;

r = Discount rate expressed in terms of percent

The formula selection criterion for the benefit-cost ratio measure of project worth is to accept all projects having benefit-cost ratio greater than one. Thus the three indicators NPV, B/C and IRR are arrived at by discounting which can used for economic analysis. Which indicator is appropriate depends on the kind of decision being guided. The opportunity cost was worked out (total cost of lining plus O&M charges as 1.5% of the total cost) at discount rate 12% with project life taken as 10,15,20 & 25 years.

An economic analysis concerns the welfare of a defined group of people, usually a nation. The economic analysis is only useful as decision guide if it is realistic. Technical solutions and project components must be not only technically feasible, but also socially and politically feasible. **Figure** 3 shows the main stages of cost-benefits (economic) analysis.

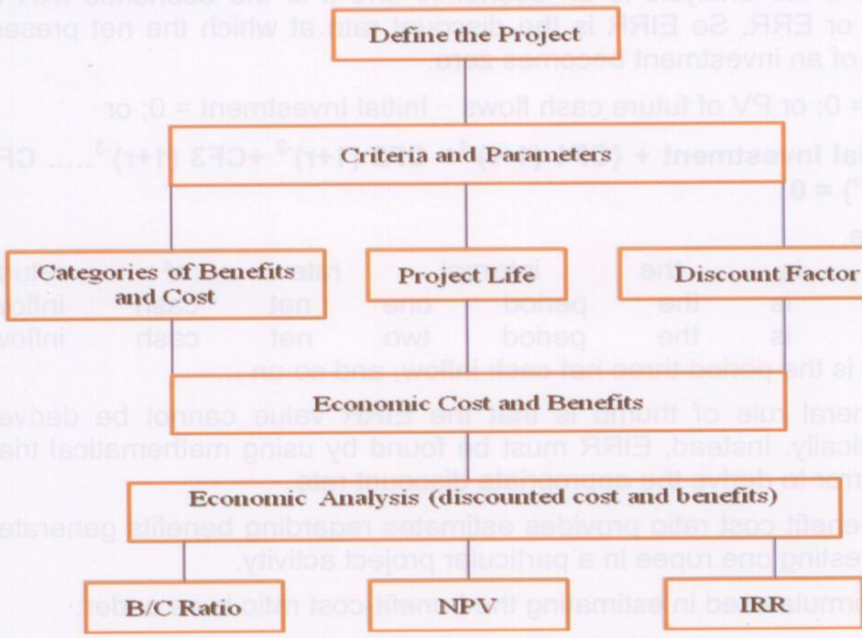

Figure 3 Stages of Cost-Benefits analysis

The economic analysis of LBDC canal lining was conducted keeping in view the following two alternatives

- ALTERNATIVE 1 WATER SAVINGS INFLOW-OUTFLOW TEST

  Value of water is rs. 5000/ac.ft.

  Expected life for canal lining 10 years

  Discounted factors 10%, 12% and 15%

- ALTERNATIVE 2 WATER SAVINGS INFLOW-OUTFLOW TEST

  Value of water is rs. 5000/ac.ft.

  Expected life for canal lining 15 years

  Discounted factors 10%, 12% and 15%

3.5 Development of spreadsheet model

The spreadsheet model has been developed for conducting economic analysis. The data was treated with uniform procedures and techniques which reduces the deviations of results. The model provides an opportunity of overview of inter-related variables/parameters, which indicates the abnormal figure/outliers. The spreadsheet model is constructed in a truly original way which contributes to transparency, provides a check on the accuracy of the analysis, and facilitates sensitivity, risk and alternative scenario analysis. The model used for consistency check, data cleaning, the required economic parameters have been derived in the spreadsheet model.

4. EVALUATION OF SEEPAGE LOSSES

Pre and post lining seepage investigations through inflow-outflow methods were carried out as essential ingredients towards economic evaluation of canal lining. The seepage investigations of unlined and lined channels of selected sites were carried out in LBDC using inflow-outflow method from June-July 2012. Out of five lined channels two are concrete and other three are brick. **Figure** 4 shows seepage losses and estimated volume of water of selected lined and un-lined sites.

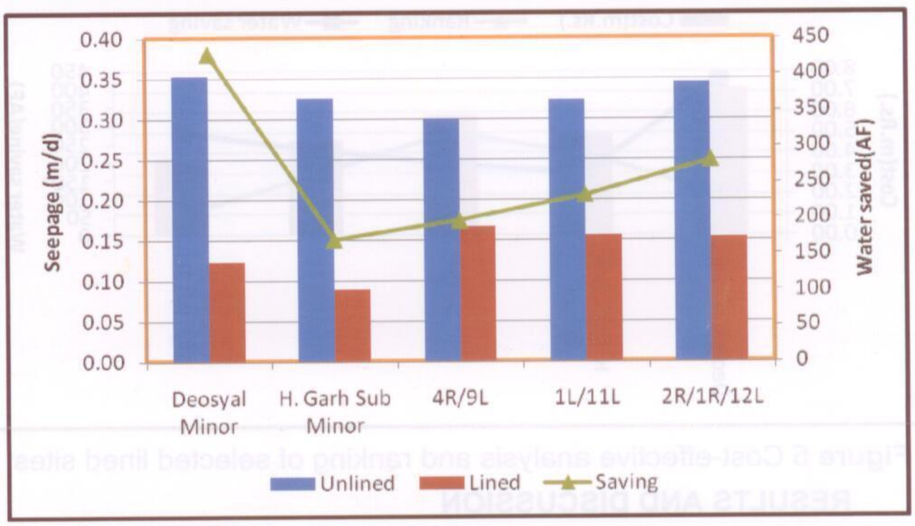

Figure 4 Seepage loss and water saved of lined channel in LBDC

Figure 4 shows that total annual irrigation water saving of 1305 AF of five lined channels in LBDC. The saving of irrigation water by lining means that an additional amount of irrigation water has been made available at the tertiary irrigation level. The result indicates the predicted annual available water at root-zone within the range of 169 to 428 AF. Deosyal minor (concrete) showing highest water saving of

428 AF whereas lowest saving of 169 AF was observed at Hassian Garh minor (concrete).

5. COST-EFFECTIVENESS OF CANAL LINING

A least-cost analysis is also another type of analysis, cost-effectiveness analysis. In cost-effectiveness analysis the benefits and costs are not expressed in a common unit of measurement, but both are quantified and then different courses of action are compared on the basis of the relative costs per unit benefits. For canal lining scheme we might calculate the cost per AF of water saved. Cost-effectiveness analysis is often used in fields where benefits are difficult to value economically.

Figure 5 shows that the most cost-effective lined reaches are (i) 2R/1R/12L, (ii) Deosyal Minor, (iii) 1L/11L whereas Hussain Garh sub minor and 4R/9L were not very cost-effective. The most important consideration is the tremendous difference in water savings. The completed canal lining has an estimated water savings of 1305 AF per year assuming that the selected sites are operated 300 days per year. The selected lining sites showed effective role in controlling seepage and in lowering groundwater levels.

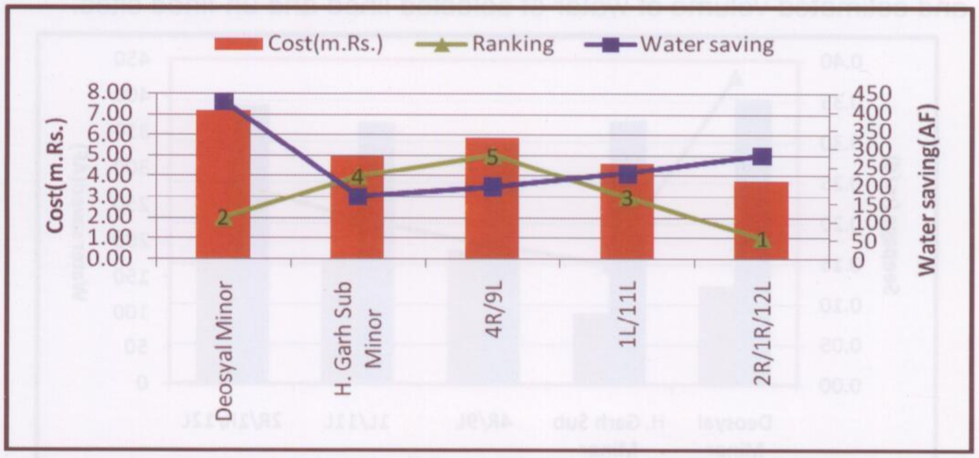

Figure 5 Cost-effective analysis and ranking of selected lined sites

6. RESULTS AND DISCUSSION

6.1 Assessment of Economic Indicators (B/C ratio, NPV, EIRR)

The results regarding alternate-1&2 summarized in **Table** 1 reveals that the magnitude of benefits cost ratio was greater than one at discounted factor of 12 percent under multiple scenarios of expected life. The Net Present Value (NPV) was computed to be positive under all option of expected life at discount factors of 10 and 12 percent. The results presented in **Table** 1 show that the NPV is negative at discount factor of 15 percent under multiple scenarios of expected life which indicates that LBDC lining may not be significantly profitable.

The analysis results of Deosyal minor presented in **Figure** 6 shows that the NPV at 12 percent after 15 year period NPV was worked out to be positive value of 1.33 with minimum net cash flow value (0.38). Similarly, the magnitude of Economic Internal Rate of Return (EIRR) was estimated as negative for first 6 years and shows positive value after 8 year period. The discounted capital cost plus O & M incurred during 15 years was Rs. 4.84 million and total discounted benefits were Rs. 12.66 million, while net benefits over the 15 year period were Rs. 7.82 millions. Thus the Deosyal minor lining is showing marginally economical feasible after 8 year period.

The results regarding Hussain Garh sub minor shows that the NPV at 12 percent discount factor was negative up till 8 year under expected life of the canal lining of 10 and 15 years. Similarly, the magnitude of Internal Rate of Return (IRR) was estimated as negative for first 4 years and shows positive value after 5 year period. The discounted capital cost plus O & M incurred during 15 years was Rs. 2.12 million and total discounted benefits were Rs. 5.01 million, while net benefits over the 15 year period were only Rs. 2.89 millions. It is concluded that with these results the Hussain Garh sub minor canal lining may not be beneficial under alternate-1 & 2.

Table 1 Economic Analysis of Canal Lining in LBDC (Alternate 1 & 2)

Sites	Expected Life of Canal Lining (Years)	Discounted Factor (%)	Benefit Cost Ratio(BCR)	Net Present Value (NPV) (Rs. Millions)	Internal Rate of Return (IRR)
Deosyal Minor	10	10	2.56: 1	2.28	13.95 %
		12	2.14: 1	0.84	12.09 %
		15	1.65: 1	-1.00	< 10 %
	15	10	3.21: 1	3.09	13.32 %
		12	2.62: 1	1.33	13.52 %
		15	1.95: 1	-0.76	> 15%
H G sub minor	10	10	2.14: 1	0.55	11.37 %
		12	1.93: 1	0.12	12.38 %
		15	1.65: 1	-0.39	> 12 %

	15	10	2.69:1	0.86	10.81 %
		12	2.36: 1	0.31	11.97 %
		15	1.96: 1	-0.30	> 12 %
4R/9L	10	10	2.11 :1	0.60	11.90 %
		12	1.90 :1	0.09	11.96 %
		15	1.63 :1	-0.49	> 12 %
	15	10	2.65:1	0.55	10.34 %
		12	2.32 :1	0.05	12.52 %
		15	1.93 :1	-0.52	> 13 %
1L/11L	10	10	2.17 :1	0.78	11.65 %
		12	1.81 :1	-0.03	12 %
		15	1.40 :1	-1.09	> 12 %
	15	10	2.72:1	1.21	11.08 %
		12	2.22 :1	1.22	12.06 %
		15	1.66 :1	-0.97	> 12 %
2R/1R/12L	10	10	3.23 :1	2.13	10.89 %
		12	2.70 :1	1.24	12.85 %
		15	2.09 :1	0.12	15.35 %
	15	10	4.05 :1	2.68	10.12 %
		12	3.31 :1	1.57	12.29 %
		15	2.47 :1	2.47	15.01 %

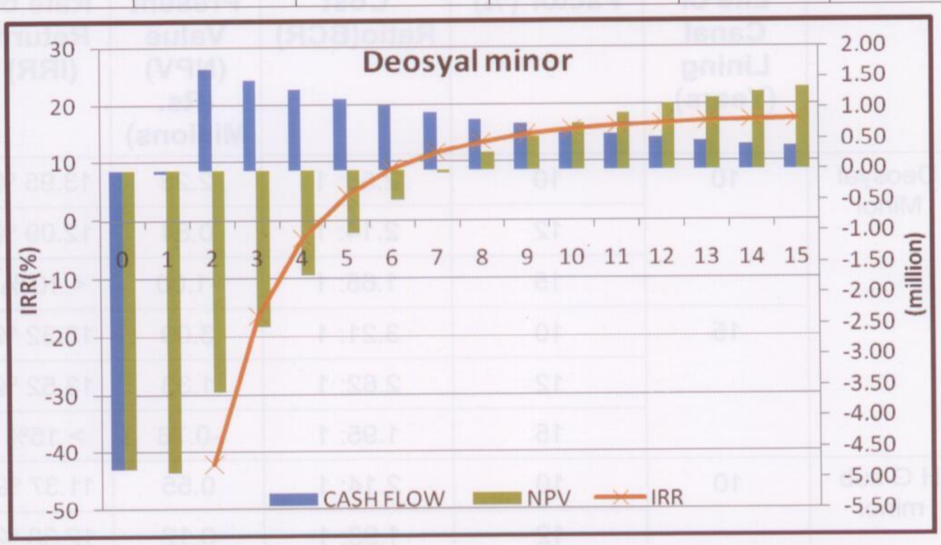

Figure 6 Net cash flow, NPV and IRR of Deosyal minor for 15 years at 12% D.F.

In economic analysis NPV assumes that cash inflows are reinvested at required rate of return, whereas IRR assumes that cash inflows are reinvested at computed IRR. Second NPV measures profitability in absolute manner and IRR measures in relative manner. The economic analysis shows that economic justification of LBDC canal lining programme is not so straightforward even while applying multiple scenarios of discount rate and expected life. The indicators of economic viability, i.e. NPV and IRR of the Hussain Garh sub minor, 4R/9L and 1L-11L have been found to be quite low. Whereas, B-C ratio of all selected sites were worked out more than one. However, in case of Desyal minor and 2R/1R/12L all three economic indicator i.e. B-C ratio, NPV and IRR have been found to be marginally well which established the economic viability of the canal lining of these selected sites in the area.

6.2 Economic Evaluation of Alternates

The economic analysis usually revolves around a special alternative. To seek the best alternative or to improve the present plan is the main aim. The best alternative is relative to a group of alternatives. Therefore, to seek of alternatives is an important step in the economic analysis. To determine alternative, either a fixed number of years or the estimated life of the project is used in economic analysis. The following alternates have been used to establish economic analysis of LBDC selected sites (**Table 2**).

