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COMSATS 1st Meeting on Water Resources in the South: Present Scenario and Future Prospects (November 1&2, 2001

Commission on Science and Technology for Sustainable Development in the South

COMSATS Headquarters: 4th Floor, Shahrah-e-Jamhuriat,
Sector G-5/2, Islamabad, Pakistan.
Tel : (+92 - 51) 920 4892, 921 4515-7 Fax : (+92 - 51) 921 6539
Email: info@sciencevision.org.pk, Website: http://www.sciencevision.org.pk

SPECIAL ISSUE

SCIENCE VISION

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We regret to announce the death of a member of our editorial board, Dr. Abdul Hafiz, a renowned agricultural scientist.

SCIENCE VISION is published by **COMSATS** as a quarterly journal covering its programmes, the activities of the Networks of International Science and Technology Centres of Excellence and contains scientific articles related to advances in Science and Technology in the North and the South.

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Tables and Illustrations: (i) should be separate from the text; (ii) should be numbered according to the order in which they are mentioned in the text; (iii) facts and figures should be carefully revised and any discrepancies removed; (iv) each table should have a short explanatory caption.

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FOREWORD

Developing countries of today are blessed with an abundance of natural resources, but the reason for their slow socio-economic growth is their inability to make an efficient and sustainable use of these resources. The most important element in this regard is that plans (both short-term and long-term) have not been backed by effective monitoring and concrete follow-up, a situation that has hindered the path of sustainable development.

Among various challenges currently being faced by these developing countries, the issue of water-resources and their effective management has of late emerged as one of the most critical ones, mainly due to the changes in regional and global climatic patterns. This issue has assumed even more significance due to the recent drought-like situation that has had a considerable impact on various sectors of countries in our region. Water Management involves every person on the planet----from the simple act of how water is used by individuals to the more direct involvement of everybody in how water is used in the industry. Therefore, we have to play a proactive role in our respective capacities and should strive to listen to expert opinion on this subject.

In view of the scarcity of water-resources and its attendant problems, the Commission on Science and Technology for Sustainable development in the South (COMSATS), with the advice of its member countries, held a two-day meeting titled ***"Water-Resources in the South: Present Scenario & Future Prospects"*** on the 1st and 2nd November, 2001. The meeting, which was attended by eminent experts, scientists, researchers and engineers from member countries of COMSATS, focused on various burning issues related to water-resources, and thought-provoking discussions and presentations were made during the course of the meeting. The topics of the meeting ranged from the existing situation of water-resources in the developing countries to the issues and challenges that they will face in the years to come.

There were a total of five technical sessions, and these sessions had a thematic sequence of topics. The speakers came up with very useful recommendations, which encompassed areas of drought-preparedness and management, hydrological modelling, recycling through bio-filters, seawater pollution, and ground-water salinity. In addition, various strategies for efficient sustenance and management of water-resources were discussed during the meeting. These recommendations and concluding note may be found in the first section of this document.

In the end, I would like to express my gratitude to the member-countries of COMSATS, the diplomatic community, and distinguished speakers and participants of the meeting for their highly valuable support of this effort. I also owe a deep sense of appreciation to my team at COMSATS, whose untiring and dedicated efforts made this meeting a huge success.

In the end, I would like to appreciate the dedicated efforts of the team that worked tirelessly to come up with this compilation. In this regard, the names of Mr. Salman Malik, Mr. Irfan Hayee and Mr. Imran Chaudhry are worth mentioning.

Dr. Hameed Ahmed Khan
(Executive Director COMSATS)

WELCOME ADDRESS

Dr. Hameed Ahmed Khan
Executive Director
Commission on Science and Technology
for Sustainable Development in the South (COMSATS)

The Chief Guest, Dr. Ishfaq Ahmad,
Excellency, Mr. Lu Shulin,
Ambassador Peoples Republic of China,
Excellency General C. S. Weerasooriya,
High Commissioner,
Democratic Socialist Republic of Sri Lanka,
Fellow Scientists,
Participants of the Meeting,
Ladies and Gentlemen,

With great pleasure, I welcome you all to the COMSATS "1st Meeting on Water-Resources in the South: Present Scenario and Future Prospects". The Meeting has been organized to take stock of water-related problems and issues that our region faces today and to work out strategies for better management, utilization and sustainability of water-resources in the South.

Water resources and water management have, of late, emerged as burning issues all over the world, following the changes in regional and global climatic patterns. They have assumed special significance in our region, due to a drought-like situation that has made considerable impact on various sectors of our countries. Water Management involves every person on the planet ---- from the simple act of how water is used by individuals, to the more direct involvement of everybody in how water is used in the industry. Therefore, all of us will have to play a role in our respective capacities and should strive to listen to expert opinion on this subject.

In view of the scarcity of water and its attendant problems, COMSATS decided to hold this two-day meeting of eminent scientists, engineers and experts on this important issue. A technical committee shall look into the research/review papers to be presented here and pass recommendations at the conclusion of the meeting. It is hoped that this conference will contribute significantly to the water-management field in the COMSATS countries.

The participants of the meeting include eminent environmentalists, reservoir engineers, climate scientists, power experts and government representatives. The meeting will have more than 20 speakers and a large number of participants.

Before I proceed further, I wish to acknowledge the role of our respected Chief Guest, Dr. Ishfaq Ahmad Sahib, in bringing the critical issue of water-resources to light and in the organization of this conference today. It was his initiative and drive that convinced COMSATS to take up this topic, which no doubt has great implications for sustainable development in the South. I am really grateful to you Dr. Sahib, for your timely advice and guidance in this regard. I believe it is high time that institutions like COMSATS come forward and contribute to the development and sustenance of regional water-resources and provide solutions for related problems.

