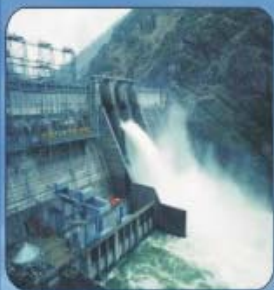


C O M M I S S I O N O N S C I E N C E A N D T E C H N O L O G Y



# **Water Resources in the South: Present Scenario and Future Prospects**



Commission on Science and Technology  
for  
Sustainable Development in the South

3

COMSATS' Series of Publications on Science and Technology

# **Water Resources in the South: Present Scenario and Future Prospects**

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**Commission on Science and Technology for  
Sustainable Development in the South**

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## **PREFACE**

In order to deliberate upon the issues related to water resources, COMSATS organized a two-day meeting at its Headquarters on the 1<sup>st</sup> and 2<sup>nd</sup> November, 2001. The meeting, which was attended by eminent experts, scientists, researchers and engineers from COMSATS' member countries, focused on various crucial issues related to water-resources, and thought-provoking contributions were made during the course of the meeting.

The meeting had five technical sessions, and these sessions had a thematic sequence of topics, which included the areas of drought-preparedness and management, hydrological modeling, seawater pollution, ground-water salinity, recycling through bio-filters. In addition, various strategies for efficient management and sustainability of water-resources were discussed, and recommendations were made for potential implementation of these strategies.

This book is a selected compilation of the technical papers presented at the meeting. It is expected to be the first in a series of COMSATS' publications that we hope to bring out in the area of water-resources. This series may prove to be the right beginning in the streamlining of efforts aimed at solving water-related issues in our member countries. The references in the various articles of this book have been arranged in two systems: Numeric and Harvard Referencing Method.

I would like to thank Dr. Ishfaq Ahmad for his continued guidance and support to COMSATS over the years. He was instrumental in initiating activities related to water-resources at COMSATS, and his valuable suggestions enabled us to arrange this meeting. Our gratitude is also due to the speakers, participants and other individuals who made this meeting a success. Special credit is due to the team at COMSATS, who worked wholeheartedly in organizing this meeting and in making it a success. In this regard, special appreciation and accolades are due to Dr. M. M. Qurashi, the editor of this publication, whose unparalleled interest and direction make this a significant book vis-à-vis the importance of the subject. Last, but certainly not the least important, is the acknowledgement that is due to Mr. Salman Malik and Mr. Irfan Hayee for their valuable efforts and untiring contribution to the compilation and editing of this document.

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# **Management of Water- Resources in South Asia**

*Muhammad Hanif*

# MANAGEMENT OF WATER-RESOURCES IN SOUTH ASIA

## ABSTRACT

*The South Asian Region consists of Pakistan, India, Nepal, Bhutan, Bangladesh, Sri Lanka and Maldives. The region has a high-altitude mountain terrain, sub-mountainous tracts, large flood-plains with a network of rivers and streams, deserts and large coastal areas. The South Asian Region has three distinct rainfall systems. Most of the rainfall is in summer (80%) and is brought by southwestern monsoon system. In winter, the rainfall is brought about by northeastern monsoon in Bangladesh / adjoining areas, and by western weather-system in Pakistan and other parts of the region. The winter rains are a very important source of water-supply for crops, as the water-scarcity peaks during this period.*

*Indus, Ganges and their tributaries mainly cover the sub continent. There are wide fluctuations in the river-flows during the year. The supplies peak up generally in the monsoon and during snowmelts (July- September) and the flows largely recede in the dry season, particularly in winter. A huge irrigation network , the world's largest, has been built on the rivers in the region. A water reservoir capacity of 248 MAF has been built in the region for a sustained production of crops. In addition, these reservoirs have provided an important opportunity in hydel power generation, fishing and ground-water recharge of the adjoining areas.*

*Groundwater is an important source of water supply. Large parts of the South Asian Region have a sweet-water aquifer. In all countries of the region, subsurface water is pumped through shallow wells or deep tubewells/ turbines, mainly for agricultural purposes. The total withdrawals of water from surface and subsurface are estimated at 772 MAF. About 90 % of the water-supplies in the region are used for agriculture and the remaining for households, industry and other purposes. Canals irrigation is mostly in the public sector and wells/tubewells are generally in the private sector.*

*The population of South Asia is 1.30 billion. The cropped area of the region is 204.8 million ha. Rice is the single predominant crop of the region, occupying 22.6% of the cropped area, followed by wheat in 14% area. Other important crops grown in the region are coarse grains, grown on 12.1% of area, pulses 10.5%, cotton 4.5%, oilseeds 4.5%, beans 3.8% and sugarcane 2.0%. The plantations such as tea, coconut and rubber, although having high commercial value, are grown on considerably smaller area.*

*About 40% of cropped area in this region is irrigated and 60% is dependent upon rains. Water requirements for the 8 important crop (grown on 74% of area) have been worked out at 1166 million-acre feet (MAF). Rice is the single largest irrigated crop (more than 90% irrigated) consuming 63 % of the water among these crops. In some countries, it is*

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## **Management of Water-Resources in South Asia**

*almost the only irrigated crop. Wheat is the second largest crop grown, both under rainfed and irrigated conditions. Water requirements have been estimated as: wheat 10%, coarse grains 7%, pulses 6% and sugarcane 6%. The water requirement for these five crops makes up 92% of the water requirements.*

*Prolonged dry weather, many a times, results in droughts in the region. The impact of drought is generally of universal nature, affecting vast areas in a country or the whole region. There were acute shortages of water in drought-hit areas. The crops were damaged and the pastures dried up; even drinkable water became a problem. Excessive mining of water in some areas lowered the water-table to dangerously low levels. There was massive human and livestock migration from these areas. The damage to the livestock-sector was colossal. It is proposed that the regional countries should put in place a system that forecasts droughts, assesses damages and provides relief-assistance to minimize the hardships of life. Some countries of the region have already started putting piped water-supplies and building communication-networks in these areas. The regional countries should take short and long-term measures to mitigate the affects of drought.*

*The reservoirs are useful, but there are growing concerns on building reservoirs in the countries of the region. These concerns are both national and international in character. There is a growing feeling that the reservoirs result in displacement of people/farming communities, create environmental problems and, many a times, lead to politicization of the issues. High initial capital-investment is another issue. Most of the reservoirs have watershed-management programs in the catchment areas. However, sometimes the catchment is in adjoining countries, which makes it impracticable to launch watershed programs. Once the reservoirs are built, the rapid sedimentation is a big issue and calls for appropriate policy and action plans.*

*Governments of the region need to make policies for conservation of water-resources that optimize use-efficiency. The countries of the region, in general, have agencies that have already done useful work in water-resources development, through construction of a network of water-structures such as reservoirs, dams, barrages, canals, link canals, lakes and ponds. The water-distribution systems have been geared to match water-requirements during the critical growth-stages of crops. De-silting of canals and minors and renovation of water-courses for improving water-delivery efficiency have been carried out in various parts of the region.*

*At farm level, programs have been undertaken to improve water-use efficiency, through precision land-leveling of uneven fields., sowing of crops on ridges and beds, use of pressurized irrigation-system for orchards, vegetables, floriculture and other high-valued crops. The cropping patterns are being adapted to minimize water-indent. All these works need to be furthered. Some countries of the region need to have a second look at their heavy dependence on mono-crop system of growing rice — a water-thirsty crop.*

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Figure - 1: Map of South Asia

*The statistics on subsurface water and from glacier melts, many a times, are inadequate or faulty and the countries of the region need to improve it for planning purposes.*

*Most of the rivers and creeks in their upper reaches have good-quality water. As water flows down-stream, the industrial and urban effluents load this water with heavy metals, injurious chemicals and biological pollutants. Cases of ill health, through pollution of drinkable water, have been reported in Pakistan and other countries. Iron and nitrate pollution has been noticed in Sri Lanka. The salinization of subsurface water, through intrusion of seawater, has been reported in India, Pakistan, Maldives and Sri Lanka in the coastal areas. This is an area that needs attention of the Governments in the region, in the context of appropriate legislation and implementation of sound environmental policies.*

*Over the last two decades, there is a growing participation of the farming communities in water resource development, distribution and on-farm water-management programs, in the countries of the region. Water-users' associations have been organized and actively involved in the planning and development programs of water-sector in agriculture. These farmers' organizations can be further involved in transforming agricultural/rural scenarios.*

*The studies carried out in countries of the region indicate that large O & M costs are being incurred on irrigation networks by maintaining them in public sector. At least part of this expenditure can be minimized through participation of farmers in maintenance of these canals. The subsidies on irrigation lead to an inefficient water-use. The Governments can have a second look on this issue.*

## **Management of Water-Resources in South Asia**

### **INTRODUCTION**

South Asian Region consists of Pakistan, India, Nepal, Bhutan, Bangladesh, Sri Lanka and Maldives. The map of the region is given in Figure-1. The region has high- altitude mountain terrains, sub–mountainous tracts, large flood-plains, with a network of rivers and streams, deserts and large coastal areas. The famous Indus and Gangetic civilizations thrived and prospered in this region.

Agriculture has been the main pursuit in the region since human civilization began. Land and water have been the primary resources for this activity since primeval times. Initially, the human settlements were built near the water-bodies, like rivers and lakes. Human beings learnt from experience that water is a basic input in raising crops. Agriculture continued to be mainly carried out under rain-fed conditions. Irrigated agriculture started much later.

As primary structures, wells and karezes (sub-surface irrigation ditches) are known to have been built in various parts of the world, including South Asia. These Structures helped an assured production of crops and also helped to raise farm-productivity. With expansion in human population, the land and water-resources came under pressure. The disasters, like drought, disease, insect hazards (locust and others), resulted in crop damages, many a times leading to famines. In addition, the process of degradation of land and water-resources, through salinization, water-logging, industrial effluents and other environmental hazards, is an on-going process and is a major threat to agriculture. There is a need for a judicious management of these scarce resources.

A number of efforts were initiated in the South Asian region, particularly during the last millennium, for the proper management/use of land and water-resources. This becomes more demanding at a time when large fertile tracts of agricultural land are falling victim to rapid industrialization, urbanization and other non-farm uses. Similarly, management of water-resources is of prime importance for fostering activities of agriculture sector on commercial lines.

### **SOUTH ASIAN SCENARIO**

#### **Population**

The population of the world in 1998 was 5.98 billion, Asia 3.63 billion and South Asia 1.30 billion. The population of South Asia was 21.7 % of the world population and 36.0 % of Asian population. The data is as in Table-1.1.

The world has a population of 43% engaged in agricultural discipline. However, Asian involvement in agriculture is 53% and South Asia 56%; Bhutan and Nepal have more than

Table - 1.1: Population (million)

Category	Total	Agricultural	% in Agriculture
World	5,978.40	2,575.50	43.08
Asia	3,634.30	1,956.50	53.83
South Asia	1,309.40	735.70	56.18
Bangladesh	126.90	72.00	56.74
Bhutan	2.10	1.90	90.48
India	998.10	553.20	55.43
Maldives	0.3	0.08	26.67
Nepal	23.4	21.8	93.16
Pakistan	140.0	78.0	55.71
Sri Lanka	18.6	8.7	46.77

Source: FAO Production Year Book, 1999

90% of their population in agriculture sector. The Maldives, on the other side has less than the South Asian %age population engaged in agriculture sector.

### Land

The cropped area of the world is about 1512 million ha. The cropped area in Asia is 557.6 million ha and South Asian cropped area is 204.8 million ha. This makes 12.6 % of the world-cropped area and 36.7 of the Asian cropped area. The cropped area in South Asia is 40% irrigated (82.6 million ha) and 60 % rainfed (122.2 million ha). The per-head cropped

Table - 1.2: Area Profile of South Asian Countries

Category	Land Area	Cultivated Area	Irrigated Area	Per-head Cropped area
Unit	(000) Ha	(000) Ha	(000) Ha	Ha
World	13,048,407	1,511,964	271,432	0.25
Asia	3,085,414	557,633	191,171	0.15
South Asia	412,917	204,810	82,631	0.16
Bangladesh	13,017	8,774	3,844	0.07
Bhutan	4,700	160	1	0.08
India	297,319	169,500	59,000	0.17
Maldives	30	3	-	0.01
Nepal	14,300	2,968	1,135	0.13
Pakistan	77,088	22,050	18,000	0.16
Sri Lanka	6,463	1,888	651	0.1

Source: FAO Production Year Book, 1999.

## Management of Water-Resources in South Asia

area in the world is 0.25 ha and in Asia only 0.15 ha. The cropped area per head is 0.16 ha in South Asia. The detailed data is as in Table-1.2.

### Important Crops in South Asia

The cultivated area in South Asia is 204.8 million ha. Extrapolating through a cropping intensity of 130 % from Indian cropping pattern (largest crop-machine in the region) for the South Asian region, the cropped area works out to be 266 million ha.

Eight important crops grown in the region are rice, occupying 22.6% of the cropped area, wheat 14%, coarse grains 12.1%, pulses 10.5%, cotton 4.5%, oilseeds 4.5%, beans 3.8% sugarcane 2.0%, and other crops 26 % of the cropped area. The data is shown in Table-1.3.

Table - 1.3: Area under important crops in South Asia (million ha)

Country	Wheat	Rice	Coarse grains	Cotton	Sugar cane	Pulses	Oil seeds	Beans	Total
Bangladesh	0.85	10.50	0.00	0.00	0.17	0.67	0.50	0.00	12.69
India	27.40	44.80	29.40	9.00	4.15	25.30	10.50	9.90	160.45
Nepal	0.64	1.52	1.10	0.00	0.00	0.30	0.00	0.04	3.60
Pakistan	8.30	2.40	1.80	3.00	1.10	1.71	0.90	0.25	19.46
Sri Lanka	0.00	0.82	0.00	0.00	0.00	0.05	0.00	0.03	0.90
<b>Total</b>	<b>37.19</b>	<b>60.04</b>	<b>32.30</b>	<b>12.00</b>	<b>5.42</b>	<b>28.03</b>	<b>11.90</b>	<b>10.22</b>	<b>197.10</b>

### Water Requirements of Important Crops

In South Asia, the crops are grown both under irrigated and rainfed conditions. It is little difficult to work out the exact requirement to be supplemented to the crops through the irrigation-network, in addition to rains. However, in the background of requirement of crops in Pakistan, the water requirements have been worked out for the 8 important crops at 1166 million-acre feet (MAF). About 63.6 % are required for rice alone; wheat 9.8 %, coarse grains 6.8%, pulses 5.7 %%, sugarcane 5.9 %. The water-requirement for these five crops makes 92 % of the water requirements depicted in the following Table-1.4.

## COUNTRY PROFILE

The water resource profile of the South Asian Countries is as follows:

### BANGLADESH

The cultivated area of Bangladesh is 8.8 million ha. The country has a high density of

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Table - 1.4: Water Requirements of Important Crops

Crops	Area	Water Requirements	Total	% Share
<i>Unit</i>	<i>Million ha</i>	<i>Acre inches*</i>	<i>MAF</i>	
Wheat	37.19	15	114.9	9.8
Rice	60.04	60	741.8	63.6
Coarse grains	32.3	12	79.8	6.8
Cotton	12.00	16	39.5	3.4
Sugarcane	5.42	60	67.0	5.7
Pulses	28.03	10	69.3	5.9
Oilseeds	11.90	12	29.4	2.5
Beans	10.22	12	25.3	2.2
<b>Total</b>	<b>197.1</b>	<b>29</b>	<b>1166.9</b>	<b>100</b>

*\* By Pakistan standard*

population of 834 inhabitants per km<sup>2</sup>. The average holding per farm household in 1983 was 0.9 ha. Nearly 24 per cent of farm households own less than 0.2 ha and another 46 per cent own up to 1.0 ha. Agriculture is mainly carried out under conventional subsistence-farming practices. Rice is the main crop, occupying an area of 10.5 million ha, which makes 90 % of the area under cereal crops. Other important crops grown in the country are pulses, oilseeds, jute and sugar cane. Recently a plan has been prepared to introduce and expand cotton-production in the country to meet domestic requirements and to sustain the exports of garments and other textile made ups.

Bangladesh has a tropical monsoon climate. About 80 per cent of the total rainfall occurs in the monsoon and the average annual rainfall over the country is 2320 mm. Being a deltaic country, cyclone cause heavy damage to the agricultural economy and structures. Floods, cyclones and droughts are a common feature of the climate pattern in Bangladesh. There are wide annual variations in rainfall and temperature throughout the country.

Ganges, Brahmaputra and Meghna, and their tributaries cover the flood plains of Bangladesh. The total dam capacity is 17.3 MAF. In addition, there are three barrages across the Teesta, Tangon and Manu rivers that are used as diversion structures for irrigation purposes only. In 1990, the total water withdrawal for agricultural, domestic and industrial purposes was estimated at about 12.4 MAF. ,of which agriculture makes 86%, the domestic industrial sectors make 14%. The requirement of navigation and fisheries is estimated at 8.5 MAF. Approximately 73 per cent of the total water-withdrawal comes from groundwater.

## **Management of Water-Resources in South Asia**

In Bangladesh, irrigation through major canals covers only 6 per cent of the total irrigated area, the remaining being classed as minor irrigation consisting of low lift pumps, shallow tube-wells, deep tube-wells. Government's main emphasis in Bangladesh is the expansion of small-scale irrigation.

At present, irrigation is practiced for rice (71 per cent) and wheat (9 per cent), which together occupy 80 per cent of the irrigated land. Irrigation is mainly used in the dry season.

Because of its low-lying topography, about 22 per cent of the area of the country are flooded each year. Flood control and drainage are used to reduce the depth of flooding or eliminate, through 'controlled flooding' high and untimely floods in order to provide greater security for crop production.

Water-management and flood-protection occupy a pivotal position in the planning process of Bangladesh. The major emphasis in Bangladesh is on the following issues:

- Improving use efficiency of existing facilities with an effective O&M;
- De-Silting of rivers and channels;
- Integrated flood control / drainage;
- Participation of water-users in the planning and design of new irrigation/drainage projects.

## **BHUTAN**

Bhutan is a Himalayan country with a rugged mountain terrain. Climate ranges from hot and humid subtropical conditions in the south to the incessant ice and snow in Himalayas.

The only dam in the country is the Chukka hydropower dam. Most rivers are deeply incised into the landscape, a fact that greatly limits the possibilities for run-of-the-river irrigation. The total water-withdrawal was estimated at 16.2 thousand-acre feet in 1987.

The cultivated area in Bhutan is 160 thousand ha. Out of this, about 1 thousand ha are irrigated and rest is dependent upon rains. The irrigated area is mostly under rice crop.

The irrigation-management strategy mainly focuses on:

- Sustainable improvements in water-delivery and use-efficiency;
- Diversifying the range of irrigation from mono-cropped rice system to multi-crop system;
- Increasing the role of water-users and the private sector, and to reduce recurrent government investments in irrigation schemes.

## INDIA

The total cultivable area of India is estimated at 169.5 million ha, or about 57 per cent of the land area. The cropping intensity is 130 per cent. The major cereals grown in India are wheat, rice, and coarse grains. Ninety one per cent of the farmers have land holdings less than 4 ha. The average farm size is estimated at 1.57 ha.

The rainfall in India is brought about by the monsoon system and western disturbances. The average rainfall is 1170 mm. There are places, which get world's highest rainfall of 12,500 mm. On the other extreme, there are places like Rajasthan, Gujarat, Saurashtra and Kutch, which get less than 150-mm rainfall. Most of these areas have undergone extensive drought conditions, with massive human and livestock migration. This called for an intervention from the Government to address the drudgeries of masses in these areas. Temperature variations are also marked.

The major sources of water in India are rainfall and the glacier melts. The total surface flow, including groundwater is 1570 MAF. Out of this 587 MAF are utilized. The total water-storage capacity constructed up to 1996 was of the order of 212 MAF. In 1990, the total water-withdrawal was estimated at 425 MAF, of which 92 per cent was for irrigation purposes.

India has the largest irrigated area of the world, size of the irrigated area is 59 million ha. Irrigation is mainly concentrated in the north of the country, along the Indus and Ganges rivers.

Uttar Pradesh (22 per cent of the irrigated area), Rajasthan (9 per cent) Madhya Pradesh (9 per cent) and Punjab (8 per cent) Liberal subsidies on electricity and its abundant supplies has helped to foster both production and productivity of crops. This situation has resulted in huge inefficient use of water at the farm.

The average overall water-use efficiency in canal irrigation systems is estimated at 40 per cent. Water-rates are uniform throughout the state in Andhra Pradesh, Gujarat, Kerala, Madhya Pradesh and West Bengal. However, in Bihar, Haryana, Maharashtra, Punjab, Rajasthan, Tamil Nadu, Tripura and Uttar Pradesh, the rates vary within the state from region to region or project to project.

The water-rates are higher for storage-systems than for flow-diversion schemes. Similarly, the rates for canal-lift irrigation are generally higher (double) than flow-irrigation when water lifting is undertaken by the Government bodies. The development of sprinkler and drip-irrigation is likely not to pick up in various states of India particularly in view of free or subsidized electric tariff. However, India is providing subsidy to promote drip irrigation.

## **Management of Water-Resources in South Asia**

A number of Indian states in recent years are cutting down or partially withdrawing subsidies. This is likely to promote the efficient use of pressurized irrigation systems. However since India does not have compulsion from the donor-agencies, it may take considerable time before the efficient use of water accelerates. The area under drip-irrigation is mainly concentrated in Maharashtra, Andhra Pradesh and Karnataka. The drip-irrigation is mainly followed on high-value horticultural crops/orchards.

Drainage works have been undertaken on about 5.8 million ha, which is 12 per cent of the irrigated area. In addition, 3.1 million ha are affected by salinity and about 0.24 million ha by alkalinity. These figures however seem gross under estimates.

Indian irrigation is dominated by the public sector. The O&M of most schemes require public sector involvement. India adopted a national water-policy in 1987 for the planning and development of water-resources. It emphasizes the need for river basin planning. Water allocation priority has been given to drinking water, followed by irrigation, hydropower, navigation and industrial or other uses in the order. All the states are required to develop their state water-policy within the framework of the national water-policy and, accordingly, set up a master plan for water-resources development.

All rivers in their upper reaches have good quality of water. Like elsewhere, the deterioration in quality of water starts downstream through domestic, industrial and agricultural pollutants. These pollutants also affect groundwater. The mining of groundwater in drought-hit states has resulted in lowering of water-table in large number of Indian States to very low levels. This is mainly because of the conditions of non-recharging of water in current drought conditions that forced a large number of the farming communities to migrate from water-starving areas to water sanctuaries. Indian policy of providing heavy subsidy on electric tariff has also been responsible for this situation.

## **MALDIVES**

The total cultivated area of Maldives is estimated at 3000 ha. Permanent crops as coconut and aeronaut are grown on an area of 2000 ha and annual field-crops as maize, sorghum, cassava, onion and chilies are grown on an area of 1000 ha.

The islands have a tropical climate with two monsoons, which are:

- The southwest monsoon from May to September;
- The northeast monsoon from November to March.

The precipitation is uniformly distributed between April - December. The January – March is a dry period. The mean annual rainfall is 1883 mm. The islands do not have any rivers. Rainwater is collected through water-harvesting on a small scale and used for drinking

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purposes. Maldives finds it extremely difficult to obtain suitable drinkable water. Three desalination plants are in operation, with a total production of 1000 m<sup>3</sup>/d.

## **NEPAL**

Nepal is a land locked Himalayan State located entirely in the Ganges basin. The cultivable area of Nepal is estimated at 2.96 million ha. One third of this area is in the Terai plain, 8 per cent in the Siwalik, 48 per cent in the mountain and hill region and 10 per cent in the high Himalayas. Agriculture contributed 40 per cent of GDP in 1996 and employed more than 93 per cent of the economically active population of the country. The main agricultural exports are rice, pulses and jute.

The mean annual rainfall is 1500 mm. There are two rainy seasons in Nepal: one in the summer (June to September) when the southwest monsoon brings more than 75 per cent of the total rainfall, and the other in winter (December to February) accounting for less than 25 per cent of the total. The summer monsoon-rain first falls in the southeast of the country and gradually moves westwards with diminishing intensity. This results in more rainfall in the east of the country. During winter, rainfall is brought about by westerly disturbances.

All rivers in Nepal drain into the Ganges River. The country is divided into five river basins, which are from west to east. The seasonal distribution of flow is extremely variable. The flows in rivers, both from rains and snow-melt greatly recede during January – March period. This situation improves during July – August period as snowmelt and rainfall picks up.

The surface-water resources produced internally are estimated at 168 MAF water. The groundwater-resources have not been fully assessed. The Terai and some parts of the Siwalik valley have sweet-water aquifers. A rough estimate is made by assuming a groundwater-resource equivalent to ten per cent of surface-water, i.e. approximately 17 MAF. This makes Nepal one of the Asian countries with the highest level of water-resources per inhabitant.

The total dam-capacity of Nepal is 69 thousand-acre feet. This is a small fraction of the potential dam-capacity of 117 MAF. The irrigated area in Nepal is 1.14 million ha. Irrigation is mainly done by flooding. Ninety one per cent area is dependent on surface-water and 9 per cent on groundwater. The Department of Irrigation is responsible for the management of the irrigation programs. The main irrigated crop is paddy in summer, followed by wheat crop in winter.

## Management of Water-Resources in South Asia

### PAKISTAN

Rainfall activity over Pakistan occurs mainly in two distinct periods, namely summer (June to September, the monsoon season) and winter (December to March). More rains fall during the monsoon season than during the winter season.

The annual flow of water in the Indus River system, on an average, is 140 MAF. The flow during summer is 118 MAF (84%) and in winter is 22 MAF (16). Indus is the Main River contributing 65% of water supplies, with Jhelum giving 17% and Chenab 19%. In the light of Indus-Basin Water-Treaty, Pakistan has built a series of link canals to divert water from the western rivers, to provide water to the Southern Punjab. Pakistan has built a reservoir capacity of 18 MAF water to cater for the needs during periods of scarcity, mainly winter crops. About 4 MAF capacity has already been reduced through sedimentation. The alluvial plains of Pakistan have a sweet-water aquifer of 50 MAF. Out of this, 40 MAF is being exploited through 600,000 tubewells mainly in private sector. The availability of water in Kharif is 77 MAF and Rabi 56 MAF, making total water supplies at 133 MAF.

Under On-Farm Water-Management Program, 45 thousand watercourses have been improved, out of a total of 120 thousand watercourses. A follow-up program, pursuant to improvement of watercourses to improve water-use efficiency was carried out at farmer's fields. Technologies are disseminated to Farmers on laser-leveling of fields, sowing of crops on beds and furrows, zero tillage, inter-cultural practices and balanced application of fertilizers. This helps to raise the productivity of crops and living standards of the farming community. The pressurized irrigation system e.g. sprinkler and trickle irrigation system, were introduced for high-value crops viz. orchard and vegetables. This system is particularly good for areas with an uneven topography, particularly in rainfed areas. The initial investment is very high/prohibitive and poor farming-communities, especially in drought hit Balochistan and other places, cannot afford such a high capital investment. Another problem with the pressurized irrigation system is that most of the materials are imported. Local initiatives have been taken recently, which are of infinitesimal nature. There is a need for inducting the private-sector in this area, assuring competitive and cost-effective supplies of the pressurized-irrigation materials to the interested farmers.

Rod Kohis are hilly valleys, where hill-torrents move at a rapid pace and result in soil erosion and damage to standing crops. Primarily, the structures in these areas are built to slow down the speed of the torrents. Research is underway to investigate practices and package of technology to minimize the farm-losses to soil and crops.

As water-resources are under high pressure, the Ministry of Food and Agriculture is in the process of promoting cropping pattern/production practices that minimize the requirements of irrigation-water, without compromise on farm-productivity/profitability.

A flow of 10 MAF is required to maintain ecology in the deltaic region and to avoid intrusion of sea water. There was not much water available for the purpose during the drought encountered over the last three years. As a result, the seawater intruded, causing damage to farmlands.

## **SRI LANKA**

Sri Lanka receives rainfall mainly through two monsoons. The rainfall-intensity varies markedly across the island. Based on rainfall, several agro-climatic regions (wet zone, intermediate zone, dry zone and arid zone) can be recognized. There is considerable variation around the mean annual rainfall of 2000 mm. The highest rainfalls are in the central highlands.

Groundwater resources have been extensively used. Sri Lanka's largest aquifer extends over 200 km in the northwestern and northern coastal areas. There are about 15000 tube-wells in the country. The quality of the groundwater is generally fairly good and relatively constant throughout the year. However, in some parts of the country (northern and northwestern coastal areas) excessive concentrations of iron and nitrates (due to agro-chemicals and fertilizers) have been reported. Furthermore, due to uncontrolled extraction of groundwater for domestic and agricultural uses, intrusion of brackish water has occurred in the coastal areas.

Groundwater is an important source of water for irrigation and domestic use. It is increasingly used as drinking water, especially in small towns and rural areas. The total water-demand is estimated to be 9.3 MAF. Of this, 90 per cent is for agriculture, 7 per cent for domestic purposes and 3 per cent for industrial purposes.

The total cultivated area of Sri Lanka is 1.9 million ha. Out of this 0.7 million ha are irrigated and rest is dependent upon rains. Of this cultivated area, 1 million ha are under permanent crops such as tea, rubber and coconut. Annual crops viz. paddy, sugar cane, maize, green gram, green chilies and cowpeas, are grown on 0.9 million ha. The irrigation systems in Sri Lanka are designed mainly for paddy (0.8 million ha) cultivation. Other irrigated crops are chilies (15000 ha), sweet potato, banana and green gram.

In Sri Lanka, irrigation-schemes can be classed as minor, medium or major, depending on the area they serve. Minor schemes provide facilities for less than 80 ha. In 1995, they served about 200 000 ha. Medium schemes provide facilities for areas of 80-400 ha. In 1995, they served 61 000 ha. Major schemes provide facilities for more than 400 ha. In 1995, they served 309 000 ha.

## **Management of Water-Resources in South Asia**

Storage schemes have two purposes: storage and flood control. Water is impounded in these tanks by building dams across valleys, and then released when required to service downstream areas.

Diversion weirs, commonly called anicuts, are constructed in perennial streams in the wet zone, to convey water to the fields below. In the wet zone, flood-control and drainage schemes have been incorporated into the irrigation-system mainly in the lower reaches of rivers. In the coastal areas, saltwater exclusion schemes have been commissioned where water salinity affects the agriculture. Flood bunds and pumps are the main features in flood-protection schemes, whereas gated regulators are adopted in saltwater-exclusion schemes.

Lift-irrigation schemes, with mechanically or electrically operated pumps, have been introduced recently to irrigate the highlands. It is estimated that around 1000 ha are irrigated by groundwater-wells.

In 1980, an attempt was made to establish a water-tax. However, this attempt failed because of the political unrest in the 1980s. Irrigation development, O&M and rehabilitation have been predominantly state activities. The participation of water-users has been adopted in irrigation schemes in recent years. A Water Resources Council has been established in Sri Lanka, to oversee the implementation of the action-plan of water management.

## **ISSUES AND OPPORTUNITIES FOR SOUTH ASIA**

### **Climate**

The climate is the biggest factor affecting availability of water. The South Asian Region has two distinct rainfall systems. In summer, the southwestern system brings rainfall to this region. In winter, Bangladesh and adjoining areas of India get rainfall from the North Eastern monsoon system. Pakistan and other parts of the region get rainfall from the western weather system. La-Nina (dry spell) and El-Nino (wet spell) are the two distinct phenomena that effect the availability of water extraordinarily. The details are as follows:

*a. La-Nina:* This is a situation of low or no rainfall resulting in drought. The South Asian Region suffered from this phenomenon during last 3-4 years resulted in a drought in the region, severely affecting the economy of the countries in the region.

The effects of drought are of universal nature, affecting vast areas in a country or the region. There were areas in the region, particularly in arid and semi-arid climate, where there was acute shortage of water. In these areas, the crops were damaged. The pastures dried up. Even drinking water became a problem. There was massive human and livestock

migration. The damage to the livestock was substantial. A large number of crops, especially in rainfed area were damaged, affecting the GDP. The farmers' incomes were also affected and the ambit of poverty widened.

The farmers in these areas, where feasible, pumped excessive quantities of water from the sub-surface, disturbing the ecosystem. This lowered the water-table depth to dangerously low levels, as there was no recharging system available to recoup the aquifer. This chain of events led to a vicious cycle of poverty. The countries of the region are massively involved in mitigating the effects of drought from the destitute and poverty stricken masses in the affected areas. The following short and long-term measures are proposed for drought hit areas:

#### *Short-Term Measures*

- The Governments should assess the extent of damage/likely damage and declare affected areas as calamity-hit, to cope with the extra-ordinary situation.
- The Governments should provide a relief package, providing food for the human being and feed/fodders for the animals.
- Vaccination programs may be carried out for livestock.
- The elite animals of good breeds of livestock may be taken to sanctuaries, to avoid the risk of loss of such breeds.
- Governments may provide credit-line, to enable the farmers to buy seeds, fertilizers, bullocks, farm machinery and farming inputs.

#### *Long-Term Measures*

- Governments should undertake to build up water-supply schemes in the desert/affected areas, through arranging pipeline supplies in remote water-deficit areas.
- Build up a network of roads, to facilitate the movement of goods and relief supplies in the drought-stricken areas.
- The scientists should come up with a package of crop-production practices and technologies that are low water-requiring, particularly crop-varieties that have less thirst for water.

*b. El-Nino:* This is a situation of high rainfall, often resulting in floods. The effects of floods are localized in nature and show a corridor effect, around the inundating creeks and rivers. The coverage of floods is not of the same large dimension as in droughts. The floods are quite common in the countries of the region and damage standing crops, households, farms, irrigation structures and communication links. The opportunities for a solution to this type of situation are proposed as follows:

## **Management of Water-Resources in South Asia**

- On short-term basis, the Governments may provide relief to the affectees and take other appropriate measures, as reported earlier.
- On long-term basis, the Governments should plan for mitigating the effects of floods, through building of structures and reservoirs to pond the water overflowing from the banks of rivers and creeks. Sri Lanka has successfully diverted floods through building such structures.

### **River System**

The region has a network of rivers and streams in almost all the countries. The rainfall and the snowmelt from the glaciers are the two sources of water-supply in these rivers.

There is a wide fluctuation in the river-flows during wet and dry seasons of the year. The supplies peak up generally in monsoon and during snowmelts (July- September) while the flows recede in dry season, particularly in winter. This situation calls for a judicious management of water-resources for raising crops during periods of scarcity, particularly winter crops. The rivers need to be tamed through construction of control-structures and water-reservoirs to offset the shortages in times of scarcity.

### **Water-Reservoirs**

To tame the rivers, there is a necessity to build up water-reservoirs on the river systems. A large number of such reservoirs have already been built in various countries of the region, with a reservoir capacity of 248 MAF. These reservoirs are useful for a regular supply of water during periods of scarcity, for sustained production of crops.

In addition, these reservoirs have provided an important opportunity in hydel-power generation, fishing and a ground-water recharge of the adjoining areas. The situation has helped to raise farm-incomes and eradicate poverty.

The region has a huge potential for building additional storage-capacity. However, there are inter-country conflicts on building of these reservoirs. Even within countries, many a times, there are problems in construction of these reservoirs. There is a growing feeling that the reservoirs result in displacement of people/farming community, create environmental problems and, some times, lead to politicization of the issues. High initial capital investment is another issue. Most of the reservoirs have watershed-management programs in the catchment areas. However, sometimes the catchment is in adjoining countries, which makes it impracticable to launch watershed programs. Once the reservoirs are built, the rapid sedimentation is a big issue and calls for appropriate policy and action plans.

## **Groundwater**

The groundwater involves aspects of quantity and quality of subsurface water for human use and agricultural purposes. The South Asian Region has a good sweet-water aquifer. In addition, it has a large brackish subsurface-water profile.

Almost in all countries of the region, the supplementation of canal-water irrigation through subsurface water supplies is quite common. This water is pumped through shallow wells or deep tubewells or turbines for industrial, potable and agricultural purposes. A large number of these irrigation-programs are in both public and private sector. Some countries of the region have already handed over the public-sector tubewells to the benefiting water-users.

Recharging of the subsurface water-aquifer is highly important to keep the pumping of water continued from this subsurface layer. However, the countries of the region in some areas have suffered in water-recharging programs on the following accounts:

- a. Drought affected the rainfall and water-balance.
- b. Subsidies in some countries on electric tariff and irrigation-equipment promoted in efficient use. There is a need to minimize/withdraw these subsidies, to optimize water-use efficiency and to ensure that (inefficient) mining of water does not continue.

Water recharging is important for the countries of the region, especially in the arid and semi-arid areas where water depth has been lowered substantially, in much case to 40-50 feet deep. In some places, the farmers have been mining fossilized water from depths of 800-1000 feet. This water has been used to grow crops which unfortunately did not fetch good prices in some years, inflicting huge losses to the farm economy. This is a classical case of onion-production in Balochistan, Pakistan. Such situations are quite common in other countries of the South Asian Region. Governments of the region need to make policies for conservation of water-resources that optimize use efficiency.

## **Institutional Development**

There is a need to assure that proper institutions are in place to carry out the various activities concerning water-resource development, distribution and on farm water management.

### *a. Water-Resources Development*

The countries of the region in general, has already established, agencies that have complete water-mapping of surface-water available in various parts of their country. These agencies have already done useful work in water-resources development, through

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## **Management of Water-Resources in South Asia**

construction of a network of water-structures, such as reservoirs, dams, barrages, canals, link canals, lakes and ponds. These agencies in the regional countries, in many cases have information on potential sites to meet a century's requirements of building water-reservoirs.

The estimation of subsurface water and water-supplies from glacier-melts, however, have not been adequately quantified in some countries and this need to be carried out for better planning and utilization of water resources. The responsible institutions for development of resources need to be strengthened through providing financial and technical backstopping.

### *b. Water Distribution-System*

A number of the countries of the region have established a scientific water-distribution system to meet requirements of water for crops. The drought over the last 3-4 years has given very good learning experiences on judicious water-use system. The Agricultural and Irrigation Departments were able to develop schedules for water-distribution system, depending upon crop-needs. This has helped to mitigate the ill affects of water-supplies, without much effect on productivity of crops. One classical example is the wheat crop of 21 million tons in Pakistan during 1999-2000 and 19 million tons in 2000-01, despite a water shortage of 40% during the early period of wheat crop and 60-70% during earring and grain formation stages. At the beginning of the wheat-crop season, Pakistan Irrigation Department, in consultation with Agricultural Departments, was able to rotate the water-supply in canals. In spring 2001, when shortages further worsened, the canal-supply was restricted to areas that had subsurface brackish water, so that farming/ rural communities may get drinking water. The strategy has helped Pakistan. Despite a very bad year, Pakistan has sufficient stocks of wheat for domestic consumption. It has already exported 0.7 million tons of wheat and has in pipeline, a supply of additional one million tons of wheat for export. This is a lesson repeated in some other countries of the region also that a judicious management of water-resources can help to avert disasters in agricultural sector, particularly crops.

### *c. Water Conservation*

The Governments should aim at conserving the soil and water-resources to maximize the efficiency of use.

## **Water Delivery-System**

The studies carried out by various institutions in Pakistan show that the water-losses in delivery from canal to watercourse outlets are about 40 % on an average. An equal amount of water is lost in the century-old watercourses. There is a need to minimize these losses in water-delivery through:

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- Desilting of canals and minors.
- Renovation of water-courses, through brick lining and earthing improvement.

Pakistan and other countries of the region that are conscious of this situation have already launched on-farm water management programs, in the context of their farming situations. The countries of the region need to take up crash water-management programmes, so as to quickly renovate water-delivery system, to improve efficiency of delivery.

### **On Farm Programs**

A large number of fields are so uneven that the result is unequal distribution of water applied, patchy germination and poor crop-stands. There is a need for improving water-use efficiency at the farm, to maximize productivity of crops. The following programmes are being followed in Pakistan and some other countries of the region, to optimize water at the farm:

- Precision leveling of land, in uneven fields.
- Sowing of crops on ridges and beds.
- Use of pressurized-irrigation systems for orchards, vegetables, floriculture and other high-valued crops.

Some countries of the region have used subsidies to promote use of drip and trickle-irrigation systems. This generally leads to more efficient utilization of the scarce farm-resources.

### **Cropping Patterns**

South Asia mainly grows crops with high water-requirements such as rice and sugarcane. Out of a total cultivated area of 204.8 million ha area under crops in South Asia, 60.04 million ha are under rice crop alone. This far exceeds the area under any other crop. Some countries have almost one irrigated crop, rice. Another high water-requiring crop is sugarcane that covers 5.42 million ha in the region.

As drought is a frequent visitor to this region, it is advisable that regional agricultural institutions may focus on promoting cropping-patterns that minimize water-use for agricultural purpose. In Pakistan, the crop-substitution program includes persuading farmers not to grow rice in cotton zone. Similarly, the sowing of sugarbeet is being promoted to replace high water-requiring sugarcane.

Scientists in Pakistan are now focussing on reducing the sowing time of cotton from 150 days to 120 days. The curtailment in growing period will help to save one irrigation. The scientists also need to focus on other crops and should try to replace long period cultivars with short duration cultivars.

## **Management of Water-Resources in South Asia**

### **Water Pollution**

Most of the rivers and creeks in their upper reaches have good-quality water. As water flows downstream, the industrial and urban effluents load this water with heavy metals, injurious chemicals and biological pollutants. The quality of ground-water is also deteriorating rapidly. Cases of ill effects of such industrial effluents have been reported in Pakistan and other countries of the region. In Sri Lanka, the pollution with iron and nitrates has been reported. The salinization of subsurface water, through intrusion of seawater, has been reported in some countries of the region in coastal areas. This is an area, that needs the attention of the Governments in the region, in the context of appropriate legislation and implementation of sound environmental policies.

### **Participation of the Farming Communities**

Over the last two decades, in the countries of the region, there is a growing involvement of the farming communities in water-resource development, distribution and on-farm-water management programs. Water users' associations have been organized and are actively involved in the planning and development programs of the water-sector in agriculture. These farmer organizations can be further involved in transformation of agricultural rural scenarios.

### **Pricing of Water**

The studies carried out in countries of the region indicate that large O & M costs are being incurred on irrigation-networks by maintaining them in public sector. At least part of this expenditure can be minimized through participation of farmers in maintenance of these canals. The studies carried out by IWMI in Pakistan and other countries of the region indicate a successful experiment. It has been demonstrated that farmers can maintain canals and water-distribution systems, quite efficiently. This can be followed up further. The rebate on electric tariff and installation of tube-wells generally leads to their inefficient use. All such concessions and subsidies need to be withdrawn, for conservation of water-resources and their efficient utilization.

### **ACKNOWLEDGEMENT**

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# **Water-Resources Situation in Pakistan: Challenges and Future Strategies**

*M.A. Kahlowan and Abdul Majeed*

## **WATER-RESOURCES SITUATION IN PAKISTAN: CHALLENGES AND FUTURE STRATEGIES**

### **ABSTRACT**

*Pakistan, once a water-surplus country, is now a water-deficit country. The rainfall is neither sufficient, nor regular, to meet the growing needs of water. About 70 per cent of the annual rainfall occurs in the months of July to September. The surface water resources of Pakistan mainly consist of flows of the Indus River and its tributaries, which bring in about 138 million acre feet (MAF) of water annually. The Indus River alone provides 65% of the total river flows, while the share of Jhelum and Chenab is 17 and 19%, respectively. The months of peak-flow are June to August during the monsoon season. The flow during the Kharif (Summer) is 84% and during Rabi (Winter) season is 16%. The alluvial plains of Pakistan are blessed with extensive unconfined aquifer, with a potential of over 50 MAF, which is being exploited to an extent of about 38 MAF by over 562,000 private and 10,000 public tubewells. In Balochistan (outside the Indus Basin), out of a total available potential of about 0.9 MAF of groundwater, over 0.5 MAF are already being utilized, thereby leaving a balance of about 0.4 MAF that can still be utilized, though some aquifers are already over exploited. The Indus River System, as such, will not be able to continue self-reliance in agricultural production. Due to enormous amounts of sediments brought in by the feeding rivers, the three major reservoirs – Tarbela, Mangla and Chashma – will lose their storage capacity, by 25% by the end of the year 2010, which will further aggravate the water-availability situation.*

*This article takes stock of the present situation of water-resources, present needs and future requirements and the challenges imposed, and suggests short, medium, and long-term strategies to cope with the situation.*

*The suggested short-term strategies include starting a mass-awareness campaign, propagation of high-efficiency irrigation systems, changes in cropping-patterns, identification of feasible surface-water storage sites and dams, and activation of water-user organizations. The medium-term strategies suggest giving priority to lining of distributaries, minors and watercourses in saline groundwater areas, construction of small dams and installation of tubewells in technically feasible areas, improving flood and drought-forecasting methods, and a much wider application of conjunctive water-use approach and propagation of high-efficiency irrigation systems. Institutional reforms for better co-ordination and a wider formulation of a national water-policy are other priority areas under the medium-term strategic plan. Long-term strategies include formulation of a regulatory framework on groundwater abstraction, construction of large storage dams, better flood and drought-forecasting mechanisms and resolving water-distribution problems between provinces. It is recommended that a National Commission on Water, supported by an*

## Water-Resources Situation in Pakistan: Challenges and Future Strategies

*experts panel, be created to steer the formulation of the strategies and ensure the implementation of the strategies proposed.*

### INTRODUCTION

Water is essential for sustaining quality of life on earth. This finite commodity has a direct bearing on almost all sectors of economy. In Pakistan, its importance is more than ordinary due to the agrarian nature of the economy. The share of agricultural sector in the Gross Domestic Product (GDP) of Pakistan is about 24%. Agriculture is the major user of water, and sustainability of agriculture depends on the timely and adequate availability of water. The increasing pressures of population and industrialisation have already placed greater demands on water, with an ever-increasing number and intensity of local and regional conflicts over its availability and use. Historically, the high aridity-index of the country is adding further to the significance of water in developmental activities in Pakistan.

Though, once, a water-surplus country with huge water-resources of the Indus River System, Pakistan is now a water-deficit country. At present, the annual per-capita water-availability in Pakistan is about 1,100 cubic meter (m<sup>3</sup>); below 1,000 m<sup>3</sup>, countries begin experiencing chronic water stress (Population Action International, 1993). Table-1 gives the comparison of per-capita water-availability upto the year 2025 in some selected countries of the World, including Pakistan.

The situation in Pakistan indicates that the country is nearing conditions of chronic water-stress. Meanwhile, the gap between demand and supply of water has increased to levels creating unrest among the federating units. The extended drought during recent years reduced fresh-water supplies of the country, which has highlighted the importance of development of new sources and adopting water-conservation measures for extremely judicious use of the finite quantity of water.

**Table - 1: Per Capita Water-Availability in Selected Countries (m<sup>3</sup>)**

COUNTRY	1955	1990	2025
China	4,597	2,427	1,818
Mexico	11,396	4,226	2,597
Philippines	13,507	5,173	3,072
Iraq	18,441	6,029	2,356
USA	14,934	9,913	7,695
Pakistan	2,490	1,672	837

*Source: Population Action International, 1993*



Figure - 1: Indus River System

## WATER-RESOURCES

Figure-1 is a map of Pakistan showing the river system with dams and barrages and the irrigated areas.

The water-resources of Pakistan include surface water, rainfall, and groundwater. The extent of availability of these resources is location-specific. A brief description of water-resources of Pakistan is given in the following sections.

### 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.

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 e.g., 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

## Water-Resources Situation in Pakistan: Challenges and Future Strategies

**Table - 2: Inflows in Western Rivers (in MAF)**

	<b>Kharif</b>	<b>Rabi</b>	<b>Total</b>
Maximum (Year)	154.7 (1959-60)	35.1 (1990-91)	186.8 (1959-60)
Minimum (Year)	71.5 (1999-2000)	15.7 (1971-72)	97.7 (1971-72)
Mean (77 Years)	115.9	22.8	138.7
<i>Source: WAPDA and IRSA reports</i>			

small rivers and streams, which are only seasonal with flow depending on rain fall and carry practically no water during the winter months. and carry practically no water during the winter months. The 77-year record of the Indus River (1922-23 to 1999-2000) indicates that the watersheds of the Indus River yield about 138.7 MAF of water annually, see Table-2.

It is worth mentioning that the Indus River alone provides 65% of total river flows, while the share of Jhelum and Chenab is 17 and 19 % respectively. The months of peak-flow are June to August, which is the monsoons period in the sub-continent. Flows for Kharif and Rabi crop seasons are 84 and 16 % respectively. Thus, it becomes all the more important to store as much water as possible during the high-flow period, for use during low-flow period. Under such circumstances, the availability and integrated management of storage-reservoirs in the country becomes very important.

After the Indus Basin Treaty between India and Pakistan (1960), the availability of water to Pakistan is limited to the three western rivers, namely Indus, Jhelum and Chenab, while India is entitled to divert flows of Ravi, Beas and Sutlej. This treaty also provided for the construction of a number of link canals, barrages and dams on the Indus and its two tributaries, Jhelum and Chenab, transferring at least 20 MAF of water for the irrigation of areas that were cut off from irrigation-systems of rivers Ravi, Sutlej and Beas after the Indus Basin Treaty.

During the current century, the Indus Basin has developed the largest contiguous irrigation-system in the world. The system includes Indus River and its major tributaries, 3 major reservoirs (Tarbela, Mangla and Chashma), 19 barrages/headworks, 12 link canals, 45 canal commands and some 99,000 watercourses. The total length of the canal-system is, 58,450 Km, with 88,600 watercourses, farm channels and field ditches running another 160,000 Km in length.

Hill torrents in the hilly areas of the country provide another source of surface water, which has not been developed to its full potential. There are 14 distinguishable hill-torrent areas in all the four provinces of Pakistan, with a total potential of about 19 MAF at about 1,200 sites. Out of this, almost 60 per cent can be developed for crop production. This

**Table - 2(a): Provincial Water Developmental Potential**

<b>Province</b>	<b>Water Development Potential (MAF)</b>
Punjab	2.7
NWFP	7.3
Balochistan	7.86
Sindh	0.78

water offers excellent opportunity to irrigate almost 6 Million acres of culturable wasteland in the hill torrent areas. Province-wise development potential of the hill torrents is shown in Table - 2(a).

### **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 Northwest.

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.

In the Sindh plains, high-intensity rainfall occurs during July and August and its intensity continues to decrease from coastal areas towards central parts of the Sindh. The southern Punjab and northern Sindh are the areas of very low annual rainfall-less than 152 mm. The areas above the Salt Range, including the districts of Jhelum, Rawalpindi, Attock and Mianwali, receive high rainfall, above the average of 635 mm per year.

The winter rains are generally widespread. Northern and northwestern area of NWFP and the northern areas of Balochistan receive comparatively high order of rainfall during winter. The magnitude of the annual rainfall over nearly 21 million hectares (Mha) of Indus Plains and Peshawar valley averages about 26 MAF. The present contribution of rain to crops in the irrigated areas is estimated at about 6 MAF.

### **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



## Water-Resources Situation in Pakistan: Challenges and Future Strategies

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. This aquifer, with a potential of about 50 MAF, is being exploited to an extent of about 38 MAF by over 562,000 private tubewells and about 10,000 public tubewells. Figure-2 shows the province-wise growth of tubewells for extracting water since 1965.

In Balochistan, groundwater, extracted through dug wells, tubewells, springs and karezes, is the main dependable source of water for irrigation of orchards and other cash crops. This is because almost all the rivers and natural streams are ephemeral in nature, with seasonal flows only. It is estimated that, out of a total available potential of about 0.9 MAF, 0.5 MAF is already being utilized, thereby leaving a balance of 0.4 MAF that can still be utilized. This, however, creates misconception, as the aquifers are not continuous but are limited to basins due to geologic conditions. It is pointed out that, in two of the basins (Pishin-Lora and Nari) groundwater is being over-exploited, beyond its development potential, creating mining conditions and causing a huge overdraft of groundwater that is threatening to dry up the aquifers in the long term.