Table 2 Economic comparisons of different alternates

Alternate-1		**Alternate-2**	**Canal lining**
Diesel Tubewell & Electric Tubwell		**Reservoir**	**LBDC**
Description			
No. of working hours	12.5 hr/week		
No. of days	300/yr		
No. of tubewells required to cope 807 MAF	18 (assumed that a T/W having discharge capacity of one cusec will extract groundwater in one hour = **0.0826** AF)		
Operational cost @ 300/hr	2.93 million		
Capital cost	@ Rs 250,000/tubewell		
Present value	7.50 million	9.50 million	14.82 million
Future value (after 10 year) including maintenance & operational cost	36.00 million	10.08 million	21.62 million

In economic analysis, results shows that annual water saving of selected five lined channels in LBDC was 1305 AF. The saving of irrigation water by lining means that an additional 1305 AF of irrigation water has been made available at the tertiary irrigation level.

In Alternate-1 it was assumed that out of total saved water, tubewells contribute 498 AF as seepage loss to the groundwater. **Table 2** reveals that 18 number tubewells required coping 807AF saved water with an average capital and operating cost of Rs. 7.5 million. **Figure** 7 shows the cost comparison of canal lining, tubewell and reservoir. The results shows that a payback period is less than four years and an amount of 15 millions can be saved within a 10 years period in case of canal lining if compare with tubewells. However in alternate-2, storage reservoir shows the most economical alternative and an amount of Rs. 5 million can be saved even as capital cost. Moreover, storage reservoir can save Rs. 25 million and 11 million in comparison with tubewells and canal lining respectively (**Figure** 7) over the period of 10 years. Hence, storage reservoir may be allowed to store surplus irrigation water, which can be pumped out later on as and when needed. However, this option can only be feasible in fresh groundwater zones. The **Figure** 7 reveals that tubewells option is not economically feasible as compare to canal lining as well as with reservoir.

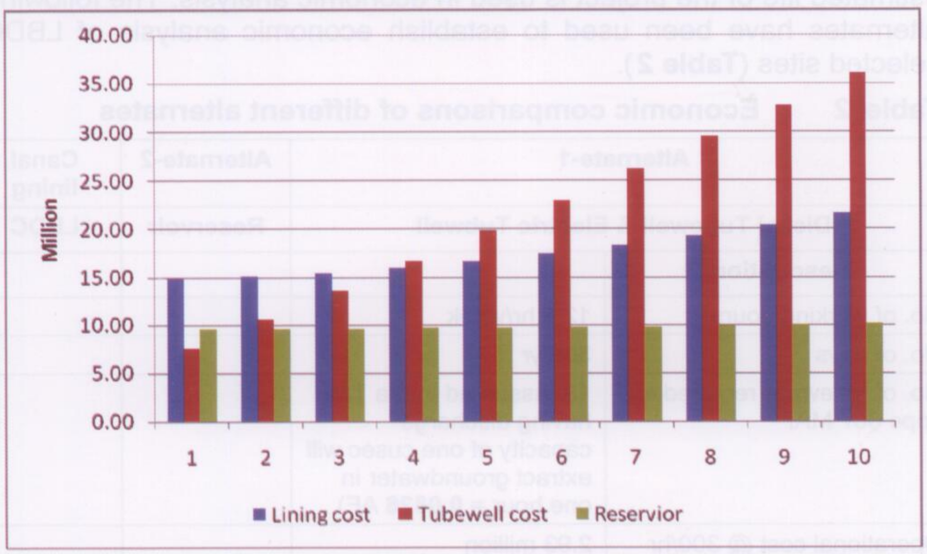

Figure 7 Cost comparison of canal lining, tubewells and reservoir

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The conclusions are based on the pre and post lining seepage investigations and using the results of water saving through inflow-outflow methods. Following are the conclusions.

- The average seepage losses were within the range of 0.30 to 0.35 m/d with an average of 0.33 m/d for unlined channels and from 0.09 to 0.16 m/d with an average of 0.14 m/d for lined channels.
- The result indicated low seepage rate in concrete lining, ranging from 0.09 to 0.12 m/d and succeeded in higher reducing loss rate (69%). Whereas brick lining showed moderate degree of seepage reduction (49%) of the actual seepage. Furthermore, the overall difference in seepage losses in the lined and unlined sections is around 59%.
- In economic analysis, results show that annual water saving of selected five lined channels in LBDC was 1305 acre-ft. The saving of irrigation water by lining means that an additional 1305 acre-ft of irrigation water has been made available at the tertiary irrigation level.
- In cost-effectiveness analysis the benefits and costs are not expressed in a common unit of measurement, but both are quantified and then different courses of action are compared on the basis of the relative costs per unit benefits. The cost per unit benefits were compiled for cost effectiveness of each site and ranked accordingly. The most cost-effective lined reaches are (i) 2R/1R/12L, (ii) Deosyal Minor and (iii) 1L/11L whereas Hussain Garh sub minor and 4R/9L were not very cost-effective.
- A spreadsheet model has been developed in a truly original way which provides an opportunity of overview of inter-related variables/parameters and used for data cleaning,

consistency check and sensitivity analysis in accordance with the economic viability.

- The magnitude of benefits cost ratio was greater than one at discounted factor of 12 percent under multiple scenarios of expected life. The Net Present Value (NPV) was computed to be positive under all option of expected life at discount factors of 10 and 12 percent. Whereas, the NPV was negative at discount factor of 15 percent under multiple scenarios of expected life which indicates that LBDC lining may not be significantly profitable.
- The benefits cost ratio ranged from 1.40:1 for the expected life of LBDC lining 10 years to 4.05 in case expected life of 15 years. At 12 percent discount factor, the average value of B/C ratio was worked out to be 2.09:1 and 2.55:1 for the expected

life scenarios of 10 and 15 years respectively. At 15 percent discount factors, the average value of benefits cost ratio was 1.68:1 and 1.99:1 for expected life of 10 and 15 years respectively. The results showed that the benefits are more than double the costs of the selected sites.

- The economic analysis shows that economic justification of LBDC canal lining programme is not so straightforward even while applying multiple scenarios of discount rate and expected life. The indicators of economic viability, i.e. NPV and IRR of the Hussain Garh sub minor, 4R/9L and 1L-11L have been found to be quite low. The NPV results shows that the economic profitability is not very attractive and justifiable under the sensitivity analysis even at decrease benefits by 10 percent using water saving derived via inflow-outflow method. However, in case of Deosyal minor and 2R/1R/12L all three economic indicator i.e. B-C ratio, NPV and IRR have been found to be marginally well which established the economic viability of these selected lining sites.
- Canal lining is cost-effective only when the useful life of the improved canal exceeds eight years. The cost comparison of canal lining with tubewell shows a payback period of less than four years. The cost of the canal lining might be justified in consideration of reduce storage and reduction of pumping costs where pumping is necessary. Cost per unit of water developed through groundwater abstraction is much higher than the water saved through canal lining. However, results indicated that storage reservoir as an alternate of canal lining is the most economical option and thus huge investment can be saved even as capital cost in addition to O & M cost.

7.2 Recommendations

- The pre-lining and post-lining investigation gave relatively higher seepage rate as compare to the results observed in other areas of Pakistan where similar inflow-outflow tests were conducted. The result indicated higher reducing loss rate in concrete lining whereas, brick lining showed moderate degree of seepage reduction of the actual seepage. The variation in estimation of seepage rates by the same inflow-outflow method is evidenced through a number of other investigations by various agencies. Uncertainty of estimation can be attributed to some systematic or random errors in discharge measurements and need further investigations. This leads towards the need for considering reasonable tradeoff between huge investments on canal lining and the expected water savings. Thus this invites attention to selective lining of those channels/reaches which shown to have a high seepage rates.

- The study proposed that economic justification of selected sites of LBDC canal lining may not be clear-cut even while applying multiple scenarios of discount rate and expected life. Critical decision factors for the economic justification include method of seepage estimation, irrigation water price, the true expected life and discounted factors to be used for the analysis.
- Water conservation via canal lining can be captured more quickly than other options. The economic value of water saved per acre-ft as a result of canal lining is the highest and incremental, among all known sources of production /conservation of irrigation water.
- The canal lining in saline groundwater areas is feasible, it is therefore emphasized that lining of all irrigation networks in the saline zone should be ensured. This will not only supplement drainage in saline zones but also save recharging fresh water from the wastage.

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SIGNIFICANCE OF WATER CONSERVATION FOR SUSTAINABILITY OF WATER RESOURCES OF PAKISTAN

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Key Words: Water Conservation, Water sustainability, Municipal & Industrial & Environment and Agriculture Water Requirement

ABSTRACT

Water is essential for sustaining life and at the same time, it is an important component for almost all development activities including food security, livelihood, environment, economics and power generation. But we stand today at the verge of global water crisis. The 20th Century has inherited us with the population and technological explosions which has laid down a massive impact on our water supply. More and more freshwater sources are being consumed and contaminated. There is a dire need to conserve water and make this a National character. Water conservation is a strategy implemented by a water utility to reduce demand. The strategy may take the form of incentives or measures which permanently reduce demand without reducing consumer satisfaction. Water conservation strategies not only affect water supply and distribution budgets, they reduce wastewater treatment volumes and increase environmental awareness and sustainability. The aims of this research paper are to:

- Identify schemes through which effluent water may be treated to make it usable
- Propose steps to minimize water losses from reservoirs to farm

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- Highlight the role of modern and high efficiency irrigation techniques such as sprinkler, furrow, bed and drip irrigation at the place of conventional flood irrigation to harness water
- Propose rainwater harvesting technique at domestic as well as commercial level
- Look at different areas where water is wasted or misused in domestic sector to raise awareness amongst the stakeholders

INTRODUCTION

The water situation in Pakistan is alarming. Pakistan is a country of 188 million which is expected to inhabitate 225 million till 2025. The increasing pressure of escalating population and industrialization has placed a great demand of water. With the pressure of population growth, per capita surface water availability is reducing. The largest stake holder for water in Pakistan is the Agriculture sector consuming on average 90% compared with 3% used by industry and 8% used by households. A country whose economic back bone depends on the well being of the vast irrigation network is deteriorating day by day. Moreover the wastages in the system due to damaged banks and the conventional flood irrigation system are a serious barrier to the concept of water conservation. The per capita water availability in Pakistan at the time of independence was 5,260 cubic meters, which has drastically reduced to only 1,036 cubic meters, placing Pakistan towards one of the water-scarce countries

SURFACE WATER

The main source of surface water resources of Pakistan is based on the flows of Indus River and its tributaries. Since early 20th century, barrages have been constructed on Indus River System, together with a system of Link Canals and a large contiguous irrigation system as shown in **Figure-I**. The average annual flow of Indus River system is approximately 144 Million Acre Feet (MAF) [1]. The average annual canal diversions are of the order of 104 MAF [1]. The months of peak flow are June to August, which is the monsoon period. Flows for Kharif and Rabi crop seasons are 84 & 16 percent, respectively. Thus it becomes very important to store as much water as possible during high-flow period, for use during the low-flow period. Under such circumstances, the availability and integrated management of storage-reservoirs in the country becomes critical.

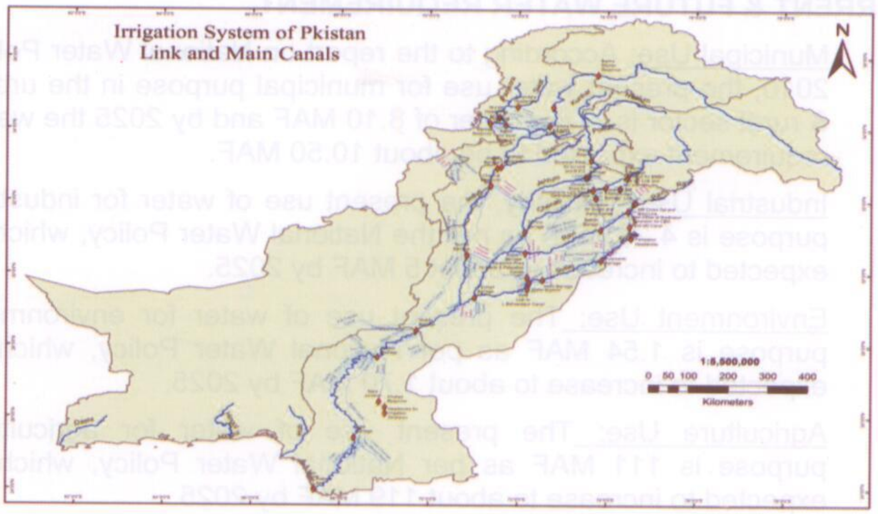


FIGURE-I: Irrigation System of Pakistan

GROUND WATER

Pakistan's Primary ground water resource is in the irrigated areas of the Indus Basin, while the secondary source is the area outside the Indus Basin. The importance of groundwater in Pakistan can be anticipated from the fact that quantitatively about 80% of the canal water supplies are supplemented by groundwater. Groundwater has emerged as an exceedingly important fresh water resource and its ever-increasing demand for agriculture, domestic and industrial uses ranks it as of strategic importance. The total ground water potential in Pakistan is about 56 MAF [2] while the extraction is of the order of 48 MAF [2] which makes limited potential of ground water. After the introduction of weir-controlled irrigation, the ground water table started rising due to poor irrigation management, lack of drainage facilities and the resulting additional recharge from the canals, distributaries, minor works, water courses and irrigation fields. At some locations, the water table rose very close to the surface causing water logging and soil salinity reducing productivity.

IRRIGATION EFFICIENCY

Pakistan despite being an agrarian country, has demonstrated extremely low irrigation efficiencies, creating problems related to water conservation and water logging & salinity. The estimated irrigation efficiency in Pakistan is about 36% [3] which means that only 36% of the water that reaches the fields is actually used by the crops. Irrigation efficiency is a compound of three efficiencies i.e. canal-head, water course and farm efficiency.

CURRENT & FUTURE WATER REQUIREMENT

- Municipal Use: According to the report on National Water Policy 2010, the present water use for municipal purpose in the urban & rural sector is of the order of 8.10 MAF and by 2025 the water requirement expected to be about 10.50 MAF.
- Industrial Use: Similarly, the present use of water for industrial purpose is 4.28 MAF as per the National Water Policy, which is expected to increase to about 5 MAF by 2025.
- Environment Use: The present use of water for environment purpose is 1.54 MAF as per National Water Policy, which is expected to increase to about 1.70 MAF by 2025.
- Agriculture Use: The present use of water for agriculture purpose is 111 MAF as per National Water Policy, which is expected to increase to about 119 MAF by 2025.