## WATER REQUIREMENTS

### Agricultural Demands

Pakistan is a country, which is required to double its annual food production every 15 years, in order to maintain its status-quo in meeting requirements of food. This target, on the surface, may not look so demanding, as the country is bestowed with enough fertile

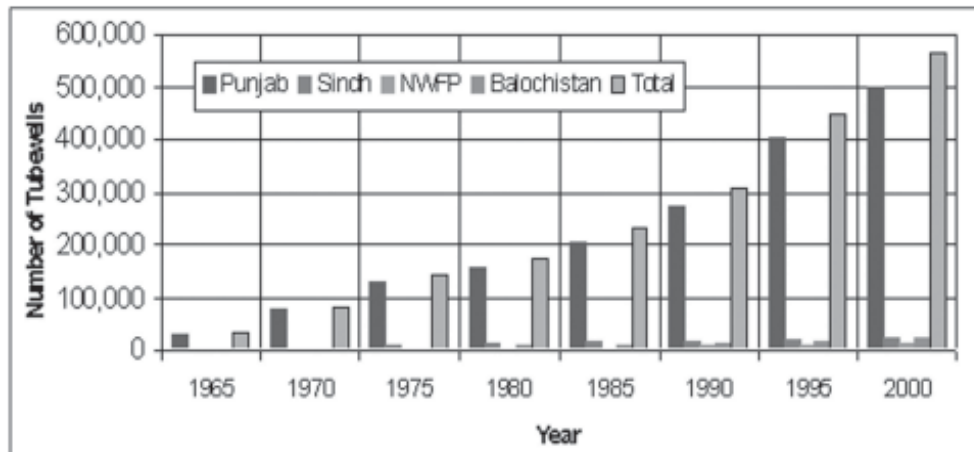


Figure - 2: Growth in Number of Tube Wells

**Table - 3: Agricultural Water Demands (MAF)**

<b>Crops</b>	<b>1990</b>	<b>2000</b>	<b>2025</b>
Wheat	26.27	28.8	56.91
Rice	18.78	22.24	16.68
Cotton	13.68	15.71	19.35
Sugarcane	11.35	13.41	13.93
Other Crops	28.93	30.59	46.74
<b>Total with Losses @70%</b>	<b>168.32</b>	<b>188.28</b>	<b>261.14</b>

and productive lands and sufficient freshwater-resources. Despite the availability of these basic resources, unfortunately the country has to import large quantities of food commodities every year. With the current population of about 140 million people growing at the rate of almost 2.5% per annum, the country would have to feed 120 million additional mouths by the year 2025. Table-3 shows the production and water-requirements of some major crops needed to maintain self-sufficiency in these food grains, which may be compared with Table-2.

#### **Domestic and Industrial Needs**

Table - 4 shows the domestic present and future domestic requirements, based on a per-capita demand of 46 m<sup>3</sup> per annum. The corresponding industrial water-demand is considered negligible when compared with the domestic and agricultural demands.

### **MAJOR CHALLENGES**

#### **Water Scarcity**

The population growth and per-capita water-availability since 1940-41 is shown graphically in Figure-3. Currently the same is about 1,100 m<sup>3</sup> per person, a drop of over 60% in sixty-year periods. Average canal-water supplies to the Indus Basin canal commands are around 104 MAF. Out of this, around 38 MAF are available during the Rabi-season. The shortage of water during the current Rabi- season (2001-2002) would be over 40 per cent from that of the normal year. This shortage of water not only affected the Rabi-season crops (area

**Table - 4: Water Demand for Domestic Use**

<b>Year</b>	<b>1990</b>	<b>2000</b>	<b>2025</b>
Population (Million)	110	140	260
Water Demand (MAF)	4.1	5.2	9.7

## Water-Resources Situation in Pakistan: Challenges and Future Strategies

and productivity) but would also affect the plantation of cotton crop, especially in the Sindh province, as the crop is planted much earlier than in Punjab.

- The key issues related to water availability include the following:
- Annual and seasonal variability in availability of surface water and impact of global warming
- Seawater intrusion due to low flows below Kotri, resulting in ecosystem degradation
- Reduction in capacity of storage reservoirs due to sedimentation
- Increase in domestic and industrial demands and consequent reduction in supplies for irrigation
- Poor delivery-efficiency in irrigation and municipal water supply systems, and
- Deterioration of water-quality due to disposal of untreated urban sewage and/or agricultural drainage effluent
- Depleting groundwater tables, due to over exploitation
- Salt-water intrusion, due to up-welling from underlying saline aquifer
- Deteriorating performance of public tubewells, resulting in increased pumping costs

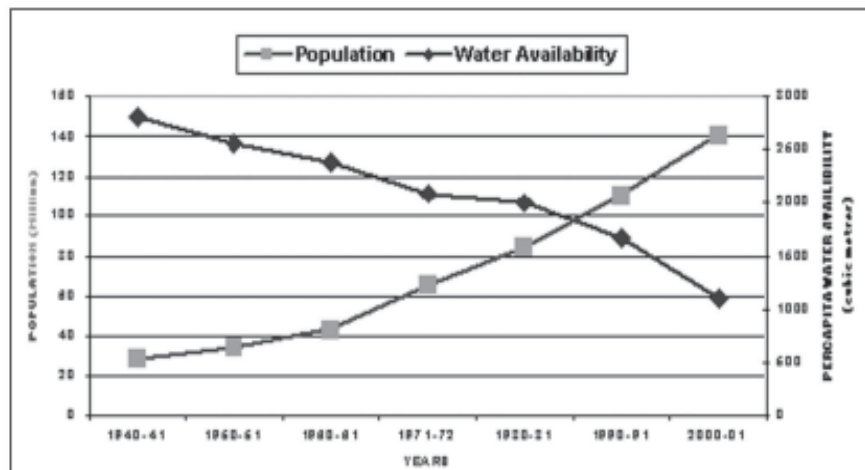
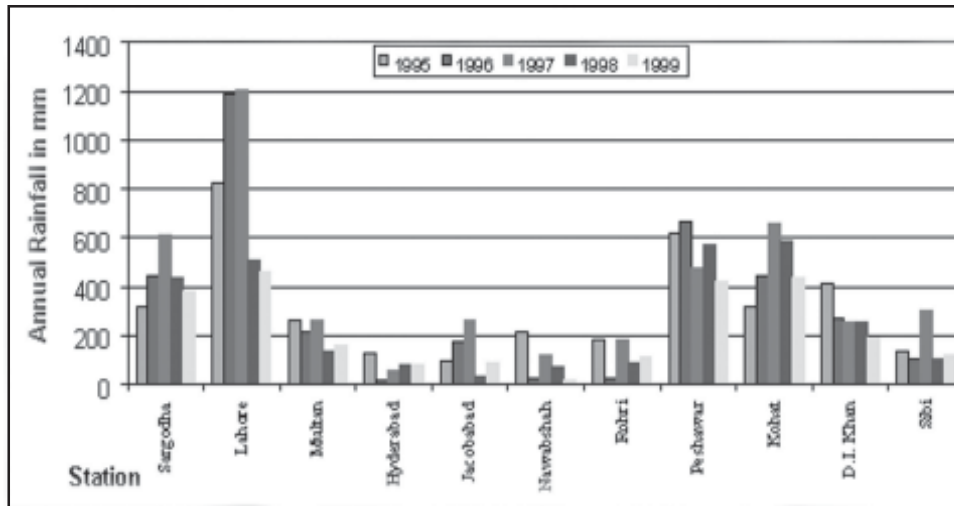


Figure - 3: Per-Capita Water-Availability

### Drought

Frequency of occurrence of droughts has increased in recent years. The Drought phenomenon (dry year) has been observed to occur in 4 out of 10 years, instead of 3 out of 10. The precipitation during the years 1997-2000 has been exceptionally low as in this period the precipitation over most of the country has been less than 50% of the normal, causing severe loss to agricultural production. The rainfalls have been showing a generally decreasing trend since 1997, which was the peak-year (Figure-4). The effect of the continued low rainfalls over most of the country since the last three years has resulted in low river flows and drought conditions. Not only precious human lives were lost, but also



Source: Pakistan Meteorological Department rainfall data

Figure - 4: Rainfall over Irrigated Areas

thousands of livestock heads died due to damage to the rangelands and fodder crops. The catastrophe exposed the serious limitations in our water-development, management, and utilization systems and policies, which calls for a comprehensive strategy/policy on water to streamline the problems of water- resources of the country in the near and far future.

The recent long drought-conditions have affected 75 out of 106 districts in Pakistan. Estimates show that, between November 1999 and July 2000, 143 humans and 2.48 million livestock died. The loss has been more pronounced in the arid areas of Balochistan and Sindh. In addition, increased incidence of malnutrition, diarrhea, respiratory infections, measles, malaria, school drop-outs, and permanent dislocation of families have been observed. The drought has also been responsible for seawater intrusion in deltaic areas, migration of cattle due to worsening state of range and wetlands, and depletion and deterioration of groundwater reservoirs. The effect on agricultural crops has been tremendous: the total loss is estimated to be about Rs. 50 billion, including the total loss of crops in 3 Million hectares of Barani (rain-fed) areas.

#### Inadequate Storage and Sedimentation

Sedimentation in the three major reservoirs – Tarbela, Mangla, and Chashma – is going to decrease their storage capacities by over 40% by the end of the year 2010. In this situation, their capability to continue supplies to the irrigation-system need to be re-

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Table - 5: Reduction in Capacities of Major Reservoirs

Reservoir	Year Commissioned	Live Storage Capacity			Decrease	
		(MAF)			(%)	
		Starting	2000	2010	2000	2010
Mangla	1967	5.3	4.5	4.2	15	21
Tarbela	1974	9.7	8.8	7.3	9	25
Chashma	1971	0.7	0.3	0.2	57	71
<b>Total</b>		<b>15.7</b>	<b>13.6</b>	<b>11.7</b>	<b>13</b>	<b>25</b>

*Source: Three Years Development Programme (2001-04), Planning Commission, GoP*

assessed and appropriate solutions found. The estimated loss of the storage-capacity of the three major reservoirs till 2010 is given in Table-5.

### Groundwater Over-draft and Water logging and Salinity

The continued abstraction of groundwater has resulted in over-pumping and consequent lowering of water table in many areas. Prominent areas among these are Lahore, parts of Balochistan and some densely populated urban areas of the Punjab and Sindh. Efforts to recharge the depleting aquifers need to be undertaken immediately.

Figure-5 shows the water-table in canal commands as bars, to illustrate rising or lowering trend. It is clear from the figure that, in 26 canal commands, water-table is fulling, with various degrees of depletion. Depletion is generally in those canal-commands where water-allowance is lower and crops are heavily dependent on tubewell irrigation. The figure further shows rising trend in 17 canal-commands with various rising levels. The rise in water-table seems to be high for those canal-commands that have higher water allowance. Most of these canals are in Lower Indus Basin where heavy investment in drainage has been done during the past 15 years. The reasons could be very low rate of

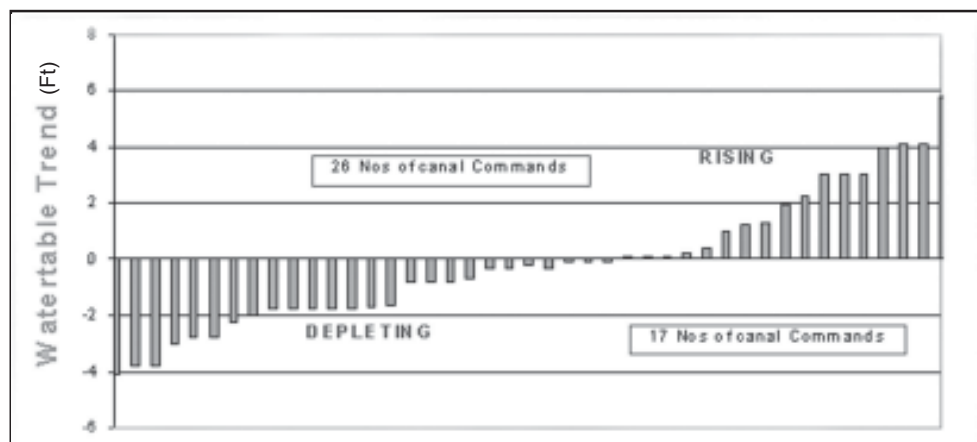


Figure - 5: Water-Table Trends in Canal Commands

groundwater-use, floods during the summer and mis-management of water. However, the overall picture shows depletion of carelessly used groundwater resources, which would be cared for till it is too late. It also indicates that there is a need to find appropriate water-allowance for canals, which will be required for the sustainability of groundwater. If surface canal supplies are not increased, the groundwater will not be available in future.

Waterlogging and salinity in Pakistan emerged as a consequence of the mismanagement of irrigated agriculture, flat topography, seepage from unlined earthen canals, inadequate provision of drainage and the use of poor-quality drainage-effluent. The menace still persists and the situation is becoming serious due to the problem of disposal of drainage-effluent. From 1978 to 1998, the area with water-table above 1.5 m ranged from 9.0 to 18.3%, and similar variations were observed between 1.5 and 3.0 m and below 3.0 m (Table-6).

The magnitude of the salinity/sodicity problems can be gauged from the fact that, at one stage, the area of productive land being lost due to salinity was at a rate of about 40,000 ha per year. A countrywide survey conducted by WAPDA during 1977-1979 showed the true status of soil-salinity in the canal commands. In this, covering 16.72 Mha, both surface and profile salinity/sodicity was established through chemical analysis. About 25% of the area was affected by surface-salinity. Province-wise position of surface-salinity is shown in Table-7. Comparisons with past surveys have indicated that the land affected by surface-salinity decreased from 42% in the early 1960's to about 25% in 1977-79 (WAPDA, 1980),

**Table - 6: Area Under Various Water-Table Depth (% of CCA)**

Year	<1.5 m	1.5-3.0 m	>3.0 m
1978	11.90	39.50	48.60
1982	13.50	43.20	43.30
1986	13.00	41.00	46.00
1988	9.00	38.20	52.80
1990	13.20	36.20	50.60
1992	18.30	32.60	49.10
1993	16.20	35.70	48.10
1994	12.00	36.00	52.00
1995	12.30	36.90	50.80
1996	10.40	40.10	49.50
1997	17.20	33.20	49.60
1998	14.70	36.60	48.70
<b>Average</b>	<b>13.50</b>	<b>37.40</b>	<b>49.10</b>

Source: SMO unpublished data

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primarily due to increased irrigation-water supply from surface and groundwater sources and management measures taken by the Government of Pakistan.

### Low System-Efficiency and Productivity

As the irrigation system of Pakistan consists of the perennial rivers, a network of inundation and link canals, distributaries, watercourses and irrigated fields, an appreciable percentage of the water is lost through seepage and evaporation. A number of studies have been conducted to estimate water-losses in earthen canals, and watercourses. Conveyance-losses in canals and watercourses are around 25 per cent and 30 per cent, respectively. The application losses in fields are around 25-40 per cent. These losses are high, due to application of old irrigation-practices by the farmers. The overall irrigation-efficiency in the irrigated areas is estimated to be hardly 30%. Similarly, in Balochistan, where groundwater is a precious and depleting resource, irrigation to apple orchards exceeds the requirements by over 100%. This is a huge loss of water, even though part of it is recoverable by pumping in fresh-water areas only, but a major part is lost to saline aquifers and due to high evaporation.

### Water-Quality Deterioration

The surface and ground-water quality is deteriorating day by day. The indiscriminate discharge of industrial and domestic wastewater into open water-bodies and groundwater is the main threat to the country's water-reserves. The absence and non-implementation of legislative measures and standards has been the root cause of the deterioration in water-quality observed over the year. The issue is becoming very serious, as many aquifers and open water-bodies, like lakes, rivers and streams, are being increasingly contaminated

Table - 7: Province-Wise Soil Salinity Status (% of Area Surveyed)

Province	Survey Period	Salt Free S1	Slightly Saline S2	Moderate Saline S3	Strongly Saline S4
NWFP	1977-79	78	8	2	2
	1971-75	75	10	4	2
Punjab	1977-79	84	7	4	3
	1953-65	72	15	5	6
Sindh	1977-79	50	19	10	18
	1953-54	26	28	17	27
Balochistan	1977-79	74	17	5	4
	1953-54	69	15	7	9
Pakistan	1977-79	72	11	6	8
	1953-75	56	20	9	13

Source:( WAPDA 1980)

by pollution from industrial, agricultural and municipal wastes. According to estimates, pollution in River Ravi, due to sewage disposal from the city of Lahore, claims the lives of over 5,000 tonnes of fish every year.

On the basis of data available from monitoring studies undertaken in the Salinity Control and Reclamation Projects (SCARP) has indicated a general deterioration of groundwater quality, though little change has been observed in surface water quality. Table-8 shows the change in water quality in SCARP areas. The table indicates appreciable increase in the areas under hazardous water, with corresponding decrease in the areas under usable water-quality.

**Table - 8: Changes in Water-Quality in SCARP Areas**

Project	Data Period	Percent Change in Water Quality		
		Usable Water	Marginal Water	Hazardous Water
SCARP I	1962-89	-8	4	4
SCARP II	1975-88	-3	1	2
SCARP III	1969-86	-10	6	4
SCARP IV	1970-85	-10	11	-1
SCARP V	1976-86	-6	8	-2
SCARP VI	1976-89	-18	8	10
SCARP VIII	1979-89	-29	14	15
Shahpur	1977-87	-6	6	0
Peshawar	1979-88	1	-2	1
Mardan	1979-88	5	-5	0
Khairpur	1965-88	-4	6	-2
Bannu	1978-88	1	4	-5
North Rohri	1977-88	-6	5	1
South Rohri	1979-88	-5	5	0
Ghotki	1978-88	-2	2	0
Larkana	1976-88	7	-7	0
Shikarpur	1976-88	-1	1	0
Sukkur	1975-88	-5	-3	8

## WATER MANAGEMENT-STRATEGIES

A three-pronged approach towards formulation of strategies to meet the growing scarcity of water needs is proposed. The general approach involves:

- a. Tapping of existing un-utilised resources and development of new and unexplored water-resources.
- b. Management of water-resources, to achieve the goal of maximum production per unit of water used.



## **Water-Resources Situation in Pakistan: Challenges and Future Strategies**

- c. Improving the institutional set-up and better governance of water-resources institutions and infrastructure.

Based on the above approach, the following strategies are suggested. These strategies are grouped as short-term, medium-term and long-term.

### **Short-Term Strategies (Time frame - 3 years)**

These strategies are suggested for management of existing water-resources with the main aim to formulate a framework for dealing with drought, during the immediate two crop seasons. Some of the suggested actions for short-term may continue during the medium and long-term strategies. Following are the details of the suggested strategies:

*Awareness Campaigns:* Most of the problems associated with the water-sector have risen from illiteracy and lack of knowledge and understanding of water-conservation practices and high-efficiency irrigation-systems among users at large. An extensive social awareness campaign is required, using mass-media and a village-to-village campaign of extension services. Moreover, effective extension-service mechanism must be developed to transfer new and efficient irrigation methods, technologies, and practices to farmers.

*Increasing On-Farm Application Efficiencies:* Precision land-levelling increases field-application efficiencies in plain areas, where basin irrigation is practiced. Efforts to introduce laser-guided land-levelling with cost-effective locally developed technology should be encouraged. Similarly, farmers in upland areas, with undulating topography, should be encouraged to use high-efficiency irrigation-systems, like trickle, bubbler, and sprinkler, to conserve water. For this, demonstration plots on cost-sharing basis need to be established in the entire country.

*Improving Conveyance Efficiencies:* Earthen improvement of distributaries, minors and watercourses, with installation of concrete control-structures, should be undertaken to enhance conveyance-efficiencies, which are presently around 55 per cent.

*Motivation To Farmers And Industrialists:* To motivate the farmers for adoption of the high-efficiency irrigation-systems, incentives/ subsidies and soft loans may be given. The local industries may be encouraged to manufacture components of the systems, for which tax holidays may be given.

*Improved Surface Irrigation Methods:* In plain areas, where row and grain crops like cotton, wheat and maize are grown; bed and furrow-irrigation methods should be made mandatory for adoption by farmers, to increase the application-efficiency of water.

*Changes In Cropping Patterns And Crop Varieties:* To conserve water, meet water shortage, and match water-requirements with supplies, appropriate changes in cropping patterns

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may be considered. This would require change over from high-delta to low-delta crops, capable of giving higher returns to the farmers. Similarly, growing drought and salt-resistant crop varieties is another option that can be considered.

*Reduction In Cultivation Areas:* To reduce the chances of crop-failures, due to anticipated water shortage, planned reduction in cultivation areas to match water-availability may be propagated in a very timely fashion.

*Regulation Of Groundwater:* To reduce and control the over-extraction of groundwater resulting in mining, groundwater use must be regulated and properly priced through appropriate legislation and its strict implementation. Subsidies given to users of groundwater in stressed areas, in particular, may be withdrawn.

*Undertaking Skimming Wells Projects:* In areas where fresh water is overlying saline water, it would help if skimming-well technology were used to pump out fresh water, without disturbing the underlying saline layer. For this, it would be necessary to undertake an investigation exercise to delineate such areas.

*Identifying New Water-Storage Sites:* To tap the surface water going to waste, identification of possible surface water storage sites for small and large dams should be done on top priority bases. WAPDA and provincial irrigation departments should be asked to complete this task as soon as possible.

*Rejuvenation Of Depleting Aquifers:* Due to ever increasing number of depleting fresh water aquifers, there is a need to rejuvenate them. Various artificial recharge measures should be tried/experimented upon, in areas where depletion of aquifers is becoming a serious problem like in Pishin Lora and Nari basin in Balochistan and Lahore area in the Punjab. Appropriate methods of artificial recharge should be identified.

*Identification Of Focal-Point Organisation:* A focal point organisation must be identified to monitor the progress of the implementation of strategies and their effect on overall water availability for crop use, drinking and other purposes.

*Involvement of Water-User Organisations:* Water User Organisations (WUOs) in irrigated areas are very effective to motivate the farmers to solve the problems related to water use because of their presence at grass root level. Their involvement in the planning, execution and management of all water- resources development projects should be ensured for sustained operation and maintenance of the projects.

*Providing Farmers With Information On Water-Requirements:* Dissemination of information to farmers regarding actual crop water requirements of various crops in major agro-climatic zones should be undertaken on top priority basis to avoid over and under irrigation. This

## **Water-Resources Situation in Pakistan: Challenges and Future Strategies**

will help in controlling wastage of water and overcoming problems like waterlogging and salinity.

### **Medium-Term Strategies (Time Frame – 3 to 7 years)**

*Lining Of Conveyance System:* Lining of canals, distributaries and watercourses is an important option to reduce water-losses and increase water-availability at the farm gate. However, since the system conveyance-loss can be recouped in good-quality aquifers by pumping, preference should be given to lining of distributaries, minors and watercourses in saline groundwater areas.

*Construction Of Storage Reservoirs:* To harness and utilize water currently going waste, small dams/storage reservoirs need to be constructed. These storages could be at appropriate sites in the Northern Areas or downstream of Tarbela. WAPDA and provincial irrigation departments have already identified most of the sites and the construction of dams for development of water-reservoirs is included in their medium and long-term plans.

*Identification Of Fresh Groundwater Areas:* To decide on where to implement the strategy regarding preferential lining of the conveyance-system, installation of new tubewells, and regulation of groundwater, it is necessary that fresh groundwater areas be identified and mapped with regard to water-table depth, potential, and quality.

*Institutional Improvements:* Lack of co-ordination between line-departments at the provincial and federal level has been one of the stumbling blocks in successful and effective implementation of various strategies and projects in the water-sector. Institutional reforms for better co-ordination and management should be undertaken.

*Finding And Developing New Resources:* Glaciers and winter snowfall in the northern areas form an important and extensive potential source of water in the Indus River System. Experiments to harness this resource in a sustainable and environment friendly fashion, limited studies should be undertaken.

*High-Efficiency Irrigation Systems:* As a continuation of the short-term strategy, the high-efficiency irrigation-systems technology should be propagated and spread all over the country. The farmers will bear the full cost of systems to cover a much wider range of crops and agro-climatic zones.

*Rejuvenation Of Aquifers:* Application of the identified aquifer-rejuvenation methods will be done on a wide scale, besides developing efficient methods for recycling of groundwater.

*Developing Drought-Forecasting Mechanism:* The country is deficient in drought-forecasting methods and techniques. Models should be developed to predict the incidence of droughts for better preparedness and to plan ahead in the event of any drought calamity.

*Developing Conjunctive Use Methodologies:* The saline groundwater extensively available in various parts of Pakistan should be made use of, through developing conjunctive use methodologies and change of crops, etc.

*Corporate Farming And Consolidation Of Land Holdings:* The land-holdings in the irrigated areas are increasingly becoming fragmented, due to inheritance laws, etc., which hampers adoption of new and modern technologies. Popularising the concept of corporate farming and consolidation of land holdings is an important area for consideration.

*Undertaking Watershed-Management:* The heavy amount of sediment loads brought in by the feeding-streams in our reservoirs must be checked. For this, undertaking watershed-management works in catchments of existing reservoirs and planning such activities in new project as well as projects in pipeline may be ensured.

*Controlling Evaporation-Losses From Reservoirs:* The methods to control evaporation-losses from open water-bodies, which are huge due to the arid climate over most of the country should be developed and the most economical methods adopted on our reservoirs.

*Formulating A National Water-Policy:* Despite heavy dependence on water for its economy, the country still does not have a national water-policy. This policy will be formed to form the basis for future planning, development, and utilisation of water-resources. The present document with little more work can provide the essential elements of such a policy.

### **Long-Term Strategies (Time Frame – beyond 7 years)**

*Regulatory Framework On Groundwater:* Uncontrolled abstraction of groundwater has played havoc in terms of quantity and quality in the arid areas of Balochistan and parts of Punjab and Sindh. This needs to be checked through a stringent regulatory framework on groundwater-abstraction.

*Construction Of Storage Reservoirs:* This policy/strategy on construction of storage dams, wherever feasible, should continue to be vigorously followed on long-term basis. Sites with the possible inter-provincial conflicts should be given priority.

*Improved Forecasting Of Droughts And Floods:* The forecasting mechanisms for floods and droughts should be strengthened and improved, for saving precious life and property.

## **Water-Resources Situation in Pakistan: Challenges and Future Strategies**

*Resolving Water-Distribution Issues:* The mechanism of water-distribution among provinces and on the field in the irrigated areas should be resolved amicably, to suit the ground situations.

*Continuation Of Activities Suggested Under Medium-Term Strategies:* A number of activities under the medium-term strategies will be continued during the long-term strategic plan. These are: undertaking the watershed-management activities, rejuvenating aquifers, propagation of high-efficiency irrigation systems, etc.

## **CONCLUSIONS & RECOMMENDATIONS**

Pakistan's water-resources have been diminishing at an alarming rate, as can be concluded from the above-stated facts. The quality of water is also deteriorating with time. To improve the situation, the suggested strategies need to be implemented in an organized and coordinated way, through concerted efforts, including better water-management at the field level and good-governance and institutional arrangements. The following overall recommendations are put forth for implementation of the proposed strategies.

- i) A focal-point organization at the federal-level should be identified. This organization is suggested to be the Pakistan Council of Research in Water-Resources, which has the mandate to undertake Research and Development activities in water-resources at the national level. The Council may be given the additional mandate to provide the necessary coordination between the various federal and provincial planning and executing agencies, besides providing the advisory role for implementing the proposed strategy.
- ii) The planning and execution of mega-projects in the water-sector would continue to be done by WAPDA. The WAPDA continue to be the key organization for implementing the component related with the operation and maintenance of existing storage reservoirs and development of additional main reservoirs in the Indus River System.
- iii) The provincial governments and its various Research and Development departments and agencies, like the On-Farm Water Management Project, the extension directorates of the Agricultural Department, will play a major role in the execution of the activities related with high-efficiency irrigation systems and lining of minors and watercourses, etc. The Irrigation Department will look after the execution of water-development projects of local and regional level like small dams and reservoirs, karez management, harnessing spring-water, groundwater regulation, and stream-flow diversions, etc.
- iv) A committee of senior officers, at policy level, is suggested to oversee the detailed design and implementation of the proposed strategy as outlined in the previous paragraphs. This committee should consist of representatives of the key institutions of four ministries viz. PCRWR, Federal Flood Commission, Pakistan Meteorological Department, Ministry of Food, Agriculture and Livestock, and the representatives of

provincial irrigation and agriculture departments. The committee should hold regular quarterly meetings, to review the progress of implementation of the strategy.

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# **Efficient and Sustainable Irrigation-Management in Pakistan**

*Illahi B. Shaikh*



# EFFICIENT AND SUSTAINABLE IRRIGATION-MANAGEMENT IN PAKISTAN

## ABSTRACT

*Pakistan, with a Geographical area of 796,101 square kilometers, possesses large rivers, like Indus which, along with its 5 tributaries, namely Chenab, Jhelum, Ravi, Kabul and Sutlej, forms one of the mightiest River-Systems of the world. The River-System comprises 2 storage reservoirs, 19 large river headworks, 43 Canal Systems measuring 58,000 kilometers, some 1.6 million kilometers of water-courses and field Irrigation Channels. Pakistan has big rivers like Indus, Chenab, Ravi, Jhelum and Sutlej, where discharges in summer season vary from 100 thousand Cusecs to 1,200 thousand Cusecs (3 thousand to 34 thousand cumecs) and can cause tremendous loss to human lives, crops and property.*

*In order to manage the huge Irrigation-System, Planning has been made, in consultation with four Provincial Irrigation Departments and Government of Pakistan, to establish Provincial Irrigation and Drainage Authorities and Farmer Organizations, which are under way. Due to limited capacity of storage at Tarbela and Mangla Dams on river Indus and Jhelum, with virtually no control on Chenab, Ravi and Sutlej, devastating problems are faced between July and October in the event of excessive rainfall in the catchments. This chapter discusses, in detail, the irrigation-network in Pakistan and the efforts to establish Irrigation and Drainage Authorities, Farmer Organizations, etc, for efficient and sustainable management of irrigation in Pakistan.*

## INTRODUCTION

Pakistan, with a Geographical area of 796,101 square kilometers, possesses large rivers, like Indus which, along with its 5 tributaries, namely Chenab, Jhelum, Ravi, Kabul and Sutlej, forms one of the mightiest River-Systems of the world. The River-System comprises 2 storage reservoirs, 19 large river headworks, 43 Canal-Systems measuring 58,000 kilometers, some 1.6 million kilometers of water-courses and field Irrigation-Channels. Pakistan has big rivers like Indus, Chenab, Ravi, Jhelum and Sutlej, where discharges in summer season vary from 100 thousand Cusecs to 1,200 thousand Cusecs (3 thousand to 34 thousand cusecs) and can cause tremendous loss to human lives, crops and property. Due to limited capacity of storage at Tarbela and Mangla Dams on river Indus and Jhelum, with virtually no control on Chenab, Ravi and Sutlej, devastating problems are faced between July and October in the event of excessive rainfall in the catchments (see Figure-1).

Pakistan comprises four major administrative units; Punjab, Sindh, North West Frontier Province and Balochistan, besides the Federally Administered Tribal Areas. Pakistan's

## **Efficient and Sustainable Irrigation-Management in Pakistan**

population as estimated in 2001 is 140 million. The population growth-rate is estimated at 2.1%. The overall density of population is 174.63 per kilometers. However, there is large regional variation in population-density. Pakistan is a country with a very diverse social and geographic landscape, comprising high mountains in the north, to desolate plateaus, fertile plains, sandy deserts, coastal beaches and mangrove forests in the south. It has the largest share of the highest mountain-peaks in the world and has more glaciers than any other land outside the North and South Poles. Pakistan's glacial area covers some 13,680 sq.km, which represents an average of 13 per cent of mountain-regions of the upper Indus-Basin.

### **THE IRRIGATION NETWORK**

The Irrigation system of Pakistan is the largest integrated irrigation network in the world, serving 34.5 million acres (13.96 million ha) of contiguous cultivated land. The system is fed by the waters of the Indus River and its tributaries. The salient features of the system are three major storage reservoirs, namely, Tarbela and Chashma on River Indus, and Mangla on River Jhelum, with a present live-storage of about 15.4 BM<sup>3</sup> (12.5 MAF), 19 barrages; 12 inter-river link canals and 43 independent irrigation canal commands (Figure-2). The total length of main canals alone is 58,500 Km. Water courses comprise another 1,621,000 Kms.

Diversion of river waters into offtaking canals is made through barrages, which are gated diversion weirs and a system of link canals (Figure-2). The main canals, in turn, deliver water to branch canals, distributaries and minors. The water-courses get their share of water through outlets in the irrigation channels. Distribution of water from a watercourse is effected through a time-schedule or "warabandi", under which each farm gets water for a specified period once a week. The time-share of "wari" is proportionate to the farm area owned by a farmer under the command of the water-course.

The system draws an average of 106 MAF (131 BM<sup>3</sup>) of surface-water each year for irrigation. Supplemented by an annual groundwater pumpage of some 50 MAF, the average depth of water available at the farmgate is 3.07 feet per acre. Approximately 3 million individual farms, with an average size of about 12 acres (5 ha), benefit from this system.

### **WATER AVAILABILITY & UTILIZATION**

Pakistan has a diverse agro-ecological setting and is divided into three hydrological regions; (a) the Indus- Basin, which is the major source of Pakistan's water, (b) the Kharan desert in west Balochistan, with inland drainage and (c) the arid Makran coast along the Arabian Sea in the southern part of Balochistan. The deserts in the south (Thar and Cholistan) have no water-resources. Most of the Indus-Basin has been formed as a result of alluvial deposits brought by rivers from the mountainous ranges in the north. The flows in the

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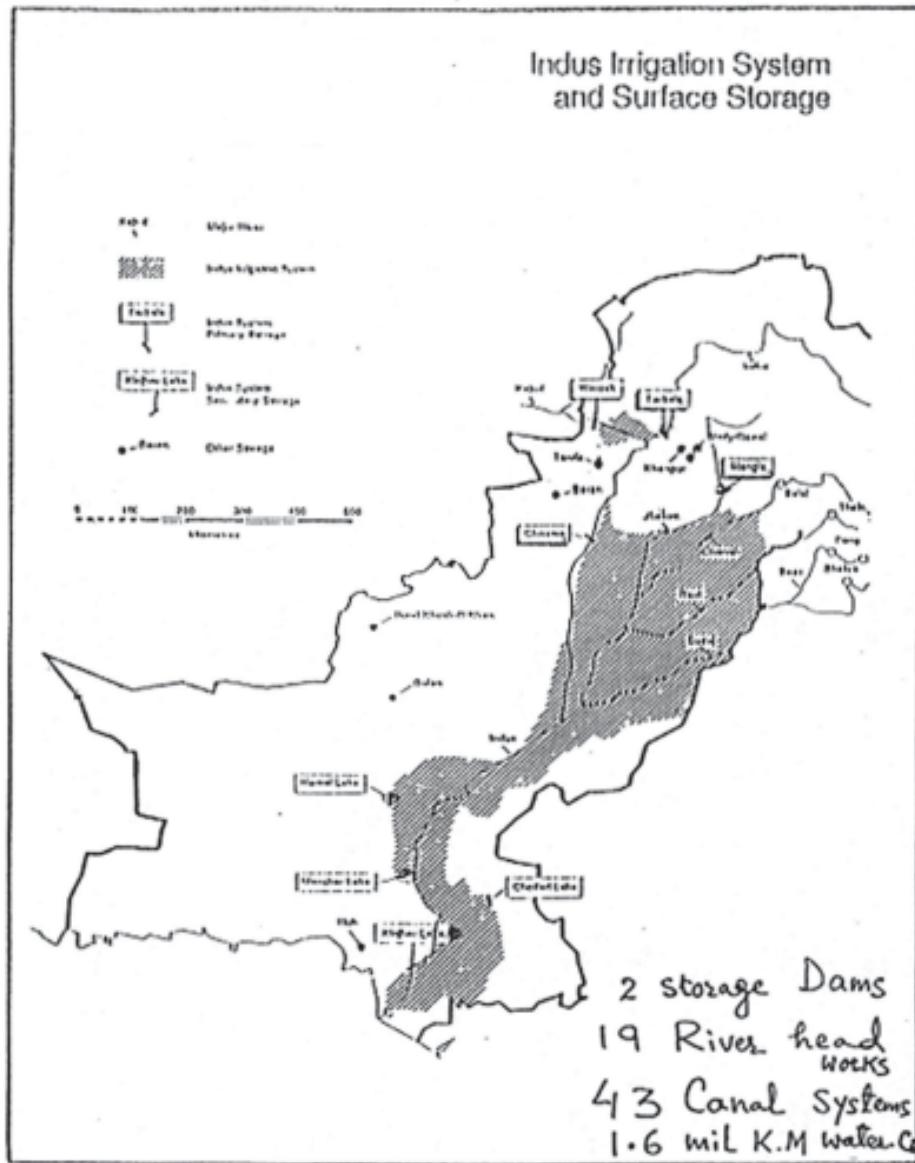


Figure - 1: Indus Irrigation-System and Surface-Storage

## **Efficient and Sustainable Irrigation-Management in Pakistan**

Indus River are from glacial snow melt, as well as rainfall outside the Indus Plains. Under the Indus- Water Treaty (1960), the flows of the three eastern rivers, the Sutlej, Beas and Ravi, have been allocated to India and water from the three western rivers, the Indus, Jhelum and Chenab is available for Pakistan.

The flow of the Indus River and its tributaries constitutes the main source of surface-water for the country. Based on 74 years of historic data from 1992-93 to 1996-97, the average annual inflow of the western rivers at the rim-station amounts to 140 million acre feet MAF (173 BM<sup>3</sup>). The flow varies from year to year; the maximum was 186.79 MAF (230 BM<sup>3</sup>) in 1959-60 and the minimum was 86 MAF (106 BM<sup>3</sup>) in 1999-2000. This presents a variation of more than 65% in the annual average-flows.

The groundwater storage-capacity in Pakistan is estimated to be around 55 MAF (67.8 BM<sup>3</sup>). The hydrogeological conditions are mostly favourable for pumping by tube-wells. It is estimated that 15,504 large-capacity public tube-wells and 469,546 private tube-wells of low capacity are currently installed in the country. Thus, the groundwater pumpage in the Indus-basin has increased from 33.4 MAF (41 BM<sup>3</sup>) in 1959 to about 50 MAF (62 BM<sup>3</sup>) in 1999-2000. Quality of groundwater is variable, with about 79% of the area in Punjab and 28% in Sindh as fresh groundwater suitable for irrigation. However, indiscriminate pumping, without proper monitoring, and lack of knowledge about the chemistry and hydrodynamics of the aquifer has already contributed to the pollution of the aquifers in certain pockets.

At the time of independence of Pakistan in 1947, about 64 MAF of water was being utilized annually in the irrigation canals in the country. With the construction of more barrages, link canals, and storage dams, water-use has increased to an average of 106 MAF (131 BM<sup>3</sup>). Per-capita availability of water has gone down from 5,104 cubic meter in 1950 to around 1,200 cubic meter currently- Out of the 35,040 MAF flowing to the sea, a total of about 20 MAF (25 BM<sup>3</sup>) can be used for future development through construction of multi-purpose storages, remodeling of canals and irrigation extension schemes. There is little potential for increase in water availability for Pakistan from surface or groundwater sources. However, the 9th Five-Year Plan envisages that about 4.32 MAF can be made available through conserving measures and installation of tube-wells in fresh groundwater areas.

Currently, 97% of the fresh water in Pakistan is used in the agriculture-sector and only 3% is available for domestic and industrial use. The competitive demands from different sectors has not yet emerged as a key issue in Pakistan but is likely to become a major issue in the future. A review of growth trends shows that as the income of a country increases, the use of water by different sector changes dramatically, and the water needs of the industrial and domestic sector changes dramatically and the water needs of the industrial and domestic sector grow rapidly until in high-income countries water requirements are 47% of the available water. In the immediate future, Pakistan needs to review strategies for

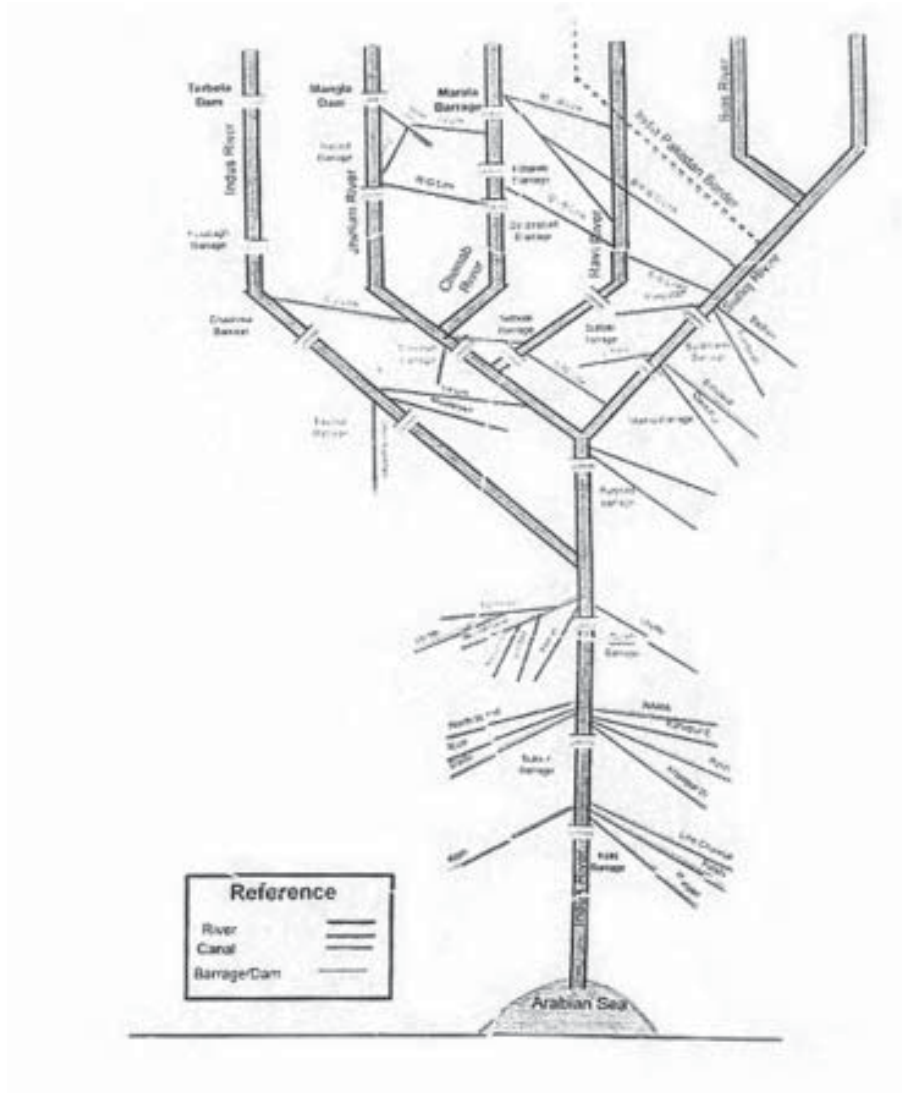


Figure - 2: Schematic Diagram Indus-Basin Irrigation-System

## **Efficient and Sustainable Irrigation-Management in Pakistan**

reallocation of water from irrigation to domestic and industrial use to harvest economic benefits. The rate of return of a cubic meter of water used for agriculture is less than 10% of return on municipal and industrial use. Conservation measures in agriculture can therefore help in increasing the productivity of water.

### **IRRIGATION AND WATER-MANAGEMENT ISSUES**

Water-resources development and management has acquired new dimensions in Pakistan. A host of factors constrain the performance of irrigation, which are multi-faceted and multi-dimensional. The major constraints facing the irrigation management broadly include; Physical Constraints, Financial Inadequacies, Institutional Issues and Environmental Problems. The Physical Constraints have been caused by the agricultural development beyond the system design capacities, scarcity of irrigation water, lack of storages, and gradual deterioration of the network due to the overstressing and aging. The main Financial Issues include inadequate maintenance funding, rise in maintenance expenditure of public tube-wells, and flood works, as well as escalating expenditures on establishment, stagnation of abiana rates, and a widening gap between the expenditure and cost recovery. The Institutional Issues have emerged because the changes in the institutional set-up have lagged behind the changes that have taken place in the resource-base and socio-economic context over the years. On the Environmental Front, the main problems are waterlogging and salinity, salt-imbalance, and increasing pollution of water-bodies.

A small fraction of the population pays tax; agricultural income tax has never been imposed on full-scale basis, despite its potential to generate resources for the country. The revenue from abiana (water tax) is also not collected seriously and there is massive leakage in the system. There is a legal framework in place for the organization of Water User Association (WUA), as the Punjab (1981) and Sindh (1982) Water-User Association Ordinances provide for such associations at the water-course level, while the Punjab Irrigation and Drainage Authority Act (1997) and the Sindh Irrigation and Drainage Authority (1997) provides for establishing Farmers Organizations (FOs) at distributary and minor levels. Despite this, the WUAs do not feel empowered to undertake the responsibility of operating and maintaining their watercourses or have any autonomy in the management of their water-resources. Similarly, a uniform policy exists for the water supply and sanitation sector, but it is not fully implemented. The National Environmental Quality Standards exist, but these are not enforced seriously.

The Indus-Basin Irrigation System was installed almost a hundred years ago and, now, its efficiency has come down to such an extent that more than 50 per cent of the irrigation-water is lost in transit and during application to the crops. The quantum of wastage of precious irrigation-water is not only the limiting factor for expansion of the irrigated area and realizing the maximum benefits per unit of already irrigated land, but it also has aggravated the severity of the twin menace of waterlogging and salinity. Crop-yields on

average Pakistani farms are considerably lower than the average yields attained by many other countries of the world, under similar agro-climatic conditions. The mounting pressure of population has furthered the importance of conservation and better management of the scarce resource. Thus, the low productivity of irrigated agriculture and ever-increasing pressure of population present a major threat to the country's food- security in the future. Therefore, this underscores the dire need to save every drop of water wasted in the irrigation-system and at the farm-level, through active participation of the end-users.

The importance of water for Pakistan can not be under-estimated, particularly for irrigated agriculture in the country. In Pakistan, irrigated agriculture covers 16.2 million hectare (74%) out of the total cultivated area of 22 million hectare. Irrigated agriculture uses 97% of the available water and provides over 90% of agricultural, produce; it accounts for 25% of GDP, earns 70% of the export revenue and employs 50% of the work-force directly and another 20% indirectly. Although the share of agriculture in GDP has declined over the years, it is still the largest single contributor to GDP. However, despite its importance, the level and growth of agricultural production falls short of its real potential. The sustainability of irrigated agriculture is threatened by continuous deterioration of the irrigation infrastructure.

The need for improvement and up-gradation of the irrigation system has become imperative. Indeed, over the last three decades, some damages have occurred due to floods, causing stoppage of irrigation-water to large areas, with huge economic losses. Recent surveys have revealed that numerous important hydraulic structures are in a precarious state and the need for rehabilitation is urgent. Besides rehabilitation, the system also needs overall improvements to allow efficient operation and equitable water-delivery, in order to cater for the enhanced water-demand and to meet the challenges of 21st century.

In order to address the sustainability issues, a number of policy-interventions have been proposed. While the main thrust of the policy-framework remains on institutional reforms, other policy interventions like Global Water Law, Dis-investment of Fresh Groundwater Tube-wells, Groundwater Regulatory Framework, Optimizing Irrigation-Water Allocations and Alternative Rate Mechanisms, are also proposed for optimizing the overall Irrigation Management. A sectoral strategy and National Water Policy are also being formulated, to have a historic approach for development and management of the water sector.

At the moment, the irrigation and drainage system of Pakistan suffers from a number of fundamental problems, notably;

- Unsatisfactory planning and programming of public expenditure on drainage;
  - Delays in Implementation;
  - Unsatisfactory planning, funding and execution of operation and maintenance (O&M);
  - Deteriorating capabilities of key-institutions;
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## **Efficient and Sustainable Irrigation-Management in Pakistan**

- Lack of public participation;
- Inadequate investment in drainage;
- Poor monitoring of drainage projects and infrastructure, and
- Inadequate investment in research on drainage, and lack of application of research-results to policy and planning.

### **FARMERS' PARTICIPATION IN CANAL-IRRIGATION AND WATER-USERS ASSOCIATIONS**

Nature has blessed this country with the World's largest and most integrated system of irrigation. This network was installed almost a hundred years ago and now its efficiency has been reduced to such an extent that more than 50 per cent of the irrigation-water is lost in transit and during application to the crops. The quantum of wastage of precious irrigation-water is not only the limiting factor for expansion of the irrigated area and realizing the maximum benefits per unit of already irrigated land, but also has aggravated the severity of the twin menace of waterlogging and salinity. Water-Users Organizations were not a part of the agricultural system in Pakistan till the late 1970s. With the onset of the On-Farm Water- Management (OFWM) Pilot Projects, their involvement was experimented upon, at times when it was considered a politically explosive and socially vulnerable issue, and it proved successful. Under various OFWM Programs, efforts were exerted to involve them at tertiary levels of the irrigation-system and, by now, they are contributing 55 per cent of the cost of the civil works on the watercourse. The usefulness of farmers' participation in other countries fostered the testing of some pilots on their participation at secondary levels of the system. A few pilot-surveys have been conducted so far and the results have shown that the WUA's participation can play a promising role in the operation and maintenance of the already deteriorating irrigation-systems, not only in improving productivity but also in sustaining the environment. Their performance will, nevertheless, hinge upon effective organizational efforts, imparting necessary training to them, proper recognition and adequate legislative support from the government, as well as commitment from operating agencies.

The Government has recently taken strategic initiatives to address the longstanding issues of irrigation-management that had been reflecting on the performance of the sector. The new strategies primarily focus on better governance, decentralization, participatory management and sustainability. Under the institutional reforms agenda, Provincial Irrigation Departments (PIDAs) are being transformed into Provincial Irrigation and Drainage Authority (PIDA). The responsibilities of management would be decentralized at canal command level to Area Water Boards (AWBs), while most of the existing functions at the distributary / minor level would be performed by the Farmers Organizations (FOs). The focus of most of the above activities would initially be on pilot AWB and pilot FOs on the System. Subsequently, the reforms package will gradually be extended to other AWBs and FOs, on the basis of the results of monitoring and learning- experience of the pilot



programmes. The Government has enacted the legal framework and the reform agenda is under implementation, to varying degrees in all Provinces.

The strategy consists of the following interlinked parts:

- Restructuring the Provincial Irrigation Departments (PIDs), to form Public Utilities (PUs) around canal commands;
- Actively promoting formation and development of Farmers Organizations (FOs);
- Strengthening federal agencies, notably the Water and Power Development Authority's (WAPDA's) Water Wing, so as to better implement their federal responsibilities; and
- Formalizing water markets and individual water-property rights.

PIDAs have been established in all the four provinces; one Area Water Board (AWB) in each province has been notified. Also, Punjab and Sindh have notified rules and regulations for FOs. Other provinces are in the process of doing the same; 30 FOs have been registered in Punjab. Formation of 23 FOs have been completed, following by registration in Sindh Province under PIDA Act.

NWFP has designated the existing Northern Irrigation Circle Mardan as Area Water Board, Swat Canals (Pilot) and its Members have already been notified. The On-Farm Water-Management of the Agriculture Department have already constituted a FO in 31 Lora Canal scheme in Lakki Marwat district and they are busy in forming FOs in Peshawar and Charsadda areas.

The Farmers' Organization for K.K. Bund Irrigation Schemes, in Balochistan, have been registered. FOs registration for rehabilitation of Lasbella Canal is being processed.

The issues of physical / financial sustainability of irrigation and drainage network is assuming increasingly critical proportions. The specific policy-interventions, which are under consideration, include the following:

- i) Drainage cess and / or other appropriate measures, including cost-sharing by non-agricultural beneficiaries, to finance the O&M cost of drainage infrastructure.
- ii) Mechanisms for financing the O&M costs of flood-works, which may inter-alia include transfer (or cost sharing) of non-irrigation flood-infrastructure to the local bodies / other relevant beneficiaries and/or charging flood-cess, etc.
- iii) Redefining water-rates and alternate rate-mechanisms to enhance the incomes and to rationalize assessment costs. For a start, flat-rate assessment could be introduced in pilot FOs.
- iv) Redefining water-rates for water-use by non-agricultural users.

## **Efficient and Sustainable Irrigation-Management in Pakistan**

- v) Adequate O&M funding for proper upkeep of the existing irrigation-infrastructure. Revision of yardsticks, enhanced allocations and shifting of resources from SCARP tube-wells to canals operations.
- vi) Need to reassess the impact of the increase in investment vis-à-vis O&M requirements and the increases in “abiana” to sustain such investments.

The following points regarding institutional and environmental issues are now under active consideration of the Government:

- i) Willingness to invest in social mobilization and capacity-building of the upcoming new institutions (i.e AWBs and FOs) is absolutely essential for the success of the ongoing institutional reforms. For the new entities to be sustainable, the upcoming FOs would require technical assistance and support for quite some time, which may account for about 20-30% of the Investment Costs.
- ii) There is pressing need to take steps for expediting the capacity-building process for the upcoming FOs if the targets, for formation of FOs and transitioning of the management responsibilities to them, are to be met.
- iii) In order to optimize integrated resource-management, comprehensive and holistic interventions for rationalizing existing canal-water allowance need to be undertaken. Appropriate policy also needs to be developed, to address the emerging environmental issues in order to preserve the water-quality and land-base for sustainability of the irrigated agriculture.

## **CONCLUSIONS**

Owing to scarcity of water, proper management of water-resources is essential for the Agriculture Sector, which is the largest user (97%) of water. The development of Pakistan's economy strongly depends on its ability to properly operate and manage its water-resources. The efficient and effective use of all water- resources in Pakistan requires formulation and implementation of an appropriate water-sector policy. The Ministry of Water and Power is formulating a National Water Policy to face the challenges of water-scarcity. The overall objective is to utilize the available water-resources to meet the socio-economic and environmental needs for sustainable development in the country.

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# **Optimal Utilization of Water-Resources at Mangla Reservoir**

*Qamar-uz-Zaman Chaudhry*

# OPTIMAL UTILIZATION OF WATER-RESOURCES AT MANGLA RESERVOIR

## ABSTRACT

*Pakistan has an agro-based economy, but most parts of the country are arid or semi-arid. As such, a large part of the agricultural activity depends on irrigation water, which mostly comes from two main reservoirs, namely, Tarbela and Mangla. Optimal utilization of the available capacities of these reservoirs, therefore, becomes an important issue.*

*At the time of the dam-design, the Probable Maximum Flood (PMF) value calculated for the dam was 26 lac cusecs. Now, Pakistan Meteorological Department (PMD) has eighty years of data, analysis of which suggests that the present PMF value of 26 lac cusecs is much on the higher side and should be revised downward to around 16 lac cusecs. This revision can allow raising of the present Maximum Conservation Level (MCL) of Mangla by 15-20 ft, which can be accomplished at a fraction of the original cost. The storage capacity of the dam would be increased by about 1 million acre ft.*

## INTRODUCTION

Mangla Dam was built on the river Jhelum in 1960 mainly to replace waters of the three eastern rivers allocated to India under the Indus Water Treaty.

The catchment area of the Jhelum river is about 12,870 sq. miles. Of this, 3,605 sq. miles area (about 28%) is located at an elevation higher than 10,000 ft above Mean Sea Level (MSL). The area above 4,000 ft constitutes about 82% of the total area. The basin is bounded in the north by the great Himalayan Mountains and contains whole of the Kashmir valley.

The climate of the Jhelum basin can be divided into four seasons. These are winter (December-February), the hot weather (March-May), the summer monsoon (June-September) and the transition (October-November). During winter season, precipitation over major portion of the basin is in the form of snow. In April, May and June, the snowmelt gives rise to high sustained river flows at Mangla, which normally reach their maximum in June. During the summer monsoon season, precipitation is concentrated in the southern and western portions of the basin and features intense rainstorms. It is these rainstorms, which usually gives rise to major floods.

Any proposal to carry out the structural raising of Mangla dam deserves special attention because it could boost the dam's irrigation and power potential. Besides socio-economic and geotechnological considerations, the two major issues involved in the decision-making

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### **Optimal Utilization of Water-Resources at Mangla Reservoir**

process relate to: (i) the availability of water in the system, and (ii) the magnitude and volume of the highest possible flood or the probable maximum flood (PMF).

A correct assessment of these two factors will determine whether the structural raising of the dam is at all needed and, if so, then exactly how much. Hydrologists appear divided on the issue of water-availability. Some believe a 40-ft raising of the dam is not commensurate with the water-potential of the dam. They argue that, during quite a few seasons, the Dam's filling even up to the present conservation-level of 1,202ft had not been possible. They fear that an increase in the dam's capacity could increase the number of water-deficient years, as well, and thus make the project uneconomical.

### **WATER AVAILABILITY & RE-EVALUATION OF PMF**

The inflow at Mangla constitutes around 70% of snow-melt water and spring water, plus around 30% rainfall. Dam filling under the increased capacity shall necessitate more than normal snowfall during winter, followed by more than normal rainfall during summer. Such occasions would be relatively few. Thus, the water-availability for the increased capacity (built at such high cost) remains doubtful.

The second most important factor to be considered in the context of raising the capacity of Mangla dam is the accurate assessment of the magnitude and volume of the highest possible flood, called the PMF. It is customary to express the PMF in terms of its peak (discharge) value, even though its volume is equally important. Essentially, it is on the PMF-value that the Maximum conservation-level of the reservoir is fixed and the detailed dam-operating procedure is formulated.

In the case of Mangla reservoir, a great deal has gone wrong with regard to the PMF. As it exists today, Mangla PMF is grossly over-estimated and we have under-utilized the dam's capacity right from the beginning. PMF study of the Mangla dam was carried out by two international companies. The first study was done in 1959 by M/S Binnie<sup>1</sup> and its UK Partners, in association with M/S Harza of USA, while second study was carried out alone by M/S Harza<sup>2</sup>, in 1992.

### **DISCUSSION ON VARIOUS STUDIES**

Before commenting on the two studies, it is necessary that a few basic and simple elements regarding the concept of the PMF are brought out. PMF occurs as a result of the heaviest possible precipitation, technically called the probable Maximum precipitation (PMP). The PMP is caused by the extremely rare combination of the most rain-producing meteorological factors, which may act together to produce such an imaginably high rainfall, the equal of which has never occurred before. Thus, the starting point in computing PMF is the estimation of the PMP, which, in turn, calls for an in-depth understanding of those

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meteorological factors that are necessary to cause PMP. In Pakistan, the essential causes of the heaviest rainfall are the low-pressure weather-systems, which originate in the Bay of Bengal during monsoon season and then move across India, to arrive in the vicinity of the Mangla catchment. Turning of these monsoon depressions (towards the catchment) and their intensification, etc, is caused by another weather-system called the westerly waves. Cause of the extremely heavy rainfall in Mangla catchment develops when, on an extremely rare occasion, the position of the arriving intense monsoon-depression (to the south) and that of the intense westerly waves (to the north) get mutually juxtaposed along a North – South axis. The first step in computing PMP is to look for a past event in which the “heaviest-ever” recorded rainfall and thus the run-off had occurred. Then the actual rainfall is further enhanced (theoretically) by assuming the situation of saturated atmospheric condition to release more (additional) rain. Such precipitation (rain) is then converted into run-off, to compute the PMF, using any standard rainfall / run-off model like, for example, HEC Model.

Now, turning to the Mangla PMF study, it appears that the foreign consultants did not possess full understanding of the local rain-producing meteorological factors. The British and American Meteorologists live and deal with the temperate region and its atmospheric environment, while Pakistan is located in the region which becomes meteorologically tropical during summer and temperate during winter. This regional characteristic causes much more complex weather-systems, which are not easily comprehended by the visiting meteorologists of European or American origin. It further appears that this lack of knowledge of the foreign consultants forced them to play safe by aiming at a very high value of the PMF, with safety margin comparable to the one normally adopted in USA for Hurricane-related rainfall.

In achieving such a high value of PMF, they violated the very basic procedure of PMF computation. As indicated earlier, the first step in the PMP/PMF computational procedure is to select the past event of the heaviest rainfall, which in case of Mangla, up till that time, was the event of the year 1929. The consultants of the study, however, selected an event, which was relatively insignificant in terms of rainfall and flood intensity. This was the flood of 1956. However, strangely enough, despite selecting one of the lowest storms, they produced the highest PMF value. This was done by multiplying the actual storm rainfall with an additional multiplication factor called the Wind Maximization Factor, which was actually not applicable to Mangla storms (since the wind-factor is applicable to the coastal belt only and not as far inland as Mangla).

PMF value of 26 lac cusecs was computed by M/S Binnie<sup>1</sup> and Partners and M/S Harza. Against this, the highest flood actually experienced at Mangla over a period of more than 80 years is less than 11 lac cusecs, which occurred in 1992. The figure of 26 lac cusecs for PMF resulted in fixing the maximum conservation level of the dam at 1,202ft. (Crest level of the dam is around 1,232ft and the level in case of PMF could be taken to 1,228ft).

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## **Optimal Utilization of Water-Resources at Mangla Reservoir**

Thus, around 26ft of the useable space was kept empty for the PMF situation. A feeling that 26 lacs of the PMF (as against 11 lacs actually experienced so far) was on the higher side prompted WAPDA to revise the study. However, strangely enough, the revision was again awarded to none but M/s Harza (which was already co-author of the first study). This was done early in 1992. No wonder that, in this revised study also, the PMF of Mangla again reached close to the previous value of 26 lac cusecs. On the face of it, the previous PMF value got confirmed through the revised study and thus the situation with regard to the water-conservation in the reservoir remained unchanged. Flaw in the entire exercise stemmed from the decision to award the revised study to M/S Harza, which was in no position to prove its (own) earlier study wrong. Indeed, Harza is a good international firm having long-standing association with WAPDA, but this did not deny WAPDA the right to an independent check of its work through some other national / international firm, since quite a few companies of equally good repute are available at the international level.

In 1995, Pakistan Met. Deptt., in one of its detailed studies conducted by its Director, Mr. Abdul Majid, strongly pointed out flaws in this overestimated Mangla PMF value of 26 lac cusecs. Some conservative estimates suggest that this under-utilization of Mangla Dam has caused a loss of about Rs. 20 billion<sup>3</sup> to the national exchequer so far.

## **CONCLUSIONS**

The gist of what has been stated above is that an independent study of the Mangla PMF needs to be done, through a firm not involved in the earlier studies. Involvement of Pakistan Meteorological Department must be ensured in the study, since the subject of PMF is a hydro-meteorological subject directly related to the technical function of Pakistan Meteorological Department.

On the basis of the various studies<sup>4,5</sup>, the present author is of the firm view that the PMF value is most likely to range between 15 lac and 17 lac cusecs. This shall allow a raising of Mangla's present maximum conservation level to 15ft above the present level of 1,202 ft. The first 6 ft can be raised without any structural change, while the remaining raising can be achieved either by raising the emergency spillway (present level 1208 ft) or just by putting gates on it. This can be done at a fraction of the cost of rupees 50 billion needed for raising the Dam upto 40 ft. In view of the water-availability constraint, the option of raising the level, on the basis of revised PMF, should be exercised first. It shall be much more beneficial to use the available funds in the construction of some new dams, rather than raising the Mangla dam too much, without first utilizing the dam's available potential.

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# **Strategic Sustainable Development of Groundwater in Thar Desert of Pakistan**

*Nayyer Alam Zaigham*

# STRATEGIC SUSTAINABLE DEVELOPMENT OF GROUNDWATER IN THAR DESERT OF PAKISTAN

## ABSTRACT

*Thar Desert forms the extreme southeastern part of Pakistan, covering about 50,000 km<sup>2</sup> area. It is one of the densely populated deserts of the world. Population of Thar is living primarily on limited agricultural products and by raising goats, sheep, cattle, and camels. The region is characterized by parallel chains of the NE-SW trending parabolic stable sand-dunes having desertic varieties of vegetation, generally on windward sides, upto the crests. Interdunal areas are favourable for agricultural activities, where crops are mainly dependent on rainwater. Average rainfall is significant but inconsistent, due to recurrent drought-cycles causing inverse impact on food-production and socio-economic development. In spite of extensive groundwater-exploration projects, accomplished by a number of organizations, the water-crisis of the region could not be controlled, most probably due to lack of systematic exploration & development of deep groundwater potential. Management of the available water- resources is also not adequate, even to sustain a short period of drought-cycle. On recurrence of a drought-cycle, a significant section of the population is compelled to migrate towards other parts of the Sindh province, which affects their socio-economic stability.*

*An integrated research study, based on geo-electric scanning, drilling and seismic-data analyses, has been carried out to delineate subsurface hydro-geological conditions beneath the Thar Desert. Regional gradient maps of surface elevation, top of subsurface Oxidized Zone, top of coal-bearing formation(s) and the deeply buried basement have been prepared, covering almost the whole of Thar Desert. These gradient maps, analyzed in conjunction with the annual rainfall data, reveal the existence of encouraging subsurface hydrogeological conditions, associated with the sedimentary sequences and the basement. From the results of the study, it is observed that perch water aquifers, commonly being utilized throughout the Thar, are present at the bottom of the dunesand-zone, with fluctuating yield controlled by the annual rainfall cycles. At places, vertical electric-soundings indicate good prospects for better water, associated with the basement complex. The strategic development of groundwater, based on scientific exploration and exploitation, from the deep sedimentary and basement aquifers, can de-desertify the Thar, accelerating the socio-economic stability of the people of the region.*

## INTRODUCTION

In the northeast, the Thar desert extends towards Punjab Province and eastward across the Indo-Pakistan border, spreading over an area of about 200,000 km<sup>2</sup> (Figure-1). In the Pakistani part of Thar, the habitations are concentrated in the form of small villages scattered all over the desert. This desert is one of the most densely populated in the world. The population of

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## Strategic Sustainable Development of Groundwater in Thar Desert of Pakistan

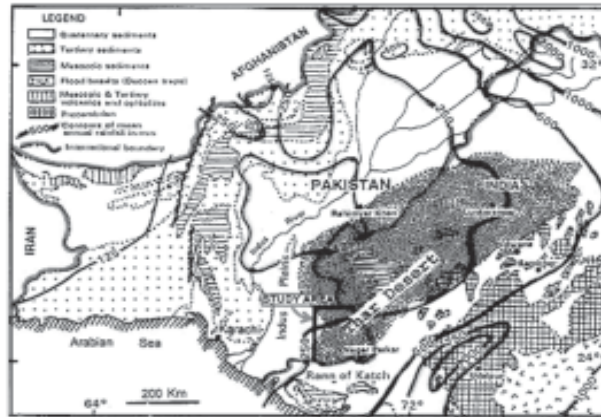


Figure - 1: Index map of Pakistan showing location of study area, regional geology, contours of annual rainfall and eastward of the extent Thar Desert

Thar ranges from 850,000 to 950,000 (Baanhn Beli, 90; SAZDA, 1988; Qadri, 1983). Stabilization of the sand dunes and siltification in the interdunal valleys have provided good environment for cultivation and, consequently, raising of goats, sheep, camels, cattle, etc., which is the primary source of livelihood in the Thar Desert.

Physiologically, the study area is bounded by the Punjab Plains in the north, by the Indian border in the east and south, and by the irrigated Indus Plains in the west. In the south, there are salt marshes and mud flats of the 'Rann of Kutch', a former shallow arm of the Arabian Sea. In general, the terrain is topographically higher in the northeastern part of the Thar Desert. The elevation ranges from sea level in the south to more than 200 m in the northeast around Gadro area.

Parallel chains of NE-SW trending, large stabilized dominantly parabolic dunes form steep ridges 5-16 km long, with an average relief of 50m, locally up to 80m. Dunes have vegetation (grasses, shrubs, bushes, and trees) on windward sides up to crests (Figure-2). The interdunal valleys are wide and filled with silty and clayey sediments, useful for cultivation where crops are mainly dependent on rainwater. These valleys constitute almost one third of the total area. In Thar Desert, the rainfall is significant (average 350 mm annual) but capricious and uncertain; drought cycles have inverse impact on food-production and socio-economic development. On commencement of a drought-cycle, people of Thar usually migrate with their animals, temporarily, to other parts of Sindh due to poor management of the available water, which consequently affects their socio-economic stability.

Considering the unfavourable climate and its impact on agricultural practices, the magnitude of population, the livestock, and the cultivated areas are surprisingly large. The crops grown are mainly millets and pulses. The agricultural crops are Bajri (*Pennisetum Typhoideum*), Guar



**Figure - 2: A general panoramic view of Thar Desert showing broad interdunal valley and typical vegetational growth**

(Cluster beans, *Cyamopsis Psoralioides*) and Til (*Sesamum Indicum*). The breeding of livestock is the main source of livelihood in the region. According to an agricultural census the livestock population is more than 0.35 million.

A number of organizations have worked for the development of groundwater-resources, but the water-crisis of the region could not be controlled, most probably, due to lack of systematic exploration & development of shallow and deep groundwater-resources. Almost the entire Thar Desert has been reconnoitered geologically, through test-drilling supported by the geophysical exploration under the coal- exploration program (Fassett and Durrani, 1994; JTB, 1994; Zaigham and Ahmad, 1996). The northeastern part of Thar Desert was also hydrologically investigated in a joint WAPDA-BGR venture (Ploethner, 1992). Technical management of the so far developed water-resources seems inadequate, because this has



**Figure - 3: Water crisis compels people of Thar with herds to migrate temporarily during drought period**

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not provided sustainability, even against a short period of drought. On recurrence of the last spell of drought-cycle persistent during 1996-2000, a significant section of the population was compelled to migrate from Thar area, due to acute water-shortage even for their domestic needs (Figure-3).

Present study has been concentrated on the possible occurrences of the ground-water associated with the sedimentary rocks, at moderate depth, and hard rocks at deeper depth, and also to the factors controlling the recharge of groundwater at shallow and deeper depths. It is hoped that the study would provide guidelines to back up water-deficiencies for the socio-economic development in one of the less- developed regions of Pakistan, where population is rapidly growing and the environments are already conducive to food productivity as compared to other desert regions.

### CLIMATIC CONDITIONS

Thar desert has semi-arid to arid climate. The present climatic situation in Pakistan is mainly influenced by the circulation of the monsoons, which depends on the movement of the intertropical convergence-zone. Strong, humid and cold southwest-monsoons prevail in the summer months from May to September. The strength of the southwest monsoon depends mainly on the pressure-gradient between the low air-pressure in Central Asia and high air-pressure above the Indian Ocean.

Rate of annual rainfall increases from northwest to southeast (Figure-1). In the north of the Thar Desert, a, low rainfall region (with an average annual rainfall of less than 100 mm), exists around Rahimyar Khan. On the other hand, in the southeast, comparatively high annual rainfall,



**Figure 4: Typical blooming morning view of Thar Desert after heavy rain (September 1994). Geophysical logging was in progress under GSP coal exploration project in interdunal valley flanked by stabilized sand dunes, which look like green**

up to 1000 mm, is received on the Indian side, across the border, around Udaipur. At western margin of the desert at Umarkot, an average of 208 mm/yr rainfall was observed for a period of 42 years from 1897 to 1929/1938 to 1946 (Radojicic, 1980), but an average of only 160 mm/yr rain was recorded from 1944 to 1958, indicating a cyclic fluctuation of precipitation. To the southeast at Nagarparkar, about 360 mm/yr rainfall was recorded. However, the rainfall is erratic and continuous spells of droughts, lasting for up to four years, have been experienced.

Practically, no rivers or streams exist in the Thar and the drainage is internal. Rainwater flows to the nearest topographic low, as sheet flow that eventually either evaporates and/or infiltrates. Most of the rains occur during July-August monsoon from southwest direction, whereas the prevailing winds are from the northeast during the rest of the year. During a good rainy-season, the area becomes "Green Hilly Thar" (Figure-4).

The winter rains are insignificant. Dust storms are common, with winds of 140 to 150 km/hr from April to June in the desert. The maximum temperature rises to over 45°C during the hot months of April, May and June. The mean maximum and minimum temperatures average 35°C and 19°C, respectively, over the year.

### GENERAL GEOLOGY

The Thar Desert lies in the southeastern part of Pakistan, on the western edge of the stable Indian Peninsula. The whole area is covered with extensive & thick cover of duned-sands, extending down to an average depth of 80m. Surface rock exposures are almost absent, except limited outcrops of granitic basement in Nagarparkar. A few scattered outcrops of Mesozoic and Tertiary strata are exposed across the Indo-Pakistan border in the Jaisalmer and Rann of Kutch areas of India. Due to lack of surface-exposures of the prevailing subsurface geological sequences, the geology of the Thar Desert has been poorly understood. Mainly, geophysical and drilling data have provided subsurface geology (Figure-5).



Figure - 5: Locations of seismic profiles and geological cross-section. Geologic legend:  
 1) Quaternary sediments/Desert dune-sands, 2) Tertiary sequences, 3) Mesozoic-Jurassic sequences, 4) Lavs flows-Deccan traps, 5) Pre-Cambrian units, 6) Rhyolites-Malani beds



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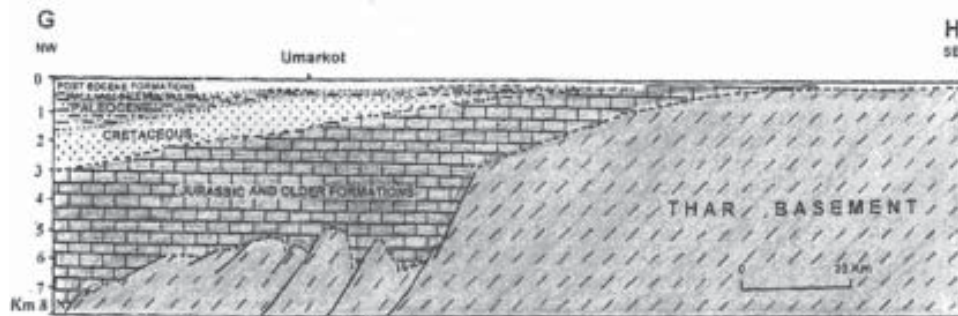


Figure 6: Geological cross-section of the Thar Rift interpreted from seismic data (Zaigham and Ahmad, 1996)

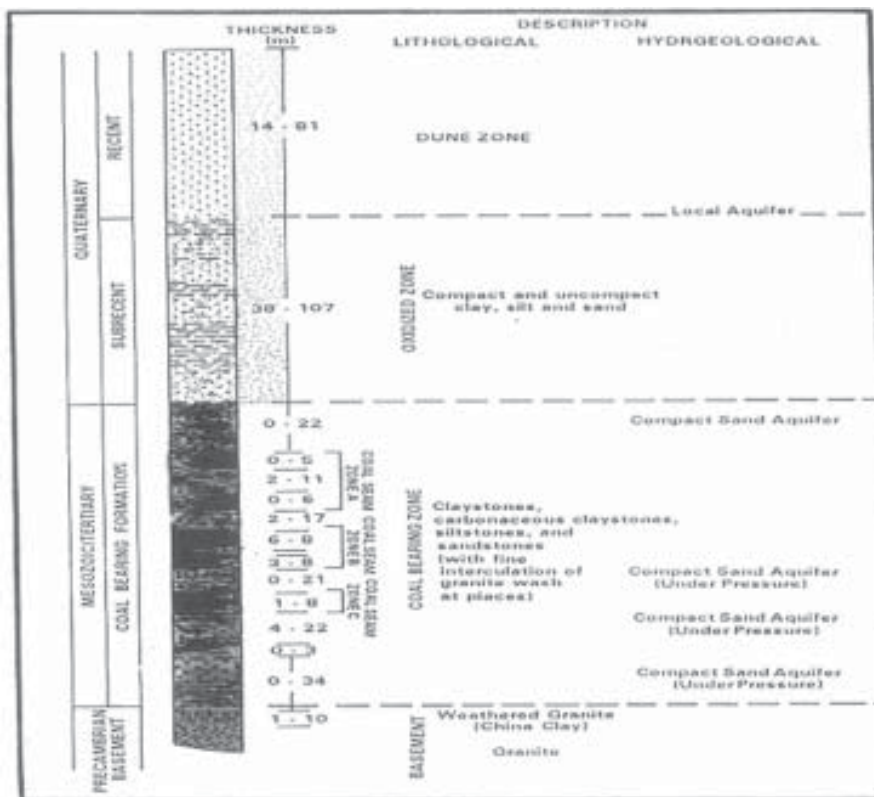


Figure 7: Generalized lithological column representing the stratigraphic units encountered in holes drilled for coal exploration and also showing hydrogeological conditions in the Thar Desert (modified after JTB, 1994).



The interpretation of seismic-data (Zaigham and Ahmad, 1996) shows that the Thar Desert rests upon a structural platform where granitic basement is at shallower depths (Figure-6). The granite basement has pre-Jurassic rifting, which caused flexure and the ultimate development of the Thar basin. The basement shows rise towards southeast and deepening towards northwest, as a result of Paleozoic-Mesozoic divergent tectonics. The consistent depositional trends of the stratigraphic sequences from Mesozoic to Tertiary periods indicate that the incipient rifting of the basement was pre-depositional. The younger formations are preserved and overlie the older in the northwestern part, where geological sequences are well developed. The older formations may be encountered at greater depths towards the basin and shallower on the continental shelf area towards southeast.

Results of the geo-electric, drilling and geophysical/geological log data (Rehman et al., 1993; Fassett and Durrani, 1994; Zaigham and Ahmed, 1996) indicate four major divisions of lithological sequences almost throughout the Thar Desert (Figure-7).

**Dune Zone:** This zone consists of well-sorted eolian sand. The soils of the desert contain about 8 % clay and silt, near the surface and about 15 % clay and silt in the subsoil (Kazmi, 1985; Qadri, 1983). The thickness of this sand-zone varies from north to south. It is thinner in the northern part of the desert, about 5 to 15 m thick in Gadro-Khokhrapar area. The thickness increases from about 40 to 93 m in the central and southern Thar in Chachro-Islamkot-Mithi area.

**Oxidized Zone:** It consists of compact and loose clays, silts and sands with ironstone concretions and siderite nodules. This litho-unit is distinguished from other subsurface units by its iron oxide and limonite stainings. The thickness of this zone ranges from 11 to 209 m. The age of this unit is considered Sub-Recent (Fassett & Durrani, 1994). This oxidized zone lies unconformably over the coal-bearing formation.

**Coal-Bearing Formations:** The coal-bearing sequence consists of claystones, siltstones, sandstones and lignite, with intercalations of siderite bands, nodules and granite-wash at places. The thickness of this sequence ranges from zero to 185 m, hosting lignite beds with a cumulative thickness ranging from 0.5 to about 34 m.

**Basement Complex:** Granitic basement is encountered at depths ranging from 112 to 279 m in holes drilled in the east and southeast of Chachro (Fassett & Durrani, 1994). On the other hand, rhyolitic/basaltic basement was reported in a well near Pabban locality, about 8 km south of Gadro (Hindel, 1980). Further south along the border with India, the dioritic basement was reported, encountered at 253 m depth in a drill hole (Ploethner, 1992).

Based on the geoelectrical resistivity survey, this basement complex, having high resistivity of 50 to 150  $\Omega$ m, was interpreted to be a deep fissured sandstone aquifer, bearing fresh water, by Schildknecht & others (1991) under the WAPDA-BGR Groundwater Exploration Project.

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On the other hand, results of the deep vertical electric soundings (VES) indicate two trends of apparent resistivity values at different sites in the area south of Chachro (Zaigham & Ahmed, 2000). One trend indicates massive granitic basement and the other trend reveals the presence of layered Archean metasediments.

### HYDRO-GEOLOGICAL CONDITIONS

There is no surface perennial water available in the Thar. Based on the results of dug-wells' inventories, covering about 8500 km<sup>2</sup> area between Gadro and Virawah in the eastern Thar along the Pakistan border, it is observed that the perched aquifers are hosted in friable sandy/silty layers sealed underneath by clay-layers (Ploethner, 1992). The depth to water-table varies from 5 to 15 m in and around Gadro area, 30 m to 45 m in Chachro area and goes even deeper in areas west of Chachro. Their thickness and lateral extent are limited. The majority of the dug wells have a depth to groundwater ranging from 20 to 80 m (Figure-8). In general, the quality of groundwater ranges from saline to brackish.

Based on the analysis of integrated groundwater data, collected during GSP-USGS-JTB-USAID Coal Exploration Programme, the following facts have been interpreted (Figure-7):

- In general, the perched aquifers occur at the interface of dune-sand zone and subrecent sediments (Oxidized zone) with fluctuating yield controlled by the annual rainfall cycles.
- The subrecent sediments of Oxidized Zone hold saline aquifers with very limited yield. Practically, this unit is considered non-water bearing.



**Figure 8: People of Thar Desert use camel-power to take out water from relatively deeper dug-wells**

- The coal-bearing sedimentary sequence hosts a number of confined aquifers under artesian pressure, with significant yield and acceptable quality [range: 4000 - 5000  $\mu\text{S}/\text{cm}$ ].
- The upper part contains generally thin layers of aquifers, but the lower part contains significantly thick and brackish aquifers.
- Analyses of the geophysical logs show that coal-bearing formations generally contain a significant sandstone aquifer above the Coal Seam Zone-A, with thickness ranging from zero to 22 m. Occasional sandstone aquifer is also reported between Coal Seam Zone B and C, with thickness ranging from zero to 21 m. A large sandstone aquifer is encountered below the Coal Seam Zone C, with thickness ranging from zero to 34 m. All aquifers in the coal formation are under pressure (Figure-7).
- Electrical conductivity values of the ground water associated with deep aquifers are in acceptable range, between 4,000 and 5,000  $\mu\text{S}/\text{cm}$ . The measurements of the field-conductivity indicated brackish quality of these aquifers.
- Results of pumping-test indicate nearly immediate recharge of the aquifers. It has also been found that, after a longer pumping, the quality of deep ground water aquifers improves.

## GROUNDWATER QUALITY

In Thar Desert, the ground water tapped by 83 % of dug wells has an electrical conductivity (EC) value ranging from 2000  $\mu\text{S}/\text{cm}$  to more than 10,000  $\mu\text{S}/\text{cm}$ . Thus, under normal standard, such quality of water is unfit for human consumption, but the water with EC of 5,000  $\mu\text{S}/\text{cm}$  is considered drinkable under duress for the arid region. As such, 48 % of the water in the dug wells may be considered fit for human consumption in the area.

Figure-9 shows the distribution of electrical conductivity (EC) of groundwater in the Thar Desert. The distribution-pattern indicates three prominent good-quality groundwater zones. In the northern part, EC values less than 3000  $\mu\text{S}/\text{cm}$  prevail, exclusively associated with the perched aquifers encountered in the shallow dug-wells. The perched aquifers contain mostly fairly good to brackish groundwater, but show extreme lateral variation in ground-water salinity over small distances.

The area between Gadro/Khokrapar and Chachro is dominated by EC values greater than 10,000  $\mu\text{S}/\text{cm}$ , indicating poor groundwater prospects. In the central part, south and southeast of Chachro extending from Pakistan-India border to Islamkot, EC values between 2,000 and 5,000  $\mu\text{S}/\text{cm}$  are found, particularly in the relatively deeper aquifer(s). The hydrogeological data indicate good groundwater prospects, particularly associated with deep-seated sedimentary aquifers. Another good prospective area is reflected by the EC values ranging from less than 2,000 to 3,000  $\mu\text{S}/\text{cm}$ , in and around Nagarparkar, where the basement units are exposed. In the area between the central zone and Nagarparkar, EC measurements of the dug well water (values mainly range from 5,000 to 10,000  $\mu\text{S}/\text{cm}$ ) indicate brackish to saline water- quality. In this area, deep sedimentary aquifers have not been explored in detail.

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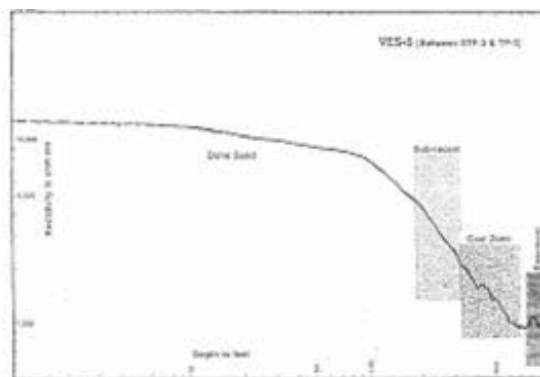
Source: JTB, 1994; Ploethner, 1992; GSP, 1962

**Figure - 9: Distribution of electrical conductivity of groundwater in the Thar Desert**

Occurrences of better groundwater ( $EC < 2000 \mu S/cm$ ) are associated only with the exposed granite unit in Nagarparkar area (Fig.9), where basement is exposed otherwise no good-quality groundwater is so far exploited, associated with the basement at deeper depths throughout the Thar region. At places, vertical electric soundings have indicated good prospects for the good quality groundwater associated with the basement complex (Figure-10).

### REGIONAL GRADIENTS

Basic tendency of water is to flow to the lowest topography on the down slope. In view of this physical property, the regional gradient-maps of surface and major subsurface interfaces



**Figure 10: Deep vertical electric sounding shows layered basement indicating groundwater potential in basement units**

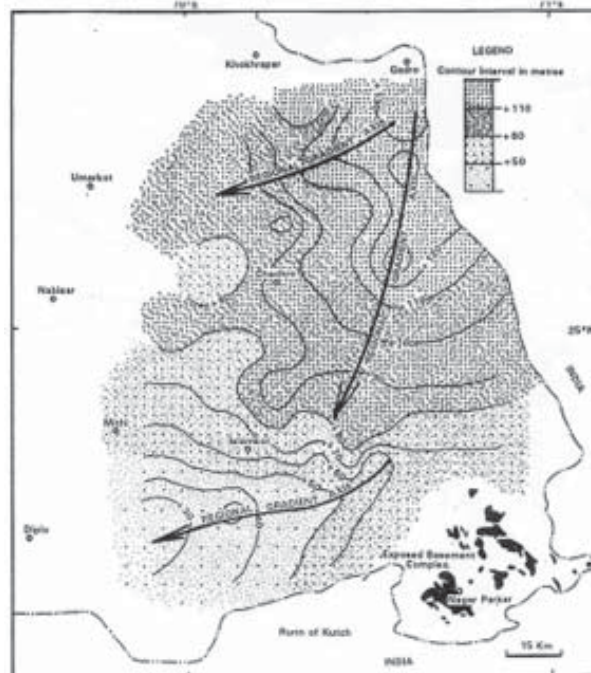
have been generated to study the surface and the subsurface water-movements in the Thar Desert. For this study, the spot elevations and the collar elevation of the drill holes have been used. The drill holes are located more or less on uniform grid, covering almost the whole Thar Desert. Moreover, all the holes were drilled in the interdunal valleys.

### Surface Gradient

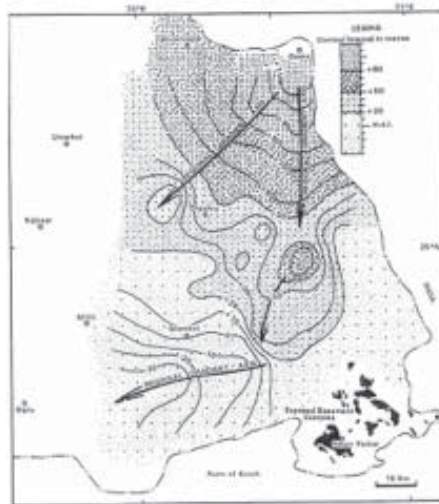
Figure-11 presents the smoothed topographic map to illustrate the regional surface-gradients. Three surface-gradient trends are distinct across the Thar Desert. Originating from northeastern corner of the study area, one trend is towards west, approaching Nabisar-Umarkot area, and the other trend is towards south, approaching Islamkot area. There is a significant change in regional gradient striking in east-west direction along Mithi-Islamkot area. South of Mithi-Islamkot alignment, there is a west-trending gradient, starting probably from the western edge of the subsurface continuation of the Nagarparkar basement complex.

### Gradient at Top of Oxidized Zone

Figure-12 shows depth-contours on top of the zone of subrecent sediment or the bottom of the dune zone. The trend of contours shows that the gradient-pattern is more or less similar to

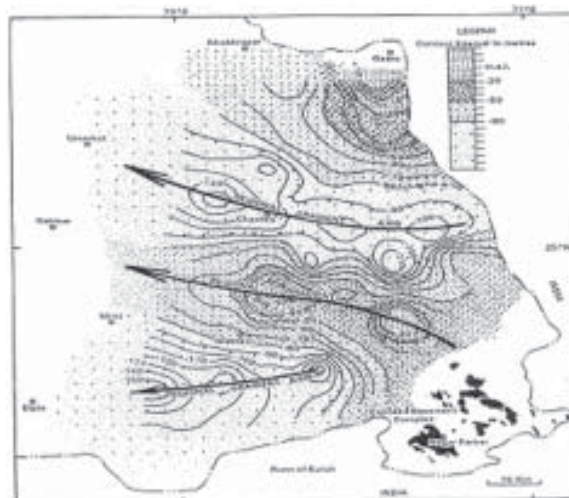


**Figure 11: Map showing smoothed topography of the Thar Desert illustrating regional gradient trends which control over-all movements of water-recharge conditions**



**Figure 12: Subsurface configuration of top of the Oxidized Zone in Thar Desert. Arrows show major gradient trends**

the surface-gradient trend. Thus, it is inferred that the depositional environments for the Oxidized Zone were initially similar to those under which the Dune Zone was deposited. In the southeast of Chachro, there is a significant subsurface mound-like body, indicating a possible differential erosional feature. Moreover, there is also a marked change of south-trending gradient in Mithi-Islamkot area. South of this area, the main gradient is towards the west, as in the case of the surface-gradient trend.



**Figure 13: Subsurface configuration of top of coal-bearing formation beneath the Subrecent Oxidized Zone in the Thar Desert**



Compaction of the deposited sediments and the surface oxidization seem to be due to the prevailing last glaciation, earlier to about 22,000 years BP. Perched aquifers occur at the bottom-part of the dune-zone on the top of the Oxidized Zone consisting of mainly clays as underneath seal.

### Gradient at Top of Coal-Bearing Formation

Configuration of the top of the consolidated sedimentary sequence, underneath the subrecent Oxidized Zone, shows a different gradient trend (Figure-13). It is almost trending NNW, perpendicular to the trends of the overlying zones of unconsolidated sediments. It is interesting to note that between Islamkot and Chachro there is a ridge-like structure, striking in regional gradient direction bounded by elongated depressions on either side. To the east, both the depressions appear to terminate, possibly against the subsurface continuation of the basement complex, but westward they are broader and continuous. Based on the available data, two possible interpretations are proposed here:

- *Either*, the area between Islamkot and Chachro represents a horst block and the depressions on its northern and southern margins are the counter-graben blocks;
- *Or*, the depressions are the buried palaeo-channels representing deeper erosion of the coal-bearing formation, whereas the central part, between Islamkot and Chachro, represents the area where the formation was relatively less eroded.

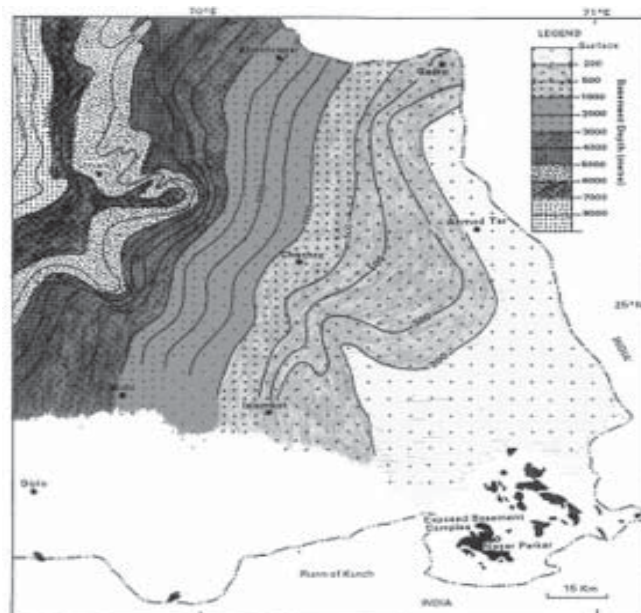


Figure 14: Thar Basement configuration analyzed from seismic resistivity and drilling data

### Gradient of Thar Basement

Figure-14 shows the basement configuration interpreted from the seismic data, deep-resistivity data and drilling data (Zaigham and Ahmad, 2000; 1996; Fassett and Durrani, 1994). Depth contours show three distinct anomalous zones of curvatures. The first zone lies in the southeastern part of the map, i.e., southeast of Chachro, where the contours indicate gentle dipping with 0.7% gradient. Further southeast of 200-meters contour, the basement appears at shallower depth, i.e., less than 200 meters. The pattern of shallow depth contours also indicates that the lateral extensions of geological formations in the northeast and in the southwest are bounded by relatively steeper gradients.

In the second zone, which lies to the northwest of Chachro, there is a sharp gradient of depth-contours trending northeast-southwest, indicating steep slope of the basement in northwest direction. In this zone, the basement gradient ranges from 4% (between 500 and 1000-meters Contours) to 9.8% (between 1000 and 3000-meters contours).

The pattern of the basement depth-contours abruptly changes beyond contour of 3000-meters, which, in fact, is the third anomalous zone. The trend of the gradient beyond 3000-meters contour indicates a steep large-scale offset of the basement in the northwestern side. There are very steep slopes, with limited lateral extent, indicating irregular surface of the basement. The basement is deepening around Umarkot area continuously towards northwest, with an average gradient of 11.3%.

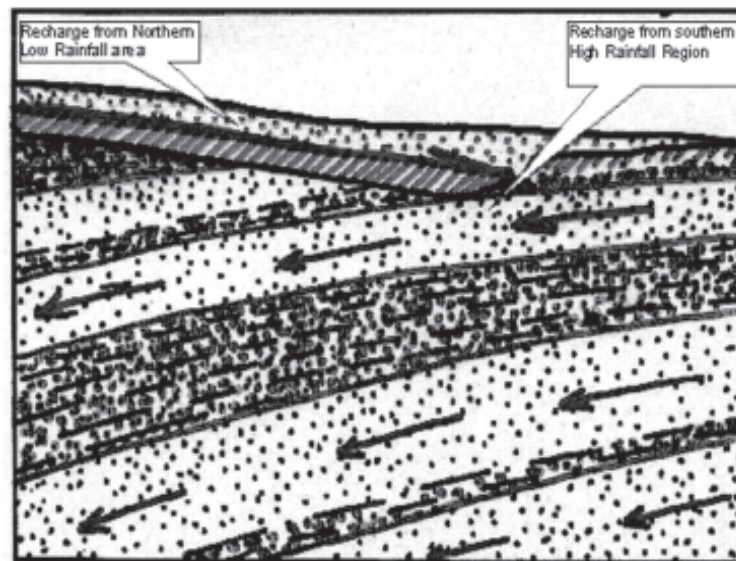
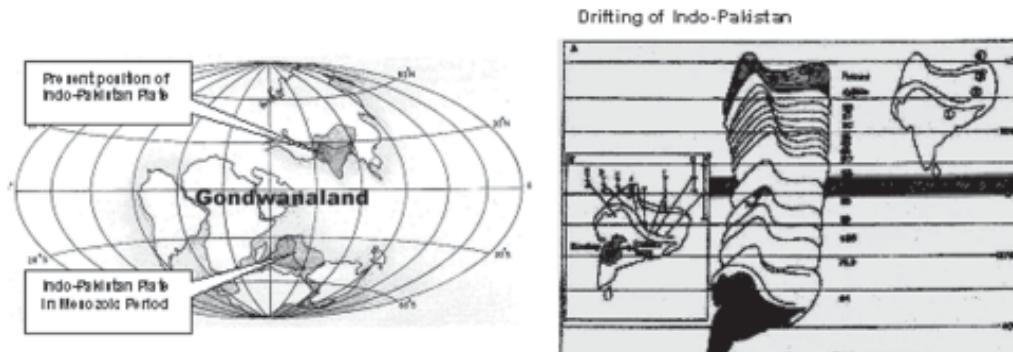


Figure 15: Schematic model shows the relationship between the regional gradients and the recharge conditions (groundwater flow) based on the rainfall conditions





**Figure 16: Left inset shows papaeo-Mesozoic position of Indo-Pakistan subcontinental plate comparing it with the present-day position. Inset on the right shows northward drifting of Indo-Pakistan plate from late-Mesozoic time to present-day**

## DISCUSSION

From the integrated surface and subsurface study, it is found that the regional gradients associated with the Dune Zone and the Oxidized Zone are from north to south, southwestward and westward. This study reveals that, regionally, the groundwater recharge to the unconsolidated sediments, i.e. the Dune Zone and the Oxidized Zone, is from the areas lying in the north of the Thar Desert (Figure-15). Figure-1 shows very arid areas in the north of the Thar Desert, where average rainfall is reported about 100 mm/yr or less. Moreover, in the northern part of the Thar Desert itself, the average rainfall is about 160-200 mm/yr with occasional drought cycles. The whole rainfall picture of the areas in the north of the Thar Desert and northern part of the Thar Desert itself indicates very poor recharge-conditions to the perched water aquifers throughout the area. That is why, any drought cycle affects the living activities of the Thar Desert immediately and adversely.

On the other hand, the regional deep-seated gradients associated with the sedimentary sequences and the basement are almost in the opposite directions to that of surface gradient and the subsurface gradient on the top of the Oxidized Zone. Moreover, the average rainfall conditions are also reverse, as compared to the northern and northwestern areas. In the southeast, i.e. the Nagarparkar area (where the basement rocks are only exposed) the average rainfall is about 360 mm/yr. Further southeast, the rainfall goes up to 1000 mm/yr in Udaipur area of India across the border. The higher precipitation in the southeastern Thar, i.e. Nagarparkar and surrounding areas, provides good recharge conditions to the confined aquifers of the consolidated sequences and the basement.

Moreover, aquifers associated with the Nagarparkar basement complex may also provide good- quality connate water. Palaeomagnetic study (Klootwijk, 1979) indicates that the area had remained in the southern polar region at about latitude 40°S, covered with ice from time,

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to time as a part of the Gondwanaland during Paleozoic-Proterozoic time (Figure-16). During Paleozoic time, intracontinental rifting developed flexure basins and associated fault systems, with a number of fracture zones, due to the stretching of the upper crustal part of the Gondwanaland (Zaigham et. al, 2000). Such rift-basins and ice-covers created a number of sweet-water lakes, which might have served as the source of sweet water for the basement aquifers. Seismic study illustrates the presence of the deep-seated pre-Mesozoic fossil rift in the Thar Desert of Pakistan (Figure-6). In addition, at places, the earth-resistivity soundings have also indicated good prospects for good-quality groundwater associated with the basement complex (Zaigham and Ahmed, 2000).

Based on exploitation of the deeper water resources associated with sedimentary sequences and the basement rock units, a better socio-economic development of Thar Desert could be possible. If due attention is paid to the results of the present investigations, significant sustainable agricultural targets could be achieved since, already, Nature has created environments to stabilize sanddunes, siltification in interdunal valleys, and significantly encouraging rainfall conditions.

### **CONCLUSIONS**

1. The present study indicates remarkable groundwater potential in the Thar Desert. Three sources have been identified: the bottom of the Dune Zone, the coal-bearing sedimentary units, and the basement.
  2. In general, the regional gradients of the surface and top of the subrecent zone are towards south and southwest. The aquifers at the bottom of the Dune Zone significantly vary in quality (saline to brackish) as well as in their yield, being dependent on rainfall in the northern areas, where the annual average is about 150 mm. The quality of water ranges from bad to marginal, but is usable under duress. These aquifers are the main source of water in the Thar at present.
  3. The regional gradient of the tops of the coal-bearing sedimentary units and the basement are towards northwest. The rainfall conditions in the southeast are generally good; the annual average is 360 mm around Nagarparkar. Moreover, further southeast, it increases up to 1000 mm in the Udaipur area. The recharge condition of the aquifers associated with the coal-bearing sedimentary units and basement is excellent, as compared to that at the bottom of the Dune Zone. The quality of water found in coal-bearing sedimentary units is generally brackish, whereas in the basement it is sweet.
  4. In general, research-approach is lacking; in order to boost socio-economic development in Thar Desert, more detailed research studies are imperative for the formulation of a scientific systematic future strategy for exploration and development of deep water resources associated with sedimentary sequences and basement.
  5. Due attention to groundwater-research activities can de-desertify the area, since Nature has already created conducive environments to stabilize dune sands, give better siltification in valleys, and significantly encouraging rainfall conditions.
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# **Mathematical Modeling of the Upper-Indus Glaciers**

*Khalid Rashid*

# MATHEMATICAL MODELING OF THE UPPER-INDUS GLACIERS

## ABSTRACT

*Acute water-crisis last summer lead to the desperate suggestion that water-needs could be met by melting the water-resources frozen as glaciers in northern areas of Pakistan, Northern areas are a precious resource, both for the high lands and the low lands, and this resource needs to be sustained for the survival of our civilization. This is of fundamental importance in the light of global warming and world-wide glacier recession. This article present the characteristics of the Upper Indus Glaciers and suggest ways to model and understand the northern areas, in order to help in attaining the sustainability of this resource.*

## INTRODUCTION

In the spring of 2001, Pakistan was seriously considering the option of melting upper-Indus glaciers to meet the acute shortage of water. Since substantial water-flow of the Upper Indus River originates from zones of heavy snow and glacierized basins in Karakorum and Himalayan region, it is no surprise that this idea found its way to near-acceptance at the highest level of authorities. These authorities saw in it a hope to provide a quick relief to water-starved areas. Natural systems, like the northern areas of Pakistan are non-linear systems that are in a quasi-steady state. Tampering with these systems would disturb the balance and result in serious and unforeseen disastrous ecological and social consequences. Amazing, however, is the fact that this idea caught the fancy of the authorities at a time when the Glaciers in the Himalayas are melting at a rapid rate, while nations debate cuts in greenhouse gases (Marquand). These 15,000 glaciers constitute the largest body of ice in the world, apart from the two polar ice-caps. Their runoff feeds the Indus and the Ganges rivers, whose waters sustain 500 million people in the Indo-Gangetic plains

The very presentation of this idea to melt glaciers reveals the lack of basic understanding of the Upper-Indus Basin glaciers and their relationship with the Indus- valley river system, the life-giver to the Indus Civilization that now forms Pakistan. The northern areas, its high mountains, glaciers and deep valleys, are a very precious resource for both the highlands and the lowlands and this resource we must understand as best we can, so that we are able to utilize it in a sustainable way. To understand and model the northern areas, much basic research should be undertaken. This is no easy task; yet it is absolutely necessary for the survival of Indus Valley Civilization. In this paper, we present a simple introduction to glaciers, a numerical example of glacial motion and a general overview of the Upper-Indus Basin glaciers and suggest steps to initiate research and modeling of this system.

## Mathematical Modeling of the Upper-Indus Glaciers

### FORMATION OF GLACIERS

A large mass of ice that is on land, and shows evidence of being in motion or of once having moved, is called a glacier. The movement of glaciers is now invested with a new and practical interest for humans: early warning of global climatic changes may be indicated by advances or retreats of glaciers. Glaciers exist on all continents, except Australia, and at virtually all latitudes from the tropics to the poles. High latitudes and high altitudes have something in common, for they are both cold. Mountain glaciers, such as those that exist at higher elevations in mid-latitudes and tropics, are particularly sensitive indicators of climate-change.

Glaciers do not just freeze, they grow by a gradual transformation of snow into glacier ice. A fresh snowfall is a fluffy mass of loosely packed snowflakes, which are small, delicate ice crystals, grown in the atmosphere. As the snow ages on the ground, for weeks or months, the crystals shrink and become more compact, and the whole mass becomes squeezed together into a more dense form, called granular snow. As new snow falls and buries the older snow, the layers of granular snow are further compacted to form a much denser kind of snow, usually a year or more old, with little pore-space. Further burial and slow cementation – a process by which crystals become bound together in a mosaic of inter-grown ice crystals – finally produce solid glacial ice. The whole process may take from a few to twenty years. The snow is usually many meters deep, by the time the lower layers are converted to ice.

The formation of a glacier is complete when ice has accumulated to a thickness sufficient to make the ice move slowly under its own pressure. When this point is reached, the ice flows downhill, either as a tongue of ice filling a valley or a thick ice-cap that flows out in all directions from the highest central area where most snow accumulates. In mid-latitudes, such as Karakorum region, ice melts and evaporates as it flows to lower elevations. Of the total amount of water on earth ( $1388 \times 10^{15} \text{ m}^3$ ) 97.3 % is in oceans and 2.7% in fresh-water reservoirs. Of this 2.7 %, the glaciers account for 77%, i.e.  $29 \times 10^{15} \text{ m}^3$ , aquifers 22%, lakes and rivers 0.0053% and 0.00345% is in the atmosphere. If all the glaciers were to melt, the sea level would rise by about 70 meters worldwide. Changes in glaciers seem to be quite sensitive to global climate-changes. Of the numerous physical systems on Earth, glaciers are one of most responsive to climate-change. This is reason enough to study and understand the changes seen and expected in the Karakorum/Himalaya glaciers.