IDENTIFY SCHEMES THROUGH WHICH EFFLUENT WATER MAY BE TREATED TO MAKE IT USABLE

The domestic and commercial effluent is being collected and managed by Water and Sanitation Agencies, Area Water Boards and Public Health Departments at provincial level. About 1% of wastewater collected in Pakistan is treated in large part because tariffs are too low to cover the cost of primary service (water supply). Pressured by anxious homeowners and industries, utilities and cities attempt to evacuate as mush sewerage and storm water as possible out of the city, which is ultimately dumped into fresh water bodies. The waste comprises household sewerage, hospital wastes and waste from large and small industries.

To curtail the misuse of water at all levels, water tariff may be rationalized against good quality services (provided to customers) and charged on actual utilization basis.

Industries may be encouraged to adopt recycling and reuse of waste water to the extent possible. Industries must be forced to comply with the Environmental Protection Laws, to treat effluent in accordance to Environmental Protection Agency (EPA) & Environmental Quality (EQ) standards regulations. Industries in return may be offered a combination of subsidized credit for industrial pollution control investment and grant-financed common effluent treatment plans and effluent charges. Public disclosure of polluting industries, especially where compliance problems persisted may also be a part of strategy.

Industries can also be charged contamination charges in case of non-compliance EPA Regulations, in order to compensate the effluent treatment cost.

Domestic effluent may be treated by governmental organizations and cost may be recovered from water charges on actual utilization and waste produced basis. The recycled water may be utilized in agriculture, horticulture and to fulfill city sanitation needs.

PROPOSE STEPS TO MINIMIZE WATER LOSSES FROM RESERVOIRS TO FARM

Remodeling and better Operation &Maintenance (O&M) of irrigation infrastructure is dire need of time to mitigate the seepage losses and reduce dependency of farmers on groundwater. The effective monitoring and metering of irrigation water (through telemetry system) and setting up responsibility will improve the pilferages from system. The formal organizational setup of irrigation department may be revised and their role may be squeezed to the operation of barrages. Private operators with specific performance contract would invest in the necessary infrastructure (which would include on and off canal storage and control structures) and would operate the main and branch canals. Farmer's organizations (FO's) would operate the distributaries and Water User Associations (WUAs) for the watercourses. The entitlements of each level must be clearly established, that there are measurement structures at each interface and trusted, transparent measurement and reporting of entitlement and deliveries is essentially important. It would be likely that farmers will adopt conservation measure and use water efficiently and effectively.

Following steps should be taken to minimize evaporation losses from reservoirs:

- Wind breakers
- Covering the water surface
- Use of underground storage
- Integrated operation of reservoir
- Use of chemical for retarding the evaporation rate from reservoir surface

Canal conveyance losses must be reduced by:

- Canal lining and proper maintenance
- 60% to 80% of water seepage may be reduced by canal lining

Farm level water losses must be reduced by:

- Growing low delta crops
- Placing accurate indents of water by estimating exact crop water requirement

HIGHLIGHT THE ROLE OF MODERN AND HIGH EFFICIENCY IRRIGATION TECHNIQUES SUCH AS SPRINKLER, FURROW, BED AND DRIP IRRIGATION AT THE PLACE OF CONVENTIONAL FLOOD IRRIGATION TO HARNESS WATER

Today almost 2.8 billion people live in water-scarce areas, by 2030 it is expected that about half of the world's population will live in water stressed areas. Past overuse of fossil water from aquifers will make it necessary to improve the efficiency of irrigation methods. The techniques which can improve water use are very valuable. On Farm Water Management is an important aspect to enhance water productivity. High Efficiency Irrigation System (HEIS) has a considerable potential to balance surface supplies. Following measure will be helpful in vide spread deployment of HEIS:

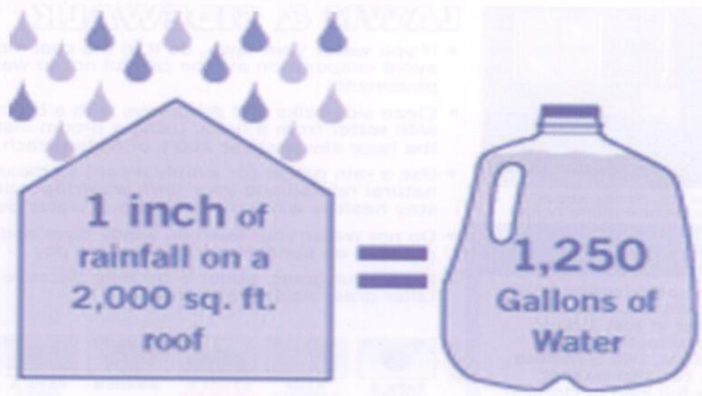
- Indigenization of high tech, irrigation system at affordable prices and access to farmers
- Make pilot demonstration projects
- Farmer awareness and on-farm trainings should be carried out at districts level, where representatives of farmer community will be invited and information will be disseminated to them for implementation
- Impart on-farm training to the farmers and build their capacity to use these techniques through demonstrations

Other program with great potential in water use efficiency is deployment of zero-tillage technology, the bed and furrow method of water application and the use of crop residue as protective covering to conserve soil moisture. These techniques must also be introduced to farmer in parallel to HEIS in areas where HEIS implementation is not economically feasible.

PROPOSE RAINWATER HARVESTING TECHNIQUE AT DOMESTIC, COMMERCIAL AND INDUSTRIAL LEVEL

Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops **(Figure-II),** the land surface or rock catchments using simple techniques such as underground tanks as well as more complex techniques such as underground check dams. Rainwater harvesting is ideal for large scale commercial & industrial applications. It is important to save rainwater for commercial and industrial use and is also a huge money saver for schools, colleges, hotels, universities, offices etc. Commercial & Industrial harvesting is an extremely cost effective method with the added benefit of reducing waster consumption and bills.

It provides water when there is a drought, can help mitigate flooding of low-lying areas, and reduces demand on wells which may enable ground water levels to be sustained. It also helps in the availability of potable water as rainwater is substantially free of salinity and other salts. The areas which are facing severe shortages of municipal water supplies and have potential to harvest rainwater especially in hilly areas may be encouraged. In low laying cities rainwater harvesting can be utilized to recharge aquifers, however provincial governments may step forward for execution of such schemes.



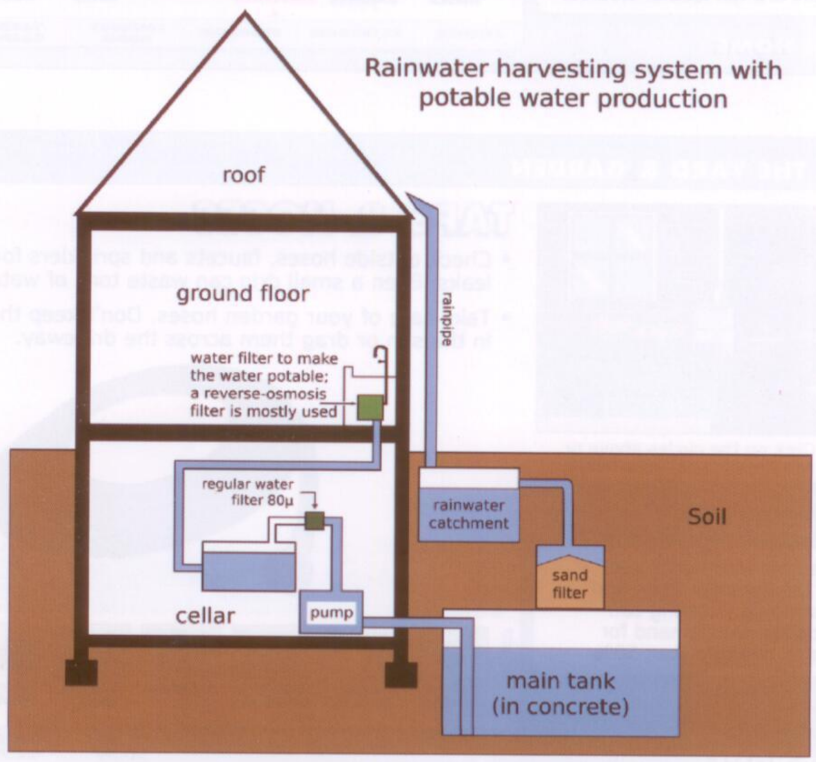
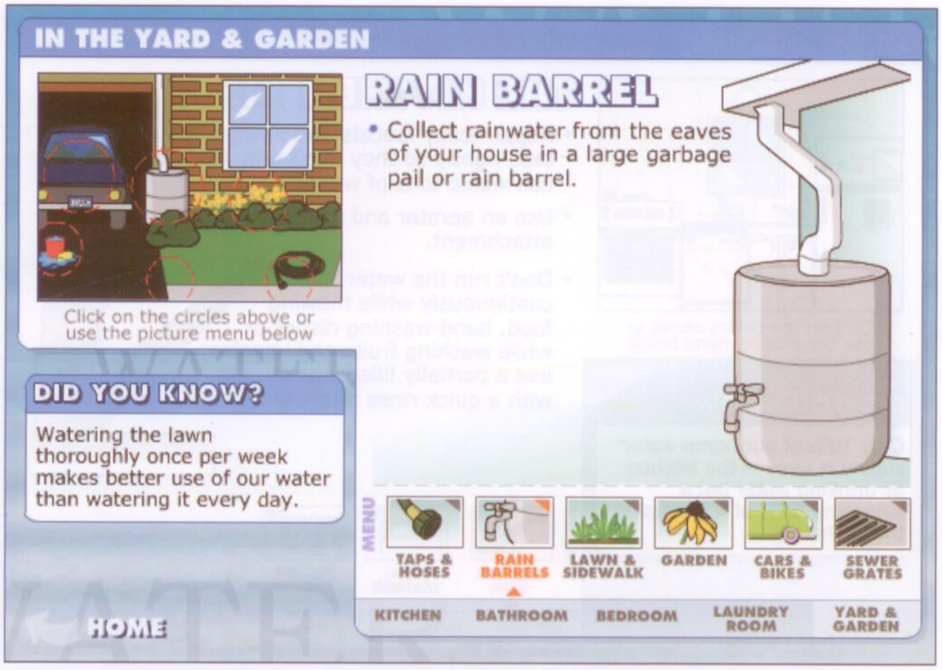


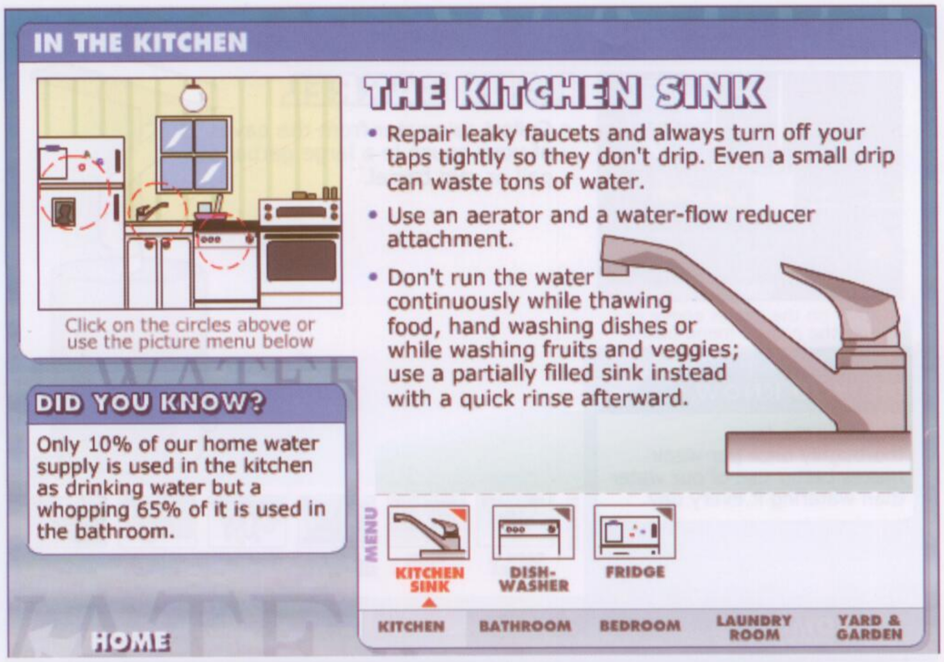
Figure-II: Rainwater Harvesting

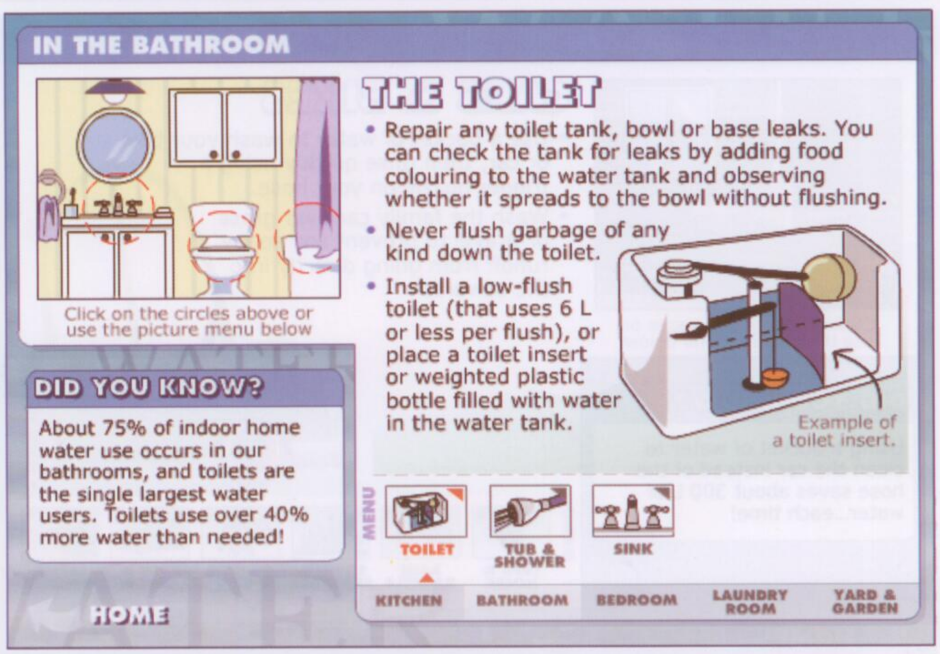
LOOK AT DIFFERENT AREAS WHERE WATER IS WASTED OR MISUSED IN DOMESTIC SECTOR TO RAISE AWARENESS AMONGST THE STAKEHOLDERS

There is still a lot of margin available in our domestic consumption practices which would lead to efficient water conservation. A few glaring examples are quoted in the following Pictograms.


IN THE YARD & GARDEN
RAIN BARREL
• Collect rainwater from the eaves of your house in a large garbage pail or rain barrel.
Click on the circles above or use the picture menu below
DID YOU KNOW?
Watering the lawn thoroughly once per week makes better use of our water than watering it every day.
MENU
TAPS & HOSES
RAIN BARRELS
LAWN & SIDEWALK
GARDEN
CARS & BIKES
SEWER GRATES
KITCHEN
BATHROOM
BEDROOM
LAUNDRY ROOM
YARD & GARDEN
HOME


IN THE YARD & GARDEN
CARS & BIKES
• Use a bucket of water to wash your bike or car, then rinse quickly using a trigger nozzle on your hose.
• Wash the family car over grass or gravel to prevent any soapy runoff from going directly into the sewers.
Click on the circles above or use the picture menu below
DID YOU KNOW?
Using a bucket of water to clean the car instead of the hose saves about 300 L of water...each time!
MENU
TAPS & HOSES
RAIN BARRELS
LAWN & SIDEWALK
GARDEN
CARS & BIKES
SEWER GRATES
KITCHEN
BATHROOM
BEDROOM
LAUNDRY ROOM
YARD & GARDEN
HOME





CONCLUSIONS AND RECOMMENDATIONS

Following actions must be taken to conserve more and more water:

- It is considered to be of paramount importance that an effective and responsive institutional structure is made available for implementation of policies that supports linkages between practice, science, policy and decision making so as to facilitate at various levels of sustainable solutions for water resources conservation.

- A comprehensive campaign may be launched in print and electronic media to sensitize the people to use water efficiently and to promote rainwater harvesting for domestic, commercial and industrial use. Information about importance of water, its scarcity and depletion, non-availability of sweet water in far flung areas and examples of how other nations are using water efficiently etc may be communicated.
- Domestic and industrial users are approached through pamphlets/leaflets communicating the importance of conservation and efficient usage of water.
- Business sector which have intensive water usage in industrial processes may be encouraged to implement modern water conservative industrial process. Groundwater extraction and piped supply to industrial consumers must be metered and substantial water rates may be charged to encourage them for adoption of efficient processes. They may be subsidized for recycling and treatment of water.
- Schools and community buildings (e.g. mosques, hospitals etc) must be installed with water efficient toilets, urinals, taps and showers etc.
- Leak management may consists of active leak detection and repair, pressure management to reduce unnecessary high pressure areas in the system, improved response time to main breaks and leaks and improved flow metering. Masses may be encouraged to report any such event through a toll free number or online complaint registration. The system may be monitored against response time and fault removal inspections mechanism.
- Course and articles on water conservation may be incorporated in the syllabi at all levels.
- Increase water productivity by bringing high value crops in the cropping system.
- Water statistics must be made more reliable and transparent; Ministry of Water & Power must issue final figures for water resources after consulting with WAPDA, Provincial Irrigation Departments, IRSA and Water Resources Council.
- In coastal areas drinking water can be obtained by installing low

cost water treatment plants that use solar energy for the desalination of sea water, the salt obtained from this process can be used in commercial and industrial applications.

- More multi-purpose dams must be constructed to store the water during monsoon season.
- The rain water runoff must be stored through developing appropriate water structure and check dams to strengthen the water shed management programmes.
- The telemetry system must be made functional.
- Incentives to those farmers who are adopting high efficiency irrigation techniques.
- Awareness among farmers may be promoted through Farmers Associations , educating them on the use of water efficient techniques and growth of low delta crops.
- The political consensus on construction of dams and reservoirs must be developed to overcome the critical water scarcity condition of the country.

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TRENDS IN LEVELS OF DISINFECTION BY-PRODUCTS IN DRINKING WATERS OF TWIN CITIES

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Abstract

Chlorination of drinking water for elimination of water borne diseases has been applied for over an era. As disinfection progresses, reactions among natural organic matter (NOM) and chlorine results in formation of trihalomethanes (THMs) which are potential carcinogen to human health. At present no significant data, relating THMs formation potential (THMFP), their quantification and analysis have been reported in Pakistan. Therefore the present study discusses monitoring of THMs presence in two water supply systems in twin cities of Islamabad and Rawalpindi, Pakistan and their subsequent THMFP. Drinking water samples of the twin cities were analysed for possible presence of THMs. Water distribution network was monitored over period of 3 months; Water samples were collected from 19 different sampling sites including water filtration plant, underground storage tank and consumer taps from Rawalpindi and Islamabad. A simple and rapid method solid phase micro-extraction (SPME) was used for the extraction of THMs (Trichloromethane (Chloroform), Bromodichloromethane (BDCM), Dibromochloromethane (DBCM), Tribromomethane (bromoform). The concentration of the targeted compounds was analyzed using GC Gas Chromatography Shimadzu 2010 series coupled with electron capture detector. The results confirmed the presence of THMs in 16 sampling sites out of twenty representing 95% of drinking water samples contaminated with THMs. Only four sites met the standard value of 80 µg/L as per World Health Organization (WHO) standards.

Keywords: *Trihalomethanes, Distribution network, Disinfection byproducts, Chlorination, Solid phase micro-extraction (SPME)*

1. Introduction

Water is one of the most fundamental compounds to sustain life, but it may also be the cause of many illnesses termed as water borne diseases. On the other hand, many organic pollutants may be present in drinking waters at levels high enough to cause other adverse health effects. Ingestion of drinking water containing these contaminants may lead to liver and kidney damage, immune system, nervous system, and reproductive system disorders as well as several types of cancers [Calderon 2000; Fawell 2000].

Disinfectants have been added to drinking water since the early 1900. It is the most important stage in the treatment of drinking water supplies, as it removes or inactivates pathogenic organisms responsible for waterborne diseases. Chlorination is most commonly used disinfection method because of its high oxidizing property, low cost, ease to use and efficiency to improve the quality of drinking water (Karim et al., 2011; Pardakhti et al., 2011; Chowdhury, 2012a,b). However, in 1970s it was discovered that chlorine reacts with natural organic matter (NOM) and produces potentially harmful chlorinated disinfection by-products [Rook 1974, Beller 1974]. Over 600 DBPs have been reported in treated drinking water and simulated laboratory disinfection tests, as a result of disinfectants [Krasner *et al.*1989]. There are two major types of chlorinated disinfection by-products viz trihalomethanes (THMs) and haloacetic acids (HAAs). THMs are the major disinfection byproducts produced as a result of chlorination. These THMs have been further categorized into four species chloroform ($CHCl_3$), bromodichloromethanes ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$) and bromoform ($CHBr_3$). It was reported that compounds formed as a result of chlorination are not only mutagenic but also potential carcinogenic [Beller, 1974]. But in general, the brominated DBPs are both more genotoxic and cancer-causing than are chlorinated compounds, and iodinated DBPs were the most genotoxic of all but have not been tested for carcinogenicity [Richardson *et al,* 2007]. Many studies point towards association between cancer and exposure to THMs-contaminated potable water [Goi *et al,* 2005]. Most developed nations have published regulations or guidelines to control DBPs and minimize consumers' exposure to potentially perilous chemicals while sustaining adequate disinfection and control of targeted pathogens. In 30 years since the THMs were identified as DBPs in drinking water, significant research efforts have been directed toward improving our understanding of DBP formation, occurrence, and health effects. The Maximum Contaminant Level (MCL) currently regulated by the US-EPA for total THM and total HAA are 80 µg/l and 60 µg/l respectively [Richardson 2003; Serrano and Gallego 2007]. So it is important to regulate and monitor the formation of THMs with the view to ensure the compliance of the guidelines set. Undoubtedly, this will present a number of operational challenges for local water authorities.

The nature of chlorinated disinfection byproducts (CDBPs) formed depends on the quantity and the chemical composition of organic species originally present in drinking water. Number of other factors such as temperature, pH, chlorine dose, retention time and amount of organic matter present also affect formation of chlorinated disinfection byproducts (CDBPs) in water. El-Shahat and his coworkers [2001] and Hellur-Grossman *et al*. [2001] also stated higher THMs formation during the summer months than during the winter months, where at higher summer temperatures results in higher rate of THMs formation. Nevertheless, the seasonal changeability of NOM may play a major role in this escalation in THMs formation.

There are numerous analytical methods for the analysis of THMs such as solid phase microextraction (SPME), liquid-liquid extraction, static headspace technique and many others Kuran and Sojak, 1996 and Van Langenhove 1999. Among all these techniques SPME is the latest, sensitive and most expedient technique for the analysis of THMs.

2. Material and methods

2.1. Identification of sampling sites

THMs formation, their correlation and variability were assessed through experimental investigation using water samples from main water source, intermittent storage reservoirs and consumer taps from twin cities of Rawalpindi and Islamabad as shown in Table 3 for THM analysis and quantification periodically. Sampling strategy was planned in consultation with the Water and Sanitation Authority (WASA) and Capital Development Authority (CDA). The pretreated water samples were collected in 2-litres glass bottles and refrigerated at 4±1 °C.

2.2. Reagents and standards

2.2.1 Reagents Stock Standard Solutions (SSS)

Bromodichloromethane, dibromochloromethane, chloroform and bromoform (Standard analytes) were purchased from Dr Ehrenstorfer (Germany) while Methanol was purchased from Merck (Germany). Stock standard solutions were prepared by measuring accurately in 10 mL and 100 ml volumetric flasks with GC grade methanol as solvent and stored at 4 °C.

2.2.2. Sample Storage

Pre-treated water samples were collected in 1-litre container and were refrigerated at 4 °C. All samples were analysed within 1st few hours of collection. The glass vials were fully filled with water leaving no headspace, and were stored in dark at temperature <4°C for further analysis. A sample volume of 40 mL was collected into clean glass vials, and it was added with sodium thiosulfate (10 mg for 10 ml of sample) to remove any chlorine residual (APHA, 2012)

2.2.3. Sample extraction and preparation

Solid-phase micro-extraction (SPME) is a unique sample analysis procedure for complex matrices and for analytes necessitating lower levels of detection. SPME eliminates most of the drawbacks associated with extracting organics. It requires no solvents or complicated apparatus. Therefore SPME has gained widespread acceptance as the technique of preference for many applications including: flavors, fragrances and contaminants in food; environmental and biological matrices; organic volatiles in pharmaceutical compounds. SPME was performed using a Supleco Cat. No.57344-U solid-phase micro extraction fibre assembly fitted with a 75 µm (Car PDMS) fibre.

2.3. GC conditions and Conditioning of SPME fibre

SPME fibre was conditioned at a very high temperature with injector temperature 280 °C, column temperature 200 °C and detector temperature 220°C. The fibre was conditioned for 1 h prior to first time use to desorb all the contaminants. Daily conditioning of SPME fibre is very important for accurate results while conditioning of 15 min is required on daily basis. Stock solutions of the standard analytes were run on gas chromatograph to detect their signals and retention times. Gas chromatographic conditions were optimized for THMs detection. Helium gas was used as carrier gas. It flows throughout the analysis in the column at a flow rate of 126.9 mL/min. Nitrogen gas was used as makeup gas with the flow rate of 5.0 mL/min. Nitrogen gas flows only at the time of sample analysis. Temperature of column, detector and injector was adjusted according to the signals. Temperature of injector and detector were set at 220 °C and 200 °C respectively. Whereas a temperature ramp was for the column was prepared with the initial temperature of 50 °C for 1 min. Temperature ramp of 15 °C per min was given to the column. Final temperature of the column oven was 200 °C with a hold time of 2 mins. Current of one ampere was applied to the detector 15 min prior to the analysis.

3. Results and discussion

3.1. Physiochemical analysis

It is always important to know the organic load of the water way because considerably high content of organic pollutant will results in trihalomethanes formation. *Disinfectants and Disinfection byproducts Rules* by the US Environmental Protection Agency specifies maximum total organic content levels of 2 mg/L in treated water and 4 mg/L in source water to ensure acceptable levels of disinfection byproducts. [EPD,2010]. Physical and chemical analysis of water samples from both treatment plants along with surface water samples is given in Table 1.

3.2 *Gas Chromatographic analysis*

The relationship between retention times and peak areas of stock solutions of standard analytes are shown in Figure 1. It is obvious from figure that with increase in retention time peak areas also increases. Chloroform has retention time of 4.17 min with peak area of 3989. Whereas bromoform elutes at 7.02 min which is later than all the analytes. Bromoform has the peak area of 41763.

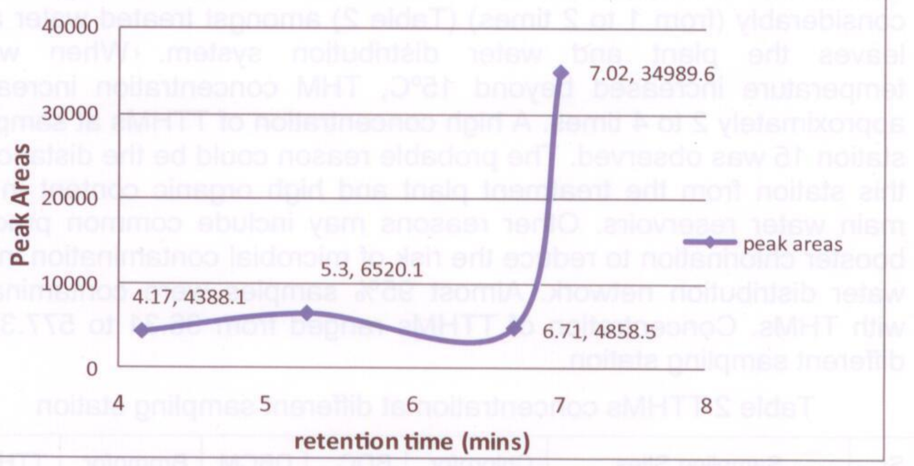

Fig. 1. Correlation between peak area and retention time

Table 1 physiochemical analysis of surface water samples

Parameters	Treated water		Surface water samples	
	Rawal Dam	Simly Dam	Rawal Dam	Simly Dam
TOC (mg/L)	4.89	2.25	9.0	5.0
pH	8.17	8.0	8.2	8.15
Temperature (°C)	8.5	8.8	14.3	15.6

TDS (mg/L)	160.4	150.8	160	158.5
EC (µS/cm)	334	327	329	321
Turbidity (NTU)	3.41	2.21	8.5	7.8
Free chlorine (ml)	0.38	0.35	0.0	0.0
Monochloramines(ml)	0.0	0.0	0.0	0.0
Dichloramines (ml)	0.0	0.0	0.0	0.0

4. THMs monitoring and quantification in twin cities of Rawalpindi and Islamabad

Water samples from twin cities were analysed and subsequently quantified for THMs presence using optimized SPME and GC conditions. Results indicated that THM concentrations differ considerably (from 1 to 2 times) (Table 2) amongst treated water as it leaves the plant and water distribution system. When water temperature increased beyond 15ºC, THM concentration increased approximately 2 to 4 times. A high concentration of TTHMs at sampling station 15 was observed. The probable reason could be the distance of this station from the treatment plant and high organic content in the main water reservoirs. Other reasons may include common practice booster chlorination to reduce the risk of microbial contamination in the water distribution network. Almost 95% samples were contaminated with THMs. Concentration of TTHMs ranged from 36.31 to 577.39 at different sampling station.