### THE BUDGET OF A GLACIER

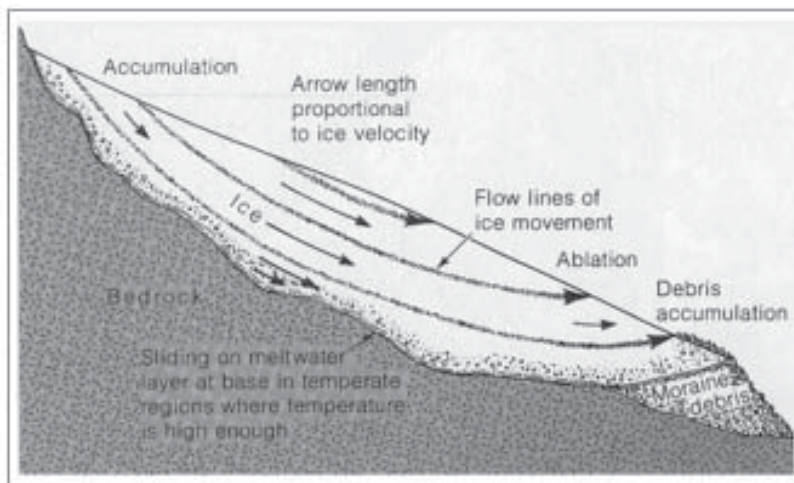
During winter, the typical glacier grows slightly as snow falls everywhere on the ice surface. In summer, the glacier shrinks, mainly as the snow on the surface of the lowermost reaches melts and evaporates to uncover solid ice, while the upper reaches stay snow-covered.

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The annual growth budget of a glacier is the amount of solid water added by snow, the accumulation, minus the amount lost, called ablation. The difference between accumulation and ablation is a measure of either growth or shrinkage of a glacier. Glacier budgets fluctuate from year to year, and many show long-term trends of growth or shrinkage, in response to climate variations over periods of many decades. In temperate climates, ablation occurs mainly by melting under the Sun's rays and less by evaporation. Warm air may blow over lower regions and speed the melting further; the air becomes chilled in the process. If the air is humid, it may precipitate rain, causing even more ablation. The melt waters from Upper Indus Basin glaciers and high altitudes in northern areas are the main source of water in the Indus and its western tributaries and are therefore a question of survival for Pakistan.

### HOW ICE MOVES

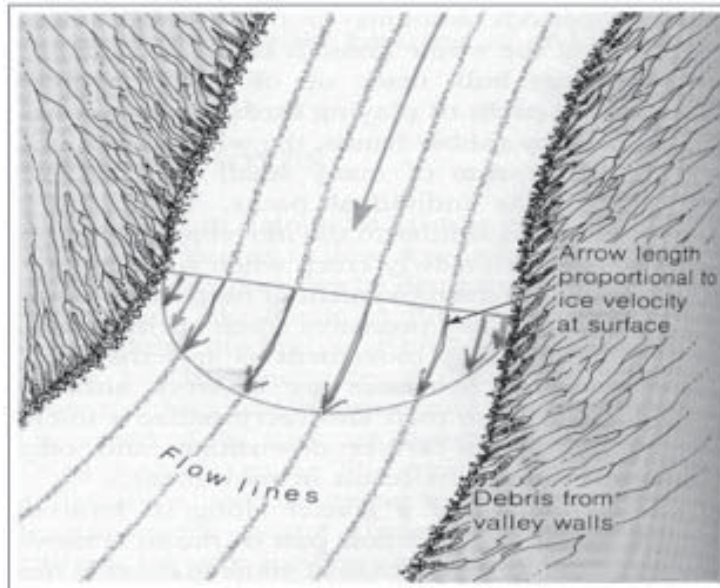
Once the ice on a slope builds to a great enough thickness, it moves throughout its bulk by internal sliding or flowing movement, as well as its base. The internal flow throughout the ice accounts for much of its motion. Under the stress of its weight, the individual ice crystals slip tiny distances of about  $10^{-7}$  of a millimeter in short time intervals. The sum total of all these movements of enormous number of ice crystals over longer time periods, amounts to larger movements of the whole mass. This movement is similar to the movements shown by some metals, which slowly creep when subjected to a strong stress. Other processes that give rise to movement are also at work. Ice crystals tend to melt and



**Figure-1: How ice flows in a typical valley glacier. The rate of movement decreases towards the base. If the temperature at the base is sufficiently high than the ice pressure will cause melting, the entire thickness of the glacier will start sliding along the liquid layer next to the ground (Press and Siever)**



## Mathematical Modeling of the Upper-Indus Glaciers



**Figure-2: A Valley Glacier Moves More Rapidly At The Centre And With a Greatly Reduced Velocity Along The Valley Walls. From (Press and Siever)**

recrystallize a microscopic amount farther downslope, and other crystal distortions result in movement.

The sliding of a glacier along its base accounts for an important part of the total movement. The ice at the base of some glaciers is near the melting temperature, and much of the movement takes place there. Some of the sliding is caused by the melting and refreezing of the ice at the base. The centre of the tongue of ice moves faster than the edges where friction of the ice against the rock walls hinders the flow. Typically, a rapid movement is about 75 meters in one year.

Sudden movements of glaciers, called **surges** occur after long periods of slow movement. Surge may last for one to three years and travel at more than 6 kilometers in one year. Surges may be caused by increase in melting of the base of the glacier, allowing it to slide rapidly, or intermittent releases of ice that piles up in the middle parts of the glaciers while the lower parts are melting. Surges in the Upper Indus Glaciers are relatively frequent and catastrophic. This is not surprising, in view of the large differential in climate along the length of the glacier, because at places the elevation changes are very rapid. The Kutiah Glacier in Karakorum holds the record for the fastest glacial surge. In 1953, it raced more than 12 kilometers in three months, averaging about 113 meters per day.

### AN EXAMPLE FROM THE THEORY OF GLACIAL MOTION

A non-linear differential equation in two independent variables furnishes a mathematical description of the conditions in a glacier, particularly in the glacier tongue, or ablator, and appears in the following form (Finsterwalder).

$$\boxed{[(n+1)\kappa u^n - a] \frac{\partial u}{\partial x} + \frac{\partial u}{\partial t} = -a \quad (1)}$$

It pertains to a central longitudinal section of a glacier moving down a slightly inclined, straight bed.

The variables  $u$  and  $x$  refer to oblique axes in the plane of the section:  $u(x,t)$  is the vertical depth of the ice at time  $t$  at a distance  $x$  along the bed. (Figure-3). The velocity distribution is assumed to be of the form  $v = \kappa u^n$ , where  $\kappa$  depends on the slope of the bed and the

exponent  $n$  is a constant lying between  $\frac{1}{4}$  and  $\frac{1}{2}$ . The remaining symbol is an ablation constant; it represents the annual melting on horizontal surfaces. This particular example here concerns a receding glacier on a very flat bed.

Let the shape of the longitudinal section of the glacier at time  $t = 0$  be given in dimensionless variables by

$$\boxed{u = 2 \frac{4-x}{5-x} \quad \text{for } 0 \leq x \leq 4 \quad (2)}$$

and for numerical values of the parameters take  $n = \frac{1}{3}$ ,  $\kappa = 0.075$ ,  $a = \frac{1}{2}$ . Then Equation

(1) becomes

$$\boxed{[0.1\sqrt[3]{u} - 0.5] \frac{\partial u}{\partial x} + \frac{\partial u}{\partial t} = -0.5 \quad (3)}$$

The characteristics equations for equation (1) read

$$\boxed{\frac{du}{dx} = -a, \quad \frac{dx}{ds} = (n+1)\kappa u^n - a, \quad \frac{dt}{ds} = 1. \quad (4)}$$

## Mathematical Modeling of the Upper-Indus Glaciers

Their goal solution is a two-parameter family of curves in the  $(u,x,t)$  space; in this case the curves are plane and are given by:

$$\begin{aligned} x + \xi &= -\frac{\kappa}{a} u^n + u = u - 0.15u^{\frac{4}{3}} \\ u + \eta &= -at = -0.5t \end{aligned}$$

where  $\xi$  and  $\eta$  are the parameters. From this two-parameter family, we select the one-parameter family of curves which passes through the points of the initial curve given by equation (1); the surface formed by the totality of these curves constitutes the solution of the problem. We select a set of points on the initial curve and calculate the corresponding characteristic parameters; for example the point  $t = 0, x=3, u=1$  yields  $\xi = -2.15, \eta = 1$ . Then the projections of these characteristic curves may be drawn in a  $(u,x)$  plane and graduated at (say equal) intervals in  $t$ ; curves joining the points with the same values of  $t$  give the shape of the longitudinal section at various values of  $t$ . (Figure-4).

For a rapid quantitative survey we can solve the equation (1) by finite difference method and avoid the laborious integration of the characteristic equations. The details of the numerical solution, the algorithm and the computer program will be the subject of a specialised presentation elsewhere. Here we present the results geometrically in Figure-4.

## THE UPPER INDUS BASIN GLACIERS

The UIB(Upper Indus Basin) in the Karakorum and Himalaya mountains constitutes the heaviest snow and glacial cover on mainland. (See Figure-6).

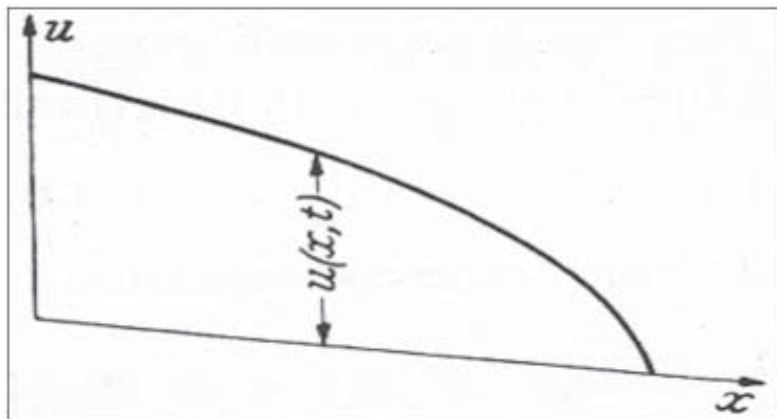


Figure - 3: Longitudinal Section of a Glacier

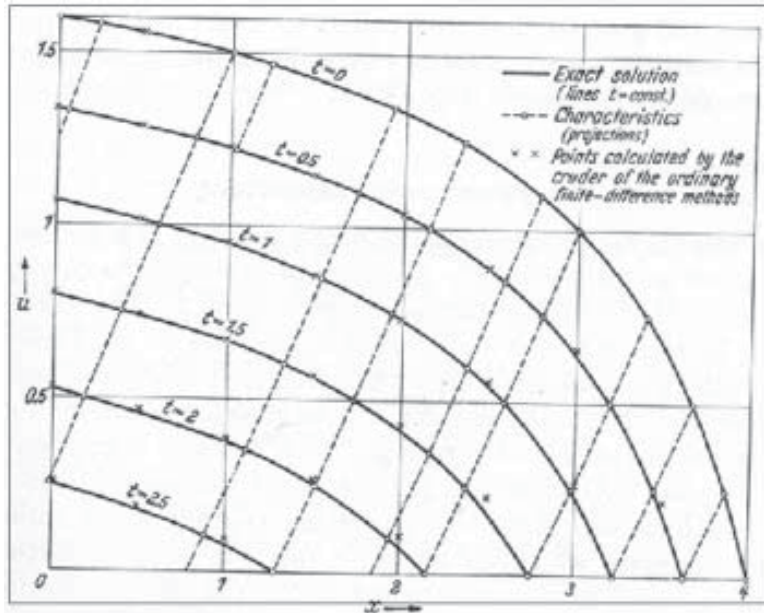


Figure-4: Profile of a Glacier at Various Times as an Example of The Integration of A First Order Partial Differential Equation



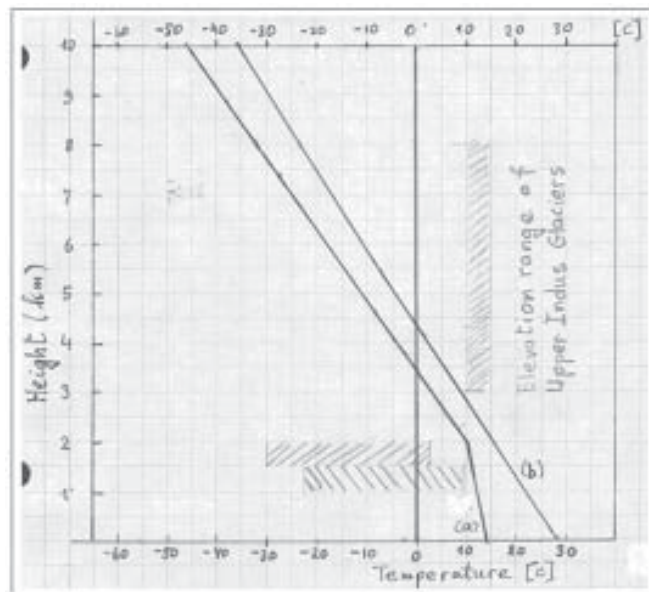
Figure-5: The Karakoram Range Showing The Extent of Perennial Snow and Ice, and The Major River Systems. (From Hewitt 1989a)

## Mathematical Modeling of the Upper-Indus Glaciers

This region has the largest concentration of peaks higher than 6000 m; the glacialised basin area is about 15150 km square, with total snow and ice-cover of 22000 km square. The bulk of the glacier landscape lies between 3000 to 6000 m elevation. There are many glaciers of large size, exceeding 25 kilometer in length.

One special characteristic of the UIB glaciers is the large elevation range from the terminus to the highest parts of the watershed. For some glaciers, this range exceeds 4500 meters. These glaciers are subject to three different weather-systems, namely extremely cold, temperate and semi arid. These features make the Karakorum glaciers different from glaciers in North America, Japan, New Zealand, and even Pamir and Himalayas. For this reason, it is instructive to pay attention to Figure-6 that shows the variation in January and July average temperatures with height for 30°N (Neilburger 1973).

We note that the January average temperature is below freezing at about 3000 meter above sea level and in the summer month of July this is the case at about 4500 meter above sea level. Large parts of UIB glaciers lie in a temperature range below freezing through the year. So the conditions above an altitude of 4500 meter are conducive to glacier-growth, particularly in winter, if there is enough precipitation. Melting takes place at the middle and lower zones, i.e. the ablations zones, of the glaciers between 4500 to



**Figure-6: Temperature Variation With Height. (a) January Average. (b) July Average. [////] is the Temperature Range from 3000 to 8000 Meters Above Sea Level In July. [\\\\\\\\] Is The Range In January**

3000 meters above sea level, mainly in the months of June, July and August. In the accumulation zone, with an altitude greater than 5000 meters, the temperatures do not rise above the freezing point. So the growth of the glaciers take place in this zone. From here, there is a flux of ice to the lower altitudes ablations zones where most of the melting takes place in the summer months. Climate gradients are difficult to understand. Karakorum has the largest range of altitude-variations and atmospheric changes with altitude and precipitation, as a function of altitude, needs to be understood. In Karakoram the gradients dominate the glacier hydrology.

One of the most important elements of UIB Glaciers that we need to understand is the measurement and quantification of melt water that can depend on various external factors, such as rain and temperature variations and internal factors, such as ice pressures at the base of the glaciers, debris cover, and surges. Snow-melt and melt-waters from this glacier-zone provide half or more of the flows of the main Indus(Hewitt 2001). In Figure-7 we show the hydrographs of Hunza, Kabul and Indus rivers. The discharge increases very substantially in the months of May to September. These are the months when snow-cover disappears from areas below 4500 meters above sea-level and is the time when rapid melting takes place between 3000 and 4000 meters on the middle and lower zones of the glaciers. A detailed study of melt-water for the Biafo glacier basin has been carried out by Hewitt (1989b). Being an important source of water for the Indus River, the understanding of these investigations is a necessary exercise at national level that cannot be over-emphasized.

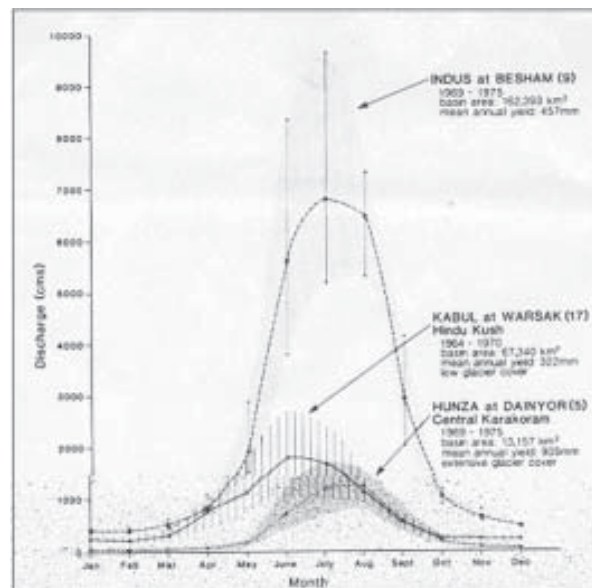


Figure-7: Hydrographs of Indus, Kabul and Hunza Rivers (from Hewitt 1989b)

## Mathematical Modeling of the Upper-Indus Glaciers

Biafo glacier is an important source of water for the Indus river. For the Hunza river, the contribution of the melt-water is, on a relative scale, more than that for the Indus and Kabul rivers, as we can infer from the locations of the discharge maximum. For Hunza River the maximum lies in early June whereas the maximum for Indus and Kabul rivers is in June and July. In June and July, monsoon rains also contribute to the discharge more than in June, which is a monsoon-weak month.

Studies with extensive measurements of ice-loss in the ablation area of Miari glacier in the Karakorum mountains have been made as a part of a joint Canada-Pakistan Ice-Hydrology Project, whose aim was to estimate ice-loss in ablation-areas of glaciers, to predict the stream flows (Young, Schmok 1989). I am not aware if this Project is still ongoing. Needless to say, such studies for the Karakorum glaciers must be undertaken as a national or an international effort, to achieve an understanding of UIB glaciers and stream-flows.

A very necessary national task would be to estimate the total ice-flux from high- altitude accumulation zones to lower altitude ablation zone for the UIB glaciers, because this number is an important measure required in the estimation of overall stream flows. There is an urgent need for extensive field-observations and measurements. These can be very difficult to perform, in higher latitudes, because of the difficult terrain and in the ablation-zones because of the large number of crevices. A fruitful approach would be to train local people of these areas to perform these observations and measurements.

## ARTIFICIAL MELTING OF GLACIERS TO MEET WATER SHORTAGE

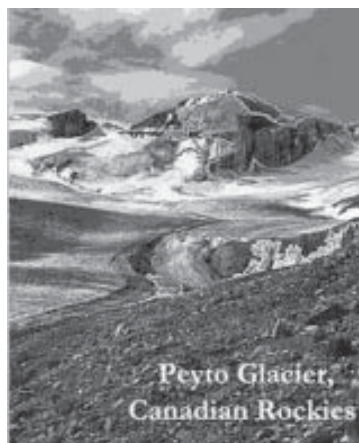
In the spring of this year, Pakistan was facing nearly 30 MAF (Million Acre Foot) of water-shortage for irrigation, about 50 % of its total needs. Farmers, people and, of course, the Government were deeply concerned. It was in this backdrop that a daily paper (THE NEWS of 12-03-2001) carried the following story by G N Mughal: *Pakistan may use laser technology to melt glaciers. Pakistan is seriously considering the option of using laser technology to melt some of its northern areas glaciers and snow lying underneath*.

Although this story appear to be the usual high-level rhetoric of our powerful authorities to calm the thirsty and desperate farmers, but reliable sources indicated the seriousness with which this option was under consideration. This was truly a shock. I have never heard of any attempts to melt artificially the snow and ice cover. Before looking at technological details of such an option, let us work out the energy balance of such an experiment. The energy required to melt 1 cm<sup>3</sup> of ice is 333 Joules. So to melt 30 MAF (about 4.2 km<sup>3</sup>) of ice 1.2 x 10<sup>19</sup> Joules of energy are required. Any good CO<sub>2</sub> laser can have a power of 1000 kW and an efficiency of 20%. Assuming that we have excellent optics to illuminate 100 cm<sup>2</sup> of ice area and that we have the technological capability of operating the lasers, and we want to melt 30 MAF of ice in one month, the electric power required



comes out to be 23,000 one-thousand megawatt power plants! If we suppose that we are a super advanced civilisation that could provide this much power, the cost at 5 rupees per Kwh would come out to be 8.28 million billion rupees or 133 trillion US dollars. Who could foot this bill?

Another idea that made the headlines quoting Chief Engineering Advisor, Government of Pakistan, for artificial melting of snow was to spray glaciers with charcoal dust. Dusting of the ice surface with soot has been shown to accelerate greatly the spring-melt over small experimental areas, particularly in polar latitudes, by lowering the albedo substantially (Arnold, 1961). Taking the solar flux at the surface of the earth to be 700 watts/meter square, the albedo is lowered to zero (i.e. total absorption of solar energy) and no cloud cover at all ( something quite seldom), then to obtain 30 MAF of water one would have to spray 15,000 km<sup>2</sup> of snow and ice cover. So artificially melting snow and ice cover is a science fiction story!



**Figure - 8: Peyto Glacier, Canadian Rockies**

## **CONCLUSIONS AND RECOMMENDATIONS**

- The glaciers of northern areas are an extremely precious resource, for the highlands and the lowlands, and this resource we must understand so that we can preserve it and utilize it in a sustainable way. At the moment, the area is like a black box, the behavior of which we can only unravel by undertaking basic research on these mountains.
- There should be ongoing monitoring of rates of snow-melt and snow-coverage in the Upper Indus-Basin Glaciers and of the high altitude snow-peaks. So, we need to set up monitoring stations. This is no easy task but, without monitoring, there is no chance of ever understanding this region. An essential ingredient of monitoring is trained manpower. There are very few persons trained in snow and ice hydrology. So we



## Mathematical Modeling of the Upper-Indus Glaciers

need to train manpower. One way to do this would be to support financially and technically, with infrastructure, M.Phil and Ph.D theses related to these areas. It would be very worthwhile to hold an international conference on Karakorum Mountains in the year 2002, not only to hear from the experts about the past, present and future of this area, but to commemorate the year 2002 as the year of the mountains. Once some manpower becomes available, a national Mountain Research Institute should be established. At present, there are no stations directly measuring the high-altitude climatic conditions, i.e. precipitation and temperatures. Finally, to model water run-off from the Upper Indus-Basin Glaciers, an integrated approach would be required, incorporating Data collected by satellites, ground measurements and global climatic trends.

- Majority of the Pakistanis and the Government decision-makers are unaware of the lack of understanding of glaciology and hydrology of these glacier regions. In the absence of monitoring-system, no reliable forecast is possible. It appears that the Himalayan glaciers are diminishing, but the Karakorum glaciers are expanding (Hewitt 2001). Whether this is good news or bad news, we can only determine by working out the end-effect on the amount of melt-waters and their reaching the ultimate users.

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# **The Climate and Flood-Risk Potential of Northern Areas of Pakistan**

*Shaukat Ali Awan*

# THE CLIMATE AND FLOOD-RISK POTENTIAL OF NORTHERN AREAS OF PAKISTAN

## ABSTRACT

*The extreme floods in northern parts of Pakistan are caused by glacier lake out-bursts and Dam-Breaks following landslides, which block river valleys. Geographically, glacier dams in mountain rivers and valleys have occurred from the east-western and west-western Karakoram ranges and in the lesser Karakoram range. Floods which arise from Karakoram region pose greater problems, as these floods are neither homogenous nor stationary. These floods arise from various generating mechanisms i.e. generated by melting of snow and glacier and those generated from the monsoon rainfall and dam-breaks following landslide into the river and out-burst of glacier lake. The estimation of present and future risk of flooding at sites in northern Pakistan requires an understanding of the climate, which provides the generating mechanism of floods. Climates are extremely variable and depend on broad global circulation-patterns and local topographic influences.*

*The variables of the climate are studied, using available data, with emphasis on temperature and precipitation. Spatial Co-relation in precipitation and temperature of various northern-area stations have been conducted to find Correlation Coefficient, using regression analysis. This is spread over intra-seasonal and inter-station comparisons. The time-series analysis of the climatic variables has been conducted to examine, geographically and statistically, the trend in their behaviour. This may be reflected in the hydrological regime of glaciers and rivers and it can cause non-linear flood-series through changes in any one of the flood-generating mechanisms.*

*The climate feed-back mechanisms have been discussed, which are practically important because they assist in seasonal prediction of climate and flow in the Indus. Additionally, if climate-warming is causing an upward trend in winter and spring temperatures and reduction in snowfall, the effect might be felt more widely over the region.*

*The non-linear changes with elevation and differences between windward and leeward sides indicate the complexity of the rainfall-distribution in the region. The study gives monthly seasonal and annual total distribution of meteorological variables between various northern-areas stations, while discussing each one with its impact and the co-relation with the other over a wider prospective.*

## THE CLIMATE OF NORTHERN PAKISTAN

The assessment of the present and future risk of flooding at sites in northern Pakistan requires an understanding of the climate, which provides the generating mechanisms of

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## **The Climate and Flood-Risk Potential of Northern Areas of Pakistan**

floods. Mountain climates are extremely varied and depend on both broad global circulation-patterns and local topographic influences. In this study, the variability of climate is investigated, using all available data, with special emphasis on temperature and precipitation. Since the measurement-network is of low density, studies have been carried out to assess the extent to which climate at ungauged sites can be inferred from available records, using correlation and regression analysis.

Mountain climates are influenced by the broad global circulation-patterns associated with latitude, position in the continental mass and proximity to the oceans. During the winter and spring, the Karakoram area is affected by broad-scale weather-systems, originating primarily from the Mediterranean or from the area of the Caspian Sea (Singh *et al*, 1995) from airmass convective storms in the pre-monsoon season, and from monsoon systems during the summer. Even in the summer, there are indications that at least some of the higher-level precipitation is also originating from westerly systems (Wake, 1987). However, in winter, under the prevailing influence of the Tibetan anticyclone, more local conditions prevail. Mountain climates are also influenced on the medium and local-scale by elevation, valley orientation, aspect and slope, as well as the height and number of upwind barriers to the airflow.

Thus, mountain climates are much more spatially variable than neighbouring plains and require a much greater density of measuring stations to define the climate and hydrological regime with the same level of accuracy as on neighbouring lowlands. However, for logistic reasons, the density of measuring stations in mountain-regions is typically much lower than in lowland areas and stations are generally concentrated at lower elevations in valleys and, thus, give a biased representation of the climate. This is certainly the case in the Karakoram. Nevertheless, inferences must be made from the available data.

### **Temperature**

The principal influence on temperatures is that of elevation, but local factors, such as aspect and the duration of sunlight and shadow from neighbouring mountains and heat-reflection from bare hillsides, may produce strong local differences. Mean monthly and annual maximum, minimum and mean temperatures are shown in Table-1. Mean monthly temperatures are shown for the short period automatic weather-stations in Table-4.

The prevailing influence of elevation can be seen in these statistics, with the highest mean annual temperature recorded at the lowest station, Balakot. However the influence of elevation is not uniform and Gupis, which is at a similar elevation to Skardu, is consistently more than 1° C hotter throughout the year. Temperatures at Balakot and Dir are suppressed by greater cloudiness and rainfall, especially during the summer months. Gilgit has the highest average range of temperatures of the stations investigated, and Karimabad, Gupis and Astore the lowest range in the valley, whilst the high-level stations

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at Kunjerab and Shandur have significantly lower ranges. This is likely to be a local effect, dependent on shading or reflection from surrounding hills and duration of sunshine and the persistence of snow at high levels.

Valley floors and levels below 3000 meters receive little precipitation (generally less than 200 mm) and therefore contribute little to runoff. There is considerable orographic enhancement of precipitation and at 4000 meters annual precipitation of greater than 600 mm may be expected. The zone of intermittent melt reaches this level from late March to mid November and continuous melt of any remaining snow can be expected to occur from late May to late September.

### **SOME CONCLUSIONS**

Major summer storms are accompanied by a drop of 12-15°C in daily mean temperature. Daily maximum temperatures are more affected and may fall by as much as 20°C. This results in a drop in the freezing level of more than 2000 m and the occurrence of snow, rather than rain, over much of the high Karakoram basins.

Such reductions in temperature have practical implications, both for short-term flood-forecasting and also for design flood estimation, where based on analysis of storm rainfall. The assessment of effective storm rainfall over a basin, for design purposes, must take into account the freezing-level and the contribution proportion of the catchment below this level.

Evidence from the largest monsoon and post-monsoon rainfalls in the records suggests that the direct contribution of rainfall to river-flow is small in northern catchments, whereas it may result in the most devastating floods in foothill basins. In most instances, the reduction in melt-runoff in high-altitude basins, due to reduced temperature and energy inputs, more than compensates for direct runoff from rainfall, and the occurrence of rainfall is often accompanied by a sharp reduction in flow.

### **PRECIPITATION**

Precipitation is the basic-input to the hydrological cycle, making a direct contribution through rainfall or a delayed contribution as snow. Precipitation is also a factor in the occurrence of mass-movement, though freeze-thaw action and mechanical weathering, as a medium for conveyance of debris-flows, etc., and as a lubricating agent for mass-movement with slipping and sliding mechanisms.

Studies of precipitation-distribution in Northern Pakistan and neighbouring mountains have been more limited due to the limited availability of data, especially at higher elevations. An early study by Hill (1881) suggested that rainfall in the northwest Himalayas increases

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## The Climate and Flood-Risk Potential of Northern Areas of Pakistan

**Table - 1: Maximum, Minimum and Mean Temperatures (For the Main Stations)**

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
<b>(a) Maximum Temperature</b>													
Astore	2.4	4	8.4	14.6	19.2	24.5	27.1	27	23.5	17.2	11.1	5	15.3
Bunji	9.6	12.5	17.9	24	28	33.7	36.2	35.7	32.5	25.7	18.5	11.8	23.9
Drosh	8.8	11	15.9	22.5	28.6	35.6	36.8	35.9	33	26.6	18.9	11.8	23.8
Dir	11.3	12.3	16	22.1	27.3	32.5	31.4	30.3	29	24.8	20.1	13.9	22.6
Gilgit	9.2	12.3	17.7	23.7	28	33.9	36.1	35.4	31.9	25.3	18	11.2	23.6
Skardu	2.6	5.4	11.7	18.3	22.5	28.2	31.5	31.2	27.2	20	12.7	6	18.2
Gupis	4.1	6.6	12.2	18.5	23	29	32.1	30.9	26.4	19.9	13.6	5.8	18.5
Balakot	14	15.4	19.5	25.3	31	35.3	32.3	31.3	30.9	27.5	21.9	16	25
Chilas	12.3	14.5	20.1	26.1	31.1	37.6	39.6	38.6	35.1	28.4	20.9	13.7	26.5
Karim-abad	2.1	4.3	9	16.1	20.2	25.8	28.5	29.4	23.8	18.1	10.7	4.3	16
Misgar	-1.1	1.7	7.2	12.3	16.3	21.2	24.6	25.2	20.8	14	6.9	0.5	12.5
Kunjerab	-13.4	-10.9	-6.8	-0.2	3.6	6.9	11.8	11	6.6	-0.6	-6	-10.5	-0.7
Shandur	-8.9	-6.5	-1.4	5.7	10.6	14.7	19.8	19.2	14.8	7.4	0.5	-5.3	5.9
<b>(b) Minimum Temperature</b>													
Astore	-7.5	-5.7	-1.1	3.5	7.1	11	14.5	14.6	10.5	4.4	-0.7	-4.5	3.8
Bunji	0.1	2.7	7.6	12.1	15.2	19.6	23.4	22.8	18.1	11.3	5.2	1.4	11.6
Drosh	-0.1	1.2	5	10.1	14.9	20.7	23.2	22.5	18.4	11.8	6.2	2.2	11.4
Dir	-2.5	-1.1	3	7.8	11.4	15.6	19.3	18.7	13.8	7.5	2.5	-0.7	7.9
Gilgit	-2.5	0.6	5.7	9.4	11.9	15	18.5	17.9	13	6.8	0.8	-1.9	7.9
Skardu	-8.2	-5	1.5	6.5	9.6	13.5	16.6	16.2	12	4.7	-1.6	-5.4	5
Gupis	-4.9	-2.8	2.2	7.6	11.3	16	18.8	18	13.5	7.2	1.6	-3.1	7.1
Balakot	2	3.9	7.6	12.6	17.2	21	21.3	20.6	17.1	11.5	6.2	2.9	12
Chilas	0.9	3.4	8.4	13.8	18.4	24.3	27.3	26.8	22.5	14.6	7.1	2.1	14.1
Karim-abad	-4	-2.6	2.4	7.2	10.6	13.9	16.4	17.2	11.5	7.7	2.6	-1.8	6.8
Misgar	-13.2	-9.7	-5.4	-0.2	3.4	8	11.1	11.6	6.6	-0.1	-5.8	-10.6	-0.4
Kunjerab	-22.1	-20.2	-16	-10.4	-6.9	-2.8	0.8	0.4	-3.4	-10.8	-15.4	-19.4	-10.5
Shandur	-16.2	-15	-11.8	-5.8	-0.5	4.6	9.4	8.9	4.4	-2.7	-8.7	-13.5	-3.9
<i>Continue on next page...</i>													

(c) Mean Temperature													
Astore	-2.5	-0.8	3.6	9	13.1	17.7	20.8	20.8	17	10.8	5.2	0.2	9.6
Bunji	4.9	7.6	12.7	18	21.6	26.7	29.8	29.2	25.1	18.3	11.7	6.5	17.6
Drosh	4.4	6.1	10.4	16.3	21.8	28.1	30	29.2	25.7	19.2	12.6	6.9	17.6
Dir	4.4	5.6	9.5	14.9	19.4	24	25.4	24.5	21.4	16.2	11.3	6.6	15.3
Gilgit	3.3	6.4	11.7	16.6	20	24.4	27.3	26.6	22.5	16	9.4	4.7	15.7
Skardu	-2.8	0.2	6.6	12.4	16.1	20.8	24.1	23.7	19.6	12.3	5.5	0.3	11.6
Gupis	-0.5	1.9	7.2	13	17.1	22.5	25.4	24.4	20	13.6	7.6	1.4	12.8
Balakot	8.1	9.6	13.5	19	24.1	28.2	26.8	25.9	24	19.4	14	9.4	18.5
Chilas	6.6	9	14.2	20	24.8	31	33.5	32.6	28.8	21.5	14	7.9	20.3
Karim-abad	-1	0.8	5.7	11.6	15.4	19.8	22.4	23.3	17.6	12.9	6.6	1.2	11.4
Misgar	-7.2	-4	0.9	6	9.8	14.6	17.8	18.4	13.7	7	0.6	-5	6
Kunjerab	-17.6	-15.8	-11.6	-5.4	-1.4	2.1	6.3	5.6	1.5	-5.5	-10.7	-14.9	-5.6
Shandur	-12.5	-11.1	-6.8	0	5.3	9.7	14.6	14.1	9.5	2.4	-4.1	-9.2	1.2
Leh	-7.7	-5.8	0.2	5.8	9.9	14.2	17.4	17.1	13.1	6.8	0.8	-4.7	5.6
(d) Mean Temperature Range Between Minimum And Maximum													
Astore	10	9.8	9.5	11.1	12.1	13.5	12.7	12.4	13	12.8	11.8	9.6	11.9
Bunji	9.5	9.8	10.3	11.9	12.8	14.1	12.8	12.9	14.4	14.4	13.3	10.4	12.3
Drosh	8.9	9.7	10.9	12.4	13.6	14.9	13.6	13.5	14.7	14.9	12.7	9.6	12.6
Dir	13.8	13.5	13	14.3	15.9	16.9	12.1	11.6	15.2	17.3	17.5	14.7	14.6
Gilgit	11.7	11.7	12	14.3	16.2	18.9	17.6	17.5	18.9	18.4	17.1	13.1	15.6
Skardu	10.8	10.3	10.2	11.8	12.9	14.8	14.9	14.9	15.2	15.3	14.4	11.4	13.1
Gupis	9	9.3	10	10.8	11.7	13	13.3	13	12.9	12.7	12	8.9	11.4
Balakot	12.2	11.4	11.8	12.9	13.8	14.4	11.1	10.6	13.8	16	15.7	13.2	13.1
Chilas	11.4	11.2	11.7	12.3	12.7	13.3	12.3	11.9	12.5	13.8	13.9	11.6	12.4
Karim-abad	6.1	6.9	6.6	8.9	9.6	11.9	12.1	12.2	12.3	10.4	8.1	6.1	9.3
Misgar	12.1	11.4	12.6	12.5	12.9	13.2	13.5	13.6	14.2	13.9	12.7	10.1	12.7
Kunjerab	8.4	9.9	9.6	10.4	10.1	9.6	11.1	10.8	10.3	9.9	9.4	8.8	9.8
Shandur	7.1	9.2	10.7	11.5	10.5	10	10.5	10.4	10.6	9.9	9.2	8.5	9.9

with elevation, up to about 1200 m, and decrease, thereafter. Dhar and Rakhecha (1981) found that maximum rainfall occurred in the foothills of the Nepal Himalayas at an elevation of 2000 to 2400 m.

Singh *et al* (1995) studied the distribution of precipitation in the Western Himalayas of the neighbouring upper Chenab basin. Data from 31 stations for a common period of 17 years was used. The stations ranged in elevation from 305 m to 4325 m. Separate analysis was made for windward and leeward sides, and for the outer, middle and greater Himalayas.

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Separate analysis was also carried out for rainfall and snowfall, but it is difficult to draw conclusions concerning total precipitation. The windward side is assumed to be the south for both winter and monsoon rainfall.

For the Greater Himalayas, snowfall (total snow/water equivalent) increased linearly through the range of altitude from 2000 m to 4325 m, reaching a maximum of 650 mm. At higher elevations the number of snowy days increases, but the intensity of snowfall decreases. Annual rainfall decreases with elevation as the proportion of snow to rain increases. Total precipitation is of the order of 700 to 850 mm from 3000 m to 4325 m.

Whilst the upper Chenab and Jhelum basins are influenced to a much greater extent by monsoon airflow than the Karakoram, the above conclusions have some bearing on the precipitation regime of the Karakoram. Firstly, the non-linear changes with elevation and the differences between windward and leeward sides illustrate the complexity of spatial rainfall-distribution in the region and this can be expected to be repeated in the Karakoram. Secondly, since the Karakoram are further sheltered from the monsoon airflow by mountain barriers, the monsoon precipitation is likely to be less than that for the Upper Chenab and Jhelum basins at the same altitude. Thirdly, the Karakoram are affected to a much greater extent by the winter and spring westerly weather-systems for which the windward side is the west and the leeward the east.

### **CONCLUSIONS**

- a. At an elevation of about 3000 m, solid and liquid precipitation are about equal over a year.
  - b. Seasonal proportion of rainfall differs from Outer to Greater Himalayas, with 60% during the monsoon season on the windward outer Himalayas and 35% on the Greater Himalayas (windward)
  - c. For the outer Himalayas, more rainfall is received on the leeward side, except during the Monsoon season, while on the windward side the precipitation decreases at elevations over 600 m.
  - d. In the middle Himalayas, rainfall on the windward side increases with elevation up to a certain altitude (varying from 1600m to 2200 m depending on season) and then decreases. Rainfall on the leeward side is lower and has a maximum at about the same elevation range as the windward side. Snowfall increases linearly with elevation on the windward side to a maximum of 950 mm at 2500 m, but on the leeward side it first increases and then decreases. Total precipitation is significantly less on the leeward side.
  - e. Monthly, seasonal and annual totals and seasonal distribution at Gilgit, Gupis and Bunji are very similar.
  - f. These stations also receive amounts very similar to Skardu and Chilas during the period from April to September, but Skardu and Chilas receive significantly greater
-



- rainfall during the winter months. In fact, the winter-season rainfall seems to arrive earlier at Skardu than at any of the other stations, with significant amounts and percentages in December, January and February. This is surprising, as one would anticipate that, with winter-rainfall arriving predominantly on westerly airflow, stations further to the west would benefit first.
- g. Astore is similar to Chilas, Bunji and Gilgit, in receiving only small amounts of summer precipitation (amounts are greater than at Gilgit but summer percentage is lower). Astore's location further south does not appear to add greatly to the risk of monsoon incursions. Seasonal distributions at Chilas and Astore are similar.
  - h. Rainfall at Leh on the Upper Indus is the lowest for any station and its seasonal distribution is quite different from its nearest neighbour, Skardu. The seasonal distributions at Leh and Balakot are similar, with high percentages during the monsoon period, but with very different actual rainfall.
  - i. Snowfall, which is measured using a standard raingauge, is notoriously difficult to measure accurately, mainly because of the effect of windspeed on gauge-catch (Archer, 1998). However, in the prevailing low windspeed in the valleys, this is likely to be less of a problem than in high latitudes or at higher elevations. For the high-level stations at Kunjerab and Shandur as well as several other automatic weather-stations, the automatic measurement of snowfall has been unsatisfactory and not sufficiently reliable to assess annual and seasonal totals.

### Precipitation Correlation

The seasonal and annual correlation-coefficients for precipitation between valley-stations in Northern Pakistan, often separated by major topographic barriers, are believed to be sufficiently high, so that the valley-stations can give a reasonable representation of the year-to-year changes in precipitation over the region as a whole; this confirms Whiteman's (1985) suggestion that low-level stations can give a good indication of precipitation-

**Table-2: Correlation Coefficient (r) Between (A) Precipitation (Jan-Mar) – Lower Triangle – and (B) Spring Rainfall April to June – Upper Triangle, at Stations in the Northern Pakistan**

Station	Astore	Bunji	Drosh	Dir	Gilgit	Gilgit (05-35)	Skardu	Leh
Astore		0.75	0.46	0.24	0.78		0.81	
Bunji	0.57		0.17	0.17	0.79		0.65	
Drosh	0.55	0.11		0.64	0.32		0.27	
Dir	0.52	0.15	0.77		0.28		0.02	
Gilgit	0.68	0.63	0.16	0.17			0.59	-0.14
Gigit 05-35							0.72	
Skardu	0.62	0.29	0.29	0.19	0.41	0.28		0
Leh					-0.16		0.02	

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variations in the upper part of catchments. This will be investigated further, with respect to relationships between seasonal precipitation and runoff.

The following conclusions are drawn from the Tables:

- a. With the exception of Leh, all correlations are positive.
- b. Proximity appears to be the best basis for correlated precipitation, with high correlation-coefficients, for example between Gilgit, Astore and Bunji and between Skardu, Astore and Bunji.
- c. The westerly stations at Drosh and Dir in the Kabul River basin correlate reasonably with each other, but poorly with other stations.
- d. Leh exhibits no correlation with Gilgit and Skardu on a monthly, seasonal or annual basis. In conjunction with the quite different seasonal distribution of rainfall from its nearest neighbour Skardu, the lack of correlation suggests a distinct climatic boundary between the two stations.
- e. Correlation-coefficients for six-monthly seasonal totals from April to September are marginally higher than for October to March, while April to June provides the best r values of the three month series.

### **TEMPERATURE TREND**

Time series of seasonal and annual temperature are investigated graphically and statistically for evidence of trend. Other aspects of trend are sought, in first and last frost dates and in the annual extreme maximum and minimum temperature.

The 100-year change in each of the measures for Skardu and Gilgit is shown in Table-3. The Gilgit record has been broken into two blocks - from 1903 to 1964 and from 1965 to 1999. The sum of the changes is then calculated and the step between the end of the first series and the beginning of the second series is shown in the final column to indicate the effect of the change in location. The level of variance explained by the regression ( $r^2$ ) of temperature with year is low, with the highest value of  $r^2$  of 0.34 ( $r=0.58$ ) for Skardu for annual maximum temperature.

It is noted that there are both distinct similarities and differences in the trends of temperature at the two stations. At Skardu, all measures of seasonal and annual temperature show an upward trend over the twentieth century, but with rates that differ significantly between seasons. Annual temperature during the century has risen by 1.4°C, whilst the mean daily maximum has risen significantly more than the mean daily minimum. The bulk of the change has occurred during the winter-months, with the period January to March being the highest 3-month period, with an increase of nearly 3°C. This represents an elevational shift of approximately 400 m in the frost- line, which would mainly influence whether precipitation occurs as rain or snow and the amount of accumulation of snow available for melt during the spring and summer. In contrast, the increase in spring and summer-

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**Table - 3: 100-Year change in Temperature Measures at Skardu and Gilgit**

Temperature measure	Change 1900-99 °C	Change 1900-64 °C	Change 1965-99 °C	Change 1900-99 °C	Step change 1964-65
	Skardu	Gilgit	Gilgit	Gilgit	Gilgit
Mean annual temperature	1.37	-0.54	0.13	-0.41	-0.81
Mean annual daily maximum	2.35	0.44	0.9	1.34	0.31
Mean annual daily minimum	0.54	-1.52	-0.65	-2.17	-1.92
Annual absolute maximum	2.01	0.01	0.73	0.79	1.43
Annual absolute minimum	2.85	-3.36	0.24	-3.12	0
Jan - Mar mean	2.92	0.51	0.31	0.82	-0.19
Apr - Jun mean	0.99	-1.66	-0.28	-1.94	0.09
Jul - Sep mean	0.72	-0.71	-0.32	-1.03	-0.6
Oct - Dec mean	0.93	-0.56	0.8	0.24	-1.29
Oct - Mar mean	2.11	0.1	0.43	0.53	-1.28
Apr - Sep mean	0.77	-1.31	-0.3	-1.61	-0.17
Last spring frost	-10.8 days	+2.59 d	-3.6 d	-1.0 d	+17.7 d
First winter frost	+3.5 days	-2.16 d	-4.7 d	-6.8 d	-20.7 d
Frost free days	+12.0 days	-4.10 d	-0.4 d	-4.5 d	-37.2 d

temperatures has been quite modest. The change of 0.77°C from April to September, which is the season of snow and glacier-melt, represents an upward shift in elevation of only about 100 meters of the freeze-thaw boundary.

The greater backward movement of the last spring-frost than forward movement of the first winter-frost is consistent with the greatest temperature-changes occurring in the first three months of the year. In addition, the change in frost-free days with elevation is consistent with the difference between average frost-free days at Gilgit and Skardu. The two stations are separated by 750 m of elevation and have a mean difference of 30 frost-free days.

At Gilgit, in contrast, there is a mixture of positive and negative changes, even with the effects of change in station-location taken into account. The mean annual temperature has declined by 0.4°C; annual maximum temperature shows an increase, whilst annual minimum shows a decrease of over 2° C. Seasonally, winter mean-temperatures show an increase, whilst spring and summer temperatures show a decrease. Although the overall trend is different from Skardu, the rank-order of changes amongst the seasons is about

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the same. This suggests that the observed changes are real systematic changes and not simply a function of the random variability of the two series.

The effects of change in location of the station at Gilgit is shown by the figures in Table-3. There was a sharp downward step in minimum temperature in 1965, as also in winter temperatures and particularly in the number of frost free days. In contrast, maximum temperature shows a small rise. For most measures, there was greater change during the first period and very little change from 1965 onward.

### **Periodicity in Temperature**

Periodicity in the time-series may be investigated by inspecting the time series histograms. A 5-year moving average has been added to the histograms for Skardu, and periods with temperatures above and below the trend line are illustrated. However, spurious peaks and troughs occur during the significant period of intermittent data from 1936 to 1954.

Some of the lowest seasonal and annual temperatures occur right at the beginning of the record from 1900 to 1907, and these may have a significant influence on the regression relationships and derived temperature-changes. It is tempting to remove these, as subject to greater uncertainty of measurement due to a greater number of missing days. However, as this was a period of greater frequency of occurrence of GLOFS, the temperature-depression may be glaciologically and hydrologically significant.

For both Gilgit and Skardu, there is a steady rise in mean temperature from the beginning of the century up to a peak around 1915 to 1917, then a sharp decline over the following 5 years to a generally lower level, which is maintained through the 1920s at Gilgit, but at Skardu gradually builds up again to the mid 1930s after which the data become intermittent. Although the pattern of temporal changes is displayed in each season, it is more pronounced during the spring and summer seasons (Apr-Sept).

During the second half of the century, the pattern of changes has been less distinct, with no long runs of above or below-average temperature. At Gilgit, there is the suggestion of below-average temperatures during the 1960s and above-average temperatures during the 1970s, most of which is accounted for by changes during the winter months. At Skardu, the same pattern exists, but is less distinct.

Periodicities and trends are further investigated below, in relation to the occurrence and frequency of glacier-lake outburst floods.

## **CLIMATIC TREND, PERIODICITY AND STATIONARITY OF FLOW AND FLOOD SERIES**

It is concluded that there have been systematic changes, both in temperature and precipitation, during the twentieth century in the Karakoram and that these have a potential significance for the generation of floods in the rivers of the Upper Indus Basin. They are also relevant to water- resources management and to the design and operation of flood-defence and flood-forecasting systems.

Changes in precipitation have been particularly marked and the following are noted:

- a. An overall increase in precipitation; if repeated at higher altitudes (and it is not clear if this is the case) would lead to greater nourishment and vigour of glaciers
- b. An increase in summer rainfall could lead to an increased potential for summer flooding from intense summer-storms
- c. There has been a marked increase over the twentieth century in the annual 1-Day Maximum rainfall, from 10 to 28 mm at Gilgit and from 12 to 30 mm at Skardu.
- d. There appears to be a strong association between rainfall and the occurrence of mass- movement, especially landslides and debris-flows, which could lead to an increased frequency and severity of river blockage and subsequent landslides.

## **HISTORICAL INFORMATION ON GLOF FLOODS**

- 1999 (6 Aug) A debris-flow occurred from a right bank between Khalti Lake and Gupis. There is reported to be a small glacier (Charti Glacier) at the head of this valley and also 2 glacial lakes below the glacier-terminus. The debris-flow crossed the Gupis to Shandur Road and blocked the Ghizer River, creating a lake about 1.5 km in length, now known as Khankhui Lake. The duration of blockage is not known, but the flow over the debris lobe is still constricted to a 5- metre channel, with rapids downstream over a distance of 150 m. This event also occurred without accompanying rainfall.
  - 2000 (27 Jul) A GLOF and debris-flow occurred at Kande from a tributary of the Hushe River (tributary of the Shyok). Villagers referred to a supraglacial lake on the glacier before the flood occurred. A previous flood had occurred from the same source on 25 July 1997, but was much less severe than the one in 2000. Kande village was virtually destroyed in the flood, including 124 houses and a primary school. The event happened in the middle of the day, during a period of exceptionally hot weather and without rain. Villagers heard a roar in the hills about 10 minutes before the arrival of the flood and fled to higher ground and so there were no fatalities. The initial flood/debris wave did most of the damage, but sporadic bursts of water occurred for a further 8 days.
  - 2000 (10 June) A lake formed again in the Shimshal valley, as described above. Water began to flow over the top of the ice-dam on 28 May and breached on 10 June.
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The level in the Hunza was reported as increasing by 10 feet at Passu, but only 2 feet at Hunza. No serious damage resulted, as the breach occurred early in the year when the lake size was small (Focus Humanitarian Assistance, 2000).

### CLIMATIC TIME - SERIES AND LANDSLIDE/DAM-BREAK FLOODS

A significant number of floods, resulting from landslide or debris-flow dambreaks, have occurred over the last three decades, but examples from earlier dates are restricted to events of extreme magnitude. Table-4 provides a summary list of such events, drawn from a variety of sources.

#### Information on Landslide/Dam-break Floods:

1972/3. A mudflow blocked the Hunza River at Batura, following 10.3 mm rainfall in 2 days – date given as 1972 (Miller, 1984). Shi Yafeng (1980) in the introduction to the glaciological study of the Batura glacier refers to the 1973 flood, which damaged the highway and bridge over the Batura channel. The team of Chinese glaciologists was sent to Batura Glacier, in response to this event and to consider reconstruction, and work was done during 1974 and 1975. The report gives no further English description of the event.

- April 11. A mudflow, with a front 20 to 30 m high, occurred from Baltbar Nallah, a left bank tributary 18 km south of Batura. A fan was formed 300 to 400 m wide, over 150 m long and 80 to 100 m high, blocking the Hunza River and submerging the Friendship Bridge constructed in 1970 and creating a lake 12 km long (Xiangxing *et al*, 1980). Mr Ali Madad, owner and manager of the Kisar Inn, Altit, was an eye-witness to the debris flood. He recalls that he and his uncle had reached the Nallah near Gulmit when they stopped their jeep and his uncle went forward to inspect the bridge, there

Table - 4: Floods Generated by Landslide and Debris Flow Dam Breaks

Year	Date	Location	River/Basin	Source
1841	June	Lichar Ghar	Indus	Drew, Hewitt
1858	Aug	Phungurh	Hunza	Belcher, Goudie et al
1937	Jul	Faker/ Hakuchar	Hunza	Said
1974	11-Apr	Baltbar near Batura	Hunza	Cai Xiangxing <i>et al</i>
1974	14-Aug	Batura	Hunza	Cai Xiangxing <i>et al</i>
1977/78		Darkot	Yasin/Gilgit	Raschid (1995) Whiteman (1985)
1970s		Yashpur, Henzel	Gilgit	
1999	Jul	Juj Bargo	Ghizer/Gilgit	

having been some previous rains. Suddenly, he heard a roaring sound and saw a smoke-like mist upstream. A wave-front of stones and mud rushed down the valley, overwhelmed the bridge and killed his uncle instantly, along with some villagers working in nearby fields. He fled and narrowly escaped.