Table 2 TTHMs concentration at different sampling station

Sr. #	Sampling Sites	Chloroform	BDCM	DBCM	Bromoform	TTHMs
1	UGT # E-9 sector, Isb	109	8.8	6.79	BDL	124.6
2	H# D-22/5 E-9 sector, Isb	416.85	26.88	9.6	8.66	461.14
3	H# D-22/ 1 E-9 sector, Isb	249.03	21.6	16.4	BDL	287.03
4	H# D 50/8 E-9 sector, Isb	220.45	32.55	23.81	2.21	279.02
5	AHQ E-9 sector, Isb	151.7	18.23	6.73	BDL	176.66
6	Filtration plant, E-9, Isb	409.77	51.10	2.02	BDL	462.89

7	Filtration plant, E-8	362.9	9.5	3.22	BDL	375.62
8	H# 23, E-8 , Isb	298.75	10.15	1.0	BDL	309.87
9	H# 24, E-8 , Isb	152.6	6.73	2.55	BDL	161.88
10	H# 316,St # 39 G-9/1, Isb	290	6.0	1.36	BDL	297.36
11	H#298,St # 39 G-9/1, Isb	30.85	5.35	BDL	BDL	36.3
12	H # 32, St # 8, F-7, Isb	212.74	30.28	2.04	BDL	490.12
13	Wasa office, Isb	255	8.99	5.69	BDL	363.68
14	H # 17-C,F-8, Isb	114.9	8.66	2.84	BDL	126.4
15	H # 5, street 66, F-7, Isb	553.00	16.12	8.27	BDL	577.39
16	H#280,Gomal road,E-7, Isb	298.17	7.65	BDL	BDL	305.89
17	H#305, Aurangzeb road, E-7, Isb	189.62	2.8	BDL	BDL	192.42
18	H#202 hill side road,E-7, Isb	54.66	8.65	5.24	BDL	68.55
19	Filtration plant F-10, Isb	272.09	8.85	6.7	BDL	287.48

Chloroform was found to be maximum in all samples from entire drinking water supply network i.e., underground tank, overhead reservoir and filtration plants. The potential reason for contamination at different point is presence of natural organic matter in water. The reason for this high contamination level could be attributed to the fact that as the studied time period from June to August is the Monsoon season in Pakistan, more organic content is added from the adjoining areas to the water sources. In addition, it also makes underdeveloped areas more prone to water borne bacterial infection. So the practice of booster chlorination is very common during these seasons in Pakistan. Chloroform was comparatively lower in concentration in underground tank and sampling station 11.

Conclusions

Almost 95% samples were contaminated with THMs. Chloroform was found to be highest in all samples from whole drinking water source network i.e., underground tank, overhead reservoir and filtration plants. Chloroform concentration was relatively low in underground tank. TTHMs concentration ranged from 33.51 to 576.86 at different sampling station. Speciation of THMs can vary, conditional on the nature of the source water.

Future recommendations:

Further investigation is suggested for better understanding the formation of CDBPs. Further research involving the characterization and correlations of these critical water quality parameters is necessary to have better understanding of THMs formation and the associated risk to human health as a result of exposure to THMs. Water authorities need to review water treatment practices with view to improve the removal of organics form the water sources prior to disinfection, using alternative disinfectants and reducing water age in distribution system. More research is needed to determine the risk associated with DBPs.

As the DBPs issue is gaining momentum in Pakistan, the emphasis will be to minimize DBP formation whilst maintaining a microbiologically safe drinking water supplies.

Acknowledgement

This study was supported by the funds of Student Research Grant provided by Institute of Environmental Science and Engineering (IESE), National University of Science and Technology (NUST).

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RECHARGING OF DEPLETING GROUNDWATER AQUIFER IN PUNJAB, PAKISTAN - A CASE STUDY

Javed Munir[1] M.Mohsin Munir[2] Syed Abbas Ali[3]

Abstract:

Pakistan is an agricultural country and rich in fertile land. The economy of the country is largely dependent on its water resources. Ground water is one of the various resources which plays vital role in areas where the irrigation system is not fulfilling the irrigation needs. However due to excessive urbanization and construction of impermeable membrane over the natural strata, rate of ground water extraction through pumping is much higher than its recharge rate. The paper envisages preparation of small storages using inflatable rubber dams at potential sites along the rivers of Pakistan for the recharging of ground water aquifers. Based on SRTM data and ground water quality, potential sites across Jhelum, Chenab, Ravi and Sutlej Rivers have been identified. Among the identified potential sites, a site across Ravi River along Okara-Faisalabad bridge crossing has been taken as a case study. Development of various scenarios of pondage has been considered and economic benefits i.e. use of recharged groundwater aquifer for irrigation, recreational benefits (boating, fishing, swimming, etc.) development of fruit orchards by fulfilling irrigation needs from groundwater and comparing it with the incurred cost for the works involved. The determination of economic indicators i.e. EIRR, benefit to cost ratio for each scenario have been carried out to maximize benefits. Based on this conclusions and recommendations for other sites have been crafted. The paper will assist as an initial tool for detailed study of these identified potential sites for feasibility studies.

1. Inflatable Dam

An inflatable dam consists of a sealed, inflatable, rubber-coated fabric tube anchored to a concrete foundation constructed across a riveris shown as Figure 1. It is raised by inflating with air, water, or a combination of the two. When it is inflated to full design height, it impounds water and acts like any other fixed dam in this respect.

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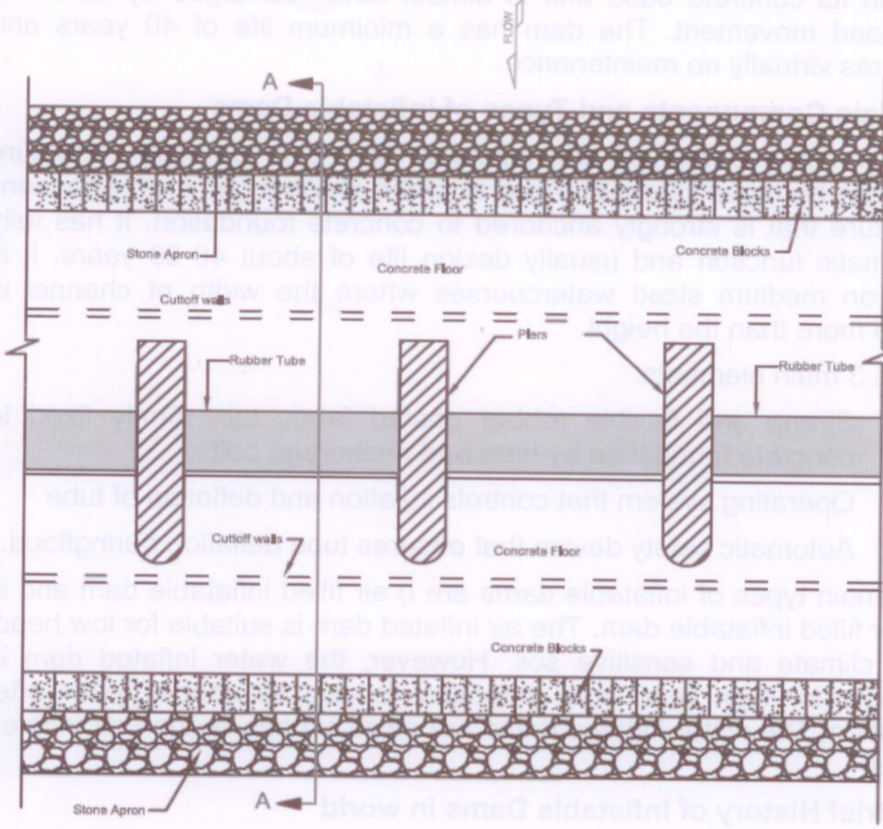
However, it is capable of being completely deflated to allow maximum run-off during a storm, thereby reducing upstream flooding, and to allow passage of sediment, debris, and ice.

The particular feature of inflated dams is the quick deflation for preventing floods. Deflation occurs automatically as the backwater reaches a certain level. Simple mechanical device is used for initiating deflation. An electronic system comprising water level sensors and valves have also been provided. Air (or water) may be pumped through supply line casted in concrete foundation below tube.

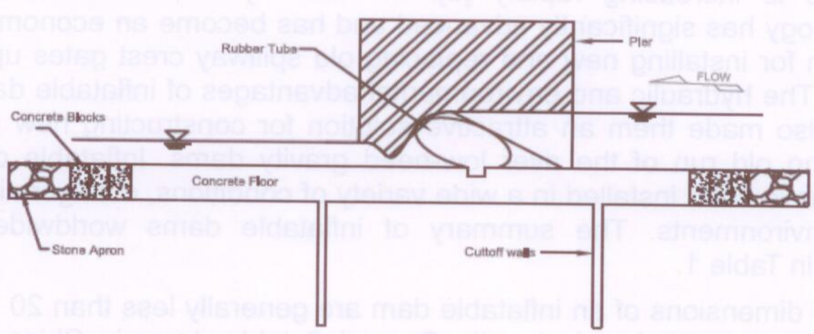
2. Advantages/Benefits of Inflatable Dams

Inflation dams can be delivered to site in one piece, unrolled and anchored to foundation. No specialist labour is required for installing them. It is suitable for channel sites having very large width and small height. The installation of foam blocks, manufactured from polyethylene, inside rubber tube protects the tube from bursting. It has another advantage of very low maintenance cost as the chance of corrosion is minimum. The presence of dam operator is not necessary for the operation.

Inflatable dams have been extensively used for raising the crest of existing dams, weirs or as flash board replacement. Other applications include intake dam / diversion weir for small hydropower plants, tidal barrier to stop tidal surges, saline intrusion to prevent contamination of agriculture land, creating artificial lakes for recreation purposes, for controlling at water treatment plants, for water supply, as stop log and as silt control device.



TYPICAL PLAN OF INFLATABLE DAM ALONG RIVER



TYPICAL CROSS SECTION A A OF INFLATABLE DAM

Figure 1: Schematic Diagram of Inflatable Rubber Dam

When the dam is deflated, the rubber body of the dam lies completely flat on its concrete base and is almost never damaged by floods or bed-load movement. The dam has a minimum life of 40 years and requires virtually no maintenance.

3. Main Components and Types of Inflatable Dams

It is generally perceived that inflatable dam is a temporary structure that can be moved from one site to other. However, it is a permanent structure that is strongly anchored to concrete foundation. It has fully automatic function and usually design life of about 40-50 years. It is built on medium sized watercourses where the width of channel is much more than the height.

It has 3 main elements.

1. Strong and flexible rubber coated fabric tube firmly fixed to concrete foundation by bars and anchorage bolts.
2. Operating system that controls inflation and deflation of tube
3. Automatic safety device that ensures tube deflation duringflood.

The main types of inflatable dams are i) air filled inflatable dam and ii) water filled inflatable dam. The air inflated dam is suitable for low head, cold climate and sensitive soil. However, the water inflated dam is suitable for high head and it retains its original shape better after deflation. The water inflated dams are more expensive than air inflated dams.

4. Brief History of Inflatable Dams in world

The first inflatable dam system known as the Fabridam was introduced in the mid 1950s. In the United States, over 200 inflatable dams have been installed since 1980, and the rate of their use on dam projects is increasing rapidly [2]. In recent years, inflatable dam technology has significantly advanced and has become an economical solution for installing new and replacing old spillway crest gates up to 5.4 m. The hydraulic and environmental advantages of inflatable dams have also made them an attractive solution for constructing new and replacing old run of the river low-head gravity dams. Inflatable dam types have been installed in a wide variety of conditions, configurations and environments. The summary of inflatable dams worldwide is shown in Table 1.

Typical dimensions of an inflatable dam are generally less than 20 feet in height and 200 feet in length. Some inflatable dams in China are Linyi Liuhang Rubber Dam Project, Taian Dawenhe River Tangzhuang Retain and Pivotal Project, Taian Dawenhe River Comprehensive Development Yanxie Rubber Dam Project and Taoyuan Rubber Dam Project etc. Some inflatable dams in the world are shown as plates**1-2.**

5. Specific Design Considerations of Inflatable Dams

Loading combinations and forces on an inflatable dam are generally the same as for concrete gravity dams.Only exceptions, clarifications and additions have been discussed here:

The effect of sediment build-up against an inflatable dam located at riverbed level may be significant and should be evaluated in addition to other conventional dead loads.The effect of external hydrostatic pressure caused by water flowing over the dam may require consideration in special cases. During deflation it is possible for the water pressure to pinch off sections of the dam, trapping air in the middle, making it impossible to fully deflate.The excellent performance of the inflatable dam under ice conditions is due to its ability to deflect and absorb the thermal expansion of ice and the impact of ice flows.

Table 1: Summary of Inflatable Dams World Wide [3]

Country	Year Introduced	Type of inflation	Number Installed World (Area ft²)
USA	1956	Air & Water	-
Japan	1968/1978	Air & Water or Air	1,900
France	1972	Water	25
Austria	1977	Water	60
Japan	1978	Air or Water	> 700 (302,000)
Germany	1984	Air or Water	40
USA	1988	Air	111
Australia	1997	Air or Water	3
Czech Republic	1980	Water	20

Plate 1: Taian Dawenhe River Tangzhuang Retain and Pivotal Project

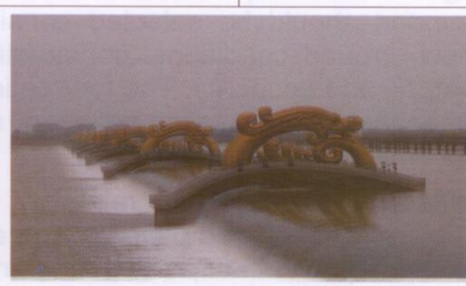


Plate 2: Taoyuan Rubber Dam Project

After the design parameters are established the tube suppliers generally perform the design and analysis of the superstructure, which includes the tube and tube attachment fittings. The substructure, which includes the piers, side walls, tube mounting base plate, aprons, and revetment, is generally analysed by the inflatable dam designer. The tube shape and tension are determined based on external pressure, internal pressure, and weir height. Design of the tube attachment fittings should account for the tension in the tube's rubberized fabric and nut tightening forces. The fittings should be constructed so that the force in the tube's rubberized fabric is evenly held.The width of the tube mounting bed plate required is dependent upon the height of the dam and the inflation medium used.

The tube does not deflate evenly i.e. the crest of the dam does not remain straight and parallel in relation to the foundation as it lowers. Discharging water rushing over a deflating dam increases the pressure acting on it, which tends to push it down in a particular place, creating a depression shaped like a "V" notch. To facilitate the start of defl ation, a "V" notch (1 vertical to 10 or 20 horizontal) is formed by the foundation pad. Deflation then starts over this area. Tube inflating medium should be selected from among water, air, and co-use of both considering natural conditions of the site (ambient temperature, foundation quality, and fill water availability), purpose and operation policy (required function, operation frequency), maintenance and control, and economics.

The tube should be designed to satisfy the necessary dam height for all combinations of design water levels and design flow rates. It should be air and/or water tight and sufficiently durable (service life of at least 30 years). It should be easily and adequately raised, and completely flattened in deflation. There should be no harmful vibrations and should be convenient for maintenance. The substructure of the inflatable dam should be designed to be safe for expected loads, provide water tightness as required, and have adequate durability. The foundation support should be selected considering the loading, effect of water flow, ground conditions, construction work, environmental conditions, safety, and economy. The foundation must not deform to a point where it impacts the inflation/deflation and pipes embedded in the tube mounting bed plate.

Inflatable dams have relatively simple foundation and structural requirements. A bed plate holding a rail and bolt assembly anchors the dam body with clamps and nuts. Inflation and deflation involves piping that leads from the dam to an intake/exhaust valve and pump system.

The foundation investigations for these dams are also similar to concrete / earthen dams. Bends in the river channel should be avoided.

The plan configuration of the dam should be straight and normal to the flow.

Depending on the load and environmental requirements, there are various fabrics available in terms of weaves, cord counts and weights. The most improved material is Ethylene Propylene Diene Monomer (EPDM) rubber reinforced with synthetic fibre i.e. nylon. Strength is achieved by the lamination of fabric plies, and wear and weather resistance by the thickness. Most repairs are not difficult, rarely necessary, and can, depending on the position of the damage and river flow, normally be done without deflating the dam. The length of inflatable dam generally does not exceed 300 to 400 feet due to the economics of shipping and handling during installation. For longer dams concrete piers are used between each dam section. The fabrics used for dam construction are capable of withstanding forces in dams up to about 20 feet in height. There are no known United States standards for inflatable dams. The fitting system consists of an embedded plate, clamping plate, and anchor bolts. Galvanized steel is generally used. Stainless steel is used if salt water is expected.

6. Inflatable Dams Potential in Pakistan

The main objectives of proposed inflatable dams in Pakistan are ground water recharge, recreational facilities, fisheries and reducing floods etc.

Design Criteria for Selecting the Suitable Sites in Pakistan

The design criteria defined for the selection of potential dam sites are as follows:

- It is evident from literature review that most of existing inflatable dams in the world and in China are located downstream of the bridges. Similarly, for exploring the inflatable dam sites in Pakistan, the location of bridges on Ravi, Sutlej and Jhelum have been given preference for preliminary studies. Other sites on rivers in plain areas have also been explored in the study
- Those areas where ground water is depleting are given preference
- The areas lying in sweat ground water zone has given preference
- Massive Resettlement should not be involved due to reservoir
- Geotechnical and geological ground conditions should favour the construction of dam
- Negative impact on installations i.e. railway bridge etc. should not be affected due to reservoir

- The areas near cities have given importance

Technical Analysis for proposed dam sites

The tentative locations have been identified as per developed design criteria using Google Earth software. 31 sites were selected for checking their suitability as shown in **Table 3**. The location of selected sites has also shown in **Figure 2**. The sites have been represented by respective ID. Nos. as mentioned in figures 2 and table 3.

Water quality maps developed using 2012 ground water data have been used to analyze the ground water quality at the proposed locations. As per design criteria, the proposed sites must be located in sweat water zone and the ground water shows the trend of depletion. The ground water quality map at the proposed dam locations is shown as **figure 3.** The ground water quality has been graded in three ranges on the basis of total dissolved solids (TDS) as presented in **Table 4.**

The ground water quality at the proposed location is generally good, as the inflatable dams are located on rivers. However, two sites on Sutlej River at Fatehpur and Mailsi Siphon Bridge were observed in Bad ground water zone having TDS quantity greater than 3000 ppm and were discarded from the list of selected sites.

SRTM 90 m Digital Elevation database has been used to develop Digital elevation models (DEM) of all the selected sites. Google Mapper is then used to resample the data and to generate 3 m contours at the proposed dam sites for different heights. The pond area has been accessed at different dam heights. The selection of final dam height and pond area is subject to different parameters i.e. public buildings and instalments, resettlement of people, sufficient availability of pond etc. Moreover, after analyzing different sites it has been observed that 3 m dam height is considered suitable for finding the reservoir area and capacity. It has been analyzed that the sufficient pond area and capacity of two dams at Muzaffargarh Chanab Bridge near Muzaffargarh Multan on Chanab river (ID. No. 6) and Musa Shaheed bridge on river Sutlej at Jalalpur Road (ID. No. 13) were not available. These two locations are not considered feasible for constructing inflatable dams. The pond area of sites from ID. No. 15 to 31 have been computed by taking the general slope of rivers in plain areas of Punjab i.e. 1 in 4000.

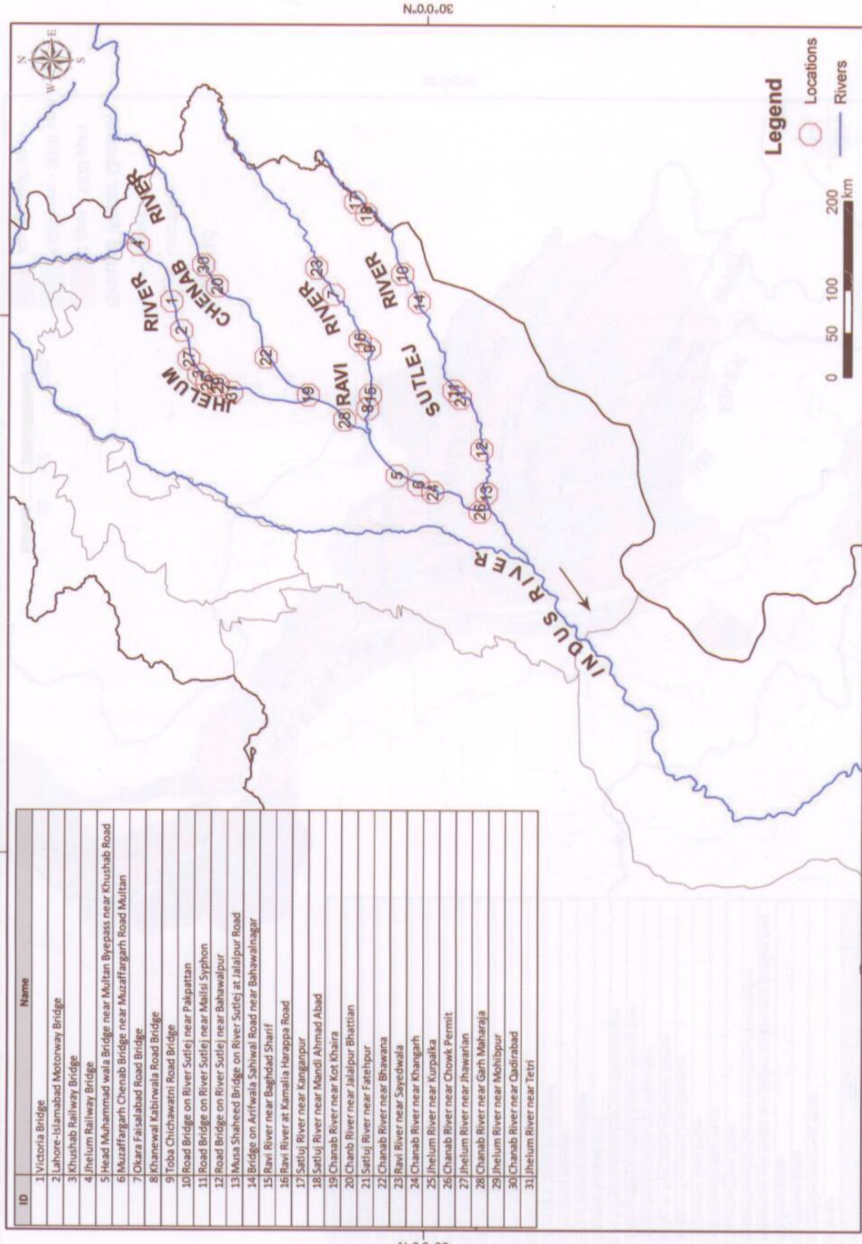
The exact capacity of reservoirs can only be determined by conducting Bathymetric survey. The bathymetric survey of all the sites is not available. Hence, the approximate capacity of those sites whose bathymetric survey is not available has determined using the criteria: Capacity of reservoir = average height of dam x pond area.

Table 3: Proposed sites of Inflatable Dams in Pakistan taken in the study for checking their suitability

ID. No.	Description of Dam	River
1	Victoria Bridge	Jhelum
2	Lahore Islamabad Motorway Bridge	Jhelum
3	Khushab bridge	Jhelum
4	Jhelum bridge on GT road	Jhelum
5	Head Muhammad-wala bridge near Multan Byepass on Khushab road	Chanab
6	Muzaffargarh Chanab bridge near Muzaffargarh road Multan	Chanab
7	Okara Faisalabad road bridge	Ravi
8	Khanewal Kabirwala road bridge	Ravi
9	Toba Chichawatni road bridge	Ravi
10	Road bridge on river Sutlej near Pakpattan	Sutlej
11	Road bridge on river Sutlej near Mailsi Syphon	Sutlej
12	Site near road bridge (N5) on river Sutlej near Bahawalpur	Sutlej
13	Musa Shaheed bridge on river Sutlej at Jalalpur Road	Sutlej
14	Bridge on Arif wala Sahiwal road near Bahawalnagar	Sutlej
15	Ravi River near Baghdad Sharif	Ravi
16	Ravi River at Kamalia Harappa Road	Ravi
17	Satluj River near Kanganpur	Sutlej
18	Satluj River near Mandi Ahmad Abad	Sutlej
19	Chanab River near Kot Khaira	Chanab
20	Chanb River near Jalalpur Bhattian	Chanab
21	Satluj River near Fatehpur	Sutlej
22	Chanab River near Bhawana	Ravi
23	Ravi River near Sayedwala	Chanab

24	Chanab River near Khangarh	Jhelum
25	Jhelum River near Kurpalka	Chanab
26	Chanab River near Chowk Permit	Jhelum
27	Jhelum River near Jhawarian	Jhelum
28	Chanab River near Garh Maharaja	Chanab
29	Jhelum River near Mohibpur	Jhelum
30	Chanab River near Qadirabad	Chanab
31	Jhelum River near Tetri	Jhelum

The latest average cost of some inflatable dams around the world has been used to compute the cost of proposed inflatable dams in Pakistan. The latest average cost used in the analysis is $ 30,000 / m which includes the cost of concrete floor, pile foundation, river training works i.e. guide banks, marginal bunds, saddle dam, rubber tube, automatic safety device, control system, operation and maintenance, contingencies and all the allied studies.



ID	Name
1	Victoria Bridge
2	Lahore-Islamabad Motorway Bridge
3	Khushab Railway Bridge
4	Jhelum Railway Bridge
5	Head Muhammad wala Bridge near Multan Byepass near Khushab Road
6	Muzaffargarh Chenab Bridge near Muzaffargarh Road Multan
7	Okara Faisalabad Road Bridge
8	Khanewal Kabirwala Road Bridge
9	Toba Chichawatni Road Bridge
10	Road Bridge on River Sutlej near Pakpattan
11	Road Bridge on River Sutlej near Mailsi Syphon
12	Road Bridge on River Sutlej near Bahawalpur
13	Musa Shaheed Bridge on River Sutlej at Jalalpur Road
14	Bridge on Arifwala Sahiwal Road near Bahawalnagar
15	Ravi River near Baghdad Sharif
16	Ravi River at Kamalia Harappa Road
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20	Chanb River near Jalalpur Bhattian
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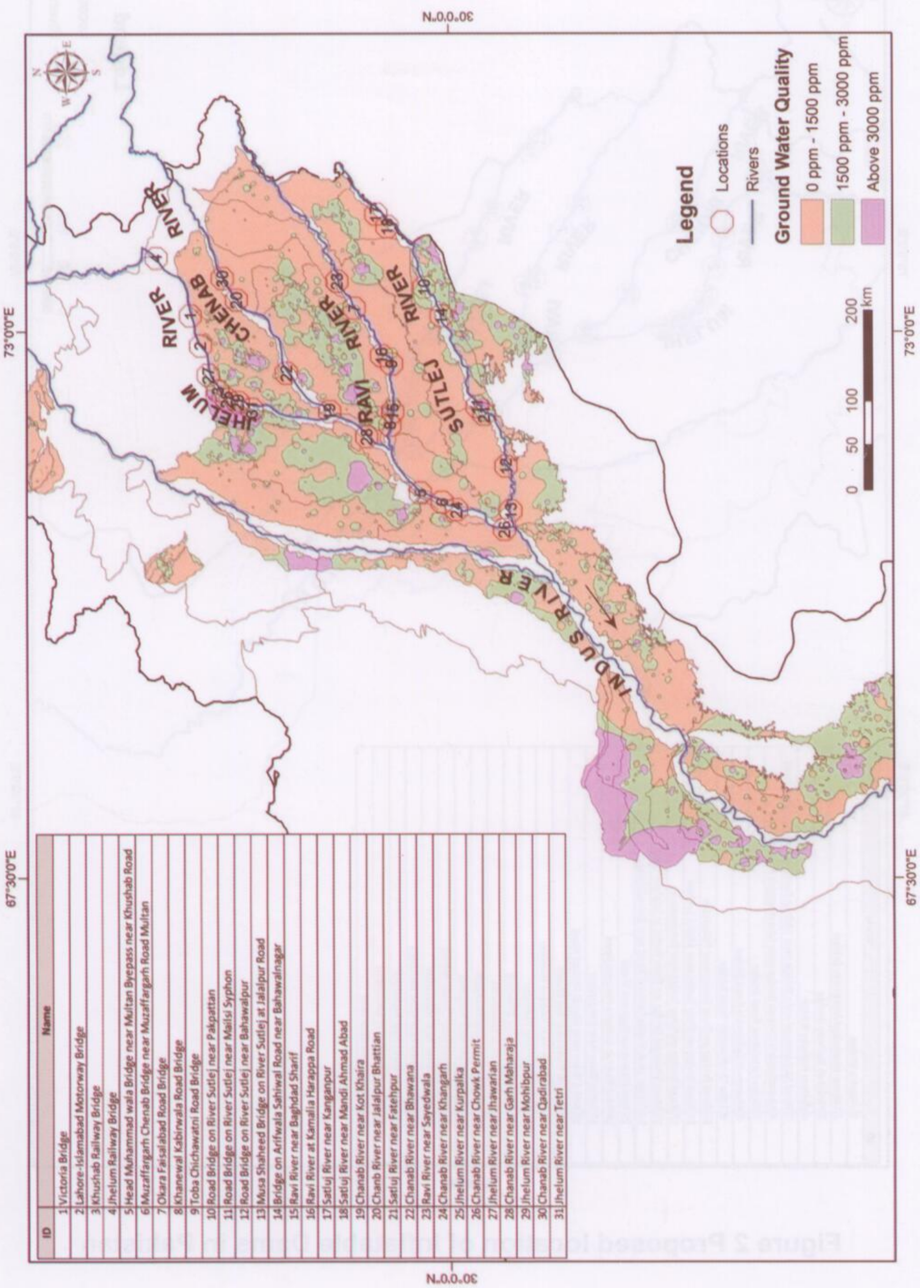
22	Chanab River near Bhawana
23	Ravi River near Sayedwala
24	Chanab River near Khangarh
25	Jhelum River near Kurpalka
26	Chanab River near Chowk Permit
27	Jhelum River near Jhawarian
28	Chanab River near Garh Maharaja
29	Jhelum River near Mohibpur
30	Chanab River near Qadirabad
31	Jhelum River near Tetri