- 1974. A debris flow from a left-bank gully followed heavy rainfall and blocked the Hunza River, which then had a flow of 250 m<sup>3</sup>/sec. The mudflow had a front 5 m high; the stage rose rapidly and submerged the bridge over the Hunza. One hour later, the river cut through the fan deposits
- Raschid (1995) quotes a resident of Darkot on the Upper Yasin River as saying "In 1977 a flood of rocks and mud all but obliterated the village and destroyed every inch of farmland". Whiteman (1985) refers to this event as occurring in 1978.
- 31 Jul/August. A debris-flow from a small steep left-bank nallah at Juj Bargo produced a debris lobe across the river against the rock-face on the right bank. A lake was formed upstream and destroyed the small village of Juj Bargo and still (in 2001) extends about 1 km in length upstream from the remaining barrier. The site is a short distance upstream from Gakuch and the Ishkoman confluence.

#### **SUMMARY OF CONCLUSIONS ON FLOOD STATIONARITY**

Changes in the climate have had, or may have had, an influence on the magnitude and frequency of flooding in rivers in northern Pakistan.

With respect to snow and glacier melt, the magnitude of temperature-changes during the spring and summer are insufficient to have caused a major change in the flood-potential of catchments. However, changes in winter-temperatures are sufficient to have influenced the amount and altitudinal distribution of snow available for melt in the subsequent season and this may influence the magnitude of the summer peak.

Changes in precipitation may be more significant in flood-generation. Not only have the seasonal and monthly totals shown a significant upward trend, but also the maximum annual daily amount. It would thus be inappropriate to include the full 100 year data-set in the assessment of rainfall-frequency at Gilgit and Skardu, but rather to restrict the analysis to the last few decades.

Changes in amount and intensity of precipitation may also play a role in the frequency of landslides, which create river- dams and subsequent flood-waves. It is possible that the greater reported number over the last few decades is a reflection of more frequent occurrence, due to increased rainfall, but it may also be due to the recent presence of scientific observers to record the events. However, it is clear that there are sufficient

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occurrences of landslide and debris-flow blockages of many rivers, so that the possibility must be considered in any design-estimation. A previous occurrence implies that there is a risk of future recurrence.

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# **Drought-Mitigation Interventions by Improved Water-Management**

(A Case Study from Punjab - Pakistan)

*Asrar-ul-Haq*

# **DROUGHT-MITIGATION INTERVENTIONS BY IMPROVED WATER-MANAGEMENT** (A Case Study from Punjab - Pakistan)

## **ABSTRACT**

*The article presents the main features of the water-scarcity management plan that was implemented during the last two Rabi seasons, to optimize wheat-production in the Punjab province. Due to severe drought conditions in the country, the river-flows remained well below the normal range, resulting in overall 18% and 43% shortfall in canal-water supplies during the Rabi seasons of 1999-2000 and 2000-2001, respectively. In order to address the adverse impacts of the serious water-shortage, the Punjab Irrigation Department formulated a comprehensive and action-oriented plan, in consultation with the Agriculture Department and the farmers' representatives. The main thrust of the plan focused on: conserving water during the slack-demand periods and its reallocation during sensitive growth-stages, priority canal-water allocation to the saline groundwater areas, and providing one to two waterings to the non-perennial areas.*

*The implementation of Rabi Plan was closely monitored throughout the crop-season by the senior irrigation-managers and the needed adjustments were made in timely response to the actual water-availability. The information regarding the Plan and its subsequent operation was disseminated through the media and the Extension Wing of Agriculture Department. In order to improve internal water-management regime, as well as to ensure farmers' participation in planning and efficient operation of the canals, Water-Allocation Committees at the canal-command level and canal-division level were established throughout the province.*

*As a consequence of the innovative and bold water-management interventions, the province harvested bumper wheat-crops, despite serious water-shortages. The paper highlights the need for close and continuous monitoring of the planned operations, as well as, the significance of other non-water inputs, like realistic support-price, timely sowing of wheat, improved availability of fertilizers, better seeds, and efficient extension services. The experience of the last two crop-seasons has demonstrated that considerable scope exists for optimizing the water- management at macro and micro-levels. It also brings into focus the importance of advance resources-planning, timely dissemination of the information regarding canal-operations and local-level water-management for mitigating the impacts of droughts.*

## **THE SETTING**

Pakistan has the distinction of having the largest contiguous gravity-flow irrigation-system in the world. The irrigation-system serves as a lifeline for sustaining the agriculture in this part of the world, having arid to semi-arid climate. Irrigated lands supply more than 90 per cent of agricultural production, and account for 25 per cent of GDP. They supply most

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of the country's needed food-grain and also are the source of raw materials for major domestic industries.

Irrigation in the Indus Basin has a long history, dating back to the Indus Civilisation. Irrigation development on a scale unknown in history, however, started about the middle of 19<sup>th</sup> century under British rule. The inundation canals were first improved, and then gradually converted to properly- regulated perennial channels, by means of weirs and barrages constructed across the rivers. Large inter-basin link canals and storages were subsequently constructed, as a consequence of Indus Water Treaty in 1960s and the first half of 1970s. The existing storage capacity of Tarbela and Mangla reservoirs, constructed as a sequel to Indus Water Treaty, is rather small; being less than 10% of the average annual river flows. The construction of these storages and link-canals allow operation of the Indus-Basin Irrigation System in a more integrated manner, with greater control and flexibility. This, however, requires comprehensive advance planning and technical expertise to optimise canal operations (Haq, 1998).

The Punjab Irrigation network was designed as a 'protective' system, with low cropping intensities. However, over decades of canal-system operation and as a consequence of rapid growth of population, the irrigation demand has increased way beyond the designed capacities. The Irrigation network of the Province comprises 21 canal-systems, about 8000 km of drains, 6000 large-size public tubewells and around 500,000 small-capacity private tubewells, 31 small dams and an extensive flood-protection infrastructure. There are 14 major barrages on the five rivers flowing in the heart of this valley, with a total off-take canal capacity of 3400 cusecs of irrigation supplies and another 3100 cusecs capacity of inter- river links. The colossal canal network provides irrigation facilities to 8.5 Mha of fertile lands in the Punjab. Of this, 5.3 Mha receive year-round (perennial) supplies, while 3.2 Mha get canal water only during six summer months (non-perennial canals). There are two main crop- seasons, i.e. Summer (Kharif) and Winter (Rabi). Cotton, sugarcane and rice are the main Kharif crops, while wheat is the principal Rabi crop. The groundwater development, by means of small-capacity private tubewells, has played a significant role in supplementing irrigation-water supplies during the last three decades and, in most of the Fresh Groundwater areas, the tubewells are contributing around 40% of the overall irrigation water requirements (PGC, 2000).

## **WATER MANAGEMENT REGIME**

The waters of the Indus Basin Rivers stand apportioned between the four Provinces of Pakistan, through the Water Apportionment Accord of 1991. The province-wise Accord allocations are presented in Table-1, while the historic uses (1977 – 82) are given in Table - 2 (GOP, 1991). The Indus River System Authority (IRSA) was established in 1993 for water-allocation and the implementation of the Water Accord. This Authority prepares the forecast of water-availability for each crop-season i.e. Kharif and Rabi, and determines the provincial shares, in accordance

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Table - 1: Accord Allocations\* (BCM)

Province	Kharif	Rabi	Total
Punjab	45.6	23.21	68.81
Sindh**	41.75	18.23	59.98
NWFP	4.28	2.83	7.11
Civil Canals***	2.21	1.48	3.69
Baluchistan	3.51	1.25	4.76
<b>Total</b>	<b>95.14</b>	<b>45.52</b>	<b>140.66</b>
	<b>+</b>	<b>+</b>	<b>+</b>
	<b>2.21**</b>	<b>1.48**</b>	<b>3.69**</b>

Note: \* Para 2 Allocations  
 \*\* Including already sanctioned Urban and Industrial uses for Metropolitan Karachi  
 \*\*\*Un-gauged Civil Canals above the rim stations.

Table - 2: Actual Average Historic Uses 1977-82 (BCM)

Province	Kharif	Rabi	Total
Punjab	42.62	24.29	66.91
Sindh	35.41	18.34	53.75
NWFP	2.24	1.59	3.8
Baluchistan	1.59	1.01	2.6
<b>Total</b>	<b>81.83</b>	<b>45.23</b>	<b>127.06</b>

with the provisions of the Water Accord. The Provincial Irrigation Departments formulate the canal regulation program for the crop-season, according to the provincial shares intimated by IRSA. If the available share is less than the crop requirements, a canal rotational program is prepared, to distribute the available supply equitably over the entire canal-system. Water-Allocation Committees, comprising representatives of Irrigation and Agriculture Department, as well as representatives of the farming community, are constituted at all the main canals and branch canals level to formulate, approve and monitor the implementation of the rotational programs.

#### WATER AVAILABILITY DURING LAST TWO RABI SEASONS

Drought conditions were experienced in Pakistan during the last two years; the water shortage was particularly severe during Rabi 2000-2001. The monsoon rains were also erratic and below normal in the canal-irrigated areas. The initial forecast of water-availability prepared by IRSA indicated that the expected water-availability for Punjab canals during the Rabi period 1999-2000 would be about 20.9 BCM, against Punjab Accord share of 23.2 BCM and projected

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<b>Box -1: Rabi Plan 1999-2000</b>	
❖	All non-perennial canals in cotton-zone were closed from 5 <sup>th</sup> Oct., instead of 15 <sup>th</sup> October.
❖	All perennial canals in cotton-zone were closed from 15 <sup>th</sup> to 31 Oct.
❖	The flow-period of NP canals in rice-zone was extended from 15 <sup>th</sup> Oct. to 31 Oct.
❖	All perennial canals in rice-zone were closed from 1 <sup>st</sup> to 15 <sup>th</sup> November.
❖	15 days watering in non-perennial canals in the cotton-zone was released from 20 <sup>th</sup> Nov. to 5 <sup>th</sup> December.
❖	All perennial channels were run with 10% shortfall during January to 10 <sup>th</sup> February 2000, to remain within Punjab share.
❖	All perennial channels were closed for a period of 20-22 days during the month of January 2000, to undertake O&M of the Barrages / Main canals and distributary system, as well as save water for use subsequently.
❖	All perennial channels in Mangla/Tarbela Command were raised to full capacity from February 11 to February 29, so as to provide crucial watering during the development stage of wheat-crop.
❖	All Non-perennial channels were given full watering for 15 days from February 21 to March 5.
❖	All perennial channels were reduced to 60% capacity from March 6 to March 31, to remain within the provincial share.

requirement of 27.1 BCM. The actual water-availability was, however, only 20.2 BCM (18% shortfall with respect to historic uses). The water-availability position became even worse during Rabi 2000-2001 and so canal-withdrawals were restricted to only 13.90 BCM, which means that an extremely severe (43%) shortage was encountered. The Punjab Canals Rabi-withdrawals for the 1990-91 to 2000-2001 decade are shown in Table-3 (PID, 2001).

**Table - 3: Punjab Canals Rabi Withdrawals (1990-91 to 1999-2001)**

Year	Water Allocation (BCM)	%Age Diff. w.r.t. Average (+/-)	%Age Diff. w.r.t. Historic(+/-)	%Age Diff. w.r.t. Accord (+/-)
1990-91	27.43	17.83	12.23	18.18
1991-92	23.79	2.2	-2.66	2.5
1992-93	26.17	12.41	7.08	12.75
1993-94	23.06	-0.95	-5.65	-0.65
1994-95	25.21	8.3	3.15	8.62
1995-96	25.94	11.43	6.14	11.76
1996-97	24.55	5.46	0.45	5.77
1997-98	22.64	-2.75	-7.36	-2.46
1998-99	23.23	-0.21	-4.95	0.09
1999-2000	20.2	-13.23	-17.35	-12.97
<b>2000-2001</b>	<b>13.9</b>	<b>-40.3</b>	<b>-43</b>	<b>-40.1</b>

### RABI PLAN, 1999-2000 AND 2000-2001

In order to address the adverse implications of this serious water shortage, PID/PIDA formulated an action-oriented and comprehensive "Rabi Plan", in active consultation with the Agriculture Department and the farmers' representatives. The main thrust of the Plan focused on the following innovative and bold concepts:

1. Conserving water during the slack-demand period and re-allocating it during the critical / sensitive crop-growth stages.
2. Priority canal-water allocation to the Saline Groundwater (SGW) areas, which cover about 30% of the irrigated lands in Punjab.
3. Providing one to two waterings to the non-perennial canal command areas.

In order to implement the above strategies, the broad pattern of canal regulation / management (see Box-1) was planned to optimize the water use.

**Table - 4: Last 10 Years' Wheat Crop Figures**

Period	Area (Mha)	Production (M.Tons)	Average Yield (Tons/ha)
1990-91	5.71	10.51	1.84
1991-92	5.67	11.49	2.03
1992-93	5.96	11.74	1.97
1993-94	5.77	11.21	1.94
1994-95	5.9	12.71	2.15
1995-96	5.97	12.43	2.08
1996-97	5.84	12.37	2.12
1997-98	5.94	13.81	2.32
1998-99	5.94	13.21	2.22
1999-2000	6.18	16.48	2.67
2000-2001	6.08	15.2	2.5
Average	5.91	12.84	2.17

**Table - 5: Last 5 Years' Wheat Crop Figures for Irrigated and Un-irrigated Areas**

Crop	Irrigated Area		Un-Irrigated Area		Total	
	Area (Mha)	Production (M.Tons)	Area (Mha)	Production (M.Tons)	Area (Mha)	Production (M.Tons)
1995-96	5.26	11.49	0.713	0.936	5.97	12.43
1996-97	5.08	11.57	0.76	0.801	5.84	12.37
1997-98	5.21	12.59	9.725	1.22	5.94	13.81
1998-99	5.23	12.16	0.705	1.045	5.94	13.21
1999-2000	5.46	15.53	0.71	0.94	6.18	16.48
Average	5.25	12.67	0.72	0.98	5.97	13.66

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<b>BOX - 2: RABI PLAN 2000 – 2001</b>	
❖	All the Non-perennial canals in Cotton Zone were closed 15 days in advance (01 October instead of 15 October).
❖	All perennial channels in Cotton Zone closed for 3 weeks (10-31 October).
❖	Extension of flow period of NP channels in Rice-Zone by 5 days (upto 20 October).
❖	10 days closure of all Perennial channels in Rice Zone.
❖	Two weeks watering in Cotton Zone for Wheat-Sowing (20 November to 05 December).
❖	Perennial Canals running
	55% Capacity: Upto 15 February
	70% Capacity: Upto 28 February
	30% Capacity: During March
❖	Non Perennial Channels: Closed

The implementation of Rabi Plan was closely monitored throughout the crop season by the senior irrigation-managers and the needed adjustments were made timely, in response to the actual water-availability. The information regarding the Rabi Plan and its subsequent operation was disseminated through the media and the extension wing of Agriculture Department

### INTERNAL WATER-MANAGEMENT AT CANAL-COMMAND LEVEL

In order to improve internal water- management regime, as well as to ensure farmers' participation in planning and operating the canals, for equitable and efficient distribution of irrigation water, Water Allocation Committees at the Canal Command level and at the Canal Division level were established throughout the Province, as below (PID, 2000):

### WATER MANAGEMENT IMPACT ON WHEAT PRODUCTION

As a consequence of the innovative and bold water-management interventions, complemented by improved agricultural practices and incentive offered by enhanced support-price, the province harvested a bumper wheat crop. The following analysis demonstrate the overwhelming impact of water-management optimization on the record wheat-production (GOPb, 1999; GOPb, 2001):

**Table - 6: Wheat Areas and Production in Saline Groundwater Areas**

District	1998-99		1999-2000		%age increase	
	Area (Mha)	Production (M.Tons)	Area (Mha)	Production (M.Tons)	Area (Mha)	Production (M.Tons)
Faisalabad	0.24	0.55	0.25	0.77	4.1	40
TT Sing	0.14	0.35	0.14	0.47	0	34.2
Kasur	0.16	0.4	0.17	0.51	6.2	27.5
Bahawalpur	0.27	0.55	0.28	0.71	3.7	29

- The Wheat-crop figures for the last 10 years presented in Table-4 show that, despite 18% water-shortage during 1999-2000, the area under wheat increased by about 5% and the wheat-production increased by 28% over the last 10 years' average. Although wheat area and production declined during 2000-2001, compared to 1999-2000 bumper crop, yet the cropped area was 3% more than last 10 years average, while the crop-production was 18% higher than the last 10 years average production despite the most serious drought-conditions, which resulted in 43% shortage of canal water.
- It may be noted that the wheat-production in the un-irrigated areas declined by about 5% during 1999-2000 over the last five years average, due to erratic rainfall during 1999-2000 (Table-5).
- The wheat production in four selected SGW districts, where canal-water is the only source of irrigation, increased by 27-40% during 1999-2000 over the corresponding last year figures (Table-6). This clearly demonstrates the positive impacts of priority water-allocation to SGW areas.

## **CONCLUSIONS**

The following main conclusions can be drawn from the experience gained out of the water-scarcity management programme undertaken by the Punjab Irrigation Department / PIDA during Rabi 1999-2000 and Rabi 2000-2001. The management-interventions were unique in the sense that they were implemented on an unprecedented mega-scale, involving over 8.5 million hectares of the commanded area in the Punjab.

1. It has been demonstrated that considerable scope exists for optimizing the water-management / allocation at macro-level. It also brings into focus the significance of the following optimization alternatives:
  - Re-allocating water within the crop-season, to better match the crop water-requirements. Additional canal-closures can be planned for the purpose during the slack-demand periods. This also helps in improving the drainage-environment in the root-zone, particularly in the waterlogged areas.
  - Allocating preferential canal-supply to the saline groundwater areas.
  - Priority-water allocation during sensitive / critical crop-growth stage.
  - Providing one to two canal-watering to non-perennial areas, which traditionally do not receive canal-supplies during the Rabi season.
  - Conjunctive groundwater use.
2. Importance of advance resource-planning, in collaboration with all the stake-holders (Irrigation Department, Agriculture Department, Water-Allocation Committees, etc.), is brought out. The advantages / need for timely dissemination of the information regarding canal-operation plans to the farmers is also highlighted.



## Drought-Mitigation Interventions by Improved Water-Management

<b>BOX- 3: Canal Command Level Water-Allocation Committees</b>		
<b>Composition:</b>		
i)	Superintending Engineer	Convener
ii)	Director of Agriculture or his representative	Member
iii)	Representative of Deputy Commissioner	Member
iv)	Three Farmer' representatives from the head, middle and tail reaches of the canal system	Members
<b>Functions:</b>		
i)	Receive share of each main canal-system from the Directorate of Regulation for each crop season viz. Kharif and Rabi	
ii)	Prepare the water-distribution program on 10 – day basis, taking into consideration the Accord-allocations, cropping-pattern and crop water- requirements.	
iii)	Review and monitor the actual operation of the Canal System with reference to the water-account, vis-à-vis. the canal share.	
iv)	Devise ways and means to streamline and improve the water-management operations and affect equitable distribution of available supply.	
<b>Divisional Water-Allocation Committees</b>		
<b>Composition:</b>		
i)	Executive Engineer	Convener
ii)	Assistant Director Agriculture or his nominee	Member
iii)	Assistant Commissioner or his nominee	Member
iv)	Three farmers' representatives from the head, Middle and tail reaches of the system	Members
<b>Functions:</b>		
i)	Receive the share of each canal division from the Superintending Engineer.	
ii)	Formulate regulation / rotational programs of the distributaries and minors in the canal–division, for affecting equitable distribution of the available supply.	
iii)	Assess the canal-water demand in a crop season and assist the Executive Engineers in determining the indents of various channels on 10-day basis.	
iv)	Monitor the operation of the canal-system in the division and review the water-Account vis-à-vis. the allocated share.	

3. Local-level management, through canal-command and canal-division level water-allocation committees can further enhance the beneficial impacts of the improved management regime.
4. Close and continuous monitoring of the planned operations, along with timely adjustments, in response to the actual water–availability, hold the key to the successful implementation of an overall water-management regime. This is also critical for obtaining the desired enhancement in the levels of production.
5. The following non-water factors also contributed towards the record wheat-production during the 1999-2000 Rabi season:
  - Enhanced Support Price of wheat (from Rs 240 to Rs 300 per 40 Kg)
  - Timely sowing of wheat

- Improved availability of fertilizers, better seeds and efficient extension- services, etc.
  - Favourable weather-conditions at the time of crop-maturing.
6. The enhanced dependence on Groundwater has resulted in considerable depletion of Aquifers and increased burden on farmers, because of high cost of Pumped Water.
  7. The successful model of water-scarcity management during Rabi 1999-2000 has been a good learning experience, which has been replicated quite effectively during the Rabi 2000-2001 crop, also, in the face of a much more severe water shortage.

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# **Assessment of Water-Quality**

*Iqbal H. Qureshi*

## **ASSESSMENT OF WATER-QUALITY**

### **ABSTRACT**

*Water is the most essential component of all living things and it supports the life-process. Without water, it would not have been possible to sustain life on this planet. The total quantity of water on earth is estimated to be 1.4 trillion cubic meter. Of this, less than 1% water, present in rivers and ground resources, is available to meet our requirement. These resources are being contaminated with toxic substances due to ever-increasing environmental pollution. To reduce this contamination, many countries have established standards for the discharge of municipal and industrial waste into water streams.*

*We use water for various purposes and for each purpose we require water of appropriate quality. The quality of water is assessed by evaluating the physical, chemical, biological and radiological characteristics of water. Water for drinking and food-preparation must be free from turbidity, colour, odour and objectionable tastes, as well as from disease-causing organisms and inorganic and organic substances, which may produce adverse physiological effects. Such water is referred to as potable water and is produced by treatment of raw water, involving various unit operations. The effectiveness of the treatment-processes is checked by assessing the various parameters of water-quality, which involves sampling and analysis of water and comparison with the National Quality Standards or WHO standards. Water conforming to these standards is considered safe and palatable for human consumption. Periodic assessment of water is necessary, to ensure the quality of water supplied to the public. This requires proper sampling at specified locations and analysis of water, employing reliable analytical techniques.*

### **INTRODUCTION: THE IMPORTANCE OF CLEAN WATER**

Water is the most common substance on earth and we use it every day, without giving much thought to its importance and significance. In fact, water is the most essential component of all living things, as it supports the life-processes by providing the essential nutrients to living organisms. Without water, it would not have been possible to sustain life on this planet. About 70 per cent of the Earth's surface is covered with water, which helps to regulate the earth's climate, by transporting heat from warmer to colder regions. The total quantity of water in the oceans, inland seas, rivers, lakes, underground reservoirs, ice caps of mountains and in the atmosphere is estimated to be about 1.4 trillion ( $1.4 \times 10^{12}$ ) cubic meters<sup>1</sup>. This quantity has remained the same ever since the formation of the earth. Water changes from one form to another and moves from one place to another, and is used countless times by many persons. All the water we use passes through the "water-cycle" and is used and reused, again and again.

## Assessment of Water-Quality

Water is unevenly distributed on earth. The oceans and inland seas contain about 97.2%, the ice caps of mountains and glaciers about 2.15%, surface and underground resources about 0.63% and the atmosphere about 0.02-0.05%<sup>1</sup>. Huge amount of water present in oceans and seas can not be used for most purposes, as it contains 35,000 ppm of dissolved impurities. Similarly, brackish water contains 1000-25,000 ppm of dissolved impurities. Since, for most applications, water containing less than 1000 ppm dissolved impurities is required, this water is not suitable for use. Icecaps and glaciers contain significant amount of relatively fresh water but its exploitation is not economical as yet, although the melting of mountain-snow actually recharges the water streams.

This distribution shows that, out of all the available water on earth, less than 3% is fresh water. Even out of this 75% is frozen in the glaciers and icecaps. Thus, less than 1 % of the total water that is present in rivers and underground resources, is available to meet our present-day requirements.

The surface and ground water resources are not evenly distributed on the surface of earth and about half of the land has very little or no water at all. This uneven distribution of water is partially responsible for unequal distribution of population in the world. About 5 per cent of the land where lots of fresh water is available contains half of the world population, whereas another half is distributed on the remaining land. The limited availability of water in arid and semi-arid areas adversely affects the productivity and prosperity of people and the quality of life.

The population of the world is growing exponentially and has increased from one billion in 1820 to about 6 billion in 2000<sup>2</sup>. The population-growth in Table-1 shows that it took several thousand years to build up the world population to the one-billion mark, whereas now it is taking less than 15 years to add another billion. At present, the population is increasing at the rate of about 80 million per annum. This rapid growth of population is putting a great stress on all the available resources, including water. At present about 8% of the population is facing shortage of fresh water and, with growing population, this may increase to 25% by the year 2050. It is likely that 48 countries, including Pakistan, will face fresh-water

Table - 1(a): Population of the World (Billion)

Year	1650	1750	1850	1900	1950	1980	1994	2000
Population	0.55	0.752	1.175	1.6	2.564	4.478	5.642	6.1

Table - 1(b): Population of Pakistan (Million)

Year	1951	1961	1972	1982	1993	1998
Population	33.74	42.88	65.31	87.75	122.8	136.2

shortage. The population of Pakistan has increased from 33.7 million in 1951 to 140 million in 2000, whereas water-resources have not substantially increased. It is projected that the population will increase to about 250 million by the year 2025. Therefore, careful planning and management of the existing water-resources should be given highest consideration, and the desalination of ocean-water may have to be exploited to add more water resources.

In Pakistan the availability of surface and ground water is much less than the daily per capita requirement, which will further aggravate with the rapid population growth. The per capita water availability has declined from 5100 m<sup>3</sup>/a in 1950 to about 1200 m<sup>3</sup>/a in 2000 which may soon fall below 1000 m<sup>3</sup>/a. Average annual water availability in Pakistan based on seventy years data is mentioned in Table - 2<sup>3</sup>. We use both surface and ground water for drinking and other purposes. The quality of drinking water in most areas is sub-standard as it contains many impurities. The problem of the availability of good quality drinking water is more pronounced in coastal areas as the groundwater in these areas contains high amount of dissolved salts.

**Table-2: Average Annual Water-Availability In Pakistan**

Source	Volume of Water (bm <sup>3</sup> )		
	Summer	Winter	Total
Water in Indus river system at rim stations	140	33	173
Direct precipitation	40	9	49
Total Available	180	42	222
10% evaporation loss from surface water	18	4	22
Seepage losses from irrigation system	36	8	44
Water released downstream of Kotri	6	6	12
Water available to users	120	24	144
Groundwater supply	13	40	53
Total at required points	133	64	197

*Note: High: 230 bm<sup>3</sup> in 1959 - 60 , Low: 124 bm<sup>3</sup> in 1974 - 75*

## SOURCES OF WATER-POLLUTION

Water, during its passage through rivers and through the ground, acquires various types of dissolved and suspended impurities. In addition to this, the ever-increasing environmental pollution, due to various activities of man, is contaminating the water resources with toxic substances. The main sources of water-pollution are sewage, industrial, agricultural and chemical wastes. The large-scale use of insecticides, pesticides and other agrochemicals is gradually contaminating the water- resources with toxic chemicals. Effluents from many industries are discharged into rivers and canals, without proper treatment to conform to the regulatory requirement. Similarly, untreated municipal

### Assessment of Water-Quality

effluents are dumped into water-bodies. Table - 3 shows the quantity of sewage generated, along with the population in 10 major cities<sup>4</sup>. Most of this sewage is discharged into water-bodies without any treatment, which causes water pollution.

The pollution of water in river Ravi in Lahore and Nullah Lehi in Rawalpindi / Islamabad was studied in April 2000 by JIAC, in collaboration with Pak.EPA, by measuring the following parameters<sup>5</sup>:

Parameters Measured at site	Flow rate, Temperature, Conductivity, pH, Dissolved Oxygen, Odour, Colour and Turbidity
Parameters Measured in Lab	BOD, COD, TSS, T-N, O & G, E – Coli, As, Cu, Cr, Cd, Pb and Zn

The comparison of these parameters with those of Japanese river-water indicates high pollution in river Ravi and Nallah Lehi. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD), which are the main indicators of biological and chemical pollution, were found to be much higher (BOD>100 ppm, COD>50 ppm) in most of the samples.

The level of water-pollution due to the release of effluents from various industries in Korangi site area, Karachi, was investigated by Ali and Jilani<sup>6</sup>. The parameters studied include pH, total suspended solids, total dissolved solids, BOD, COD, grease & oil and heavy metals. The data regarding five different types of industries, along with NEQS, is tabulated in table 4, which indicates that the amounts of pollutants discharged are much higher than the permissible levels.

The indiscriminate release of municipal and industrial waste is polluting the water with toxic chemicals and microorganisms that can cause various diseases. These pollutants must be removed by appropriate treatment before the water is supplied to the public. The pollution of water-resources has become a serious problem and requires serious attention.

**Table-3: Water And Sewage Quantities In Major Urban Centres**

No	Cities	Population 1998 (Million)	Water Supply (mgd)	Sewage (mgd)
1	Islamabad	0.525	42	33
2	Karachi	9.27	556	445
3	Lahore	5.064	405	324
4	Faisalabad	1.978	99	80
5	Multan	1.183	60	48
6	Hyderabad	1.152	58	47
7	Gujranwala	1.125	57	46
8	Peshawar	0.988	60	48
9	Quetta	0.561	23	18
10	Sargodha	0.456	19	15



It is necessary to properly regulate the discharge of municipal and industrial wastewater into rivers and canals. In order to reduce the contamination of surface and ground-water resources, many countries have established National Environmental Quality Standards (NEQS) for the discharge of municipal and industrial waste into water-resources. The Government of Pakistan in 1993 has also established NEQS for the release of municipal and liquid industrial effluents, which are not properly enforced<sup>7</sup>.

## POTABLE WATER

We use water for drinking and food preparation and for domestic, industrial, commercial and agricultural purposes. For each purpose, we require water of appropriate quality, which is suitable for that particular use. The desirable characteristics of water vary with its intended use. Thus, the quality of water that is good for one purpose may not be good for another. From the user's point of view, the term "water-quality" is used to define those biological, chemical, physical, and radiological characteristics by which he evaluates the acceptability of the water. In many parts of the world, the people first look at the water in a glass to see if it is crystal clear, then taste it to check if it is palatable. If the water is agreeable in these qualities they assume that it is good-quality water. Water for drinking and food-preparation must be aesthetically acceptable, that is, it should be free from apparent turbidity, colour and odor and from any objectionable taste. Further, it must not contain organisms capable of causing disease, nor should it contain minerals and organic substances which may produce adverse physiological effects<sup>8</sup>. Such water is termed as "potable water".

**Table-4: Pollution Levels (Mg/L) of Effluents From Various Industries in Korangi Site Area Karachi**

Industries ▶	Pharmaceutical	Tannery	Silk Mill	Paper Mill	Beverages	NEQS
Parameters ▼						
pH	5.2	9.0	11.8	3.9	13.0	37,417.0
TSS	848.0	450.0	466.0	2,648.0	68.0	150.0
TDS	530.0	6,818.0	5,280.0	12,146.0	18,244.0	3,500.0
BOD	1,364.0	7,620.0	6,010.0	54,696.0	18,724.0	80.0
COD	3,000.0	12,000.0	4,000.0	34,000.0	2,000.0	150.0
Grease & Oil	158.0	909.0	618.0	10,644.0	163.0	10.0
Cd	6.0	889.0	14.0	917.0	20.0	0.1
Cr	1,052.0	1,600.0	100.0	400.0	400.0	1.0
Cu	129.0	240.0	200.0	3,942.0	107.0	1.0
Pb	75.0	1,000.0	117.0	1,083.0	780.0	0.5
Ni	100.0	800.0	300.0	2,000.0	364.0	1.0
Zn	812.0	1,333.0	724.0	1,217.0	4,386.0	5.0

## Assessment of Water-Quality

### TREATMENT OF WATER

Potable water is produced by treatment of raw water, involving various operations in water-treatment plants. In many part of the world the availability of potable water is limited, due to lack of appropriate treatment plants and financial constrains. The unit operations involved in the production of potable water include Aeration, Coagulation and Flocculation, Sedimentation, Chlorination and other Disinfections Process, and Filtration<sup>9</sup>.

#### Aeration

Aeration is a process, in which air is thoroughly mixed with water to remove or decrease the concentration of substances, which produce unpleasant taste and odor, such as hydrogen sulphide and some organic compounds. It also helps in reducing the concentration of carbon dioxide and oxidation of iron and manganese. However, many of the taste and odour-producing compounds from industrial wastes and those released by disintegration of organisms are not highly volatile and can not be removed by aeration alone.

#### Coagulation and Flocculation

Surface waters contain dissolved inorganic and organic materials, suspended inorganic matter and biological substances, such as bacteria and plankton. Inorganic matter present in the form of finely divided particles, or as colloidal particles, is the main cause of turbidity, whereas organic compounds are generally the cause of unpleasant taste, odor and colour. Some colloidal metallic hydroxides may also produce colour. The size of the fine particles producing turbidity may range from molecular dimension to 50 $\mu\text{m}$  or larger. Particles greater than 1 $\mu\text{m}$  in diameter are generally referred as silt and settle down on standing under gravity. However particles smaller than 1 $\mu\text{m}$ , classified as colloid, remain suspended for a very long time, as their surface area to mass ratio is very large. The removal of colloidal material requires the use of procedures, which agglomerate the small particles into larger aggregates. Certain chemical agents called coagulants, such as salts of aluminium and iron, are used for this purpose. The addition of a chemical to a colloidal dispersion causes the destabilization of particles by reduction of forces that tend to keep the particles apart. The chemical should be rapidly mixed and uniformly dispersed in water to increase the particle-to-particle interaction. The entire process occurs in a very short time and initially results in particles of submicroscopic in size. This process is called Coagulation. These particles then gradually agglomerate to form larger aggregates by chemical bridging or physical enmeshment mechanism. This process is termed as Flocculation.

The coagulation and flocculation processes are sensitive to many variables such as pH, coagulant concentration, presence of anions, etc. The mechanism for the removal of particles by metal coagulants and polymers involves neutralization of electrical charges,

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Table - 5: Quality-Criteria for Domestic Water-Supplies

Parameter	Level	
	Permissible	Desirable
Color (Cobalt-Platinum scale)	75 units	< 10 Units
Odor	Virtually absent	Virtually absent
Taste	Virtually absent	Virtually absent
Turbidity	Virtually absent	Virtually absent
	Inorganic Chemicals	
pH	6.0-8.5	6.0-8.5
Alkalinity (CaCO <sub>3</sub> )	30-500 mg/liter	30-500 mg/liter
Ammonia	0.5 mg/liter	<0.01 mg/liter
Arsenic	0.05 mg/liter	Absent
Barium	1.0 mg/liter	Absent
Boron	1.0 mg/liter	Absent
Cadmium	0.01 mg/liter	Absent
Chlorides	250 mg/liter	< 25 mg/liter
Hexavalent Chromium	0.05 mg/liter	Absent
Copper	1.0 mg/liter	Virtually absent
Cyanide	0.01 mg/liter	Absent
Dissolved Oxygen	>4.0 mg/liter	Air Saturated
Fluorides	0.8-1.7 mg/liter	1.0 mg/liter
Iron(filterable)	< 0.3 mg/liter	Virtually absent
Lead	< 0.05 mg/liter	Absent
Manganese	< 0.05 mg/liter	Absent
Nitrates + Nitrites	< 10 mg/liter	Virtually absent
Phosphorus	10-50µg/liter	10µg/liter
Selenium	0.01 mg/liter	Absent
Silver	0.05 mg/liter	Absent
Sulfate	250 mg/liter	< 50 mg/liter
Sulfides	0.01 mg/liter	Absent
Total Dissolved Solids(TDS)	500 mg/liter	< 200 mg/liter
Zinc	1.5 mg/liter	Virtually absent
	Organic Chemicals	
Carbon - Chloroform extract		< 0.04 mg/liter
Methylene blue active substances	0.017 mg/liter	Virtually absent
Chlordane	0.003 mg/liter	Virtually absent
DDT	0.042 mg/liter	Virtually absent
Dieldrin	0.017 mg/liter	Virtually absent
Endrin	0.001 mg/liter	Virtually absent
Heptachlor	0.018 mg/liter	Virtually absent
Heptachlor epoxide	0.018 mg/liter	Virtually absent
Lindane	0.056 mg/liter	Virtually absent
Methoxychlor	0.035 mg/liter	Virtually absent
Organic phosphate	0.1 mg/liter	Virtually absent
Taxophane	0.005 mg/liter	Virtually absent

## **Assessment of Water-Quality**

compaction of electrical double-layer, adsorption and bridging and mechanical enmeshment. These processes are involved in varying degrees in coagulation flocculation system.

### **Sedimentation**

The solids in their natural form, such as silt or modified form by coagulation and chemical precipitation, settle down under the effect of gravity. Initially the particles with density greater than that of water begin to settle with accelerated velocity, until the resistance of the liquid equals the effective weight of the particle. Thereafter, settling-velocity remains constant and depends upon the size, shape and density of the particles as well as the density and viscosity of the water. The separation of coagulated or suspended matter from water under the influence of gravity is known as sedimentation.

### **Disinfection**

Surface and ground-waters generally contain microorganisms, which cause diseases such as typhoid, cholera, dysentery, etc. Many epidemics have been attributed to waterborne diseases, especially in developing countries. In Pakistan, about 25% of all the reported diseases and 30% of all the deaths are attributed to the use of contaminated water. Therefore potable water should be free from disease-producing organisms, in addition to its physical and chemical qualities. The destruction of harmful and other objectionable organisms can be achieved by disinfection of water, which kills the disease-producing organisms. Disinfection-processes may include one or a combination of both physical and chemical treatment, such as filtration, reverse osmosis, boiling, irradiation with ultraviolet light, metal ion treatment, chlorination and treatment with surface-active chemicals. Except for chlorine and some of its compounds, most of these disinfectants have one or more serious limitations. Therefore chlorine and its compounds are used for municipal potable water treatment. The quality of disinfected water is checked by counting the number of coliform bacteria E.Coli employing multiple tube fermentation or membrane filter technique. According to WHO and EPA good quality water should not have more than one bacterium per 100 ml. Water containing more than 10 bacteria considered as contaminated.

### **Taste and Odour**

Many organic and inorganic substances, though present in small quantities impart objectionable taste and odour to water. Generally inorganic compounds such as metal ions in concentration of few ppm impart taste to water whereas organic materials and hydrogen sulphide are mainly responsible for imparting odour to water. Most of the odorous substances present in water are removed by aeration, coagulation and flocculation, sedimentation, filtration and chlorination. The remaining substances are removed by

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treatment with activated carbon, which is considered to be the best treatment procedure for odour and taste control.

### **Filtration**

Water purification involves the removal of suspended silt, clay, colloids and microorganisms including algae, bacteria, and viruses. Most of the suspended particles and other impurities are removed by coagulation, flocculation, and sedimentation processes. The remaining particles are removed by passing the water through a filtering unit. The filtering unit may consist of a thin porous layer of filter aid deposited by flow on a support or a bed of granular non-porous material held in place by the force of gravity. The filters are generally classified into four categories, depending upon the type of filter media used and quantitative rate of filtration. These include slow-sand filter, rapid sand filter, high-rate rapid-sand filter and diatomite filter. Rapid sand filters, consisting of a bed of sand about 30 inches thick on top of a bed of gravel, are commonly used for filtration of water.

### **QUALITY ASSURANCE**

The production of potable water involves a number of processes to remove physical, chemical and biological impurities. The effectiveness of these treatment- processes is checked by analyzing the final product to assess the various parameters of water-quality. The treated water should conform to the National Quality Standards (NQS) established by The Government for water-quality. In countries where NQS are not established, WHO water-quality Standards<sup>10</sup> may be used, which are given in Table - 5. Periodic assessment of water is necessary to ensure the quality of water supplied to the public. This requires collection of representative samples from selected locations and measurement of various physical, chemical and biological parameters. The sampling should be done carefully, to avoid contamination and the concentrations of the substances should not change during storage as a result of chemical, physical and biological processes in the samples. Various parameters of these samples can be measured, employing suitable analytical techniques available in Handbooks<sup>11,12</sup>. In order to get reliable data, it is necessary to determine the accuracy and precision of each technique by analyzing a Standard Reference Material. Water, which conforms to the National Quality Standards, is considered safe and palatable for human consumption and can be used in any desired amount without any adverse effects on health.

### **CONCLUSIONS**

- The requirement of water is increasing, with ever-increasing population; as such per-capita availability is decreasing.
  - Underground water-resources are depleting, due to drought-conditions and heavy municipal pumping and private abstraction of water.
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### Assessment of Water-Quality

- Proper attention is not being given to water-quality and the data regarding water-quality is not readily available.
- Microbial contamination in water is common in many areas, due to cross-contamination between water and sewerage lines, poor maintenance, unreliable and irregular chlorination, which result in frequent outbreak of waterborne diseases.
- The release of untreated municipal and industrial effluents into water-bodies is adversely affecting the quality of water.

### RECOMMENDATIONS

- To meet our future water-requirements, it is necessary to formulate and implement a National Policy for water-resources management.
- NEQS for the release of municipal and industrial effluents should be enforced, to prevent the pollution of water-bodies.
- Sewage-treatment plants should be installed in all major cities.
- National guidelines or standards for drinking-water quality be formulated.
- A program of regular monitoring of water-quality be formulated and implemented.
- Environmental Data-bank be established in EPA. Data regarding water-quality from various sources may be collected, evaluated and stored for future reference.
- A program for training of personnel in analytical methodologies be prepared by EPA. It should include sampling procedures, measurement techniques, quality control and quality assurance of data, data analysis and its co-relation.

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# **Evaluation of Water-Quality by Chlorophyll and Dissolved Oxygen**

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# EVALUATION OF WATER-QUALITY BY CHLOROPHYLL AND DISSOLVED OXYGEN

## ABSTRACT

*This article focuses on the impact of Chlorophyll and dissolved Oxygen on water-quality. Kalar Kahar and Rawal lakes were selected for this research. A Spectrophotometer was used for determination of Chlorophyll a, Chlorophyll b, Chlorophyll c and Pheophytin pigment. Dissolved Oxygen was measured in situ, using dissolved-oxygen meter. The  $\delta^{18}\text{O}$  of dissolved Oxygen, like concentration, is affected primarily by three processes: air-water gas exchange, respiration and photosynthesis;  $\delta^{18}\text{O}$  is analysed on isotopic ratio mass-spectrometer, after extraction of dissolved Oxygen from water-samples, followed by purification and conversion into  $\text{CO}_2$ . Rawal lake receives most of the water from precipitation during monsoon-period and supplemented by light rains in December and January. This water is used throughout the year for drinking purposes in Rawalpindi city. The water-samples were collected from 5, 7.5, and 10 meters depth for seasonal studies of physiochemical and isotopic parameters of water and dissolved Oxygen. Optimum experimental conditions for  $\delta^{18}\text{O}$  analysis of dissolved Oxygen from aqueous samples were determined. Stratification of dissolved Oxygen was observed in Rawal Lake before rainy season in summer. The water-quality deteriorates with depth, because the respiration exceeds the photosynthesis and gas exchange. The concentration and  $\delta^{18}\text{O}$  of dissolved Oxygen show no variation with depth in 1998 winter sampling.*

*Kalar Kahar lake gets water from springs, which are recharged by local rains on the nearby mountains. It is a big lake, with shallow and uniform depth of nearly 1.5 meters. A lot of vegetation can be seen on the periphery of the lake. Algae have grown on the floor of the lake. Water-samples were collected from the corner with large amount of vegetation and from the center of the lake for dissolved Oxygen and Chlorophyll measurements. Chlorophyll result shows that Kalar Kahar Lake falls in Eutrophic category of Chlorophyll concentrations. Dissolved Oxygen ranges from 0.3 to 9.1 mg/l with minimum at the morning and maximum at 16.00 hours of the day. These alarming dissolved Oxygen results show that fish can not survive in these conditions.*

## INTRODUCTION

Chlorophyll 'a' is a blue-green microcrystalline solid, while Chlorophyll 'b' is a green black microcrystalline solid. Chlorophyll 'a' is of universal occurrence in the green plants; Chlorophyll 'b' occurs in higher plants and green algae. All plant-life contains the primary photosynthetic pigment Chlorophyll 'a'. Chlorophyll concentration is an indirect estimation of the biomass and the photosynthesis-rate of the primary producers. According to Sakamoto and Vollenweider, lakes

can be classified as Eutrophic lakes, with Chlorophyll 'a' concentration 5-140 mg/m<sup>3</sup>, Mesotrophic lakes with 1-15 mg/m<sup>3</sup> and Ologotrophic lakes with 0.3-2.5 mg/m<sup>3</sup>. Chlorophyll has been used to ameliorate bad breath, as well as to reduce the odors of urine, feces and infected wounds. Good dietary sources of Chlorophyll include dark green leafy vegetables, algae, chlorella, wheat-grass and barley grass. Supplements of Chlorophyll as powder, capsule, Tablet, and drinks are also available. Several kinds of Chlorophyll have been discovered. All green plants contain Chlorophyll 'a' and, for planktonic algae, it constitutes about 1 to 2 % of the dry weight<sup>1,2</sup>.

Data on King County Lake (Lake Washington and Lake Sammamish) elucidate that dissolved Oxygen concentrations may change dramatically, with depth, particularly as thermal stratification persists. Oxygen is added to the water via diffusion through wind-mixing and produced in the top portion of the lake during photosynthesis. Respiration also consumes dissolved Oxygen. Oxygen depletion is greatest near the bottom of the lake, where settled organic matter decomposes. Water temperature influences the amount of gas that water can hold. As water becomes warmer, it becomes saturated more easily with Oxygen, meaning it can hold less of the dissolved gas. The amount of algae present can control the dissolved oxygen-concentration and the pH, as well as the amount of nutrients. Algae produce Oxygen during daylight hours but use up Oxygen during the night, in respiration, and when they die, sink, and decay. These same processes basis the changes in lake pH<sup>3</sup>.

### **SAMPLING SITES**

Rawal and Kalar Kahar lakes, and Humak, Tarlai and Gandaf ponds were selected for samplings.

#### **Rawal Lake**

Rawal dam was constructed in 1960 across Kurrang river near Islamabad. It is 33.54 m high and 213 m long. The storage capacity is 58.6 million cubic meters. The Rawal lake receives most of the water from precipitation during the monsoon period (August-September), and supplemented by light rains in December and January. The stored water is used throughout the year for drinking purposes in Rawalpindi City. Water-samples were collected in July & December 1998 and July & December 1999, for extraction of dissolved Oxygen. 400 µl of saturated solution of mercuric chloride per one liter of water-sample was used as an preservative<sup>4</sup>. The samples were taken from: surface, 5, 7.5 and 10 meters depth.

#### **Kalar Kahar Lake**

Kalar Kahar lake gets water from springs, which are recharged by local rains on the nearby mountains. It is a big lake, with shallow and uniform depth of nearly

1.5 meters. A lot of vegetation can be seen on the periphery of the lake. Algae has grown on the floor of the lake as shown in Figure - 1. Water- samples were collected from (i) the corner with large amount of vegetation and from (ii) the centre of the lake. The samples were also collected for the measurement of Chlorophyll.



**Figure - 1: Algae is Seen on the Floor of the Kallar Kahar Lake (Sun-Set View)**

### **Humak and Tarlai Ponds**

Humak and Tarlai ponds, near Islamabad, are not very big in size. These are roughly 20m<sup>2</sup>, with no outlet. These are filled by surface runoff when there is rainfall. The water in the ponds evaporates with time. The water- samples were collected for estimating dissolved Oxygen and Chlorophyll measurement.

### **INSTRUMENTS**

*Dissolved Oxygen* (by digital DO<sub>2</sub> meter-model 9071, Jenway, UK)

*pH* (by pH meter, CD 62, WPA, UK)

*EC and temperature* (by digital EC meter LF 191, WTW, Germany)

*Chlorophyll concentration* (by Visible and U V Spectrophotometer)

*δ<sup>18</sup>O of dissolved Oxygen in water and δ<sup>18</sup>O & δ<sup>2</sup>H of water-samples* (by Isotopic ratio mass- spectrometer).

### **METHODS**

#### **Chlorophyll**

*Chlorophyll Sample Collection, Preservation and Filtration:*

0.5-2.0 liter of water-sample is often convenient for measurement of Chlorophyll in the biomass. Smaller amount can be used for denser population. Water-samples should be measured as soon as possible after collection. The constrains should be placed on filtering of the water-samples that are to be used for the extracted analysis. From the time of collection to the measurement, the sample should be stored in the dark, on ice. Whole water-sample can be held up to 2

weeks in the dark at 4 °C. Used opaque bottle, because even exposure to light during storage will alter the Chlorophyll values. Samples on the filters taken from water having pH 7 or higher may be placed in airtight plastic bags and stored frozen for 3 weeks. Samples from acidic water must be processed promptly, to prevent Chlorophyll degradation.

Water-sample was filtered through glass-fiber filters (Whatman GF/A). Filtration assembly was attached with suitable source of reduced pressure. Glass-fiber filter containing green pigment should be immediately analysed for Chlorophyll. Placed the glass-fiber filter in beaker and added pure acetone for Chlorophyll extraction. The sample was then crushed by glass rod. Filtered this extract through cellulose nitrate filter paper. Same procedure was repeated until the glass-fiber filter was absolutely clear from Chlorophyll. The extract was diluted to the desired volume. Sample was then transferred to the amber glass bottles and wrapped with black paper, to avoid exposure to light and stored at 4°C<sup>5, 6, 7</sup>.

*Spectrophotometric determination of Chlorophyll:*

Spectrophotometer was used for determination of Chlorophyll a, Chlorophyll b, Chlorophyll c and Pheophytin pigment. Checked the optical density of the two cells (1 cm path length each) using acetone. Transferred approximately 3 ml acetone to the one cuvette and measured the optical density at 750 nm and adjusted the zero. Similarly, clarified extract was added to the second cuvette and the absorbance measured at same wavelength. Same measurements were then repeated at 664 nm. Extract was then acidified with 0.1ml 0.1M HCl. Gently agitated the acidified extract and measured the optical density at 750 and 665 nm within 90s. Subtracted the 750 nm value from the reading before (OD 664 nm) and after acidification (OD 665 nm). Following formulas was used for the calculation of Chlorophyll a and Pheophytin a.

Chlorophyll a, mg/m <sup>3</sup> =	$\frac{26.7 (664_b - 665_a) \times V_1}{V_2 \times L}$
Pheophytin a, mg/m <sup>3</sup> =	$\frac{26.7 [1.7 (665_a - 664_b) \times V_1]}{V_2 \times L}$
where:	<p>V<sub>1</sub> = Volume of extract, L  V<sub>2</sub> = Volume of sample, m<sup>3</sup>  L = Width of cuvette (cm)</p>
and	664 <sub>b</sub> , 665 <sub>a</sub> = Optical densities of extract before, and after acidification respectively
The value 26.6 is the absorbance correction and equals A x K where	A = Absorbance coefficient for Chlorophyll a at 664 nm = 11.0, and K = Ratio expressing correction for acidification

*Determination of Chlorophyll a, b, and c (trichromatic method):*

Transferred extract to a 1-cm cuvette and measured optical density (OD) at 750, 664, 647, and 630 nm. Used the optical density readings at 664, 647, and 630 nm to determine Chlorophyll a, b, and c, respectively. The OD reading at 750 nm is a correction for turbidity. Subtracted this reading from each of the pigment OD values of the other wavelengths before using them in the equation below.

Calculate the concentrations of Chlorophyll a, b, and c in the extract by inserting the corrected optical densities in the following equations:

$$\begin{aligned} \text{a) } & C_a = 11.85 (\text{OD}_{664}) - 1.54 (\text{OD}_{647}) - 0.08 (\text{OD}_{630}) \\ \text{b) } & C_b = 21.03 (\text{OD}_{647}) - 5.43 (\text{OD}_{664}) - 2.66 (\text{OD}_{630}) \\ \text{c) } & C_c = 24.52 (\text{OD}_{630}) - 7.60 (\text{OD}_{647}) - 1.67 (\text{OD}_{664}) \end{aligned}$$

where

$C_a$ ,  $C_b$ , and  $C_c$  = concentrations of chlorophyll a, b, and c, respectively, in mg/L, and  $\text{OD}_{664}$ ,  $\text{OD}_{647}$ , and  $\text{OD}_{630}$  = corrected optical densities at the respective wavelengths.