Figure 2 Proposed location of Inflatable Dams in Pakistan


ID Name
1 Victoria Bridge
2 Lahore-Islamabad Motorway Bridge
3 Khushab Railway Bridge
4 Jhelum Railway Bridge
5 Head Muhammad wala Bridge near Multan Byepass near Khushab Road
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7 Okara Faisalabad Road Bridge
8 Khanewal Kabirwala Road Bridge
9 Toba Chichawatni Road Bridge
10 Road Bridge on River Sutlej near Pakpattan
11 Road Bridge on River Sutlej near Mailsi Syphon
12 Road Bridge on River Sutlej near Bahawalpur
13 Musa Shaheed Bridge on River Sutlej at Jalalpur Road
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24 Chanab River near Khangarh
25 Jhelum River near Kurpalka
26 Chanab River near Chowk Permit
27 Jhelum River near Jhawarian
28 Chanab River near Garh Maharaja
29 Jhelum River near Mohibpur
30 Chanab River near Qadirabad
31 Jhelum River near Tetri
67°30'0"E
73°0'0"E
30°0'0"N
JHELUM RIVER
CHENAB RIVER
RAVI RIVER
SUTLEJ RIVER
INDUS RIVER
N
S
E
W
Legend
Locations
Rivers
Ground Water Quality
0 ppm - 1500 ppm
1500 ppm - 3000 ppm
Above 3000 ppm
0 50 100 200 km

Similarly, the computed average cost has been used to find out the cost of proposed inflatable dams in Pakistan. The ground water quality, dam height, dam length, reservoir area, reservoir capacity and project cost of all the proposed sites are shown in Table 6. The contour plan of some potential sites is attached as Annexure A.

Table 4: Range to grade ground water quality

Sr. No.	Range of Total Dissolved Solids in PPM	Quality
1	0-1500	Good
2	1500-3000	Marginal
3	>3000	Bad

HYDROLOGICAL STUDIES

The proposed inflatable rubber dam (situated just downstream of Okara-Faisalabad Bridge) is to be constructed across Ravi river about 70 km downstream of Balloki barrage and 120 km upstream of Sidhnai barrage in Tandlianwala tehsil of district Faisalabad.

For the generation of long term flows at rubber dams site, the post accord stream flow data downstream of Balloki Barrage observed from 1991 to 2013 (23 years) has been used. Since the site is situated about 70km downstream of Balloki Barrage and there is no further major contribution of flows within that reach, so the same flows may be considered adequate at dam site. Keeping in view heavy monsoon/flood flows during the months of July, August and September, water availability has been estimated with and without flood periods at this site. Highest flows occurred during the month of August while minimum flows were observed in November. The computed mean annual flows are 5,070 cusecs with whole year whereas without the flood period the mean annual flows fall to 1,817 cusecs. The monthly distribution of flows with and without flood period has been shown in Figures 4 and 5.

Flow duration curves have also been developed using the daily flow data downstream of Balloki barrage for the period 1991-2013 and are presented in Figure 6.

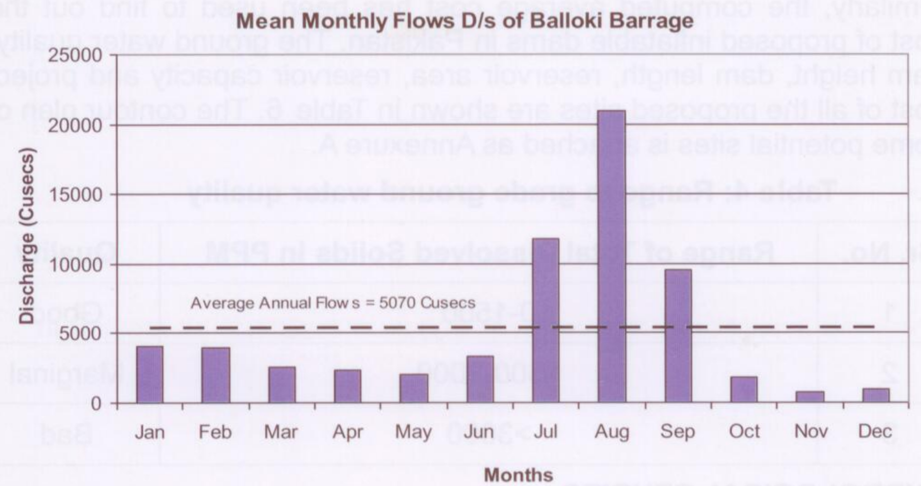

Figure 4: Mean Monthly Flows at Dam site-1 with Flood Period (1991–2013)

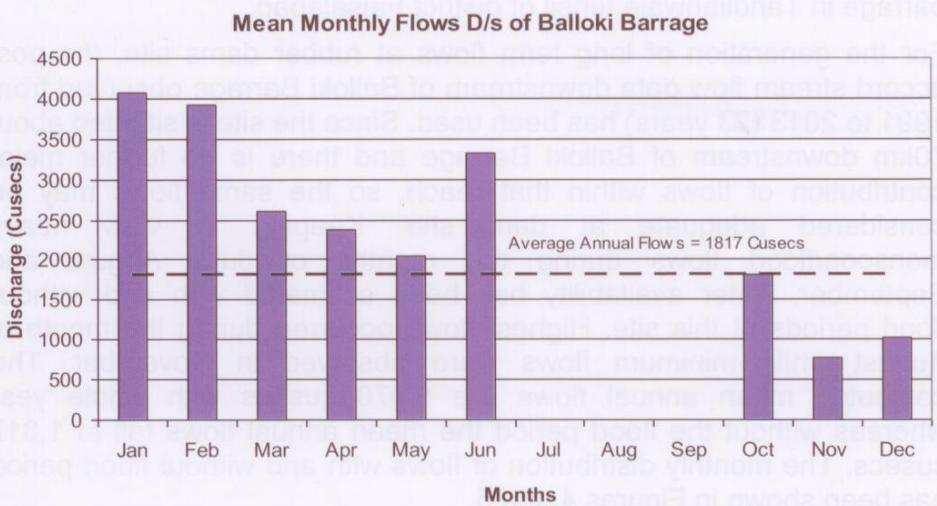

Figure 5: Mean Monthly Flows at Dam site-1 without Flood Period (1991 – 2013)

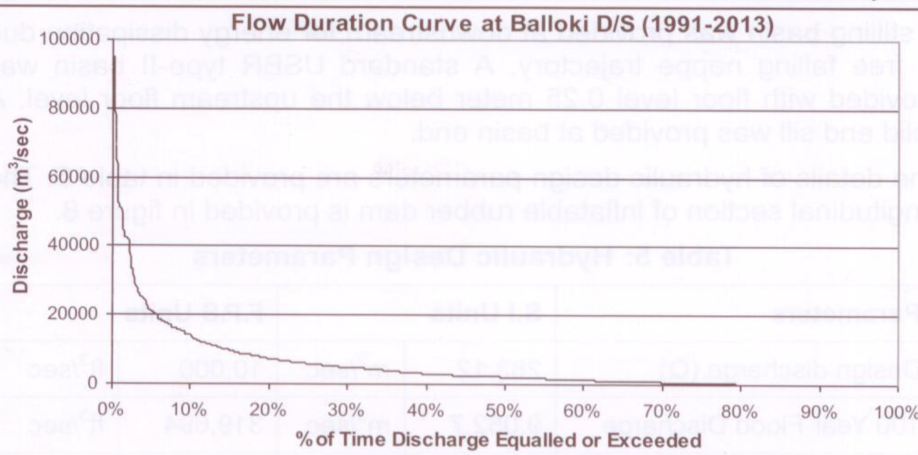

Figure 6: Flow Duration Curve at Balloki Barrage Downstream

HYDRAULIC STUDIES

The conceptual hydraulic design for inflatable rubber dam, downstream of Okara-Faisalabad Road Bridge at Ravi River was carried out against a design discharge of 283.17 m^3/sec (10,000 ft^3/sec). The rubber dam was provided approximately 300 meter downstream of Okara-Faisalabad Road Bridge and the distance between road bridge and dam axis was sufficient to avoid any flow constriction.

The inflatable rubber membrane is installed on a concrete pad that serves as a permanent fixture within the river. The concrete pad consists of abutments, piers, upstream floor and stilling basin. Seven spans of equal width (60.0 m each) have been provided separated by 1.0 meter thick pier. The concrete pad must be checked for the maximum expected flood. During high flow season or flood events, the rubber dam will be deflated and the river will flow without any obstruction. From a hydraulics point of view, the matter of concern would be scour upstream and downstream of the concrete pad at this flood event. The scour depths upstream and downstream of the concrete pad were estimated against 100 year return period flood discharge of 9,052.7 m^3/sec (319,694 ft^3/sec). Sheet piles have been provided in design at start and end of concrete pad for safety against estimated scour.

The sub surface analysis for the inflatable rubber dam was carried out using Khosla's Theory, considering the most critical scenario with maximum upstream pondage and no tailwater level. An upstream water level of 172.0 m asl (564.30 ft asl) i.e. up to crest elevation and zero tailwater at downstream side was considered. The structure was found to be safe against uplifts pressures. A safe exit gradient of 0.16 for fine sand bed material was considered.

A stilling basin was provided at downstream for energy dissipation due to free falling nappe trajectory. A standard USBR type-II basin was provided with floor level 0.25 meter below the upstream floor level. A solid end sill was provided at basin end.

The details of hydraulic design parameters are provided in table 5. The longitudinal section of inflatable rubber dam is provided in figure 8.

Table 5: Hydraulic Design Parameters

Parameters	**S.I Units**		**F.P.S Units**	
Design discharge (Q)	283.12	m^3/sec	10,000	ft^3/sec
100 Year Flood Discharge	9,052.7	m^3/sec	319,694	ft^3/sec
Height of rubber dam (D)	3.0	m	10.0	ft
Crest level	172.00	m asl	564.30	ft asl
Upstream floor level	169.00	m asl	556.46	ft asl
Downstream floor level	168.75	m asl	553.64	ft asl
Number of Bays (N)	7.0	No.	7.0	No.
Bay Width (B)	60.0	m	196.85	ft
Total Clear Waterway (W)	420.0	m	1,377.95	ft
Number of piers	6.0	No.	6.0	No.
Pier width	1.0	m	3.28	ft
Abutment width	2.0	m	6.56	ft
Bed material	Fine Sand		Fine Sand	
Upstream cutoff depth	6.0	m	19.7	ft
Downstream cutoff depth	7.5	m	24.6	ft
Upstream cutoff elevation	163.00	m asl	534.77	ft asl
Downstream cutoff elevation	161.25	m asl	529.03	ft asl
Floor thickness (t_f)	1.0	m	3.28	ft
Concrete floor length (b)	19.55	m	64.1	ft
Exit gradient (G_E) (Allowable G_E = 0.16)	0.10	-	0.10	-

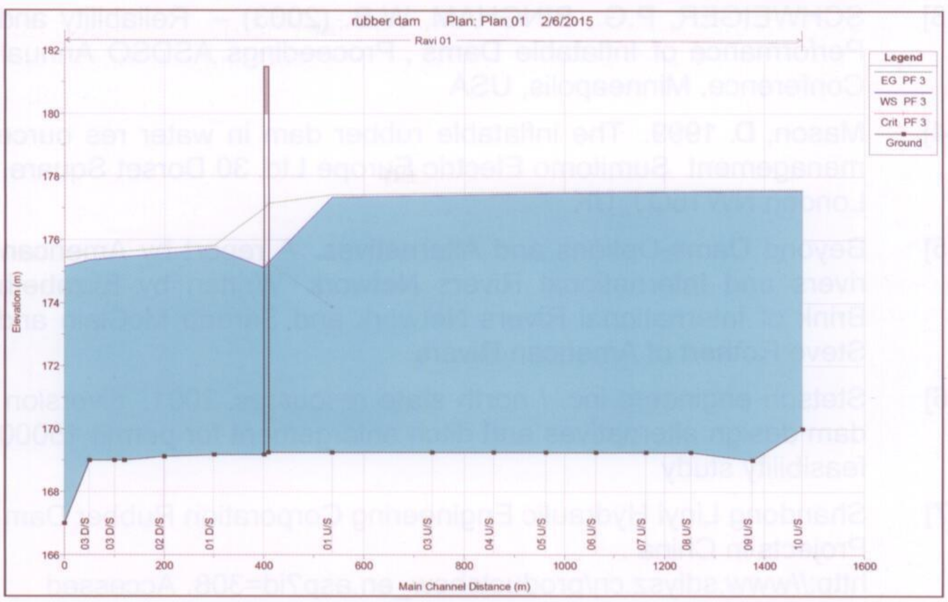

Figure 7: HEC-RAS flow profile for 100 year flood at Ravi site (without rubber dam)

Figure 8: Inflatable Rubber Dam Longitudinal Section

Conclusion and Recommendations

1. The case study reveals that that there is much provision on the rivers in Punjab for small storages using inflatable rubber dams. The analysis concludes that twenty seven (27) sites as summarized in Table 5 are considered suitable for constructing inflatable dams in Pakistan.
2. Ground water recharge by the use of rubber inflatable dams can be successfully achieved having flexibility in operation of available flows during lean and flood period.
3. The study can be further extended by carrying out feasibility studies considering detailed aspects related to economic benefits for the potential sites presented in the paper.