After determining the concentration of pigment in the extract, calculated the amount of pigment per unit volume as follows:

$$\text{Chlorophyll a, mg/m}^3 = \frac{C_a \times \text{extract volume, L}}{\text{Volume of sample, m}^3}$$

## **Dissolved Oxygen**

Value of Dissolved Oxygen were measured in situ, using Jenway dissolved Oxygen meter, model 9071.

### *Extraction and $\delta^{18}\text{O}$ Analysis of Aqueous Dissolved Oxygen:*

The extraction assembly, designed and fabricated locally, is shown in Figure - 2. It consists of one liter flat-bottom flask, with 19/26 socket. An adapter is fitted in this socket. This adapter has two ends. One end has 14/23 socket for the evacuation of flask and second end is attached with one liter sample-bottle through a needle valve. The flask assembly and adapter is placed over a magnetic stirrer. One-liter flask, with adapter, is evacuated for the removal of air. Stopcocks towards evacuation system are closed and the needle valve is opened slowly. When approximately 800 ml of water is poured into the flask, the needle valve is closed. The water is stirred with magnetic stirrer. The line-valve towards rotary vacuum pump is closed and the stopcock towards purification traps is opened slowly, the gas starts flowing in the line. All the other stopcocks of the line are opened, one by one, so that gas can flow through all three traps and in finally collected in 50 ml flask containing molecular sieves at liquid nitrogen

temperature. At the end, the magnetic stirrer is switched off, the ampoule is closed and detached from the line.

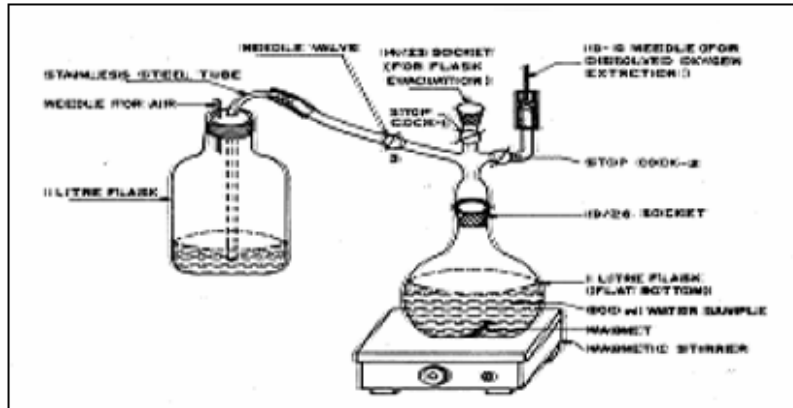


Figure - 2: Dissolved Oxygen Extraction Assembly from Water Samples

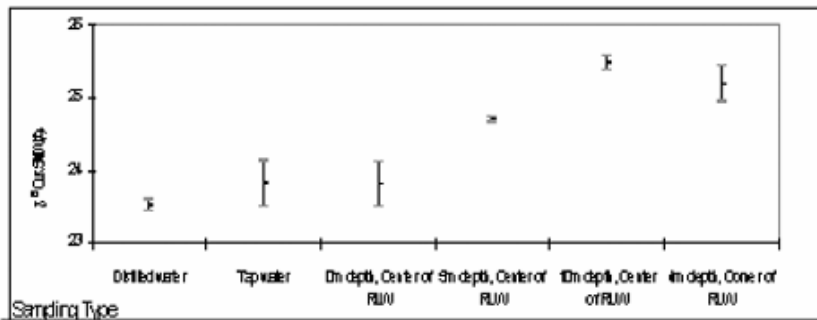


Figure - 3: Precision of d18O of Dissolved Oxygen Extracted from Distilled Water, Tap Water and Rawal lake Water (RLW) (1st Sampling, July-1998)

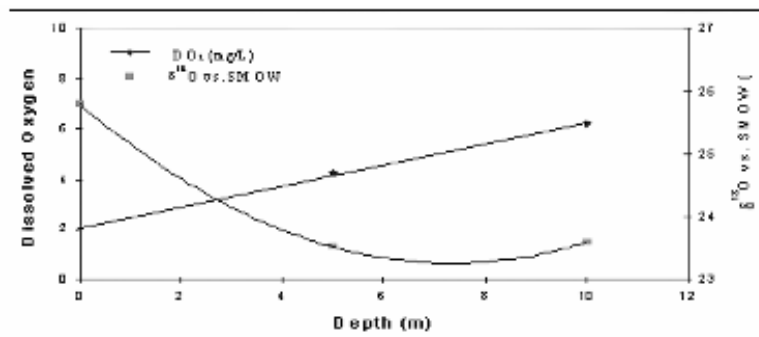


Figure - 4: Concentration and Isotopic Composition of Dissolved Oxygen at the Rawal Lake Site (1st Sampling, July-1998)

**Table-1. Experimental conditions for  $\delta^{18}\text{O}$  analysis of dissolved oxygen**

<b>A. For extraction of dissolved <math>\text{O}_2</math></b>	
1. Water sample taken in plastic bottles at the site	1 liter
2. Preservative	Mercuric chloride
3. Evacuation time of one liter pyrex glass flask	1 minute
4. Water sample filled in the pyrex flask	800 ml
5. 5 gm molecular sieve (5 $^\circ$ A) heating (200 $^\circ$ C) time	1 minute
6. Moisture removal temperature for two traps	-80 $^\circ$ C
7. $\text{CO}_2$ removal temperature for one trap	Liquid air
8. Dissolved Oxygen adsorption time on molecular sieve	30 minutes
9. Dissolved Oxygen desorption time from molecular sieve	6 minutes
<b>B. For conversion of aqueous dissolved <math>\text{O}_2</math> into <math>\text{CO}_2</math> for <math>\delta^{18}\text{O}</math> analysis</b>	
1. Reduction furnace, cylinder type within the silica furnace was made by	Graphite furnace with spiral platinum wire, inside and around
2. Reaction temperature provided by external heated furnace	700 $^\circ$ C
3. Reaction time	10 minutes
4. Gas circulatory pump speed	1.3 liters per minute
5. Non-condensed gases removal time	2 minutes
6. $\text{CO}_2$ sublimation time	3 minutes
7. $\text{CO}_2$ is purified by using	-60 $^\circ$ C slush

**Table - 2: Chlorophyll Concentrations in Kalar Kahar Lake Water Samples**

Sampling Point	Sampling Date	Chlorophyll a in the presence of Pheophytin a ( $\text{mg}/\text{m}^3$ )	Chlorophyll a, b, c, trichromatic method ( $\text{mg}/\text{m}^3$ )		
			a	b	c
KK-1 (Surface)	29-12-1999	27.39	27.89	6.57	0.59
KK-1 (3 feet deep)	29-12-1999	33.33	34.33	2.77	2.13
KK-2 (Surface)	29-12-1999	23.43	24.2	1.36	0.25
KK-2 (3 feet deep)	29-12-1999	30.03	30.97	2.2	0.6



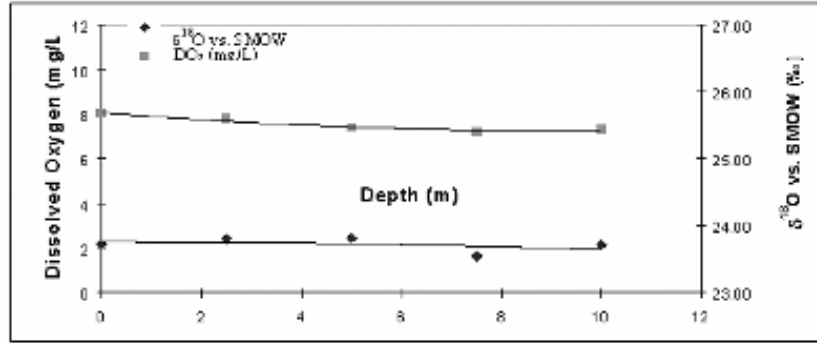


Figure - 5: Concentration and Isotopic Composition of Dissolved Oxygen at the Rawal Lake Site (2nd Sampling, Dec.-1998)

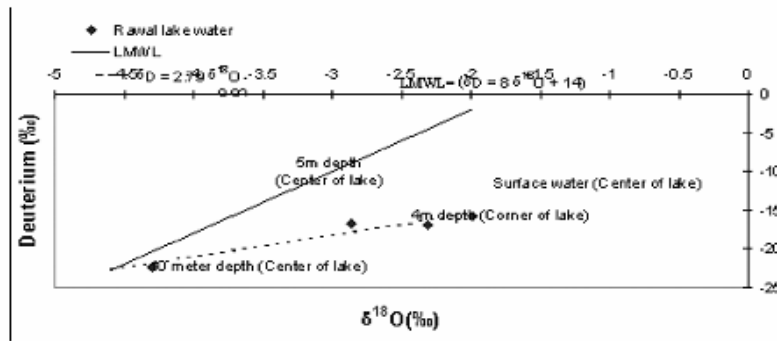


Figure - 6: Plot of  $\delta^{18}\text{O}$  versus  $\delta\text{D}$  of Rawal Lake Water Samples (1st Sampling, July-1998)

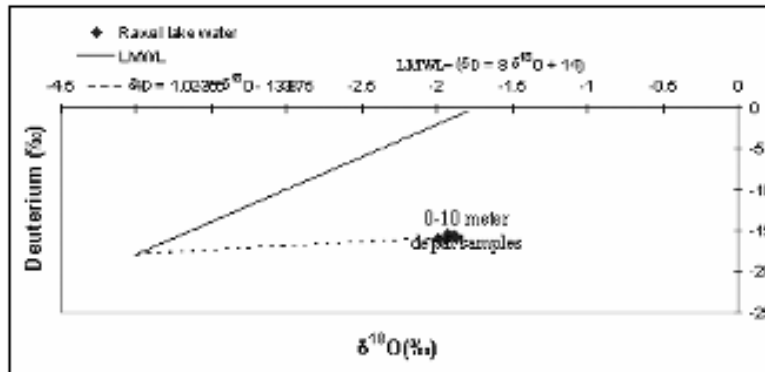


Figure - 7: Plot of  $\delta^{18}\text{O}$  versus  $\delta\text{D}$  of Rawal Lake Water Samples (2nd Sampling, December 1998)

**Table - 3: Concentrations and Isotopic Composition of Dissolved Oxygen in Kalar Kahar Lake Samples**

Sampling Point	Sampling Date	DO <sub>2</sub> (mg/L)	$\delta^{18}\text{O}$ vs. SMOW (‰)	$\delta^{13}\text{C-CO}_2$ (Dissolved in water) vs. PDB (‰)	$\delta^{18}\text{O-CO}_2$ (Dissolved in water) vs. SMOW (‰)
KK-1 (Surface)	29-12-1999	11.1	20.25	-2.83	41.49
KK-1 (3 feet deep)	29-12-1999	11.1	20.87	-3.71	41.8
KK-2 (Surface)	29-12-1999	14.9	19.39	-2.78	41.54
KK-2 (3 feet deep)	29-12-1999	14.9	19.15	-2.75	41.36

**Table - 4: Isotopic & Physico-Chemical Data of Pond Water Samples**

Sampling Point	Sampling Date	E. C. $\mu\text{s/cm}$	Temp. $^{\circ}\text{C}$	$\delta^{18}\text{O}$ vs. SMOW (‰)	$\delta^2\text{H}$ vs. SMOW (‰)
Humak Pond (Center)	15-12-1999	1129	8	-3.50	-22.64
Humak Pond (Center)	22-12-1999 (after rain)	445	14	-1.45	+0.62
Humak Pond (Bank)	22-12-1999	415	15.2	-1.26	+2.2
Terlai Pond	22-12-1999	468	10.3	-2.06	+1.3
Gandaf Pond	24-12-1999	166	15.6	2.48	+18.46

**Table - 5: Concentrations and Isotopic Composition of Dissolved Oxygen in Pond Water Samples**

Sampling Point	Sampling Date	DO <sub>2</sub> (mg/L)	$\delta^{18}\text{O}$ vs. SMOW (‰)	$\delta^{13}\text{C-CO}_2$ (Dissolved in water) vs. PDB (‰)	$\delta^{18}\text{O-CO}_2$ (Dissolved in water) vs. SMOW (‰)
Humak Pond (Center)	15-12-1999	12.1	21.62	-14.24	27.07
Humak Pond (Center)	22-12-1999	13.7	19.83	-7.4	38.2
Humak Pond (Bank)	22-12-1999	16.2	20.68	-8.28	38.47
Terlai Pond	22-12-1999	8.8	18.31	-8.86	38.23
Gandaf Pond	24-12-1999	13	22.91	-8.6	42.89

The ampoule containing the purified dissolved aqueous Oxygen sample is attached at CO<sub>2</sub> preparation system. Then the sample is introduced in the evacuated line. The valve towards rotary pump side is closed and the circulatory pump is switched on. The U-trap is immersed in a flask containing liquid nitrogen. Carbon dioxide prepared in the line is frozen in U-trap and non-condensed gases are removed by opening the valve. The liquid nitrogen flask was replaced with Freon slush at -65°C temperature. The carbon dioxide frozen in U-trap sublimates and is recollected in another evacuated ampoule at liquid nitrogen temperature. Non-condensed gases trapped in the frozen carbon dioxide are released on sublimation. The sample ampoule is detached from the line and <sup>18</sup>O is analyzed on mass spectrometer<sup>8</sup>. Optimum experimental conditions for <sup>18</sup>O analysis of dissolved Oxygen of aqueous samples are described in Table-1 and the precision of <sup>18</sup>O of dissolved Oxygen extracted from distilled water, tap water and Rawal lake water (RLW) are depicted in Figure-3.

## RESULTS AND DISCUSSION

### Rawal Lake

The EC values of Rawal lake vary from 306 µs/cm to 462 µs/cm. The pH varies from 6.65 to 7.84, temperature varies from 15.6°C to 32.2°C. <sup>18</sup>O values of dissolved Oxygen from Rawal lake have variations from 24.15 ‰ to 29.5 ‰ and indicate that gas-exchange dominates photosynthesis and respiration<sup>9,10</sup> at the surface of water, as the dissolved Oxygen has values close to 24.2‰, both in July and December (Figure - 4, 5). However in December, the EC, temperature, dissolved Oxygen concentration and <sup>18</sup>O of dissolved Oxygen have no variations with depth. In July, dissolved Oxygen concentration decreases and <sup>18</sup>O increases with depth. Respiration dominates over photosynthesis at 5 meters and 10 meters of depth, as dissolved Oxygen is undersaturated and <sup>18</sup>O is greater than 24.2‰. This lake receives most of the water from heavy precipitation in Monsoon period (August-September) and some contribution in December/January. The water remains standing throughout the year and is subjected to strong evaporation, as evident from isotopic data (Figure - 6, 7). In July, the water is at the lowest level and by that time microbiological activity becomes dominant at large depths.

Table - 6: Chlorophyll Concentrations in Pond Water

Sampling Point	Sampling Date	Chlorophyll a in the presence of pheophytin a (mg/m <sup>3</sup> )	Chlorophyll a, b, c, trichromatic method (mg/m <sup>3</sup> )		
			a	b	c
Humak Pond (Center)	15-12-1999	300.39	301.27	128.9	28.69
Humak Pond (Center)	22-12-1999	246.88	252.35	48.15	0.4
Humak Pond (Bank)	22-12-1999	338.95	345.76	75.01	1.19
Terlai Pond	22-12-1999	248.93	255.43	35.74	1.29
Gandaf Pond	24-12-1999	4.62	4.74	0.63	0.37

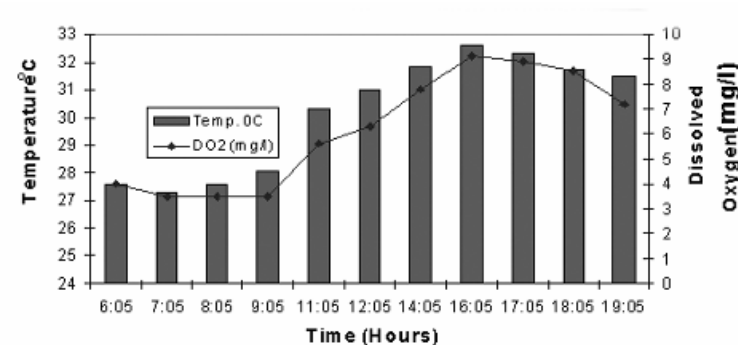


Figure - 8: Temperature and Dissolved Oxygen Behaviour in Different Hours of Day at Kalar Kahar Lake (Sampling Point-2)

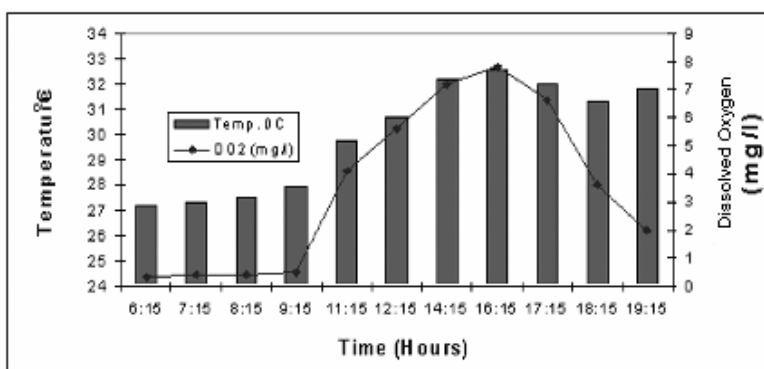


Figure - 9: Temperature and Dissolved Oxygen Behaviour in Different Hours of Day at Kalar kahar Lake (Sampling Point-4)

### **Kalar Kahar Lake**

EC varies from 3,100  $\mu\text{s}/\text{cm}$  to 3,410  $\mu\text{s}/\text{cm}$ . Temperature range from 15.8  $^{\circ}\text{C}$  to 17.7  $^{\circ}\text{C}$ . Dissolved Oxygen concentration varies from 11.1 mg/l to 14.9 mg/l.  $\delta^{18}\text{O}$  values of 19.15 ‰ to 20.87 ‰ indicate that photosynthesis dominates respiration and exchange-rate. The photosynthesis is evident from the presence of Chlorophyll in the ponds and Kalar kahar lake. The Chlorophyll concentration has a range of 23.43  $\text{mg}/\text{m}^3$ , to 33.33  $\text{mg}/\text{m}^3$  as shown in Table-2.  $\delta^{13}\text{C}$  value shows that inorganic carbon source is from rock sediments (Table- 3). Temperature ranges from 27.30  $^{\circ}\text{C}$  to 32.60  $^{\circ}\text{C}$  at point-2 (east side), from 27.20  $^{\circ}\text{C}$  to 32.60  $^{\circ}\text{C}$  at point-4 (west, vegetation side) and is observed maximum at 16:10 hours of the whole day experiment (August 31, 2001). Dissolved Oxygen concentration varies from 3.50 mg/l to 9.10 mg/l at point-2 (east side), from 0.3 mg/l to 7.80 mg/l at point-4 (vegetation side) and is observed maximum at 16:10 hours of the whole day experiment (Figure - 8, 9)).

### **Humak, Terlai and Gandaf Ponds:**

EC varies from 166  $\mu\text{s}/\text{cm}$  to 1,129  $\mu\text{s}/\text{cm}$ . Temperature range from 8.0 $^{\circ}\text{C}$  to 15.6 $^{\circ}\text{C}$  as shown in Table-4. Dissolved Oxygen concentration has values of 8.8 mg/l to 16.2 mg/l.  $\delta^{18}\text{O}$  of dissolved Oxygen range from 19.83 ‰ to 22.91‰ endorsing the dominance of photosynthesis over respiration and gas-exchange processes (Table-5). The Chlorophyll has highest value of 338.95  $\text{mg}/\text{m}^3$  in Humak pond and lowest value of 4.62  $\text{mg}/\text{m}^3$  in Gandaf pond (Table - 6).

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# **Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan**

**(A Preliminary Investigation)**

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# SALINITY OF GROUNDWATER IN COASTAL AQUIFER OF KARACHI, PAKISTAN (A Preliminary Investigation)

## ABSTRACT

*Salinity of potable groundwater has become a problem of great concern in the Karachi Metropolis, which is not only the most populous and biggest industrial base but also the largest coastal dwelling of Pakistan. Stable isotope techniques [ $^{18}\text{O}$  content of oxygen in the water molecule and  $^{13}\text{C}$  content of the Total Dissolved Inorganic Carbon (TDIC)] have been used, in conjunction with physiochemical tools (temperature, dissolved oxygen, pH, redox, electrical conductivity, salinity), to examine the quality of potable-water and the source of salinity. Surface-water samples (12 No.) were collected from polluted streams, namely: Layari River, Malir River; Hab River/Hab Lake and the Indus River. Shallow groundwater samples (7 No.) were collected from operating dug-wells. Relatively deep groundwater samples (12 No.) were collected from pumping wells/tube-wells.*

*Physiochemical analysis of water samples was completed in the field. In the laboratory, water samples were analyzed for  $^{18}\text{O}$  content of oxygen in the water molecule and  $^{13}\text{C}$  content of the TDIC, using specific gas-extraction systems and a modified GD-150 gas-source mass spectrometer. It is concluded from this preliminary investigation that the potable aquifer system in coastal Karachi hosts a mixture of precipitation (rainwater only) from hinterlands, trapped seawater in relatively deep aquifer system, as well as intruded seawater under natural infiltration conditions and/or induced recharge conditions (in shallow aquifers).*

## INTRODUCTION

Coastal Karachi is by far, the most populous (~10 million inhabitants, as per 1998 census) and the largest industrial (more than 1000 large industrial units) base of Pakistan, with a coast-line extending up to about 80 km. The major industries in Karachi include: Tanneries, Textile Industries, Chemical Industries, Detergent Industries, Iron and Steel industries, Paints and Dyes Industries, Pharmaceutical Industries, Plastic Industries, Metallurgical Industries, Vegetable Oil Industries, Food Industries, Oil and Lubricant Industries, Cement Industry, Auto Engineering Works, Machine-tool Factory, Power Plants, Oil Refineries, as well as a large number of cottage industries. Discharge of raw sewage into the natural water resources is not only affecting the quality of surface-water resources, but is also expectedly deteriorating the quality of shallow potable groundwater, through seepage of polluted stream-waters under natural conditions, as well as under artificially induced recharge conditions, caused by heavy pumping of the local aquifer.

## **Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan**

In Karachi, freshwater resources are very few. The available shallow groundwater and deep groundwater is exploited for certain domestic and industrial areas. Prolonged over-pumping of groundwater, or other alterations of the natural equilibrium between recharge and discharge regimes of coastal aquifer system in Karachi, can lead to an encroachment of the interface between seawater and freshwater, through intrusion and/or up-coning. Contamination by salty seawater can further increase the deterioration of groundwater quality in the coastal aquifer. A two to three percent mixing of coastal aquifer water with seawater makes freshwater unsuitable for human consumption. A five per cent mixing makes it unusable for irrigation<sup>1</sup>.

### **HYDROGEOLOGY OF THE STUDY- AREA**

Hydrogeologically, the city of Karachi lies in the Hab River Basin and the Malir River Basin. The Malir River Basin is drained by the Malir River and the Layari River. The coastal aquifer of Karachi is, therefore, mainly recharged by seepage from Hab River, Hab Dam as well as the Malir and the Layari Rivers. The Hab River lies on the western frontier of Sindh and for some distance the boundary between Sindh and the Baluchistan provinces. It flows about 30 kms to the west of Karachi, along the Karachi-Lasbela boundary. It falls into the Arabian Sea near Cape Monze, with a total drainage course length of 336 kms. Its principal tributaries are the Saruna, the Samotri and the Wira hab. Hab River gradually widens and, for some 80 kms from its mouth, is bordered by fine pasture land. Water is always found in pools, but the river is being utilized for irrigation and drinking purposes after building of the Hab Dam in the north-west of Karachi in the year 1980.

### **WATER-SUPPLY SCENARIO FOR COASTAL BELT OF KARACHI**

Karachi has a complex water-supply system, which developed over a period of more than 100 years. The shallow groundwater near the coastal belt is moderately saline. Today, the drinking-water supply to most of the population in Karachi is managed through three schemes: (i) reserves in the nearby Hab Dam; (ii) exploitation of relatively adequate-quality potable water in selective zones within the city, by pumping wells and dug wells; (iii) pumping of piped water from the Indus River near Thatta City, about 160 km away from Karachi. The Hab Dam reservoir-capacity is insufficient to maintain long-term supplies of drinking water to the enormous population of Karachi. During the past 15 years, a number of pumping wells has been installed to meet requirements for the irrigation-water supply (to raise vegetables, fruits, dairy and poultry) and drinking-water supply for the ~10 million inhabitants of Karachi. Excessive pumping of groundwater and continuous lowering of water-table is likely to result in intrusion of sea-water into the Malir Basin under natural seepage conditions and under artificially induced conditions of recharge of saline seawater in the coastal aquifer(s) of Karachi. It is feared that any further lowering of water table in coastal aquifer of Karachi will enhance seawater intrusion, thereby, affecting

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the quality of drinking water in the coastal aquifer system. Ultimately, the whole aquifer water will be unfit for use, not only for drinking purposes but also for domestic, industrial and irrigation purposes. It is, therefore, necessary to encourage groundwater recharge in the Malir River Basin, on one hand, and define the existing water quality scenario of coastal aquifers of Karachi, on the other hand, using modern & relatively precise techniques, such as nuclear techniques, so as to evaluate possibilities and impacts of sea water intrusion under heavy pumping of the Malir Basin.

## **OBJECTIVES AND RATIONALE**

The growing concern on deterioration of groundwater-systems due to disposal of untreated domestic sewage and industrial effluents into surface-water courses (mainly: Malir River, Layari River etc.) and its partial recharge under natural infiltration conditions, and possibly under artificially induced infiltration conditions, as well as saline sea-water intrusion in coastal aquifers of Karachi, are of great significance from hydrological, environmental and public-health viewpoint. Conjunctive use of hydrochemical, biological and nuclear techniques can provide reliable information on dynamics of groundwater flow, origin and mechanism of groundwater salinity. As a first step, it was considered necessary to initiate primary studies to:

1. Develop a general understanding about the isotopic, chemical and biological labeling of various recharge sources (rain, polluted streams/rivers, lakes, seawater) and the potable shallow and deep groundwater in coastal aquifer of Karachi,
2. Determine surface water and potable groundwater pollution characteristics,
3. Delineate spatial extent of saline groundwater, and
4. Evaluate the possible role of seawater intrusion in the coastal belt of Karachi.

It was decided to focus on evaluation of stable isotope characteristics of Oxygen ( $^{18}\text{O}$ ) of the water molecule; stable isotopes of Carbon ( $^{13}\text{C}$ ) in dissolved inorganic carbon, physiochemical and chemical characteristics (mainly parameters like E.C., salinity, redox, pH, Temperature, and chemical activities of Chloride, Sulfate, bicarbonate) of surface-water sources (polluted rivers, lakes, precipitation, local seawater), potable shallow groundwater and deep groundwater sources (dug wells, hand-pumps, pumping wells, which tap shallow and deep coastal aquifers of Karachi) and shallow sea water off Karachi Coast.

## **PRESENT INVESTIGATIONS**

### **Field Sampling**

Field sampling was performed in the jurisdiction of Karachi Metropolis during the period from November 2000 to December 2000. Surface-water samples and sediment samples

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## Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan

were collected from various locations along polluted streams/rivers namely: Layari River and Malir River, Hab Dam, Hab River and local sea (shallow seawater off Karachi coast). Shallow groundwater samples were collected from hand-pumps, dug wells and boreholes /mini pumping wells installed at depths upto 8 - 30 meters. Shallow mixed deep groundwater was collected from bore-holes / tube-wells installed at depths greater than 50 meters. Relatively deeper groundwater was collected from a few tube-wells installed at depths between 70-100 meters. All water-samples were collected in leak-tight /lined cap plastic bottles or glass bottles. Sediment samples were collected in high quality polythene bags. Sterile bottles were used for collection of water for Coliform bacterial analysis. Standard field sample preservation methods were used for subsequent chemical, biological and isotopic analysis in the laboratory<sup>2</sup>. In the field, all samples were stored under cool conditions (<12<sup>o</sup> C). The location of sampling point was monitored with the help of a Personal Navigator (Model Garmin™ GPS-100, M/S Garmin, 11206 Thompson Avenue, Lenexa, KS 66219).

### Field In-situ Analysis

Temperature, electrical conductivity, salinity, turbidity, redox potential, pH and dissolved oxygen were measured in-situ. Turbidity was measured with a portable turbidity meter (Model 6035, JENWAY). Electrical conductivity and temperature were measured with portable conductivity meter (Model HI 8633, M/S HANNA Instruments). Redox was measured with a portable ORP meter (Model: PS-19 ORP Meter, M/S Corning, Canada). Dissolved oxygen was measured with a portable D.O. Meter (Model 9070, JENWAY). Salinity was measured with a portable Salinometer (refractometer) obtained from the Center of Excellence in Marine Biology-Karachi University-Karachi.

### Laboratory Analysis

$\delta^{18}\text{O}$  values of water samples were determined by using  $\text{CO}_2 - \text{H}_2\text{O}$  equilibration method. Stable inorganic carbon isotope analyses of the total dissolved inorganic carbon (TDIC) of collected water samples were determined on  $\text{CO}_2$  gas extracted from TDIC using the routine sample preparation system by reacting 50-100 of water with 85%  $\text{H}_3\text{PO}_4$ <sup>3</sup>. The stable oxygen isotope data is expressed as  $\delta$  ‰ (delta per mill.) values relative to the international water standard V-SMOW (Vienna Standard Mean Ocean Water). The reproducibility of  $\delta^{18}\text{O}$  measurements was better than 0.1‰ for the working standards<sup>4</sup>. The stable carbon isotope data is expressed as  $\delta$  ‰ (delta per mill.) values relative to the international carbonate standard PDB (Pee-Dee Belemnite). The reproducibility of  $\delta^{13}\text{C}$  measurements was better than 0.1‰ for the working standards.  $\text{HCO}_3^-$ ,  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  were determined by titrimetric. Methods<sup>5</sup>.

## RESULTS AND DISCUSSION

It appears that five possible water-sources are contributing to the groundwater storage in Karachi. The first possible source is the rainfall. As the city of Karachi suffers from deficit of precipitation (only rainfall), the contribution to shallow groundwater storage from rain is very little. However, rainfall in the hinterlands and other areas surrounding Karachi may significantly contribute to the confined groundwater flow-system. The two freshwater sources are the Hab Lake/Hab Dam and the Indus River. Water from Hab Dam and the Indus River is piped to various residential zones in Karachi for drinking and irrigation purposes. The spring water discharges into Malir River and Layari River and the municipal/ industrial waste effluents added to these rivers are also contributing to groundwater storage as a fourth recharge source. Seawater intrusion along Karachi coast is the fifth possible source. Keeping in view this recharge-scenario of surface-water sources, we submit the following results / discussions w.r.t. our field and laboratory physico-chemical (temperature, pH, redox, dissolved oxygen, electrical conductivity, salinity and concentrations of major ion viz.  $\text{HCO}_3^{-1}$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{-2}$ ), and isotopic ( $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) investigations of surface-water and groundwater in Coastal Karachi-Pakistan. Tables-1 through 4 present a picture of these analyses. Results are discussed in the following section.

### Sources of Surface Water

#### *Local Precipitation (Rain)*

During the sampling period, no rainfall events occurred in coastal Karachi. Therefore, it was not possible for the sampling team to collect and analyze local rain for chemical and isotopic information. However, stable isotope data on precipitation for the period from 1961 to 1975 is available from the IAEA Precipitation Network for the Karachi Station (IAEA Precipitation Network Code: 41780000, Lat. 24.90N Long. 67.13E, Alt. 23 meters above mean sea level)<sup>6</sup>. The following stable isotope indices of precipitation in Karachi were, therefore, used for interpretation purposes:

Long Term Weighted Means: $\delta^{18}\text{O}$ (water): $- 3.93 \pm 1.94$ ‰ V-SMOW
--

#### *Indus River*

Physico-chemical and environmental stable isotope analysis was performed on one water-sample collected from the Indus River near Thatta city, where the river-water is partly diverted to Karachi for irrigation and drinking purposes (Table-1). The Indus River waters have electrical conductivity values below 500  $\mu\text{S}/\text{cm}$  and salinity below 1ppt. The  $\text{SO}_4^{-2}$

## Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan

**Table - 1: Physico-Chemical and Stable Isotope Analysis of Potable Surface water (Coastal Karachi)**

Sample Information		Physico chemical analysis										Major ion analysis			Stable isotope analysis	
		Geographical location Lat/Long	pH	EC (mS/cm)	Turbidity (NTU)	Temp. (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO <sub>3</sub> (ppm)	Cl <sup>-</sup> (ppm)	SO <sub>4</sub> <sup>-2</sup> (ppm)	δ <sup>13</sup> C(DIC)(‰V-PDB)	δ <sup>18</sup> O(‰V-SMOW)		
Sample Code	Sample Location/ collection point															
<b>Indus River</b>																
G-005	Indus water	---	7.6	0.48	36	24.7	-49	8.3	0	---	---	86	1.7	-8.2		
<b>Hab Dam</b>																
S-008	North west side near exit	25 -14 -54 67 -06- 87	8.3	1.4	58	27	147	---	<1	128	320	289	6.3	2.8		
S-009	Between Rest House and Check post No.1	25 -15- 40 67- 01- 17	8.3	1.47	79	27.3	79	---	<1	98	314	272	5.9	2.9		
S-010	Near Forest Office	25-16- 86 67- 06- 83	8.8	1.47	56	26.7	143	---	<1	---	---	326	1	2.9		
S-011	Mouth of feeding Stream	25 -16- 86 67- 06- 83	8.6	1.5	27	26	178	---	<1	---	---	298	4	2.9 9.8		
*Note: --- Not determined																

concentrations in the river water is 86 ppm. The stable isotope indices of total dissolved inorganic carbon (TDIC) in water and of oxygen in water molecule are as follows:

$\delta^{13}\text{C}$ (TDIC): + 1.7 ‰ PDB (n=1)
$\delta^{18}\text{O}$ (water): - 8.2 ‰ V-SMOW (n=1)

### *Hab Dam*

The water-storage in the Hab Lake was very little because the Hab River was dry, due to drought conditions in and around the study area over the past several years. Thus, most of the Hab Lake had patches of stagnant water. Results of physico-chemical stable isotopic analysis on Hab Lake water are presented in Table-1. Different patches of water in the lake showed similar values of mildly alkaline pH (~8.3), E.C (~1.4 mS/cm), and temperature (~ 27°C). The electrical conductivity values (~1500  $\mu\text{S}/\text{cm}$ ) were three times higher than the Indus river water-supply. Temperature of the water was also higher by about 2-3°C, as compared to the Indus River-water supply.  $\text{HCO}_3^-$  concentrations are moderate. Both the  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  concentrations in the lake water are around ~ 300 ppm.

The stable carbon isotope index ( $\delta^{13}\text{C}_{\text{TDIC}}$ ) of total dissolved inorganic carbon (TDIC) in lake-water varies in the range of + 1‰ PDB to +6.3‰ PDB in different patches of stagnant lake water. This is indicative of various sources of dissolved inorganic carbon in the lake or an enrichment due to biological transformation of TDIC into other carbon-containing compounds over the drought regime.

### *Polluted Rivers*

Table-2 summarizes the physico-chemical and stable isotope analysis of oxygen in water collected from polluted Layari and Malir Rivers. Results are discussed in the following section.

Layari River: The Layari River was monitored at five locations along its flow from North Karachi (upstream region) to Sher-Shah Bridge (downstream region) near Sea. The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and of oxygen in Layari River water are as follows:

$\delta^{18}\text{O}$ (Layari River Water): -5 to -2.7 ‰ V-SMOW (n=5)
$\delta^{13}\text{C}$ (TDIC - Layari River Water): -7.2 to -0.2 ‰ PDB (n=5)

There is a good correspondence between electrical conductivity and salinity along the flow in the river. Generally, the E.C. and salinity values tend to decrease downstream. Maximum values of EC (9.02 mS/cm) and Salinity (5 ppt) were observed at the origin of the Layari stream, near Yousuf Goth area. In this zone, the Layari stream receives minor

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spring-water, domestic waste-water from small isolated dwellings and wastewater from industries (flour mills, electronic industry, etc.) which host deep tube-wells with quite high salinity values. Downstream, the Layari River receives highly reducing municipal sewage of the Karachi city which comprises relatively low electrical conductivity water that is a mixture of the Indus River water and the local shallow groundwater supplied to the city for domestic use. High concentrations of  $\text{Cl}^-$  (3291 ppm) and  $\text{SO}_4^{-2}$  (ppm), coupled with mildly alkaline pH values, are found in the upstream regions of the river. However, these values decrease significantly along the flow downstream, whereby, the pH values remain slightly above neutral values. This indicates that the source of water in the upstream regions of Layari River is quite different from the downstream regions. Significantly high values of  $\text{Cl}^-$  and  $\text{SO}_4^{-2}$  in the upstream region indicate that the source of water in the river is the saline water discharged from deep tube-wells installed in the nearby industrial complexes. The  $\delta^{13}\text{C}_{\text{TDIC}}$  and  $\delta^{18}\text{O}$  (water) values are also quite enriched in this zone of Layari river, as compared to local shallow groundwater and are, in fact, relatively closer to the sea values. Downstream, as the Layari River receives sewage-water of the city, which is a mixture of the Indus River water and the local shallow groundwater supplied to the city for domestic use, the values of  $\delta^{18}\text{O}$  are consistently around -5 ‰ V-SMOW. It is, thus, speculated that the water in the extreme up-stream region of Layari River is a mixture of deep groundwater, which is partly trapped seawater (or geothermal water as there are geothermal springs nearby) and the local shallow groundwater.

#### *Malir River:*

The Malir River was monitored at three locations along its flow from Karachi East to the Sea before Ghizri Creek. The ranges of variation in stable isotope content of total dissolved inorganic carbon (TDIC) in water and of oxygen in Malir River water are the following:

$\delta^{18}\text{O}$ (Malir River Water): -4.9 to -4.6 ‰ V-SMOW (n=2) $\delta^{13}\text{C}$ (TDIC-Malir River Water): -8.4 to -0.2 ‰ PDB (n=2)
--

Like Layari River, there is good correspondence between electrical conductivity and salinity along the flow in Malir River. However, in contrast to Layari River, the concentrations of these parameters increase downstream. Lowest values of EC and Salinity were observed at the origin of the River behind Shah Faisal Colony. In this zone, the River receives minor spring water, minor domestic waste-water from small isolated dwellings and seepage from agricultural fields / vegetable farms, which use the low E.C Indus River water for irrigation. Downstream, the Malir River mainly receives slightly low reducing and Oxygen-rich municipal sewage from thickly populated areas of Mahmood Abad. The pH of the river water increases by one unit as it receives domestic and industrial alkaline effluents. High concentrations of  $\text{Cl}^-$  (971 ppm) and  $\text{SO}_4^{-2}$  (230 ppm) are found in the downstream



**Table - 2: Physico-Chemical and Stable Isotope Analysis of Polluted River/ Major Sewage Drains in Coastal Karachi**

Sample Information			Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Location/ collection point	Geographical location Lat/Long	pH	EC (mS/cm)	Turbidity (NTU)	Temp. (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO <sub>3</sub> (ppm)	Cl- (ppm)	SO <sub>4</sub> (ppm)	δ <sup>13</sup> C-TDIC (‰ V PDB)	δ <sup>18</sup> O (‰ V - SMOW)
Layari River														
S-022	New Karachi near Yousaf Ghoth	25°-00'-48" 67°-05'-50"	8.4	9	76	24.5	-13	0.3	5	660	3296	525	-0.2	-2.7
S-021	Gulshan-Abad Bridge	24°-55'-70" 67°-05'-28"	7.8	3.7	54	26.5	-345	0.6	3	---	---	---	-7.2	-5.3
S-020	Teen Hatti	24°-53'-63" 67°-03'-64"	7.2	1.3	89	26.1	2	0.4	< 1	364	233	52	-3.8	-5.5
S-019	Before Juna Dhobi Ghat (Mirza Adam Khan Road)	24°-52'-75" 67°-01'-04"	7.5	1.5	68	25.5	-58	1.2	< 1	---	---	---	-6	-5.4
S-018	Before Juna Dhobi Ghat (Mirza Adam Khan Road near Tanga Stand)	24°-52'-46" 66°-58'-99"	7.4	2.3	54	24.1	-290	0.8	2	562	443	94	-1.4	-5.2
Malir River														
S-017	Behind Shah Faisal Colony	24°-52'-31" 67°-08'-31"	6.9	1.6	75	23.7	-198	0.2	1	462	201	65	-1.4	-4.9
S-015	Bridge between Mahmoodabad and Korangi	24°-51'-07" 67°-05'-63"	7.7	3.2	97	21.6	-25	3.4	3.5	---	---	---	---	---
S-014	Quyyum Abad Ghizri Area	24°-49'-44" 67°-05'-52"	7.9	3.4	98	23.4	-310	24	5	486	971	230	-8.7	-4.6

Note: "—" Not determined

### Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan

region of the river. This is perhaps due to the effect of sea tides in the Qayyum Abad area, near Ghizri Creek.

#### *Karachi Sea:*

Table-3 presents the summary of physiochemical and stable isotope analysis of shallow seawater collected off six representative locations along Karachi coast. The pH values of ~8.1 for open seawater off Karachi Coast generally conform to those for normal ocean waters. However, pH values decrease to levels of ~7.7 near the Ghizri Creek, and the Korangi Creek which receive significant quantities of industrial acidic wastewaters. Similarly, the pH values of seawater increase to ~8.5 in the back-waters of Manora Channel, near Village Shamas-pir. Electrical Conductivity values for Karachi seawater range between 49.3 mS/cm to 53.7 mS/cm, while the salinity values are ~ 39 ppt. The electrical conductivity values higher than 53 mS/cm correspond to relatively non-polluted open seawaters on north-west and south-east sides of Karachi coast. The E.C values of open seawater drop, due to input of wastewaters from Malir River via Ghizri Creek and polluted drains around Korangi Creek. Slightly higher temperature is observed near Ghizri Coast, which is attributed to input of relatively warmer wastewaters of industrial and domestic origin. Cl<sup>-</sup> contents of seawater off Karachi coast are in the range of 21,578 to 25,230 ppm, while the SO<sub>4</sub><sup>-2</sup> concentrations are in the range of 2076 to 2210 ppm. The stable carbon isotope contents ( $\delta^{13}\text{C}_{\text{TDIC}}$ ) of total dissolved inorganic carbon (TDIC) vary in the range of - 3.9 ‰ PDB to + 0.8 ‰ PDB in different zones off Karachi coast. This is indicative of different levels and sources of dissolved inorganic carbon in seawater, due to input of domestic and industrial wastewater into the sea from key industrial trading estates (LITE, KITE, SITE etc.) via polluted drains. The highest  $\delta^{13}\text{C}_{\text{TDIC}}$  value of + 0.8 ‰ PDB corresponds to relatively non-polluted seawater along north-west coast of Karachi. The lowest  $\delta^{13}\text{C}_{\text{TDIC}}$  value of -3.9 ‰ PDB corresponds to highly polluted seawater in Korangi Creek, which receives industrial and domestic waste drains from Korangi Industrial Trading Estate (KITE). The high tide (HT) stable isotope content of oxygen in relatively non-polluted seawater, along Karachi coast, falls in the following range:

$$\begin{array}{l} \delta^{18}\text{O} (\text{seawater})_{\text{HT}}: + 0.3 \text{ to } + 1.1 \text{ ‰ V-SMOW } (n=5) \\ \delta^{13}\text{C} (\text{TDIC} - \text{seawater}): -3.9 \text{ to } 0.8 \text{ ‰ PDB } (n=5) \end{array}$$

The low tide (LT) stable isotope content of oxygen in relatively polluted seawater along Karachi coast falls in the following range:

$$\delta^{18}\text{O} (\text{seawater})_{\text{LT}}: -1.3 \text{ to } + 0.1 \text{ ‰ V-SMOW } (n=5)$$

**Table - 3: Physio-Chemical and Stable Isotope Analysis of Local Seawater (Coastal Karachi)**

Sample Information			Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Code	Geographical location Lat/Long	pH	EC (mS/cm)	Turbidity (NTU)	Temp. (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO <sub>3</sub> <sup>-</sup> (ppm)	Cl <sup>-</sup> (ppm)	SO <sub>4</sub> <sup>2-</sup> (ppm)	δ <sup>13</sup> C-TDIC (‰ PDB)	δ <sup>18</sup> O (‰ V-SMOW)
K-12	Bule-Ji Coast	24°-49'-04" 66°-50'-41"	---	53.7	78.5	25.4	208	---	39	159	24138	2076	0.76	0.74
K-17	Clifton Coast	24°-47'-43" 67°-01'-40"	8.1	52.8	52.6	25.6	135	8	39	145	25230	2180	-2.77	0.87
K-24	Ghizri Coast	24°-45'-86" 67°-07'-12"	7.8	52.1	195.5	28.3	182	2.7	39	156	24230	2210	-2.72	0.82
K-26	Korangi Coast	24°-47'-99" 67°-12'-22"	7.7	52.1	173.6	25.7	104	3.8	39	---	---	---	-3.86	1.1
K-43	Shams Pir Coast	24° -51'-05" 66° -55'-05"	8.5	49.3	---	25.3	34	---	32	196	21578	2323	-2.26	0.27

### Potable Groundwater in Coastal Aquifer

Shallow groundwater samples were obtained from hand pumps (n=1), dug wells (n=1) and shallow bores, with centrifugal pumps (n=8) installed at depths less than 50 meters (mainly between 8-30 meters); and (b) relatively deep groundwater was obtained from pumping wells (cased wells/Tube-wells) installed at depths greater than 50 meters in the coastal aquifer of Karachi. These cased wells also tap various proportions of shallow groundwater, in addition to deep groundwater. Tables-4a and 4b present the physico-chemical, bacteriological and stable isotope data of shallow and shallow mixed deep groundwater. The following section presents discussion on these data-elements.

#### Shallow Groundwater

Physico-chemical data of shallow groundwater (depth less than 30 meters) shows that the shallow wells, located in the vicinity of coast and in the proximity of polluted rivers, have relatively higher values of electrical conductivity, salinity and population of Coliform bacteria. In general, the bacteriological quality of shallow groundwater is quite poor and renders the water unfit for drinking purposes without prior treatment. The shallow groundwater is moderately saline, representing electrical conductivity values in the range of 1.1 to 1.9 mS/cm and salinity in the range of 1 ppt. The pH of shallow groundwater varies from mildly acidic (~6.3) to mildly alkaline values (~7.9). Areas with quite poor sanitary conditions have relatively low values of pH (~6.3 to 6.8). Shallow groundwater below 20 meters is slightly reducing. The dissolved oxygen is in the range of 1.5 to 7.9 mg/L. Turbidity of shallow groundwater varies between 3.6 NTU and 95 NTU. The

### Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan

concentration of  $\text{HCO}_3^-$  (356 - 514 ppm, n=4),  $\text{Cl}^-$  (82 - 169 ppm, n=4) and  $\text{SO}_4^{2-}$  (38-117 ppm, n=4) in shallow groundwater is very reasonable.

The mean chemical concentrations of  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{HCO}_3^-$  in shallow groundwater are as follows:

Mean $\text{Cl}^-$ (Shallow Groundwater): $132.8 \pm 36.5$ ppm (n=4 )
Mean $\text{SO}_4^{2-}$ (Shallow Groundwater): $63.3 \pm 36.7$ ppm (n=4 )
Mean $\text{HCO}_3^-$ (Shallow Groundwater): $423 \pm 67.4$ ppm (n=4 )

The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and oxygen in Layari River water is as follows:

$\delta^{18}\text{O}$ (Shallow Groundwater) -6.3 to -5.8 ‰ V-SMOW (n=8)
$\delta^{13}\text{C}$ (TDIC-Shallow Groundwater): -16.5 to -5.5 ‰ PDB (n=8)

The mean stable isotope content of  $^{18}\text{O}$  and  $^{13}\text{C}$  in shallow groundwater is as follows:

Mean $\delta^{18}\text{O}$ (Shallow Groundwater): $-5.9 \pm 0.32$ ‰ V-SMOW (n=8)
Mean $\delta^{13}\text{C}$ (TDIC-Shallow Groundwater): $-10.1 \pm 3.3$ ‰ PDB (n=8)

The stable-isotope results indicate that the shallow / phreatic aquifers are recharged by a mixture of fresh waters of Indus River and Hab River (draining spring water and flooded rainwater), as well as polluted Layari and Malir rivers and their feeding drains (both under natural infiltration conditions and artificially induced infiltration conditions) and, to a much smaller extent, from direct recharge of local precipitation.

### Deep Groundwater

In general, deep groundwater is mostly saline and has high electrical conductivity (range: 1.9- 19.1 mS/cm) and salinity (range: 1.7-7.4 ppt), as compared to shallow groundwater. The sampled deep groundwater from pumping wells is in fact a mixture of various proportions of shallow groundwater from freshwater phreatic/ unconfined aquifer and actual deep groundwater from the confined aquifer. In the absence of well-logs of sampled tube-wells/pumping wells, it is not possible to estimate the proportions of inputs of shallow groundwater in the discharge of these wells. Based on hydrochemical data, it is assumed that the shallow mixed deep groundwater discharged by large-scale pumping wells mainly represents the deep groundwater from confined aquifer. The more representative deep groundwater wells (sample No. G-006, G-012, G-014) are those which have relatively higher values of electrical conductivity (range: 5.1 - 19.1 mS/cm), salinity (range: 2.7 - 7.4 ppt) as well as concentrations of  $\text{Cl}^-$  (range: 1480 - 6034 ppm) and  $\text{SO}_4^{2-}$  (range: 144 -

**Table - 4(a): Physico-Chemical and Stable Isotope Analysis of Shallow Groundwater (Coastal Karachi)**

Sample Code	Sample Information		Physico chemical analysis							Major ion analysis			Stable isotope analysis		
	Sample Location / collection point	Geographical location (Lat/Long)	Approx Depth (meter)	pH	EC (mS/cm)	Turbidity (NTU)	Temp (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO <sub>3</sub> (ppm)	Cl <sup>-</sup> (ppm)	SO <sub>4</sub> <sup>2-</sup> (ppm)	δ <sup>13</sup> C-TDIC (‰ PDB)	δ <sup>18</sup> O (‰ V-SMOW)
<b>A: Shallow groundwater</b>															
<b>A-I: Hand pump</b>															
G-008	Azeem Pura (Malir)	24°-52'-60" 67°-09'- 61"	10	7.5	1.4	95	27.3	-34	3.6	0.9	--	---	---	-9.7	-6.2
G-002	Gulshan-e-Iqbal	24°-55'- 00" 67°-04'- 79"	8	6.8	1.7	35	28.6	-12	---	1	--	---	---	-10.7	-5.8
<b>A-II: Dug well</b>															
G-003	Mill Area Liaquat Abad (R.I)	---	15	7.4	1.8	56	29.2	-4	---	1	356	140	56	-5.5	-5.3
<b>A-III: Bores/Pumping wells</b>															
G-004	Garden Zoo Area (R.I)	24°-52'- 41" 67°-01'- 41"	20	7.6	1.9	79	28.8	-52	7.9	1	--	---	---	-6.6	-6.3
G-009	Shah Faisal Colony (R.I)	24°-52'-47" 67°-10'- 03"	25	7.5	1.1	29	28.2	103	2.4	1	394	140	42	-9.8	-5.9
G-011	Juna Dhubi Ghat (R.I)	24°-52'-76" 67°-01'- 03"	25	6.7	1.1	---	27.5	72	1.9	0.8	428	82	38	-10.6	-6.2
G-013	North Karachi, Iqbal Town	24°-58'-59" 67°-03'- 96"	30	6.3	1.5	3.6	27.4	59	2.8	1	--	---	---	-11.6	-5.8
G-018	Saddar (C)	---	20	7.9	1.6	7.8	28.9	37	1.5	1	514	169	117	-16.5	-6.0

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Table – 4(b): Physio-Chemical, and Stable Isotope Analysis of Shallow Mixed Deep Groundwater (Coastal Karachi)

Sample Code	Sample Information			Physio chemical analysis							Major ion analysis			Stable isotope analysis	
	Sample Location /collection point	Geographical location (Lat/Long)	Approx. Depth (meter)	pH	EC (mS/cm)	Turbidity (NTU)	Temp (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO <sub>3</sub> (ppm)	Cl <sup>-</sup> (ppm)	SO <sub>4</sub> (ppm)	δ <sup>13</sup> C-TDIC (‰ V-PDB)	δ <sup>18</sup> O (‰ V-SMOW)
G-001	Gulshan-e-Iqbal (R.L)	24°-55'-01" 67°-04'-79"	>70	7.0	2.9	27	28.6	-20	0.1	2	241	1829	129	-11.5	-5.6
G-006	PECHS Mahmood Abad	24°-51'-47" 67°-04'-35"	>70	7.5	5.5	41	30	-51	5.6	2.9	380	1480	144	-0.3	-4.2
G-007	Gulistan-e-Johar	24°-54'-53" 67°-07'-23"	>50	6.6	3.4	39	27.3	-2	4.5	2.2	376	501	142	-10.7	-5.9
G-010	Quaid Abad (R <sub>SM</sub> )	24°-52'-06" 67°-12'-18"	>50	7.5	2.3	25	22.4	118	---	1.8	---	---	---	-11.3	-6.2
G-012	Power House Area (R <sub>L</sub> )	24°-57'-51" 67°-04'-49"	~50	7.5	5.1	5.4	24.3	-023	1.7	2.7	373	2194	698	-10.4	-4.3
G-014	New Karachi Near yousaf Ghothi (R <sub>L</sub> )	25°-00'-47" 67°-05'-91"	~100	6.9	19.1	9.9	29.6	45	4.8	7.4	290	6034	2221	-13.2	-4.5
G-015	Model Colony (Malir)	--	45	6.5	3.5	7.7	23.5	139	---	2.2	144	501	102	-11.7	-6.0
G-016	Clifton (C)	24°-49'-91" 66°-57'-98"	80	7.4	7.8	2.7	28.1	23	3.7	3.6	281	3291	445	-13.2	-5.0
G-017	Sultan A bad. Hijrat Colony (C)	24°-46'-07" 67°-00'-31"	>70	8.6	6.6	12.2	28.2	-48	2.3	3.2	886	3291	132	-11.0	-5.5
G-019	Malir Halt	---	>50	7.7	1.9	---	---	---	---	1.7	211	402	113	-12.1	-5.8

2221 ppm). The deep wells located close to the coast/shoreline (sample No. G-016, G-017) also have relatively higher values of electrical conductivity, salinity, Cl<sup>-</sup> (3291 ppm each well) and SO<sub>4</sub><sup>-2</sup> (132 - 445 ppm). The mean chemical concentrations of Cl<sup>-</sup>, SO<sub>4</sub><sup>-2</sup> and HCO<sub>3</sub><sup>-</sup> in shallow mixed deep groundwater are as follows:

Mean Cl <sup>-</sup> (Deep Groundwater): 2169.2 ± 1828.0 ppm (n=9)
Mean SO <sub>4</sub> <sup>-2</sup> (Deep Groundwater): 458.4 ± 691.4 ppm (n=9)
Mean HCO <sub>3</sub> <sup>-</sup> (Deep Groundwater): 353.6 ± 215.4 ppm (n=9)

The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and oxygen in shallow mixed deep groundwater is as follows:

δ <sup>18</sup> O (Deep Groundwater): - 6.2 to -4.2 ‰ V-SMOW (n=10)
δ <sup>13</sup> C (TDIC - Deep Groundwater): -13.2 to -0.3 ‰ PDB (n=10)

The mean stable isotope content of <sup>18</sup>O in shallow mixed deep groundwater is as follows:

Mean δ <sup>18</sup> O (Deep Groundwater): -5.3± 0.7‰ V-SMOW (n=10)
Mean δ <sup>13</sup> C (TDIC- Deep Groundwater): -10.5±3.7‰ PDB (n=10)

The hydrochemical and stable isotope results indicates that the confined aquifer hosts a mixture of rainwater from hinterlands and surrounding regions around coastal Karachi, as well as sea trapped water / seawater, through intrusion under natural infiltration conditions or under induced recharge conditions.

### **Groundwater Recharge Characteristics/ Sea water Intrusion**

Presently, coastal Karachi is known to have five sources of recharge to its groundwater reserves. These are: (i) rainfall, (ii) Indus River water supply, (iii) Hab-River & Hab Lake water supply; (iv) polluted Layari and Malir rivers/ contributory channels draining mixtures of domestic, industrial and agricultural wastewater, composed of pre-said three sources; and (v) seawater. The possibilities of major contribution to groundwater recharge of shallow / phreatic aquifer directly by local rainfall seems very small, due to very poor frequency of rainfall events and rainfall intensities in the Karachi and high evaporation rates. The long-term (15 years annual record) mean monthly average precipitation for Karachi is between 0-15 mm during the months of January to June, 23 - 91 mm during the months of July to September, and 0-7 mm during the months of October to December. The remaining four sources can play a significant role in recharge of the shallow aquifer-system and deep groundwater system (confined aquifer) in coastal Karachi.

In order to postulate the origin of shallow and deep groundwater and related salinity in the shallow aquifer system and the confined deep aquifer system, the stable isotope

## Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan

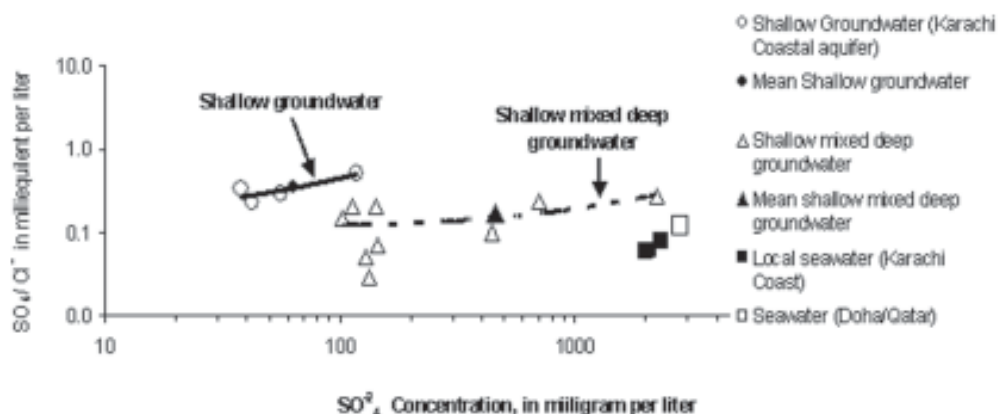
composition of oxygen and hydrochemical data of groundwater samples collected in the present investigation is statistically evaluated.

Unpolluted seawater off Karachi coast is characterized by a  $\delta^{18}\text{O}$  value of  $\sim +1$  ‰ V-SMOW and a chloride content of  $\sim 23000$  ppm. Both the Layari River and Malir River waters, as well as the Indus River water and the Hab Lake water, have extremely very low aqueous contents of chloride and sulfate ions as compared to seawater. The average mean value of  $\delta^{18}\text{O}$  in polluted river waters is  $\sim 5$  ‰ V-SMOW and in shallow groundwater is  $-5.9$  ‰ V-SMOW. Therefore, those pumping wells which are located near the coastline/shore line (where seawater intrusion could be expected) and have high chloride and sulfate values should represent seawater-intrusion and relatively enriched  $^{18}\text{O}$  values. However, for pumping-wells located comparatively far away from the coast and representing high salinity (chloride & sulfate concentrations), the contribution of saline water may be derived from upward diffusion from the freshwater-seawater interface, possibly as a result of local fluctuation of water-table due to pumping. In the present investigations, shallow mixed deep-pumping wells installed near the coast (sample No. G-016, G-017) have significantly high values of chloride (in both wells) and sulfate (in well near Clifton coast), but have  $\delta^{18}\text{O}$  values closer to polluted river water and shallow groundwater. This suggests that these coastal pumping-wells are withdrawing significant quantities of water from shallow aquifer, which also hosts recharge of seawater gushed into the coastal zone during summer monsoon period. However, possibilities of direct seawater intrusion in these wells, under prolonged pumping conditions, is yet to be verified. Noteworthy are the pumping wells with significantly high chloride-content and relatively lower sulfate-content (Well No. G-001, G-017). These samples have negative redox values and it is speculated that the lower sulfate contents are due to biological reduction of sulfate. Sulfur Isotopic analysis ( $\delta^{34}\text{S}$ ) of aqueous sulfate in these samples is in progress, to fully document this observation.

The relatively deeper groundwaters representing confined aquifer, and sampled from three pumping wells: No. G-006, G-012, G-014, have a mean  $\delta^{18}\text{O}$  value of  $-4.3$  ‰ V-SMOW and excessively high values of aqueous chloride and sulfate. One of the samples No. G-006 has  $\delta^{13}\text{C}$  (TDIC) value of  $-0.3$  ‰, PDB which is very close to the  $\delta^{13}\text{C}$  (TDIC) value for seawater. The other two wells No. G-012 and G-014 have  $\delta^{13}\text{C}$  (TDIC) values of  $-10.4$  ‰ PDB and  $-13.2$  ‰ PDB. Similar depleted  $\delta^{13}\text{C}$  values have been reported for deep saline groundwater tapped from confined aquifer in the coastal zone of Orissa-India<sup>7</sup>. It is speculated that the groundwater tapped by these wells mainly represents a mixture of recharge from rainfall in the hinterlands, flood water and spring-water drained by the Malir River Basin and the Hab River Basin around coastal Karachi, as well as seawater. For Well No. G-006, we speculate direct intrusion of seawater by excessive pumping. However, in case of the two pumping wells No. G-012 and G-014, the excessively high values of chloride and sulfate in deep groundwater away from the coast suggest possibilities of trapped seawater. To verify possibilities of seawater intrusion in shallow



groundwater and mixed deep groundwater and/or existence of trapped seawater in deep groundwater, the concentrations of  $\text{SO}_4^{2-}$  (in milligrams per liter, log scale) are plotted against  $\text{SO}_4^{2-}/\text{Cl}^-$  ratios (in milliequivalents per liter, log scale) for all analyzed water-samples (Figure-1). It is obvious that shallow groundwater and deep groundwater plot along two distinct lines.



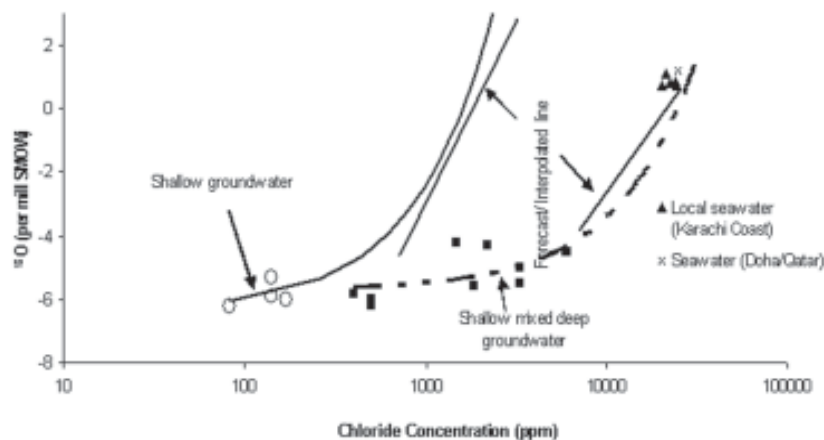
**Figure – 1: Graph of  $\text{SO}_4^{2-}/\text{Cl}^-$  Ratio and  $\text{SO}_4^{2-}$  Concentration in Shallow and Deep Groundwater, Coastal Karachi (Pakistan)**

This is further justified by demonstrating the trend of  $\text{Cl}^-$  concentrations (in ppm, log scale) versus  $\delta^{18}\text{O}$  values (in ‰ V-SMOW, linear scale) in shallow and deep groundwater and the local seawater as well as seawater from Doha-Qatar in Gulph Area<sup>6</sup>. It may be realized from Figure-2 that the extrapolated or forecast trend for shallow groundwater samples (with low  $\text{SO}_4^{2-}$  content) does not fall on the data points for local seawater (or other tropical seawater from Doha/Qatar). However, the extrapolated or forecast trend for deep groundwater samples (with high  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  contents and enriched  $\delta^{18}\text{O}$  values) falls in the vicinity of the data points for local seawater (or other tropical seawater from Doha/Qatar). This observation strengthens the possibilities of seawater intrusion in the coastal zone and existence of trapped seawater salinity/build-up of salt-water up-coning in the deep confined aquifer in coastal Karachi.

## CONCLUSIONS

The primary studies carried out during the first year of the project on conjunctive use of stable isotope techniques and conventional non-nuclear techniques have successfully provided a general view of the stable isotope composition of oxygen and inorganic carbon in water and its dissolved inorganic carbon, as well as hydrochemistry /salinity and biological pollution of potable groundwater system in coastal Karachi. The conclusions on possibilities

## Salinity of Groundwater in Coastal Aquifer of Karachi, Pakistan



**Figure - 2: Chloride Versus  $^{18}\text{O}$  Trend Line for Shallow and Shallow Mixed Deep Groundwater, Coastal Karachi (Pakistan)**

of seawater and/or existence of trapped seawater salinity/build-up of salt-water up-coning, in the deep confined aquifer in coastal Karachi, is based on few and scattered data-points. More representative sampling thus needs to be performed during the next sampling phase.

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# **Studies of Seawater Pollution on the Pakistan Coast Using Stable Carbon Isotope Technique**

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# STUDIES OF SEAWATER POLLUTION ON THE PAKISTAN COAST USING STABLE CARBON ISOTOPE TECHNIQUE

## ABSTRACT

*Environmentally stable carbon isotope ratios ( $\delta^{13}\text{C}$  ‰ PDB) of total dissolved inorganic carbon (TDIC) have been used as a natural tracer of domestic and industrial pollution- inventory in shallow seawater off the Pakistan Coast. Shallow seawater samples (sea depth range ~2-20 meters) were collected from five locations off the Baluchistan Coast (Jiwani, Gwadar, Pasni, Ormara, Sonmiani) and two locations off the Sindh Coast (Karachi and Indus Delta). Physiochemical parameters, such as pH, electrical conductivity, and Salinity, were measured in-situ.  $\delta^{13}\text{C}$  values of TDIC were measured, using gas-source mass spectrometry. Significantly depleted  $\delta^{13}\text{C}_{\text{TDIC}}$  values (as low as -7 per mill. PDB) coupled with measurable depletion in pH, electrical conductivity and salinity, are observed in samples of seawater collected off the Indus Delta, Karachi coast, Gwadar coast and Sonmiani Bay. This is indicative of considerable inputs of pollution from industrial and/or domestic waste-drains into the marine environment off these coasts. The mangrove ecosystem is also found to strongly control the  $\delta^{13}\text{C}_{\text{TDIC}}$  composition of seawater in the narrow channels of Jiawani Bay, Sonmiani Bay and in the backwaters of semi-closed Manora Channel.*

## INTRODUCTION

There is a serious lack of consciousness about marine pollution in Pakistan. Inadequate disposal of untreated industrial effluents and domestic sewage into shallow seawater off large coastal dwellings is a common practice. This has resulted not only in significant degradation of quality of sea-water, but has also affected the biotic life, specifically along the coast of Karachi. Some sporadic surveys, involving use of classical hydro-geochemical and biological techniques, have been made in the past to estimate the pollution along the coast of Pakistan<sup>1-4</sup>. Environmental isotopes provide a complementary tool to deduce valuable information about the sources of pollution, as well as distribution and fate of pollutants in the hydrosphere, including the marine environment. Among these, the stable isotopes of carbon have a strong potential for determination of pollution-inventories from domestic and industrial sources (carbon flow) and pollutant-transport in the marine environment<sup>7-9</sup>. Stable carbon isotope ratios ( $\delta^{13}\text{C}$  per mill PDB) of total dissolved inorganic carbon (TDIC) have been used as potential indicators of seawater-quality off the Karachi coast<sup>8</sup>. The stable carbon isotope ratios of marine environmental samples are of prime importance, as carbon makes up a dominant part of the marine ecosystem (living environments, marine geological matrix and the domestic and industrial waste matter). The

$^{13}\text{C}/^{12}\text{C}$  ratios in various carbon reservoirs differ, due to fractionation-effects of certain biological, geological and chemical processes. Carbonate equilibria and photosynthetic conversion of inorganic carbon into organic carbon are major processes of carbon isotope fractionation in aquatic systems. Generally, organic matter is depleted of  $^{13}\text{C}$ , with respect to inorganic carbon. Marine and land plants have different  $\delta^{13}\text{C}$  values. Potential pollutants, such as crude oil, effluents from petrochemical plants, in some instances, can be distinguished from natural marine dissolved organic carbon (DOC), particulate organic carbon (POC) and sedimentary organic carbon. Furthermore,  $\text{CO}_2$  from effluents of domestic sewage has  $^{13}\text{C}$  values much lower than the natural dissolved  $\text{CO}_2$  in marine environment and  $^{13}\text{C}$  potentially could be used as a pollution tracer. The general spectrum of  $\delta^{13}\text{C}$  in selective carbon reservoirs (or pools) in terrestrial and marine environment is shown in Table - 1.

During November-December, 2000, shallow seawater samples were collected from seven selected locations along the coast of Pakistan i.e. the Baluchistan coast, and the Sindh Coast, for studies related to the IAEA/RCA/UNDP Marine Sub-project entitled: Management of Marine Coastal Environment and its Pollution (RAS/8/083). A component of this sub-project deals with determination of the levels, behaviour and the fate of pollutants in the marine coastal environment, using nuclear techniques. This paper documents the use of environmental stable carbon isotope technique to establish a pollution-scenario of shallow marine coastal environment of Pakistan.

**Table - 1:  $\delta^{13}\text{C}$  Values for Various Reservoir/Pools**

<b>Carbon Pool</b>	<b><math>\delta^{13}\text{C}</math> ‰ PDB</b>
Atmospheric $\text{CO}_2$	- 9 to - 6
Soil $\text{CO}_2$	- 30 to - 6
Groundwater DIC	- 20 to 0 (may be more up to +14)
Marine Dissolved Inorganic Carbon (DIC)	- 8 to + 2
Marine Particulate Organic Carbon (POC)	- 26 to -18
Marine Dissolved Organic Carbon (DOC)	- 30 to -18
Organics in Marine Sediments	- 38 to -17
Marine Limestone	- 5 to + 4 (may be more up to +7)
Marine Plants	- 16 to -4
Land Plants	- 28 to -16
Biogenic Methane	- 80 to - 40
Coal	- 27 to -22
Crude Oil	- 30 to -22
Pulp Mill Effluents	- 32 to -18
Domestic Sewage $\text{CO}_2$	- 12 to - 6
Domestic Sewage POC	- 20 to -16
Domestic Sewage DOC	- 26 to -22
Petrochemical and Natural Gas	- 30 to - 50 (or more depleted)

## DESCRIPTION OF STUDY AREA

Pakistan has a coastline of 960 km, bordering the Arabian Sea. It extends from the border of India near Rann of Katch in the South-East to the border of Iran near Jiawani in the North-West (Figure - 1). The Exclusive Economic Zone (EEZ) is about 240,000 sq km. On the basis of its physiographical characteristics, the coastal area of Pakistan is divided into two distinct sections, namely, the Sindh Provincial coast and the Baluchistan Provincial coast (length: ~745 km). The Sindh Provincial Coast mainly includes the Indus River Delta-zone and the Karachi coast. With the exception of the Karachi metropolis (population over 12 millions and industrial base over 1000 large industrial units) along the Sindh coast, most parts of the coastal areas of Pakistan are sparsely inhabited. The entire coast of Baluchistan has small coastal towns and developing harbours, such as Jiawani, Gwadar, Pasni, Ormara and, Sonmiani, which have a total population of about one million. The coastal zone of Pakistan supports both living and non-living resources, which annually contribute towards the national economy. The mangrove ecosystems of the Indus deltaic region, Sonmiani Bay, and Jiawani are also of significant economic as well as scientific interest to Pakistan. The mangrove habitat supports the spawning and breeding grounds of commercially important shrimps as well as for a variety of other fishes. In the absence of an alternative resource, mangroves also serve the underprivileged inhabitants of coastal communities as a valuable source of timber, charcoal and fodder for domestic animals. The environmental pollution issues in the coastal zone of Pakistan have arisen mainly due to indiscriminate discharge of untreated effluents, domestic sewage and solid wastes, as well as agricultural runoff from coastal dwellings into the marine coastal environment. Increasing pollution along the Karachi coast has resulted in considerable thinning of the mangrove forests. The recent incidences of fish-kills off the Karachi coast and Gawadar Bay have been attributed to the growing pollution in shallow marine environment of these coasts<sup>9</sup>.

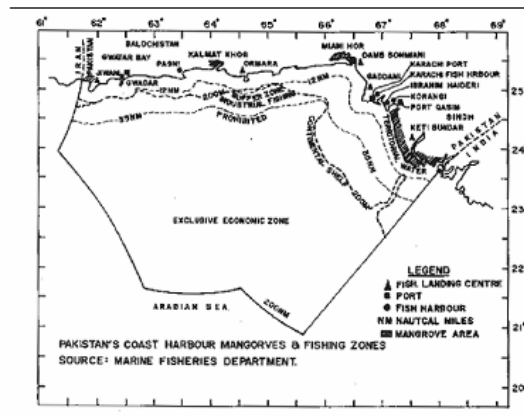


Figure – 1: Pakistan's Coast Harbour Mangroves & Fishing Zones

## SAMPLING SITES AND FIELD METHODS

About 500 ml seawater samples (depth ~ 2 -20 meters) were collected in pre-cleaned and leak-tight plastic bottles. Samples were collected from seven principal coastal locations, namely: Jiawani, Gwadar, Pasni, Ormara, Sonmiani, Karachi and Indus Delta, along the coast of Pakistan during the period Nov.-Dec., 2000 for stable carbon isotope analysis ( $\delta^{13}\text{C}$ ) of total dissolved inorganic carbon (TDIC). The samples were immediately spiked with 0.1M  $\text{HgCl}_2$  solution to avoid additional input of inorganic carbon by bio-mediated decomposition of organic matter in the samples. Samples were collected during the low-tide regime as, in this regime, the polluted river and sewage drains have adequate flow of water towards the sea. The samples were filtered through Whatman-42 and 0.45 micron nitrocellulose filter-paper in the nearby base-camp laboratory within 24 hours. The time for the occurrence of a low or high tide was deduced from the standard Tide Table Guide published by the Pakistan Navy. At some locations, waste drains/polluted rivers were also tapped during the last hour of low tide in the sea and at a suitable location in pre-outfall zone, so as to exclude the influence of high-tide intrusion of seawater in the polluted channel. Physicochemical parameters, such as pH, electrical conductivity and salinity, were measured in-situ.

## LABORATORY METHODS

Stable carbon isotope analysis of total dissolved inorganic carbon (TDIC) in water-samples was determined by gas-source mass spectrometry and using routine sample-preparation methods<sup>5,6</sup>. Seawater sample (~250 ml) was reacted with 85% pure  $\text{H}_3\text{PO}_4$  acid to liberate  $\text{CO}_2$  gas from TDIC in a vacuum line. The moisture in the evolved  $\text{CO}_2$  gas was condensed in a U-trap held at  $-80\text{ }^\circ\text{C}$ , using freon-liquid nitrogen slush. Residual moisture in the evolved  $\text{CO}_2$  gas was condensed in a subsequent U-trap, held at liquid nitrogen temperature ( $-196\text{ }^\circ\text{C}$ ). When the reaction was completed, the first U-trap was closed and the temperature of the second U-trap was raised to  $-80\text{ }^\circ\text{C}$  with "freon-liquid nitrogen slush" to evaporate and expand the sample  $\text{CO}_2$  in the vacuum-line for pressure measurements and to transfer it in a suitable vacuum-tight Pyrex glass ampoule for stable carbon isotope analysis on a modified GD-150 Mass Spectrometer. The stable carbon isotope results are expressed as  $\delta$  (*delta*) ‰ (*per mil*) values relative to the international carbonate standard, namely, PDB (*Pee-Dee Belemnite*):

$$\delta = \left\{ \left( R_s - R_{\text{St}} \right) / R_{\text{St}} \right\} \times 1000$$

where R=  $^{13}\text{C}/^{12}\text{C}$  ratio, S= unknown sample and St= known standard or reference material. The reproducibility of  $\delta^{13}\text{C}$  measurements was better than 0.05 ‰ PDB for the working standard.

## RESULTS AND DISCUSSION

Unpolluted seawaters have  $\delta^{13}\text{C}_{\text{TDIC}}$  values closer to 0 ‰ PDB. Any deviation from this value will signify input of dissolved inorganic carbon from a secondary source. The coast of Baluchistan province is sparsely populated and there are no industrial activities up to now along this coast. However, untreated domestic sewage is drained into the sea from sizable dwellings (developing harbours) along this coast. Table - 2 presents a summary of the measured ranges of physiochemical parameters and  $\delta^{13}\text{C}_{\text{TDIC}}$  contents for the marine coastal waters collected off the Baluchistan Coast.  $\delta^{13}\text{C}_{\text{TDIC}}$  contents of clean seawater collected off the five coastal locations along Baluchistan coast range between +0.6 to -0.7 ‰ PDB. The positive values of  $\delta^{13}\text{C}_{\text{TDIC}}$  are observed in shallow seawater collected off Jiawani Coast and Ormara Coast, whereas the negative values of  $\delta^{13}\text{C}_{\text{TDIC}}$  are observed for Gwadar, Pasni and Sonmiani Bay. It is important to note that relatively clean surface seawater samples are collected from approximately 5 - 10 meter bathymetry line and their  $\delta^{13}\text{C}_{\text{TDIC}}$  values are closer to typical seawater carbonate alkalinity. In contrast, the shallow seawater samples collected in the nearly inter-tidal zone (depth > 2 meters) of these coasts represent  $\delta^{13}\text{C}_{\text{TDIC}}$  contents between -2.6 to -0.6 ‰ PDB. The shift in  $\delta^{13}\text{C}_{\text{TDIC}}$  contents of clean seawater towards more negative values is indicative of input of  $^{13}\text{C}$  depleted dissolved inorganic carbon, originated from domestic sewage drained into the sea by the adjacent dwellings along these coasts. It is important to note that relatively more depleted  $\delta^{13}\text{C}_{\text{TDIC}}$  contents are observed in the mangrove ecosystem along Sonmiani Coast and Jiawani Coast. The values of  $\delta^{13}\text{C}_{\text{TDIC}}$  tend to enrich in the direction of relatively clean seawater as we move out of the mangrove ecosystem. The higher depletions in  $\delta^{13}\text{C}_{\text{TDIC}}$  values of seawater in Sonmiani Bay and along Jiawani Coast are thus attributed to the influx of carbon from the adjacent mangrove ecosystem ( $\delta^{13}\text{C}_{\text{mangrove leaves}} \sim -26$  ‰ PDB). This means that the  $^{13}\text{C}$  depleted  $\text{CO}_2$  is being produced by the decay of mangrove-leaf litter and is then incorporated into the TDIC pool of seawater as  $\text{HCO}_3^-$ . Further, depletion in  $^{13}\text{C}_{\text{TDIC}}$  contents of seawater are coupled with decrease in salinity and pH. The salinity is mainly decreased in zones adjacent to coastal dwellings.

The coast of Sindh province is heavily populated along the coastal city of Karachi and there are significant industrial activities along this coast. Seawater along Karachi coast thus receives large proportions of untreated domestic and industrial sewage, as well as agricultural run-off, from adjacent dwellings and industrial zones. The Indus River has mostly dried in the delta zone due to tapping of Indus river-water in Tarbela Dam, Headworks on Indus River and due to very little rainfall in the area during past several years. However, the Indus delta Zone has small dwellings and creeks/mangrove ecosystems. Table-3 present a summary of the measured ranges of physiochemical parameters and



$\delta^{13}\text{C}_{\text{T DIC}}$  contents for the marine coastal waters collected from selective sites off the Sindh coast (Pakistan). As expected,  $\delta^{13}\text{C}_{\text{T DIC}}$  contents of seawater off Karachi coast and in the Indus delta zone are relatively more depleted, as compared to polluted zones along Baluchistan coast. Significantly depleted  $\delta^{13}\text{C}_{\text{T DIC}}$  values (as low as -1.7 to -7.3 ‰ PDB) are observed in the Manora Channel/Karachi Harbour area and the Ghizri-Korangi Coastal area along Karachi coast. This is attributed to the large input of domestic waste and industrial waste from Layari River, Malir River and other small polluted drains into sea-environment. Seawaters collected off Korangi coast and Indus Delta along the Sindh Coast represent a decrease in pH by about 0.5 - 1 pH units. The decrease in pH along Korangi coast is attributed to input of mainly untreated industrial-waste waters and partly domestic sewage into the sea. The decrease in pH along Indus Delta is mainly due to influx of relatively low pH waters pertaining to Indus river and sewage from the nearby coastal dwellings/villages. The decrease in pH is also associated with decrease in the values of electrical conductivity and salinity. Further, the Indus delta seawaters are relatively less polluted, as compared to the seawaters off Karachi coast.

**Table-2: Summary Of Physiochemical And Stable Carbon Isotope Analysis ( $\text{C}_{\text{T DIC}}$ ) In Seawater And Polluted Drains Along Baluchistan Coast (Pakistan)**

<b>Coastal location in Baluchistan Province (n= total samples) [Lat/Long]</b>	<b>Physiochemical parameters</b>			<b>Stable carbon isotope analysis</b>
	<b>pH</b>	<b>E.C. (mS)</b>	<b>Salinity (ppt)</b>	<b><math>\delta^{13}\text{C}_{\text{T DIC}}</math> (‰ PDB)</b>
<b>Jiwani (n=7)</b> [N 25-02-61, E 67-44-47 to N25-02-82, E61-44-12]	8.7-8.8	51.4-55.7	41-43	Clean Sea: +0.3 (n=1) Mangrove Zone: -0.4 to -1.9 (n=2) Populated Coast*: -1.4 to -0.6 (n=4)
<b>Gwadar (n=9)</b> [N 25-06-23, E 62-23-53 to N 25-06-81, E62-19-85]	8.1-9.2	52.5-57.1	40-47	Clean Sea: -0.1 (n=1) Polluted Drain: -4.7 (n=1) Populated Coast: -1.8 to -0.9 (n=7)
<b>Pasni (n=5)</b> [N 25-5-65, E 23-28-71 to N 25-16-39, E63-28-71]	8.7-8.8	54.4-54.8	41-45	Clean Sea: -0.5 (n=1) Populated Coast: -1.9 to -1.4 (n=4)
<b>Ormara (n=5)</b> [N 25-13-03, E 64-38-25 to N 25-12-19, E64-40-34]	7.9-8.2	55- 56.4	38 -40	Clean Sea: +0.6 (n=1) Populated Coast: -1.1 to -0.6 (n=4)
<b>Sonmiani Bay (n=7)</b> [N 24-48-80, E 66-59-67 to N 25-26-29, E66-31-71]	8.0-8.5	48.4-50.9	37-47	Clean Sea: -0.7 (n=1) Mangrove Zone: -2.2 to -3.7 (n=2) Populated Coast: -2.6 to -1.4 (n=4)

## CONCLUSIONS

In general, this study concludes that:

- Stable carbon-isotope contents of total dissolved inorganic carbon (TDIC) can be used as a potential indicator of pollution-inputs from domestic and industrial sources, as well as carbon flow into the seawater from domestic and industrial sources, as also from the mangrove ecosystems.
- The shallow marine environment along the Baluchistan Coast is relatively much less polluted, as compared to the Sindh Coast
- Ormara Coast is the least polluted marine site of the developed zone along Baluchistan coast.
- The North-West Coast of Karachi is the least polluted marine site off Karachi city coast
- The most depleted  $\delta^{13}\text{C}_{\text{TDIC}}$  values of seawater in Sonmiani Bay and Jiawani Bay are due to the impact of mangrove ecosystem.
- Extremely depleted  $\delta^{13}\text{C}_{\text{TDIC}}$  values of shallow seawater off the Karachi Coast indicate that Manora Channel and Korangi Creek are the most polluted marine sites off the Pakistan coast. The North-west Coast and the Clifton coast are relatively less polluted coasts.

**Table-3: Summary of physiochemical and stable carbon isotope analysis of (TDIC) in seawater and polluted drains along Sindh coast (Pakistan)**

Coastal location in Sindh Province (n= total samples) [Lat/Long]	Physiochemical parameters			Stable carbon isotope analysis
	pH	E.C. (mS)	Salinity (ppt)	$\delta^{13}\text{C}_{\text{TDIC}}$ (‰ PDB)
<i>Karachi Coast (n=31), [N 24- 47-53, E 66-59-77 to N 24-48-42, E67-17-18]</i>				
<b>Manora Channel (n=11)</b>	8.2-8.5	43.7-50.8	28-36	Mangrove Zone: -5.1 to -7.3 (n=2) Polluted Drain: -3.7 to -6.0 (n=2) Populated Coast*: -6.8 to -1.7 (n=7)
<b>Clifton -Marina Club Coast (n=7)</b>	8.0-8.2	50.9-55.6	37-41	Polluted Drain: -2.5 (n=1) Populated Coast: -3.1 to -0.2 (n=6)
<b>Ghizri-Korangi Coast (n=8)</b>	7.3-7.9	51.4-55.3	39-41	Polluted Drain: -2.7 (n=1) Populated Coast: -6.6 to -3.0 (n=7)
<b>North-west Coast (n=7)</b>	ND*	53.4-55.8	39-40	Clean Sea: +0.4 ** (n=1) Populated Coast: -5.3 to +0.3 (n=6)
<b>Indus Delta (n=6)</b> [N 24-08-41, E 67-26-83 to N24-03-29, E67-41-46]	7.3-8.3	46.6-56.5	32-45	Populated Coast: -2.3 to -1.4 (n=6)
<i>ND = Not Determined</i> <i>* Seawater samples from shallow marine environment opposite coastal dwellings</i> <i>** Seawater sample off Paradise Point, North West Coast of Karachi</i>				

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# **Use of Brackish-Water for Agriculture: Growth of Salt- Tolerant Plants and their Effects on Soil-Properties**

*Javed Akhter, Sahfeeq Ahmed and Kauser A. Malik*

# USE OF BRACKISH-WATER FOR AGRICULTURE: GROWTH OF SALT-TOLERANT PLANTS AND THEIR EFFECTS ON SOIL-PROPERTIES

## ABSTRACT

A five-years field study was conducted, on a saline sodic soil, to evaluate the effectiveness of biological approach for improvement of salt-affected wasteland, in terms of soil physical, chemical and mineralogical characteristics. Kallar grass (*Leptochloa fusca* (L) Kunth), being tolerant to salinity, sodicity and alkalinity, was grown for five years, irrigated with saline under-ground water. The cropping of kallar grass improved appreciably the physical (available water, hydraulic permeability, structural stability, bulk density and porosity), chemical (salinity, pH, Sodium adsorption ratio and organic matter) and mineralogical properties of soil within a period of three years. The soil maintained the improved characteristics, with further growth of grass, upto five years. The study confirmed that salt-affected soils can be improved effectively through biological means, and that growing salt-tolerant plants is a suitable approach. Kallar grass showed a tremendous potential to improve most of the physical, chemical and mineralogical properties, without any adverse effects of saline water on soil- properties.

## INTRODUCTION

Salinity of soils and ground-water is a serious soil-degradation problem, which is growing steadily in many parts of the world, including Pakistan. It is a multi-dimensional problem in several countries and has wide macro and micro socio-economic implications. It occurs mainly, but not exclusively, in arid and semi-arid regions, low-lying areas and river valleys. Food-production in many parts of the world, particularly in arid and semi-arid regions, is severely affected due to decrease in area under cultivation, increase in area under salinization and decrease in overall productivity of good and fertile soils, as a result of improper irrigation and water-management practices (IAEA, 1995).

Soil salinity is wide-spread in all the countries where the climate is arid to semi-arid and average rainfall is less than the evapo-transpiration. Salt-affected soils cover about 10 % of the total dry land-surface of the earth (Szabolcs, 1986). These salt-affected areas are distributed throughout the world and, unfortunately, no continent is free of salt-affected soils. There are large variations in the extent, type of salinity and geo-morphological characteristics of salt-affected soils from one region to the other. Since these salt-affected soils occur in various forms, both in large areas and in small isolated locations on most of the earth's surface, the knowledge of their extent is understandably incomplete. Based on reliable data, the extent of existing salt-affected soils on our globe is presented in Table-1 (Szabolcs, 1986).

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Pakistan is located between longitude 61° and 76°E and latitude of 24° and 37°N. In major part of Pakistan the climate is semi-arid to arid because the average annual precipitation is 250 mm and ranges from 100-760mm. It is estimated that 66.7 % of the area of Pakistan receives rainfall less than 254 mm, 24.2 % between 254-508 mm and 5.4 % between 508-762 mm, and only 3.7 % more than 762 mm. The potential evapotranspiration exceeds precipitation by a factor of 8, which leads to unfavourable distribution of salts and their accumulation in the root-zone. Some of the areas are very hot, with an average summer temperature of 39°C and maximum upto 53°C. The winter is fairly cool, with an average temperature of 20°C and minimum down to -2°C.

The estimates of salt-affected area in Pakistan vary between 2.2-7.9 million hectares (Muhammad, 1978; Akbar et al., 1977; Chaudhry et al., 1978; Szabolcs, 1979). Ahmad and Dharejo (1980) and WAPDA (1985) reported that salt-affected areas range from 4.0-5.7 million hectares. Detmann (1982) estimated that 40,000 hectares of land were being lost, due to salinity and water-logging every year in Pakistan. Scholz (1982) also described the alarming situation in Pakistan, due to loss of 4 to 5 hectares of land to salinity per hour. According to a report by (MINFAL, 1999), the salinized area consists of 6.2 million hectares of arable land in Pakistan (Table-2).

The Indus basin is one of the largest alluvial plains in the world, formed by the river Indus with its five large tributaries. The Indus basin is potentially capable of providing vast amount of food and fiber for human consumption. However, the immense agricultural potential of these plains remains nowhere near realization due to numerous factors, such as poor management, lack of inputs and research, etc.

Rapidly increasing salinity and water-logging in vast areas of cultivated land is threatening the entire future of this food bowl. The worst affected areas are located in the middle of

**Table-1. Salt-Affected Soils On Continents And Sub-Continents (Szabolcs, 1986)**

Continents/subcontinents	x 10 <sup>6</sup> ha
North America	15.775
Mexico and Central America	1.965
South America	129.163
Africa	80.608
South Asia	87.608
North and Central Asia	211.686
South east Asia	19.983
Australia	357.33
Europe	50.804
<b>Total</b>	<b>954.922</b>

**Table-2: Province-Wise Summary — Extent Of Saline/Sodic Soils In Pakistan (Area in 000 ha).**

Province	Slightly Saline	Moderately Saline	Severely Saline	Very Severely Saline	Total
Punjab	472.4	804.8	738.3	652.0	2667.5
%	(17.7)	(30.2)	(27.7)	(24.4)	(43.2)
Sindh	118.1	324.7	1173.1	493.7	2109.6
%	(5.6)	(15.4)	(55.6)	(23.4)	(34.2)
NWFP	5.2	25.7	8.7	8.9	48.5
%	(10.7)	(52.9)	(18.0)	(18.4)	(0.8)
Baluchistan	3.0	74.6	464.7	805.6	1347.9
(%)	(0.2)	(5.5)	(34.5)	(59.8)	(21.8)
Total	598.7	1229.8	2384.8	1960.2	6173.5
%	(9.7)	(19.9)	(38.6)	(31.8)	(100.0)

Source: Agricultural statistics of Pakistan, 1999-00

DOABA (areas between two rivers). Under irrigated agriculture, salinity and sodicity occur in patches and area under-surface soil-salinity is 6.2 Mha, out of which 9.7, 19.9, 38.6 and 31.8 % area is very slightly, moderately, severely, and very severely, saline, respectively (Table-2). Out of four Provinces, Punjab is severely affected by salinity (43.2 %), followed by Sindh (34.2), Baluchistan (21.8 %), and NWFP (0.8 %). The irrigated plains of Indus-basin possess an extensive ground-water aquifer under 16.2 million hectares (Mha). Out

**Table-3: Water-Table Levels In Pakistan Before/After Monsoon**

<i>(Area in Million Hectares)</i>							
Province	Surveyed Area	Before Monsoon			After Monsoon		
		0-1.5 m	1.5-3m	>3 m	0-1.5m	1.5-3m	>3 m
NWFP	0.563	0.057 (10%)	0.113 (20%)	0.393 (70%)	0.065 (12%)	0.138 (25%)	0.36 (64%)
Punjab	9.971	0.539 (5%)	2.280 (23%)	7.132 (72%)	1.179 (12%)	2.806 (28%)	5.986 (60%)
Sind	5.739	0.397 (8%)	3.760 (71%)	1.118 (21%)	3.438 (60%)	1.256 (22%)	1.045 (18%)
Baluchistan	0.397	0.041 (10%)	0.198 (49%)	0.162 (41%)	0.093 (24%)	0.065 (16%)	0.239 (60%)
Total	16.67	1.034 (6%)	6.351 (39%)	8.805 (55%)	4.775 (29%)	4.265 (26%)	7.63 (46%)

Source: SCARP Monitoring Organization (1989), Planning Division, WAPDA

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of this 5.2 Mha contain water with less than 1000 mg L<sup>-1</sup> of total soluble salts (TSS), about 2.5 Mha have ground water of moderate salinity (TSS = 1000 to 3000 mg L<sup>-1</sup>) and 8.5 Mha possess water of high salinity (TSS more than 3000 mg L<sup>-1</sup>). The ground water table is severely affected by monsoon rains (Table-3).

The water-table remains within 1.5 m in 6 % of the area before monsoon and increases to 29 % of the total area after monsoon season (Table-3).

Different countries have adopted different strategies to deal with the problem. In Pakistan, various departments and agencies have suggested and applied various remedial measures to solve the salinity and water-logging problem. So far, Water and Power Development Authority (WAPDA) has completed 44 Salinity Control and Reclamation Projects (SCARPs), covering an area of about 5.17 Mha. Additionally, 14 SCARPs, covering an area of about 2.9 Mha, are under construction (ICID, 1991).

In SCARPs, Hydrological and / or Engineering approach of drainage-leaching combination is being applied. The approach involves the elimination of water-logging and salinity, by lowering the ground water table and using the pumped water to support the existing canal-water supplies and leaching the surface-salts. The story of achievements and failures of WAPDA, using hydrological approach, is controversial and complex. According to WAPDA, the salt-affected area was reduced by 17%, as interpreted from aerial photographic surveys in 1953 and 1979 (WAPDA, 1985). However, field investigations in SCARP 1, carried out by Central Monitoring Organization of WAPDA and Soil Survey of Pakistan, indicated that various targets were hardly touched (Atta-ur-Rehman 1976; Qureshi et al., 1978).

The hydrological approach is essential to achieve good drainage in the irrigated areas, but it is highly energy-intensive and creates problems of disposal and/ or utilization of pumped saline ground-water. Most of the national efforts for controlling the salinity have been commonly based on the engineering-based concepts of drainage. These efforts may be suitable in areas where fresh water is available. Therefore, research is imperative to evolve proper strategy for arid and semi-arid salt-affected lands, where the source of irrigation is only ground-water.

A final solution of the salinity problem requires leaching of salts with good-quality water, coupled with efficient drainage-system. Proper disposal sites, suitable drainage-channels, sufficient gradient for gravity-flow and good- quality water are prerequisites for engineering approach to be applied. However, In Pakistan, engineering approach is difficult to implement because of non-availability of good quality water and absence of drainage network in the affected areas. The drained water seeps into the surrounding areas if drained through unlined drainage-channels. The approach may be easier near coastal areas, where gradient for gravity-flow is available but scarcity of good-quality water and unavailability of huge

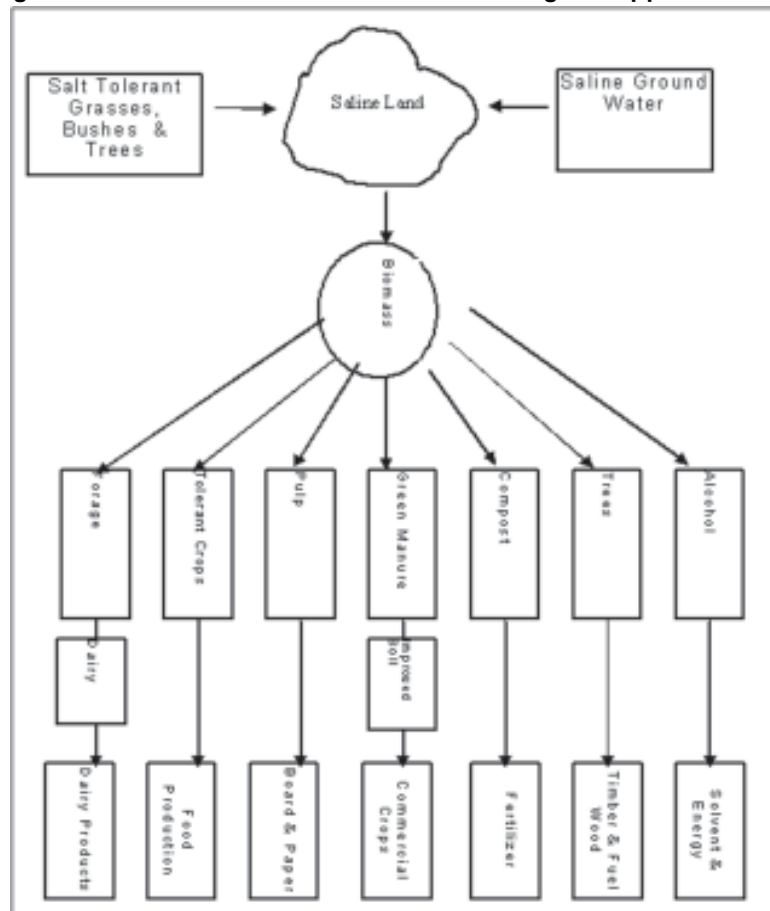
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funds required render the approach difficult to practice.

The ground-water in most of the salt-affected areas is saline and that is the basic factor, which limits the agricultural production. The saline water is not suitable for agricultural or fruit crops, but it can be used for growing salt-tolerant plants. Plants have acquired vast genetic variability during their evolution over millions of years. They have adapted to so many kinds of habitats and grow on mountains, plains, marshes, cold and hot climates and even in sea. Growing salt-tolerant plants (trees, shrubs, bushes and grasses) provide biomass, which can be used directly as fodder or fuel-wood, or converted to value-added products, such as biogas, compost and alcohol, etc., and the process is termed as 'Biological Approach' (Malik et al., 1986). The data presented in Figure-1 summarize the entire biological approach and various options available to the farmers. This approach considers

**Figure-1: A Schematic Presentation of Biological Approach**



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saline soils and brackish water as a useable resource, rather than liabilities.

Many crops and other species are being studied for their salt-tolerance and water-use efficiency the world over. In Pakistan, over 100 plant-species belonging to different genera have been screened for the limits of their salt- tolerance. Table-4 gives a list of plant-species, with the limits of their salt- tolerance, screened at NIAB. Among these Kallar grass has been the most economical and useful plant to grow on salt-affected soils (Malik et al. 1986) of Pakistan. The biological approach for utilization of saline lands and water is

**Table-4: Salt Tolerant Limits (Root Zone Salinity Causing 50% Yield Reduction) Of Different Plants (From Silver Jubilee Of Niab)**

Species	EC (dSm <sup>-1</sup> )	Species	EC (dSm <sup>-1</sup> )	Species	EC (dSm <sup>-1</sup> )
Grasses		Beta vulgaris	19	Cassia sturtii	15.8
Leptochloa fusca	22.0-14.6	Lotus carniculatus	16.7	Acacia saligna	15.7
Sporobolus arabicus	21.7	Trifolium alexandrinum	15.8	Acacia bivenosa	13.7
Cynodon dactylon	21.0-13.2	Sesbania aculeate	13	Leucanena leucocephala	12.4
Hordeum vulgare	19.5-10.0	Hasawi rushad	12.5	Acacia kempeana	11
Sorghum vulgare	16.7-15.0	Medicago sativa	13.2-12.2	Acacia aneura	9.5
Panicum antidotale	16	Sesbania rostrata	12	Acacia cunnighamii	9.4
Echinochloa crusgalli	15.9	Macroptilium atropurpureum	12	Acacia holosericea	9
Polypogon monspeliensis	13.7	Trifolium rsupinatum	11.6	Acacia adsurgens	4.3
Avena sativa	11.8-9.1	TREES		Acacia validineriva	1.7
Lolium multiflorum	11.2	Acacia sclerosperma	38.7	VEGETABLES	
Echinochloa colonum	11.2	Acacia ampliceps	35.7	Aster tripolium	31.7
Desmostachya bipinnata	9	Prosopis juliflora	35.3	Brassica napus	19.5
Panicum maximum	9.0-8.5	Prosopis chilensis	29.4	Trigonella faenum-graecum	19.2
Sorghum halepense	7	Casuarina obesa	29.2	Spinacea oleracea	14.8
SHRUBS		Acacia victoriae	28.2	Medicago falcate	13.4
Suaeda fruticosa	48	Acacia cambagei	27.7	Brassica carinata	12.5
Kochia indica	38	Eucalyptus striatocalyx	26.2	Brassica juncea	12.4-8.44
Atriplex nummularia	38	Acacia salicina	24.5	Lactuca sativa	9.9
Atriplex amnicola	33	Casuarina glauca	24.4	Brassica campestris	9.8
Atriplex lentiformis	23	Prosopis tamarogo	22.7	Eruca sativa	9.4
Atriplex undulata	22.5	Acacia calcicola	19.9	Coreandrum sativum	5.7
Atriplex crassifolia	22.5	Acacia coriacea	18.2		
Sesbania Formosa	21.4	Cassia nemophila	16.8		

not the ultimate answer for tackling the salinity problem, but it does provide an inexpensive alternative to the highly expensive leaching and drainage approach for reclamation of salt-affected soils.

In Pakistan, good-quality water is not available in sufficient quantity for irrigation and leaching of salts down to lower layers. In areas with shallow water table, salts accumulate on the soil-surface, due to capillary phenomenon. Many of these areas have saline ground-water that cannot be used to irrigate economic crops. In the developing countries, no serious attention has been given to the proper use of brackish ground-water and water flowing through the drainage channels. Presence of saline subsurface water poses a threat of salinization to fertile soils, but in Pakistan, due to lack of awareness, environmental degradation is not taken care of properly. Proper uses of brackish ground-water need to be explored; growing salt-tolerant plants on salt-affected soils is one such option available. This will increase the agricultural production, which is the backbone of economy in developing countries.

The purpose of this research was to study the physical, chemical and mineralogical changes in a highly saline-sodic soil under biological reclamation. The altering composition of soil-solution was used to explain the changes in selected properties of a highly salt-affected soil, in terms of effectiveness and sustainability of the approach over a period of 5 years.

## **MATERIALS AND METHODS**

Five-year field-study was conducted at Biosaline Research Station (BSRS) of Nuclear Institute for Agriculture and Biology (Faisalabad), situated near village Dera Chahl, 30 Km from Lahore, Pakistan. The station is located at longitude 74°7 'E and latitude 31°6 'N. Average annual rainfall is about 500 mm. At BSRS, model plots have been established to demonstrate the Biological Approach for economic utilization of salt-affected soils, by growing salt-tolerant plants irrigated with brackish ground-water. This station is used as a model for sustainable development of salt-affected land, using different techniques.

A two-factors factorial experiment was laid out in a Randomized Complete Block Design (RCBD), with three replicates. Eighteen plots of 30 m x 30 m, having similar soil-salinity and texture, were established after a preliminary survey using four-electrode electrical-conductivity probe. Kallar grass was planted on 15 plots, while 3 plots were preserved as a control/fallow. Flood-irrigations of about 75mm were applied at about 50% of soil field capacity, as indicated by neutron-moisture readings. Complete record of irrigation-water applied and rainfall was maintained. Kallar grass, being perennial species, was continuously grown for five years and 5-7 cuttings were taken per year. Three plots were randomly selected at the end of each growing season (during November) for soil sampling and to measure the required soil physical properties in-situ. Samples for analysis of physical and chemical properties of soil were collected from pre-selected depths of 0-20cm (D1), 40-60

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cm (D2) and 80-100 cm (D3). These samples were air-dried and ground to pass through 2 mm sieve. A saturated soil paste extract was obtained from sub-sample of each soil, using the method of US Salinity Laboratory Staff, 1954.