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Table 6: Summary of results regarding preliminary assessment of suitable proposed sites Inflatable Dams in Pakistan

Sr. No.	ID. No.	Description / Location of Dam	River	Ground Water Quality	Dam Height	Dam Length	Reservoir Area	Reservoir Capacity
					m	m	Million m^2	Million m^3
1	1	Victoria Bridge	Jhelum	Good	3	856	5.1	7.65
2	2	Lahore Islamabad Motorway Bridge	Jhelum	Good	3	868	5	7.5
3	3	Khushab bridge	Jhelum	Good	3	716	10	15
4	4	Jhelum bridge on GT road	Jhelum	Good	3	1064	4.3	6.45
5	5	Head Muhammad-wala bridge near Multan Byepass on khushab road	Chanab	Good	3	600	6.5	9.75
6	7	Okara Faisalabad road bridge	Ravi	Good	3	791	9.4	14.1
7	8	Khanewal Kabirwala road bridge	Ravi	Good	3	121	1.5	2.25
8	9	Toba Chichawatni road bridge	Ravi	Good	3	417	6.4	9.6
9	11	Road bridge on river Sutlej near Mailsi Syphon	Sutlej	Moderate	3	585	7.02	10.53
10	12	Site near road bridge (N5) on river Sutlej near Bahawalpur	Sutlej	Good	3	652	1.68	2.52
11	14	Bridge on Arif wala Sahiwal road near Bahawalnagar	Sutlej	Good	3	633.5	7.602	11.403
12	15	Ravi River near Baghdad Sharif	Ravi	Good	3	246	2.952	4.428
13	16	Ravi River at Kamalia Harappa Road	Ravi	Good	3	709	8.508	12.762
14	17	Satluj River near Kanganpur	Sutlej	Good	3	240	2.88	4.32
15	18	Satluj River near Mandi Ahmad Abad	Sutlej	Good	3	458	5.496	8.244
16	19	Chanab River near Kot Khaira	Chanab	Good	3	718	8.616	12.924
17	20	Chanb River near Jalalpur Bhattian	Chanab	Good	3	1531	18.372	27.558
18	22	Chanab River near Bhawana	Ravi	Good	3	980	11.76	17.64
19	23	Ravi River near Sayedwala	Chanab	Good	3	1173	14.076	21.114
20	24	Chanab River near Khangarh	Jhelum	Good	3	875	10.5	15.75
21	25	Jhelum River near Kurpalka	Chanab	Good	3	1158	13.896	20.844
22	26	Chanab River near Chowk Permit	Jhelum	Good	3	790	9.48	14.22
23	27	Jhelum River near Jhawarian	Jhelum	Good	3	1003	12.036	18.054
24	28	Chanab River near Garh Maharaja	Chanab	Good	3	1114	13.368	20.052
25	29	Jhelum River near Mohibpur	Jhelum	Good	3	559	6.708	10.062
26	30	Chanab River near Qadirabad	Chanab	Good	3	1344	16.128	24.192
27	31	Jhelum River near Tetri	Jhelum	Moderate	3	381	4.572	6.858

Sustainable Conjunctive Use of Groundwater for Additional Irrigation

Dr. Naveed Alam[1 2]

Abstract

This research aims to solve the longstanding problem of sustainable groundwater extraction in the Pakistani Punjab. The skimming technology introduced in 1980s and now used by millions of private wells in the Punjab aims at reducing or preventing saltwater upconing into the well strainers. Contrary to what many studies on the subject suggest, skimming technology cannot prevent salinization, it may only delay it. The salinization, which farmers are facing with their skimming wells, is because they do not remove any saltwater from the groundwater system: there can be no solution without removal of some saltwater, which can most effectively be performed by scavenging. Sustainable conjunctive use of groundwater for additional irrigation requires long-term salt management and that was the main research theme of my PhD research at Delft University of Technology of the Netherlands. This research develops a solution to make groundwater use for additional irrigation sustainable, i.e., to limit the salinity of pumped water in the long run.The most important results of PhD research will be presented and the derived concepts will be explained with the help of animations.

Introduction

The Punjab is characterized by its doabs: elongated islands surrounded by the five great rivers of the Indus Basin. These doabs have been almost 100% irrigated for more than a century. River water held up behind dams and barrages is distributed through an extended network of large to small irrigation canals over virtually the entire region. This irrigation turned the once desert conditions into the breadbasket of Pakistan.

An irregular irrigation supply has caused the widespread introduction of private tube wells that allow individual farmers to provide additional water exactly when their crops need it. However, fresh groundwater is limited because it has largely originated from canal leakage and

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irrigation return flow since irrigation was introduced before the end of the 19th century (Greenman et al., 1967; Asghar et al., 2002). The overexploitation of this valuable new resource has led to high salinity because of the upconing of underlying naturally saline groundwater (Asghar et al., 2002; Shah et al., 2003).

A solution to the problem has been sought by public scavenging wells and private skimming wells since the 1970s (Ahmad and Ahmed, 1985; Ahmad, 1994). Scavenger wells have a lower and an upper screen; where the lower (scavenging) screen is meant to extract and discharge the saltwater, and the upper screen extracts and discharges the freshwater. Skimming wells, however, are shallow and partially penetrate the upper zone of the fresh-saline aquifer to minimize the extraction of saltier water. They often have more screens (up to 26) that are arranged around a central point to spread out the extraction and thus skim off the fresh water. The discharge rates, penetration depth, number of screens, distance between screens, etc. are designed to either prevent or at least substantially reduce the extraction of brackish and salt water from the aquifer below the shallow screen (Saeed and Ashraf, 2005; Saeed et al., 2002a,b).

The use of skimming wells or similar techniques by farmers in the Punjab is ubiquitous. These farmers are facing the following long-term problems: (1) shallow wells falling dry; (2) salinity gradually rising to levels that are unacceptable for irrigation; and (3) the high cost of drilling, maintenance, and replacement (Saeed et al., 2002b). Still, these (skimming) wells are being promoted locally by institutions to farmers and in publications. Among these promoters are research organizations such as the International Water Management Institute, the International Waterlogging and Salinity Research Institute, the Center of Excellence in Water Resources Engineering, the Pakistan Council of Research in Water Resources, and water resources groups of Harvard University and Colorado State University. These institutes have conducted many studies to evaluate the performance of skimming wells and have played a key role in the rapid diffusion of skimming technology throughout the Pakistani Punjab (Wang, 1965; Sahni, 1972, 1973; Zuberi and McWhorter, 1973; McWhorter, 1980; Chandio and Larock, 1984; Sufi et al., 1998; Saeed et al., 2002a,b,c; Asghar et al., 2002; Saeed et al., 2003; Ali et al., 2004; Saeed and Bruen, 2004; Ashraf et al., 2011).

Our analytical and numerical 300 year simulations show that skimming wells can only delay the process of upconing, but are unable to prevent it as is evident from long-term (years) simulation, contrary to the very short simulation (days) in the previously cited papers and reports, on which different design and operational rules are based.

McWhorter (1980) is a primary promoter of the widespread diffusion of skimming well technology in the Punjab and summarized the Pakistani skimming well investigations that were designed and carried out by Colorado State University during the 1970s. In addition to the previously cited authors, he highlighted that the performance of skimming wells depends on parameters such as strainer diameter, penetration depth ratio, distance between strainers, and the thickness of the fresh- water layer below the strainers. Studies carried out in different areas of the Indus Basin concluded that skimming wells are a suitable technology if certain guidelines and operational schedules are kept. However, these studies failed to address the long-term subsurface salinity distribution, which is also the result of spatial and temporal pumping dynamics that are subject to varying economies and crop types.

The pertinent longstanding question is whether the sustainable use of groundwater is possible in the given situation and if it is possible to prevent the ongoing accumulation of salt as a result of the repeated recirculation of irrigation return flow. The sustainable use of groundwater requires the discharge of saltwater and a supply of freshwater. While the supply of freshwater is guaranteed by the (leaking) irrigation network, the discharge of brackish water may be achieved by scavenger wells or similar techniques. Since the early 1970s, the Pakistani government has made several attempts to perform such operations with negative results (Ahmad, 1994). For instance, wells have been used to extract the freshwater that had previously leaked, but these wells eventually salinized (Ahmad, 1994). Some wells were specifically designed for the central saline areas of the Punjabi doabs to dispose of saltwater (Ahmad, 1994). These wells are now totally abandoned because they gradually moved the salt water from the greater depths to the more shallow zones (Ahmad, 1994). Currently, farmers use skimming wells on a private basis; however, despite using an often extended number of strainers (screens), farmers are experiencing difficulty in preventing or reducing the salinity caused by upconing from below.

Scavenging on a scientific basis may still be an effective way to mitigate and/or prevent the upconing of saline groundwater into the fresh screen, but only if the saltwater is discharged and the volumetric flows and salt loads balance at the farm scale. A second condition is that the streamlines that are caused by the well must remain shallow. However, this is a consequence of the cells formed by a large number of wells extracting simultaneously.

The results of this PhD study show that long-term sustainable groundwater extraction in the Punjab is possible. MATLAB-based

SEAWAT models (Olsthoorn, 2014) were used to show the results of the analysis. This research explores the use of, what we call, Balanced scavenger wells to ameliorate the salinization problem so that sustainable groundwater use is possible as an additional source for irrigation.

Methods

The environment mfLab (Olsthoorn, 2014) was used to generate complex inputs for the SEAWAT models (Weixing and Langevin, 2002; Langevin et al., 2003, 2008) and to analyze and visualize its output. The model simulated the flow in an axially symmetric fashion. The two required screens were placed between −5 and −30 m and between −50 and −80 m relative to the ground surface. The initial TDS distribution used in the models was based on the recent time-domain electromagnetic (TDEM) measurements in the Punjab (Alam, 2014). The initial distribution was based on approximately 600 TDEM measurements, especially in the center of the Chaj Doab (refer to Figure 1), which was prominently known for salt upconing. Because of the similarity of the Punjabi doabs, this initial salinity condition was assumed to be generally representative of the Punjab.

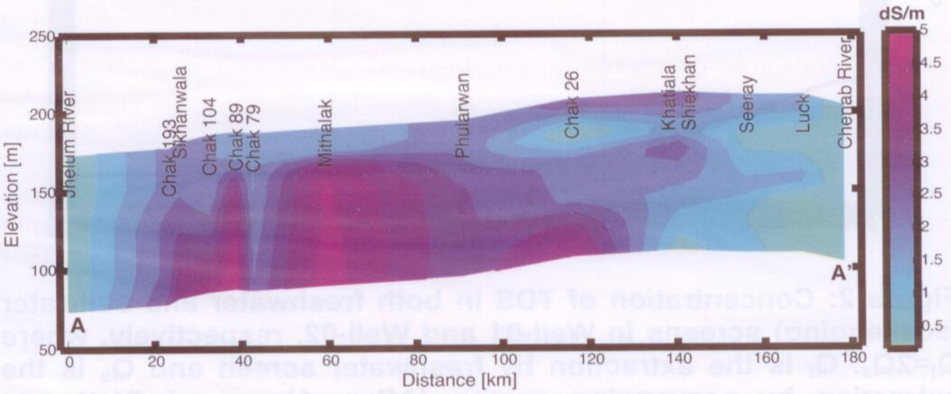

Figure 1: Vertical distribution of the electrical conductivity (EC) of the groundwater in Chaj Doab, which is profiled parallel to the adjacent rivers and almost through the center of the doab (After: Alam [2014]).

Results and Discussion

The results of our analysis and the presented case (Figure 2) show that a long-term equilibrium can be reached in which the TDS concentration of the extracted fresh groundwater does not exceed a preset limit for which a value is chosen that is acceptable for irrigation. Such cases essentially cover the range of possibilities, and the most probable set of hydraulic parameters for the Punjab was used. However, the different sets of parameters and initial salinity did not change the final (i.e., long-term) salinity of the extracted groundwater used for irrigation, and other parameter values can at most shorten or lengthen the time in which a preset equilibrium salinity is reached. Therefore, to achieve sustainability, a certain amount of brackish water has to be discharged. This can be performed by scavenging, a method in which an extra screen is installed below the regular freshwater screen. In such cases, the required extraction from such a deeper screen is determined by the derived salt and water budgets. The only free variable is the extraction of the freshwater screen Q_f.

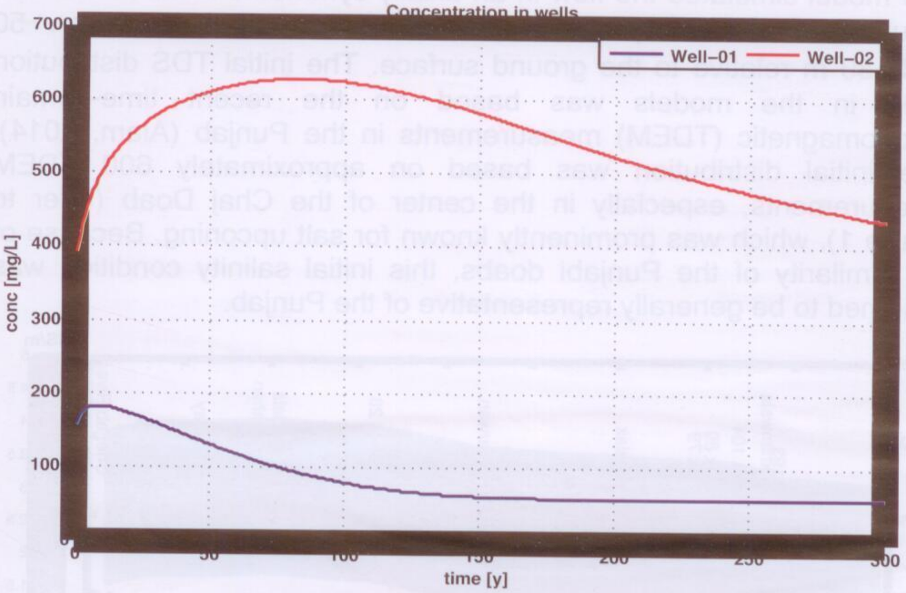

Figure 2: Concentration of TDS in both freshwater and saltwater (scavenging) screens in Well-01 and Well-02, respectively, where Q_f=2Q_s. Q_f is the extraction by freshwater screen and Q_s is the extraction by scavenging screen (After: Alam and Olsthoorn [2014]).

Maintaining the balance of both the volume in the aquifer and its salinity requires that the terms of the water budget are quantified in the field and extraction limits are adapted accordingly. Of course, the infrastructure required to reject the extracted saltwater is essential to prevent discharge into the irrigation canals. Ultimately, all salt will end up in the Indus River and may burden the downstream users, which requires national planning with respect to agricultural production. Whether such required drainage is acceptable must be investigated on an expanded national scale.

A clear disadvantage of scavenging wells is that much of the natural saltwater is unnecessarily discharged. Only the saltwater increase in the fresh aquifer caused by mixing, i.e., dispersion, must be discharged over time. The discharge of highly mineralized native groundwater is a consequence of upconing into the lower screen. The re-injection of saltwater into the aquifer at a proper depth might be a mid-term solution to delay the discharge of salt. The total volume of brackish water in the subsurface will grow by such recirculation and eventually affect the salinity in the freshwater screen.

Concluding Remarks

Based on a model analysis, it was shown that skimming technologies cannot prevent salinization, irrespective of parameters of subsurface, for which some unique pumping tests were analyzed and geophysical measurements were carried out in the Punjab.

The findings of the PhD research led to the following three main conclusions: (1) skimming wells cannot prevent long-term salinization; (2) recirculation wells can substantially delay salinization as a mid-term solution but will not prevent it; and (3) scavenging may be the only option to solve the long-term salinization problem.

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