Soil-texture was determined by sedimentation technique, developed by Jennings et al. (1922) as described by Day (1965). The amount of water retained by the soil at different pressures was measured by ceramic-plate extractor (Soil Moisture Equipment CORP. USA). The amount of AW was calculated by the following formula:

$$AW(kgkg^{-1}) = \text{Soil moisture at } 0.03\text{MPa(FC)} - \text{Soil moisture at } 1.5\text{MPa(PWP)}$$

Soil bulk-density was determined in-situ by bulk-density samplers by Blake, (1976) at the end of every growth year. The field-saturated hydraulic permeability was determined, using Guelph permeameter (Model 2800KL, Soil Moisture Equipment CORP. USA) in-situ (Reynold and Elrick, 1985). The stability index (SI) was determined using dry aggregates of 0.1 g weight and 1-2 mm size (Akhter et al., 1994).

Electrical conductivity ( $EC_e$ ) and pH of saturated paste extracts were determined for each sample by WTW conductivity meter LF-530 and Corning pH meter 130, respectively. Soil saturation extracts were analyzed for cations (Na, K, Ca and Mg). Sodium and K were determined with flame photometer (Model PFP7 Jenway) (U.S. Salinity Laboratory Staff, 1954) and Ca and Mg by titration with ethylene-diamine-tetra-acetate (EDTA). Total carbon and organic carbon were determined by a modified, Walkely-Black method (Nielson and Sommers, 1982). Inorganic carbon ( $C_i$ ) was determined with modified volumetric calcimetric method, in which soil was treated with 4N HCl in the presence of  $FeCl_2$  in a closed system and the volume of  $CO_2$  released was determined. Organic matter was derived by multiplying the organic carbon with 1.72. Mineralogical analysis was carried out with X-ray diffraction (XRD); the patterns were recorded with a Philips PW1710 microprocessor- controlled diffractometer (Raven, 1990 and Self, 1988).

## RESULTS AND DISCUSSION

The soil was highly saline sodic ( $EC_e$  22.2  $dSm^{-1}$ ; pH 10.4; SAR; 184.5) and non-gypsiferous sandy clay loam soil (Table 5). The brackish water ( $EC_e$  1.4  $dSm^{-1}$ ; SAR 9.6; RSC 9.8  $meL^{-1}$ ) was used as a main source of irrigation in reclaiming saline sodic soil. Some of the selected soil-properties of control/fallow soil and chemical composition of the irrigation water used to grow kallar grass are presented in Table-4. The results revealed that the successive cropping of kallar grass for five years, as major treatments used (T1, T2, T3, T4 and T5) had a pronounced effect in improving some physico-chemical and mineralogical properties of soil, as compared with uncropped practice system (To).

The amount of available water (AW) for plants increased (statistically) after growing kallar

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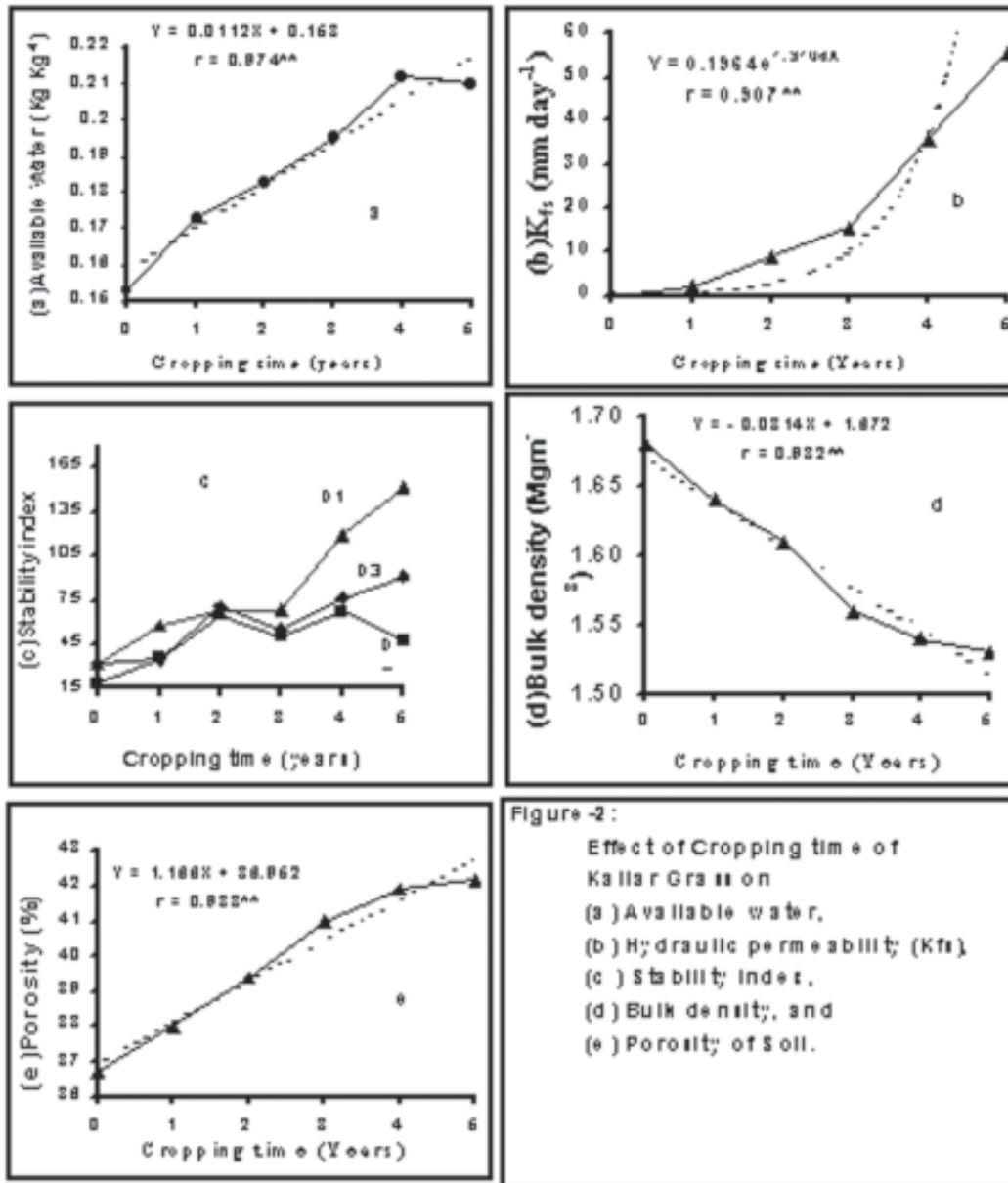
grass for 5 years. The cropping of kallar grass over all periods (1-5 year) highly increased the AW by 27.5%, as compared to uncropped soil. The maximum increase of 38.6% was found with the treatment T4 (after 4 years of cropping), followed by 37.3, 27.51, 19.6 and 13.1% after 5, 3, 2 and 1 year, as compared with To. The soil AW was found to be directly and significantly ( $p \leq 0.01$ ) related to the growing time (Figure-2a). The simple linear regression ( $AW = 0.158 + 0.012T$ ) showed an increase rate of  $0.012 \text{ KgKg}^{-1}$ , (i.e.1.2%) with highly significant  $r$  value of  $0.974^{**}$ (Figure-2a).

The saturated hydraulic permeability ( $K_{fs}$ ) of the soil increased at the upper depth D1. The effect of cropping-system on the  $K_{fs}$  was highly significant. The maximum  $K_{fs}$  value of  $55.6 \text{ mmd}^{-1}$  was obtained in T5 and minimum value of  $0.35 \text{ mmd}^{-1}$  was found in To. The maximum increase of 159- fold after T5 was followed gradually by 6.1, 25.1, 43.8 and 101.6 times with T1, T2, T3 and T4, as compared with  $K_{fs}$  of uncropped plot. The hydraulic permeability increased in an approximately exponential manner with the growing period of kallar grass (Figure-2b). The rate of increase of  $K_{fs}$   $0.982 \text{ mmd}^{-1}$  was highly significant at

**Table-5: Some Physical And Chemical Properties of Uncropped Soil And Irrigation Water Used** (Values Are Means of 3 Replicates)

(a) Physical Property	Soil Depth				
	Unit	D1	D2	D3	
Sand	$\text{gKg}^{-1}$	550	520	570	
Silt	$\text{gKg}^{-1}$	230	250	250	
Clay	$\text{gKg}^{-1}$	220	230	180	
Textural Class	Sandy clay loam				
	$\text{KgKg}^{-1}$	0.155	0.151	0.153	
Available Water	$\text{Mgm}^{-3}$	1.62	1.73	1.68	
Bulk density					
Porosity	%	38.9	34.6	36.5	
Stability index		31.9	18.6	32.6	
Hydraulic permeability	$\text{mmd}^{-1}$	0.35	0.25	0.44	
(b) Chemical Properties		Soil			IW
$EC_e$	$\text{dSm}^{-1}$	22	22.2	12.5	1.4
pH		10.4	10.5	10.4	7.6
OM	$\text{gKg}^{-1}$	3.3	1.9	1.8	-
SAR		184.4	185.2	114.5	7.8
ESP		73	73.1	62.6	-
$SAR_{adj}$		-	-	-	19.3
RSC		-	-	-	9.7
<i>D1=0-20 cm, D2=40-60 cm, D3= 80-100 cm, <math>EC_e</math>= Electrical conductivity                      OM= Organic matter, SAR= Sodium adsorption ratio, adj= Adujusted                      ESP= Exchangeable sodium percentage, RSC= Residual sodium carbonate                      IW= Irrigation water used.</i>					

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$p \leq 0.01$  level, with an excellent correlation coefficient ( $r = 0.969^{**}$ ) with high  $R^2 = 0.940$  value.

The soil-stability index (SI) in this study largely increased over all growing seasons (5 years) by 154% of control treatment. The maximum increase in SI of 247 % was observed after 5 years of cultivation, followed by 216, 110, 144 and 54 % over control after 4, 3, 2, and 1 year, respectively. The regression analysis indicated that SI increased linearly and significantly ( $SI = 29.87 + 13.37T$ ) with increase in growing-time (Figure-2c), with a high regression coefficient (b) and high  $r$  ( $0.957^{**}$ ),  $R^2$  (0.915). The SI values increased at constant rate of 13.36 for each year of agronomical practices tested.

The soil bulk-density (BD) significantly decreased in all cropping treatments (Ts) used, as compared to BD, of  $T_0$ . The application of biological approach for 5 years showed a linear reduction in BD with high  $r$  value ( $0.982^{**}$ ),  $R^2$  value of 0.964. The 96.4% BD reduction shown by regression-model resulted due to increase of cropping period. The effect of growing-period of kallar grass on soil porosity was highly significant (Figure-2d): the maximum increase 15.0% in porosity of the soil occurred after 5 year followed by 14.2, 11.7, 7.4, and 3.5% at  $T_4$ ,  $T_3$ ,  $T_2$  and  $T_1$  over  $T_0$ , respectively. The soil porosity increased in a proportional pattern by increasing the growing period (Figure-2e). The increasing rate of soil porosity (average of  $1.166 \text{ \%year}^{-1}$ ) was highly significant with an excellent value of  $r = 0.983^{**}$  ( $p \leq 0.01$ ).

The soil salinity ( $EC_e$ ) significantly ( $p \leq 0.05$ ) decreased after growing kallar-grass for five years. The cropping periods over all years significantly reduced the soil  $EC_e$  by 71.4 % over  $T_0$ . The maximum reduction of 87.3% was observed in  $T_5$ , followed by 79.9, 83.6, 64.6 and 41.8 % reduction after 4, 3, 2 and 1 year in  $T_4$ ,  $T_3$ ,  $T_2$  and  $T_1$ , respectively, as compared with  $T_0$ . The regression analysis showed that  $EC_e$  exponentially ( $\ln EC_e = 2.783 - 0.408T$ ) decreased with growing time of kallar grass (Figure-3a), with highly significant regression coefficient (b) and high correlation coefficient ( $r = 0.958^{**}$  at  $p \leq 0.01$ ) and coefficient of determination ( $R^2 = 0.918$ ). The  $EC_e$  decreased at a constant rate of 0.408 unit ( $\text{dSm}^{-1}$ ) per year of growing kallar grass. The 91.7% of  $EC_e$  reduction resulted because of increase of cropping time.

Soil pH statistically decreased in all treatments tested by cropping kallar- grass, as compared to soil pH of uncropped plots. The maximum decrease of 14.4 % in pH of soil was observed after 5 years, compared with  $T_0$ . The cultivation of kallar grass had a significant linear effect ( $r = 0.854^*$  at  $p \leq 0.05$ ) on pH with a decrease rate of 0.229 unit for each year of growing kallar grass (Figure-3b). The soil pH differed significantly at different depths of the soil-profile. As a general pattern, the soil pH gradually increased with increase in soil depth. The highest reduction of 2.5% in soil pH was recorded in upper soil-depth D1, as compared with soil reaction at the deeper depth D2 (Figure-3b).



### Use of Brackish-Water for Agriculture: Growth Effects of Salt-Tolerant Plants

A considerable decrease in SAR of soil was recorded with all the cropping treatments. Overall, five year of cropping of kallar grass reduced SAR of soil significantly (67.8%) over the uncropped control soil. The SAR reduction was 32.5, 29.3, 39.9, 51.0 and 51.2% from T1 to T5, respectively, over the mean reduction of 5 year. The SAR apparently decreased in an exponential pattern ( $\ln \text{SAR} = 4.926 - 0.343T$ ) as the growing time was increased (Figure-3c). The reduction-rate of SAR  $0.343 \text{ meqL}^{-1}\text{year}^{-1}$  was highly significant at  $p \leq 0.01$  level with the best correlation coefficient ( $r = 0.968^{**}$ ). The reduction of soil SAR was mainly due to the cropping system employed.

The effect of cropping practices on soil organic matter (OM) was highly significant ( $p \leq 0.05$ ). All treatments resulted in enhancement of OM in a progressive pattern (Figure-3d). The maximum OM value of  $8.2 \text{ gkg}^{-1}$  was found after 5 years and  $2.0 \text{ gkg}^{-1}$  was recorded in To. Maximum increase of 3.6 fold at 5 years, followed gently by 2.1, 2.9, 3.0 and 3.01 folds increase throughout 1-4 year. The soil OM significantly increased linearly ( $\text{OM} = 3.452 + 1.026T$ ) when growing periods were increased, with a good correlation-coefficient ( $r = 0.911^*$  at  $p \leq 0.05$ ). Therefore, the growth of kallar grass caused 83.0% of the observed variability in soil OM content. The content of OM increased by a rate of  $1.026 \text{ gkg}^{-1} \text{ year}^{-1}$  because of growth of kallar grass compared with uncropped soil.

Characterization of clay fraction of uncropped soil under investigation revealed micaceous-dominated mineralogy. The soil clay fraction contained a mixture of mica, illite, smectite, kaolinite, chlorite, with minor amounts of hematite/ goethite (H/G), quartz and traces of feldspar (Table-6). X-ray diffraction (XRD) confirmed that illite dominated, with an average of 44.8%, followed by randomly interstratified material mainly smectite (RIS), 24.5%, kaolinite, 10.0%, chlorite 7.5%, H/G 5.5%, quartz 4% and feldspar 3.25%. Data indicated that the soil belonged to micaceous class, with younger mineralogy and most likely with early stage of weathering in uncropped soil.

The illite content certainly decreased with cropping periods of growing kallar grass. The cropping period of five year (T1 to T5) reduced the illite content by 18.4%, followed by 12.25 and 4% after 3 and 1 year (T3 and T1) compared with uncropped soil (Table-6). The regression analysis indicated that illite decreased linearly ( $\text{Illite} = 48.831 - 1.814T$ ) with the increase in cropping time with high correlation coefficient ( $r = 0.998^{**}$  at  $p \leq 0.05$ ). The randomly interstratified (RIS) material, mainly smectite, generally increased with cropping kallar grass, compared to control soil (Table-6). An increase of 52.6% in RIS was noted after 5 years, followed by 36.8% with T3 and 21.1% with T1 over uncropped soil. The RIS increased in a linear fashion ( $\text{RIS} = 20.017 - 1.880T$ ) significantly at  $p \leq 0.05$  with  $r = 0.977^*$ .

Kaolinite, the third most important mineral in soil-clay fraction, was considerably reduced with cropping under the applied biological management system. Maximum reduction of 46.1% was recorded after 5 years of cropping, followed by 30.8 and 15.4% after 3 and 1 year, compared to To soil (Table-6). The cropping of kallar grass had a good linear and



**Table-6: Mineralogical analysis of soil-clay fraction (%) at depth D1 (0-20 cm) as a function of growing kallar- grass**

Year (T)	Illite	RIS	Kaolinite	Chlorite
0	49±3	19±2.5	13±1.6	6±1.5
1	47±3	23±2.5	11±2.0	7±1.5
3	43±3	26±2.7	9±2.3	8±1.5
5	40±3	29±2.3	7±2.5	9±1.5
Mean	44.8	24.5	10	7.5
Year (T)	H/G	Quartz	Feldspar	CEC
0	4±1.2	4±1	2±1	33±1.5
1	5±1.4	4±1	3±1	32±1.2
3	6±2.0	4±1	4±1	30±1.9
5	7±1.7	4±1	4±1	29±1.8
Mean	5.5	4	3.3	31

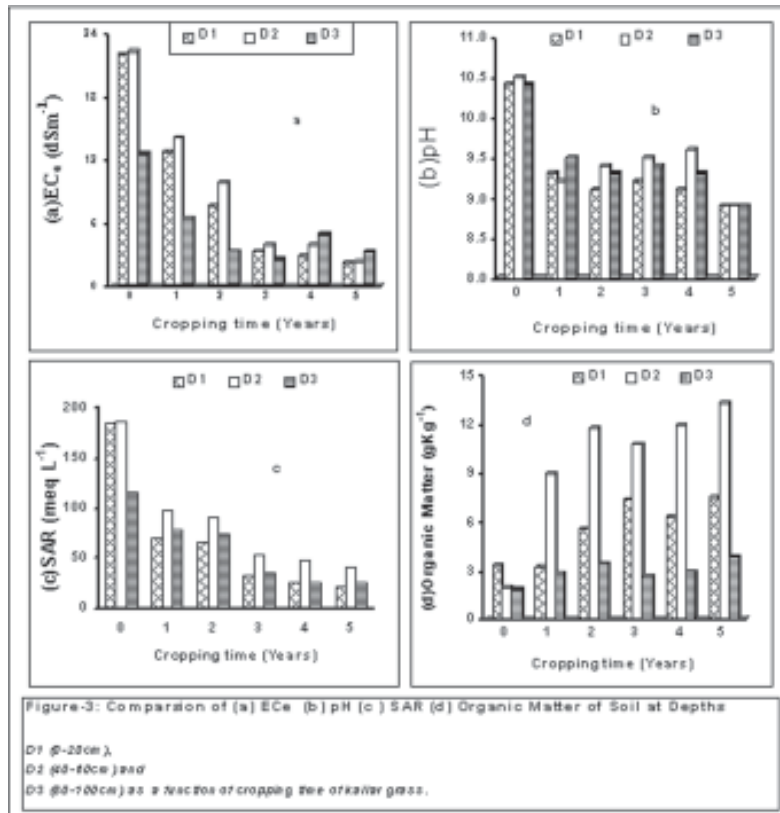
CEC = Cation exchange capacity (meq/100 g)  
H/G = Hematite/goethite

significant ( $r = 0.989^*$  at  $p \leq 0.05$ ) effect on kaolinite, with decrease rate of  $1.153 \text{ gKg}^{-1}$  per year. Chlorite, commonly recognized as unstable mineral, increased with cropping period. Five years of cropping enhanced chlorite content by 1.5 times, followed by 1.33 and 1.16 times after 3 and 1 year of cropping. The regression analysis confirmed that chlorite significantly increased in a linear manner with increase in growing seasons ( $\text{Chlorite} = 6.203 + 0.560T$ ), with significant regression- coefficient (b) and good correlation-coefficient ( $r = 0.989^*$  at  $p \leq 0.05$ ). The chlorite increased at constant rate of  $0.560 \text{ gKg}^{-1}$  per year of cropping period. The hematite/goethite (H/G) increased under kallar-grass growth, compared with uncropped fallow soil. The H/G of soil clay fraction increased by 75, 50, and 25% after 5, 3 and 1 year of cropping period, respectively (Table 6), compared to To soil. Regression analysis showed a linear relationship between H/G and cropping time with good correlation coefficient of ( $r = 0.989^*$  at  $p \leq 0.05$ ). Quartz in soil- clay fraction maintained its original composition of 4% with cropping period of growing kallar grass (Table-6). The feldspar increased by 50% and 100%, after 1 and 3 years, respectively, and no further change was noted after 5 years of cropping, compared to uncropped soil.

## CONCLUSIONS

The results confirmed that cropping of kallar-grass on a highly saline, sodic soil, irrigated with brackish water improved appreciably the soil physical (AW,  $K_{fs}$ , SI, BD and P), chemical ( $EC_e$ , pH, SAR and OM) and mineralogical properties, within a period of three years. Kallar grass maintained its growth without addition of any fertilizer for a long time. The proportion of clay-mineral component found in soil-clay fraction and significant evidences available confirmed that uncropped soils are highly unstable, very soft when wet and very hard when dry, due to greater amount of illite clay. The growth of kallar grass accelerated

## Use of Brackish-Water for Agriculture: Growth Effects of Salt-Tolerant Plants



the rate of weathering, with transformation of mica to 2:1 expansible clay, and the soil attained an appreciable improvement in soil-aggregate stability, hydraulic permeability, available water, soil-porosity or bulk density, due to increase in organic matter and leaching of soluble ions from the surface to lower depths.

The soil maintained the improved characteristics with further growth of grass upto five years. The results confirmed the sustainability of biological approach i.e. amelioration of saline lands by growing salt-tolerant plant species with brackish under-ground water.

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# **Some Interesting Aspects of Water, with Special Reference to Nuclear Desalination**

*Inam-ur-Rahman*

## **SOME INTERESTING ASPECTS OF WATER, WITH SPECIAL REFERENCE TO NUCLEAR DESALINATION**

### **ABSTRACT**

*A brief review is given of the formation, importance, resources and some unique characteristics of water. A reference has been made about the available water-resources of Pakistan and the urgent need of acquiring additional water-resources in the country. Importance of water for energy-production and energy for acquiring additional water-resources is mentioned.*

*Attractive features and feasibility of nuclear desalination, using dual-purpose nuclear power plants are discussed. Criteria for selection of suitable reactor-type and desalination process are discussed for desired water-to-power ratios. The world-wide growth of desalination-capacity, using various desalination- processes is listed.*

### **INTRODUCTION**

Some verses from the Holy Quran about water are worth considering here:

.....We made from water every living thing.

*[Sura Anbiyaa(21:30)]*

..... The companions of the fire will call to the companions of the garden. "Pour down to us water or anything that God doth provide for your sustenance". They will say: "Both these things hath God forbidden to those who rejected Him".

*[Sura Araf(7:50)]*

..... And further, thou seest the earth barren and lifeless, but when We pour down water on it, it is stirred (to life), it swells, and it puts forth every kind of beautiful growth.

*[Sura Hajj (22 :5)]*

..... The son replied: "I will betake myself to some mountain. It will save me from the water". Noah said: "This day nothing can save from the command of God, any but those on whom He hath mercy.

*[Sura Hud (11:43)]*

## Some Interesting Aspects of Water, with Special Reference to Nuclear Desalination

### FORMATION AND DISTRIBUTION OF WATER

This is part of the question how the earth was formed. The materials that make up the earth included plenty of oxygen and hydrogen. As the earth cooled and became solid, these elements combined to form water. The water so formed was trapped in rocks and was released slowly, to fill up the depressions now forming the oceans.

#### Distribution:

About 70% of the earth's surface is covered with water. The total quantity in the oceans, ice caps, rivers, lakes, underground and atmosphere is estimated to be around 1.4 billion cubic kilometers. The break-up is as follows:

Oceans and inland seas ..... ~ 97.21%

Ice-caps and glaciers ..... ~ 2.16%

Surface and underground ..... ~ 0.63%

Atmosphere ..... ~ 0.001%

**Total** ..... **=100%**

### IMPORTANCE AND REQUIREMENTS OF WATER

No living things (i.e. zoological and botanical) can survive without water, except perhaps the computer viruses!

Great civilizations had their beginnings where water-supplies used to be plentiful, and had fallen when these supplies disappeared. As water is essential for life, there have been instances where people have killed one another for a glass of water!

5 per cent of the land contains half the population of the world, due to uneven distribution of water.

There is as much water on earth today as there ever was and ever will be. The same water that was dirty is purified by the great water-cycle, over and over again, even since the formation of the water body. If the rain fell uniformly all over the earth, it would receive 26 inches a year. Every glass of water that we drink contains water-molecules that had been used countless times before. Part of the water that you used today might have been used by Pharaoh or perhaps Adam thousands of years ago!

For a balanced diet and reasonable living, more than 2000 gallons is required per person per day:

Diet..... ~2000 gallons  
Domestic & Industrial..... ~200 gallons

As the total usable quantity of water is fixed and the population is increasing, additional water-resources are needed for about 80 million people added annually in the existing world-population.

### **SOME SPECIAL CHARACTERISTICS OF WATER**

Water has greatest solubility for most of the impurities — it dissolves the impurities and dirt, purifies/cleans everything and becomes polluted, to be purified by the water-cycle. It is said that water cleans the body, just as prayers and repentance purifies the soul!

The specific heat of water is one of the highest. This helps in maintaining the temperature of all living beings at a manageable level. If the specific heat of water was low, like metals, the blood would have been boiling due to absorption of **2.5 million calories** daily produced due to our diet.

Water-density is highest at 4°C and decreases as temperature falls down or goes up. This is responsible for preserving aquatic life in the coldest ocean.

Very high values of heat of vaporization (540 calories) and heat of fusion (80 calories) are responsible for prevention of floods and water-losses due to vaporization.

### **WATER FOR ENERGY AND ENERGY FOR WATER!**

Energy is essential for economic development of a country. As a matter of fact, per-capita energy-consumption is the best index to gauge the standard of living of a country. Most of the existing energy- sources would not have been possible, without water.

On the other hand, for production of fresh water from oceans, large inputs of energy are required. Additional water-resources from more than 99% of the untapped water (Oceans & Ice-caps) have become absolutely necessary, keeping in view the increasing world-population and pollution of the existing water resources.

Let us review the variety of ways in which water becomes the source of energy. In the next section on nuclear desalination, the use of energy for production of fresh water will be discussed. Besides, energy is needed for separation of hydrogen & deuterium, which are the sources of chemical and nuclear energy.

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## **Some Interesting Aspects of Water, with Special Reference to Nuclear Desalination**

### **Energy Due To Water Movement**

- Hydro Energy
- Tidal Energy
- Wave Energy

### **Energy Due to Chemical & Nuclear Reactions**

- Hydrogen Energy  
(chemical reaction, based on combustion of hydrogen)
- Fusion Energy  
(nuclear reaction, involving D-D reaction)

### **Miscellaneous Uses of Water in Energy-Production**

Water is used as an essential item for electrical energy-production as a conversion medium in conventional and nuclear power plants. In nuclear power plants, water is also used as a coolant, moderator and shielding material.

Geothermal energy cannot be utilized, effectively, without water. A geothermal power station utilizes the high-temperature, high-pressure steam, on lines similar to the fossil and nuclear power plants.

### **NEED FOR WATER-RESOURCE PLANNING FOR PAKISTAN**

Keeping in view the increasing population and diminishing water-resources (due to pollution, scarce rainfalls, decreasing river-discharges, silting in rivers and dams) additional water resources are required. In Terbella alone, silting is estimated at a rate of 6 lacs tons daily ——— this would require 50 thousand trucks daily to remove the silt. Water-resource planning is extremely necessary and deserves top priority. This is obvious from the following data:

Total water available in Pakistan = 142 maf  
(1 maf =  $3.26 \times 10^{11}$  U.S. gallons)

Total water utilized annually = 65 maf  
(the balance is discharged to the ocean, evaporated, polluted or wasted)

**Per-capita daily water availability:**

$$\frac{65 \text{ maf/year} \times 3.26 \times 10^{11} \text{ gallons/mat}}{140 \times 10^6 \times 365 \text{ person - days/year}}$$

= 430 gallon/person-day!

Even if all the available water is used fully the per capita water availability works out to be around 430 gallons per person per day. This is about 50% of the standard daily water requirements!

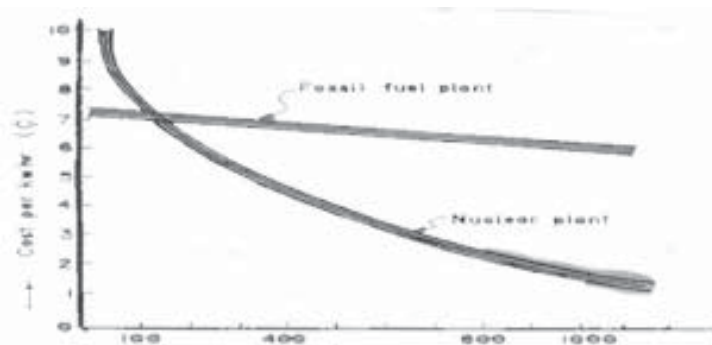
Immediate steps are hence essential for effective utilization of the existing resources and finding ways & means of alternate sources of water. These include:

- Attitude towards water-use;
- Training & education and appropriate technology-input for economic use of water in farming, industry, municipal & household use of water;
- Construction of small dams and water-reservoirs, to avoid wasteful flow of water to the oceans;
- Desalination technologies, for exploitation of huge water available in oceans i.e. 97% of total.

**NUCLEAR DESALINATION FOR PROJECTED WATER REQUIREMENTS**

**Attractive Features of Nuclear Desalination**

Nuclear energy is now a well-established source of energy and is used to produce electricity in 30 Countries. It provides 6% of total global energy and 17% of global electricity. In

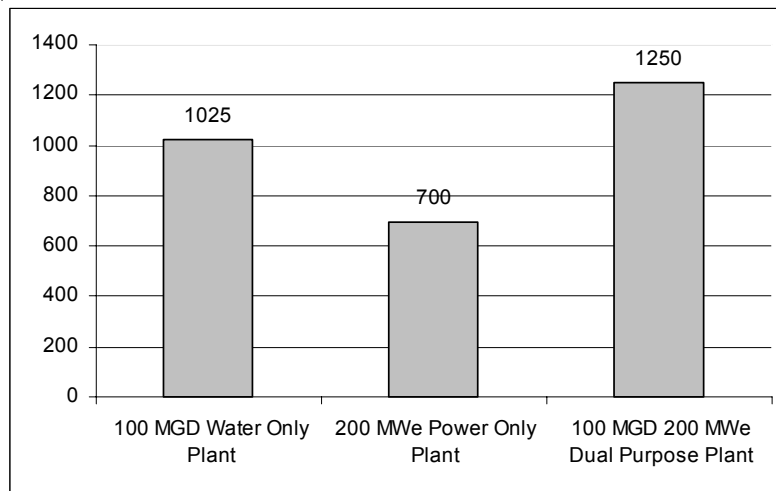


**Figure - 1: Nuclear Plant-Size to Energy-Cost Ratio**

### Some Interesting Aspects of Water, with Special Reference to Nuclear Desalination

some countries, more than 70% of electrical energy is nuclear. At the end of the year 2000, 439 nuclear power reactors with a total capacity of 352 Gwe were in operation. Total capacity of nuclear reactors used for co-generation of hot water/steam for district heating, seawater desalination and other industrial processes is about 5 GW<sub>th</sub>. The first paper regarding the feasibility of using nuclear energy for distilling seawater by R.P. Hammond of ORNL, U.S.A. appeared in 1962 ("Large scale reactors may distill sea water economically" Nucleonics 20 (12):45-49, 1962). Various reasons put forward in the paper are summarized here:

1. Nuclear energy cost (unlike conventional energy cost) is very sensitive to the plant size. Larger the nuclear power plant, lower is the cost per kwhr. Hence if energy and water requirements of a region are pooled together, the plant-size will become larger, reducing thereby the cost of electricity, as well as water. This is shown in Figure - 1.
2. Nuclear power plants have relatively lower thermal efficiency, as compared to conventional power plants. Hence, for the same electrical energy output, the nuclear power plant will have larger amount of waste-heat for dumping in oceans and rivers.
3. While high-quality steam is required to produce electrical energy, lower-quality steam is needed for desalination. At present, the maximum brine temperature used for desalination is about 250°F. At higher temperature, the formation of scale and corrosion of heat-transfer surfaces drastically reduce the distillation-plant efficiency. Most of the residual steam rejected by the turbine can thus, be used for desalination purposes.



**Figure - 2: Thermal Energy Requirements for Three Plants Using Water-Cooled Reactors**

**Table -1: Some Salient Characteristics of Commercial Desalination Process**

Process	Characteristics					
	Possible Unit Size m <sup>3</sup> /d	Limiting factor	Experience Available	Maintenance Requirement	Energy Consumption	Top brine Temperature °C
MSF Present Future	50,000 75,000 ?	Vacuum System	Highest	Low	High? (thermal)	85-130
MED Present Future	20,000 30,000	Plant Reliability	High	Low	Medium ? (thermal)	55-130
RO Present Future	10,000 15,000 (small-large)	Pumps	Medium	High	Low (electrical)	Ambient

The usefulness of a dual-purpose plant can be illustrated by considering three separate plants i.e. a 100 MOD water-only plant; a 200 MWe power-only plant; and a dual-purpose plant producing 100 MOD and 200 Mwe. The dual-purpose plant would need about 40% less energy, as compared to the two single-purpose plant. See Figure - 2.

Some other considerations for dual-purpose nuclear plants are listed here:

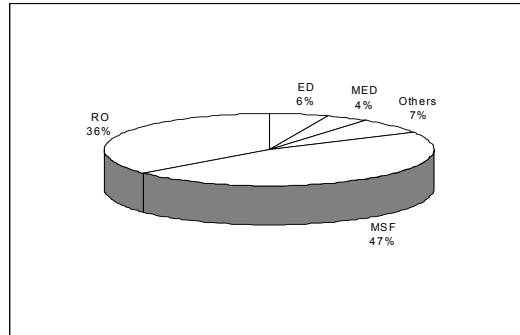
- a) Site-selection for a dual-purpose plant involves more work and studies, as compared to a single-purpose water or power-only plant. Things like availability of raw feed-water, disposal/management of concentrated brine, storage and conveyance-cost of product water should be considered while making selection of the site.
- b) Selection of the nuclear reactor type is strongly dependent on applications of the reactor. For heat-applications, specific temperature-requirements vary greatly. They range from about 100°C for desalination to 1000°C for production of hydrogen. High-temperature reactors (Gas-cooled Reactors) would yield higher power-to-water ratio, while medium-temperature reactors (pressurized water reactors) would give higher water-to-power ratio.

Revival of interest in the use of nuclear energy for desalination (besides economic factors) is also due to conservation of fossil fuels and protection of environment,

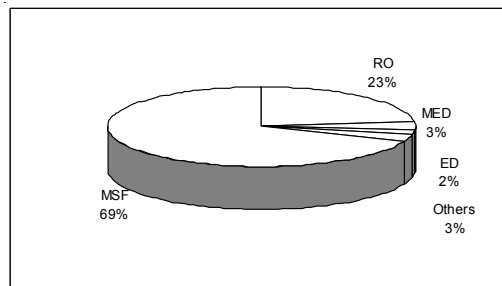
## **VARIOUS DESALINATION TECHNOLOGIES**

The desalination technologies that are commonly used in various plants operating in the world are mainly.

**Some Interesting Aspects of Water, with Special Reference to Nuclear Desalination**



**Figure - 3(a): Desalination plants with the capacity greater than 100 m<sup>3</sup>/d using various technologies**



**Figure - 3(b): Desalination plants with the capacity greater than 4000 m<sup>3</sup>/d using various technologies**

**Table - 2: World's 10 Largest Seawater Desalination Plants**

S#	Name of the Plant, Capacity and Desalination Technique
1	Al Jobail, Saudi Arabia 1,173,000 m <sup>3</sup> /d (310 mgd) 46 MSF Units 15RO Units
2	Jebel Ali Dubai 869,000 m <sup>3</sup> /d (230 mgd) 28 MSF Units
3	Taweelah Dubai 806,000 m <sup>3</sup> /d 213 mgd) 16 MSF Units
4	DohaKuwait 695,000 m <sup>3</sup> /d (184 mgd) 23 MSF Units
5	Az-Zour South Kuwait 482,000 m <sup>3</sup> /d ( mgd) 16 MSF Units
6	Shuaiba, Saudi Arabia 454,000.m <sup>3</sup> /d (120 mgd) 10 MSF Units
7	Al Khobar, Saudi a Arabia 450,000 m <sup>3</sup> /d (119 mgd) 18 MSF Units
8	Jeddah Saudia Arabia 420,000 m <sup>3</sup> /d (111mgd) 18 MSF Units 10 RO Units
9	Umm Al Nar Abu Dhabi 400,000 m <sup>3</sup> /d (106 mgd) 16 MSF Units
10	Yanbu Saudia Arabia 382,000 m <sup>3</sup> /d (101 mgd) 9 MSF Units 15 RO Units

- Multi-stage Rash Distillation Process (MSF)
- Multi-Effect Distillation Process (MED)
- Reverse Osmosis (RO)

Coupling of the selected nuclear reactor with a suitable desalination-process requires thorough investigations. While the multi-stage flash-distillation process appears to be the most favoured process for large nuclear desalination plants, there appears to be some shift recently for reverse-osmosis and multi-effect distillation processes.

Figures-3&4 show percentage of the operating desalination plants using various technologies and total, as well as country-wise, installed desalination capacity.

Tables-1&2 outlines some salient characteristics of commercial desalination processes, as well as the capacity and desalination techniques of the 10 largest seawater-desalination plants.

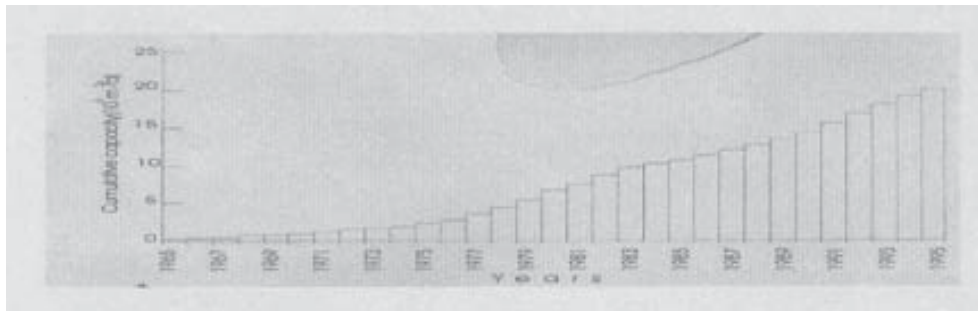


Figure - 4(a): Total installed Desalination Capacity

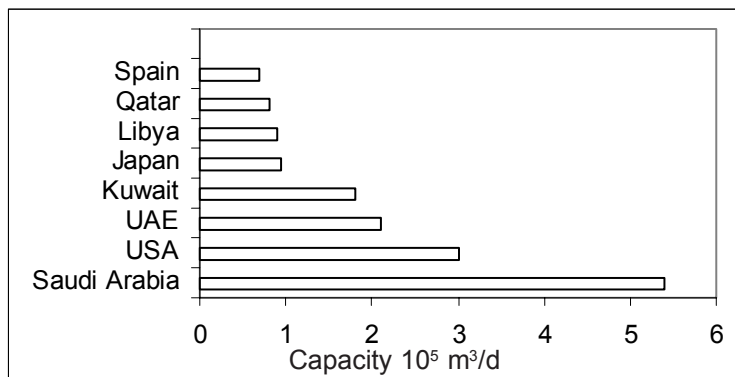


Figure - 4(b): Desalination Capacity by Country

## Some Interesting Aspects of Water, with Special Reference to Nuclear Desalination

### ALLOCATION OF COST TO WATER AND POWER IN DUAL-PURPOSE NUCLEAR PLANTS

In a dual-purpose plant, the cost of water or power could be made to appear very attractive by assigning all the benefit of the dual-purpose plant to any one of the two products. The total annual expenditure  $C_a$  is equal to:

$$C_a = C_{CE} E_a + C_{CW} W_a$$

$C_{CE}$  = Cost per KWhr of electricity  
 $E_a$  = KWhr produced per year  
 $C_{CW}$  = Cost per m<sup>3</sup> of water  
 $W_a$  = M<sup>3</sup> of water produced per year.

One of the two products could be subsidized by allocating higher prices to the other, as shown in Figure-5.

### METHODS OF COST CALCULATION

Cost of water appears to be very attractive if all the benefit of the dual-purpose nuclear plant is assigned to water. For example, if:

$C_D$  = Annual Cost of a dual-purpose plant producing P Mwe and W MGD  
 $C_W$  = Annual minimum cost of a water-only plant, producing W MGD  
 $C_P$  = Annual minimum cost of a power-only plant, producing P MWe

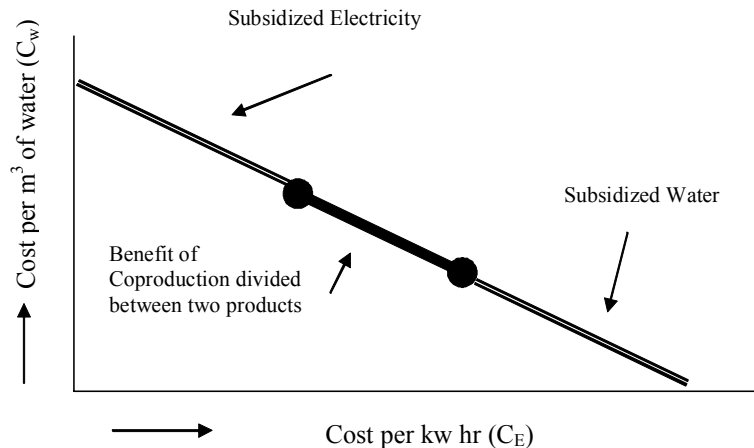


Figure - 5: Allocation of Cost to Water and Power

In case all the benefit of the dual-purpose plant is given to water, the annual cost assigned to water would be:

$$= (C_D - C_P)$$

On the other hand if all the benefit is to be assigned to power, the annual cost assigned to power would be:

$$= (C_D - C_W)$$

Even if the economic benefit is proportionately shared by power and water, the cost of both the products would be significantly lower than the minimum cost for water and power plants, i.e.  $C_p$

Normally, when a new item is produced in a multi-purpose plant (in this case water), the benefit of the plant is given to the new product to make it appear more attractive from cost-economics point of view. This should of course be done without increasing the cost of other products. The cost of water from a large nuclear dual-purpose plant becomes competitive in water-scarce areas if the annual cost assigned to water is  $(C_D - C_p)$ .





# **Alleviating Water-Problems: Marrying Old and New Ideas**

*Q. Isa Daudpota*

# ALLEVIATING WATER-PROBLEMS: MARRYING OLD AND NEW IDEAS

## ABSTRACT

*Water-scarcity presents exciting challenges to all. It invites – rather forces — an attitudinal change. This change should accompany economic, social and political incentives for conservation. There is also a need for introduction of appropriate new technologies and for reviving long-forgotten old ones. Our traditions teach us respect, and offer lessons, for water- harvesting of rainwater. Sewage and solid-waste management are shown to be linked to the solution of the water-resource problem. Ultraviolet purification is described; it can provide clean water cheaply to every citizen in the South, and can be introduced widely in Pakistan at minimal cost, thereby offering each citizen clean water. These and similar techniques introduced by national experts, working alongside the common people, can solve many water and related developmental issues.*

## INTRODUCTION

Our world is full of water – two third of it is covered with it. Despite this, expert forecasters predict shortages of water, leading to major tension that would lead to military conflagration. The earth's reserves of fresh water add up to more than 37 million cubic kilometers. The ice-caps bind more than three-fourth of this water, which is therefore inaccessible with current technology. The rest, nearly 9 million cubic kilometer, is in aquifers, and hence not easily exploitable.

The ultimate source of fresh water is the distillation of the oceans by solar radiation. The annual rate of evaporation is roughly 500,000 cubic kilometer, of which 430,000 comes from the oceans and the remaining 70,000 from waters on the continents. Fortunately, the continents receive 110,000 cubic kilometer from precipitation, so that the net effect of the hydrological cycle is to transfer some 40,000 cubic kilometer of fresh water each year from the oceans to the continents.

The maximum water that can be available for use by humans is about 14,000 cubic kilometers per year – this is the water flowing in all rivers and streams, excluding floodwaters. Of this, 5000 cubic kilometers flow in regions that are not inhabited. This leaves 9000 cubic kilometers per year, from which all human needs will have to be met. Is this going to be adequate? A simple analysis of the per capita needs could help. For this, it is convenient to work in smaller units, i.e. cubic meters (1 cubic kilometers is made up of a billion cubic meters). An acceptable quality of life can be maintained with 30 cubic meters per capita. Of this allocation, less than one cubic meter is for drinking, which needs to be of a higher quality — chemically and biologically safe.

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### **Alleviating Water-Problems: Marrying Old and New Ideas**

Other than in the most industrialized countries, industry takes 20 cubic meters of water per person. This is swamped by the requirements of agriculture. For a diet of 2500 calories per day, food-production requires 300 cubic meters per person per year. In wealthier countries, where input requirement is 3,000 calories per day, the water needed is 400 cubic meters per year per person. Adding all the requirements, it is fair to estimate the water requirement as 350 to 450 cubic meters per person per year. Given that the global water supply is 9,000 cubic kilometers per year, one may be led to assume that a world population of 20 to 25 billion can be adequately supported by the water that is available annually.

This simple calculation clearly has a flaw and it hinges on the assumption that the water is distributed around the globe in the same way as humans are. This is not so. For example, in some parts of the world, people have to make do with just 2 cubic meter of water per year, which is the bare biological minimum. For this low supply, they can pay as much as \$20 per cubic meter. In the U.S. and other developed countries, where an average urban user consumes 180 cubic meters for domestic purposes, the cost is one hundredth or less of what the poor person in the developing country pays! For sustainable development, such inequities should be removed.

Agriculture uses the largest amount of fresh-water resources. More than 85% of cultivated land is watered exclusively by rainfall. If not used, this water would be wasted. In 1970, rain-fed agriculture consumed 11,500 cubic kilometers of water; in comparison irrigated agriculture employed 2,600 cubic kilometers on 12% of the cultivated land. This should suggest that a major effort should go into optimized extraction and usage of the free rainwater that is spread widely and does not require transportation-cost to move it to places where people live and grow crops.

### **RAINWATER HARVESTING**

In Pakistan, and elsewhere generally, rain-fed areas were considered high-risk for agriculture. This meant that almost all resources were put into irrigation, thereby depriving ourselves of improving the enormous potential of our rain-fed (*barani*) areas. These *barani* areas cannot be ignored, as they nurture 80% of the country's livestock, grow 12% of wheat, over 50% barley, 65% of gram and 89% of groundnut production. Surface run-off, if stored in reservoirs, could help achieve the goal of food-sufficiency. Many of the problems of irrigation, such as water-logging and salinity, could have been avoided if we had been aware of the advantages of rainwater harvesting, a traditional method which can now be taught to the developed countries by countries in the South.

The use of rain-water harvesting has existed for 4,000 years. In Negev desert of Israel, which receives less than 15 cm of annual rainfall, hillsides were cleared to increase runoff, which was led into contour ditches. Underground storage of volume up to 300 cubic meters

have been reported. In the Mediterranean region, rainwater collected from roofs, and stored in cisterns, constituted the principal source of water from the sixth century BC until today.

In India, as early as the third millennium BC, farming communities in Baluchistan impounded water and used it for irrigation. Dams, built from stone rubble, have been found in Baluchistan and Kutch. Some of the settlements of the Indus valley civilization, dating back to 3000-1500 BC, had water-harvesting and drainage systems. The most recent to come to light is the settlement at Dholavira in Gujarat, India. The 1997 report, "Dying Wisdom" produced by the Center for Science and Environment, and dedicated to native wisdom and the rural communities of their country, looks at the "rise, fall and potential of India's traditional water-harvesting systems". This outstanding, seminal work, which took 10 years to produce, should be essential reading for our water planners.

#### **HANDLING ORGANIC 'WASTE'**

There is a fundamental connection between the present state of agricultural development, organic-waste management, sanitation and water supply. While water-supply and provision of sanitation is a big challenge for the burgeoning population, an important issue is to make organic residuals of human settlements useful in rural and urban agriculture. The content of nutrients in the excreta of one person is sufficient to produce grain, with all the nutrients, to maintain life for a single human! *This revolutionary thought provides the reason why no one needs to go hungry in this world.*

Work done in Sweden points to how agricultural production can be increased without the use of artificial fertilizers, provided that sanitation-technology could be made capable of recycling nutrients from households to agriculture. An important reason why this is needed, and is not peripheral, is that current sanitation-practices use scarce potable water to dispose off sewage, which is then difficult to manage and causes pollution of ground and surface-water supplies.

The real goal is not just to recycle water and nutrients, but also all matter, and especially organic solid wastes that constitute about 85% of all 'wastes' produced in human settlements. At the moment, only 5% of the solid waste generated in the North is biologically digested to recover nutrients. Theoretically, it is possible to use up to 85% of solid waste as recyclable resource. Moving beyond composting and urine-separating toilets, workable decomposition technologies for organic wastes that produce bio-gas and bio-fertilizers are needed. Solid-waste management becomes an issue of organizing the collection, transportation and recycling of waste. Instead of problems and pollution, the end-products may feed the growing population and be a source of clean energy. One can then move from thinking about isolated technologies to totally new system-solutions.

### **Alleviating Water-Problems: Marrying Old and New Ideas**

This is an area where our agriculturists and other scientists could valuably spend their effort and come up with profitable solutions, with wide-ranging impact on the health and economy of the country.

### **CHEAP CLEAN WATER WITH ULTRAVIOLET LIGHT**

Poor water-supply and lack of proper sanitation condemns half the population of the developing world, at any given time, to suffer from one of six main diseases associated with water-supply and sanitation. About 400 children below the age of 5 die every hour, in developing countries, from waterborne diseases. This comes to 3 million dying in a year! Diarrhea and associated diseases make them the biggest environmental threat to people.

Provision of plentiful and safe water and sanitation is essential for development; the benefits of these are increased labor and economic productivity. A citizen should, however, demand these as a basic civil right. What Pakistan needs is good sanitation, plentiful good-quality water and adequate disposal of human and animal excreta and waste. According to a former director-general of WHO, the number of taps per 1000 persons is a better indicator of health than the number of hospital beds.

The latest report on the quality of water in Islamabad, Pakistan's best cared-for city, shows that we are far from providing safe water in the country. Contamination of the water is due to sewage entering the leaking pipes in the supply chain, says one report. Boiling of water for ensuring safety is very expensive and environmentally harmful. Also, expensive home-filter, with or without ultraviolet, for removal of pathogens is not feasible for most homes. Again, as with the water-harvesting, a cheap reliable hundred-year-old idea comes to the rescue.

Low-pressure mercury arc (same as that used inside ordinary fluorescent lamps) puts out 95% of its energy at a wavelength of 254 nanometers, which is right in the middle of the range of wavelengths that kills bacteria. The Energy-efficiency of UV treatment is very high, as it uses one over two thousand of the energy that boiling does, using a bio-mass cook-stove of 12% efficiency. Unlike chlorine, which does provide long-term protection against re-infection by pathogens, UV does not leave a taste or odor and presents no risk of overdosing or formation of carcinogenic by-products caused by chlorine. The high sensitivity of bacteria to UV keeps the needed contact-time down to a few seconds, as compared with 30-60 minutes for chlorine.

In the mid 90s, when floods in India caused many deaths from water-borne disease, Ashok Gadgil of Lawrence Livermore Lab. in California, used a simple idea of UV's bio-active property to build a simple equipment that is now beginning to be used widely in India and other parts of the world. The beauty of it is that the assembly is simple and only

local materials are needed to have a system up and running within a community, in less than a day.

A curved plate helps focus the UV lamp on to a channel, which carries flowing water that is to be made bacteria-free. By using 40 Watts, such a unit can disinfect one ton of water per hour. The cost of such a system is remarkably low. Electricity cost, using the grid or a photo-voltaic array and amortizing over 10 years, as well as maintenance, gives the cost of annual provision of drinking water for a single individual (10 liters per day) at about Rs 6. No one in Pakistan has, as yet, set about installing such units in the country. Why?

## **CONCLUSIONS**

As Pakistan's population grows, there will be increased pressure on water-resources. The lack of good sanitation, which is already rare, threatens to cause even more serious health hazards. These problems invite us to search our traditions for solutions, most important among them is respect for water. Technologies, old and new, can help us use the resource sensibly. Mere technical solutions will, however, not help. We will need to build a community with national conservation ethics, backed by an improved management-capability. The problems of water- scarcity and poor sanitation can be turned into wonderful opportunities to transform our societies. It is time to change the way we do things and think anew our relationship to natural resources!

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