Being the first initiative of COMSATS in this field, the current workshop carries special significance for the Commission's mandate and strategic plan. The outputs of the meeting will help us define our future initiatives and strategy in this critically important field. The meeting is one of COMSATS' several initiatives that have been taken for accomplishing the goal of sustainable development in the less advantaged regions. For the benefit of the participants of today's meeting and for those of us who are new to the scene, I would like to, very briefly, touch upon some other programmes and activities of COMSATS.

As you may be aware, COMSATS stands for 'Commission on Science and Technology for Sustainable Development in the South', having 21 countries as its members. We have been engaged in a number of local as well as international programs. Two of our most important local projects are COMSATS Internet Services (CIS) and COMSATS Institute of Information Technology (CIIT). I take pride in CIS as one of the top ISPs of the country providing Internet services in 7 cities, and CIIT as a progressing high-quality IT institution. Another important project is the Syrian-COMSATS-COMSTECH Information Technology Center at Damascus, which was established in collaboration with COMSTECH and Syrian Ministry of Higher Education. It was jointly inaugurated by H.E. the Chief Executive General Pervez Musharraf, and the Syrian President Bashar-al-Asad during January this year. Another similar center, again with COMSTECH's collaboration, is being set up at Karachi. These are a few prime examples of the projects whereby the concept of Sustainability at COMSATS can be seen in practice.

In addition to the national-level scientific activities, COMSATS has also been involved in a number of projects with International Agencies. These include IDRC (Canada), ICIMOD, APCTT, TWAS/TWNSO, UNESCO, and UNIDO. Besides this, we have organized a number of workshops, scientific visits, scholarships and participation in conferences in COMSATS member countries. Our 1st Meeting on Science and Technology for Sustainable Development and Workshop on Non-Destructive Testing that were held here last month were the latest of such efforts.

One of our strengths is COMSATS Network of International Science and Technology Centres in the South. We are lucky to have 13 highly reputed world-renowned institutions in Bolivia, Brazil, China, Colombia, Egypt, Ghana, Jamaica, Jordan, Nigeria, Pakistan, Syria, Tanzania and Turkey, as our network members and resource-centres. These centers, in their areas of specialization, are playing a leading role in promoting cooperation and exchange for achieving a science and technology revolution in the South.

COMSATS feels proud of being one of the few institutions, which have achieved great milestones in a short period of seven years. Carrying on in the same spirit, we are planning some more programmes in the near future, which include a Workshop on Economic Impact of Bio-technology in Lebanon, on 10-11 November, 2001, an International Workshop on Networking Essentials and ICND, Islamabad, January 4-11, 2002, and Workshop on Plasma Physics Laser-Induced Plasma Spectroscopy and Applications, Tunisia, January 11-13, 2002.

COMSATS owes its achievements to the member countries, their diplomatic representatives, its dedicated team and the support of people like you. We hope to achieve more with your cooperation and guidance.

Before closing, I wish to thank Dr. Ishfaq Sahib for emphasizing the importance of a very vital issue concerning all of us. It is particularly a matter of survival for the countries of the South. I would also like to thank Dr. Sahib for taking time out of his very busy and important schedule to be with us this morning. I am particularly grateful to all the participants and speakers for their valued inputs. I must express my gratitude to their Excellencies the Ambassadors of our member countries, for their valuable contribution and for gracing the occasion today. I am particularly grateful to H.E. Lu Shulin and H.E. General C.S. Weerasooriya. Their views on the subject have made our resolve even stronger.

I would also like to mention those of our foreign friends, who made all their efforts to participate in the meeting but could not do so due to unavoidable circumstances. I may also thank my team members who worked hard for the successful implementation of this meeting. In this regard, the names of Mr. Tajammul Hussain and Mr. Salman Malik are especially worth mentioning for their untiring efforts.

I thank you all once again, and God bless you all.

KEYNOTE ADDRESS BY GUEST OF HONOUR:

H.E. General C. S. Weerasooriya
High Commissioner
High Commission of the Democratic Socialist Republic of Sri Lanka

The Chief Guest, Dr. Ishfaq Ahmad,
Dr. Hameed Ahmed Khan,
Executive Director, COMSATS,
Excellencies,
Distinguished guests,
Ladies and Gentlemen,

I am honored to be invited to the inaugural session of COMSATS 1st Meeting on "Water-Resources for Sustainable Development". It is my great pleasure to address subject experts from countries of the South, in the face of water insecurity.

I am indeed happy to speak a few words on this important subject because, in Sri Lanka an ancient civilization emerged and flourished on the river banks of the country's dry zone. Settlements quickly spread across the plains prompting an urgent need for a means of coping with the geological and geographical peculiarities of the dry zone and its frequent droughts. Thus, Sri Lanka became one of the greatest irrigation civilizations of the ancient world.

Large-scale irrigation networks began crisscrossing the parched landscape, which started as early as the first century A.D. Sri Lanka's engineers utilized the waters of the Mahaweli ganga, the longest river in Sri Lanka, and the other rivers that flowed down to the plains from the mountains of the wet zone.

The construction of their canals and channels exhibited an amazing in-depth knowledge of trigonometry; and the design of their reservoirs revealed a thorough grasp of hydraulic principles. The method of regulating the flow of water from these tanks, as the artificial lake reservoirs are called today, was ingenious. By the third century B.C. Sri Lankan engineers had invented the BISOKOTUWA (valvepit), the prototype of sluices regulating the flow of water from contemporary reservoirs.

It is highly interesting to mention that in the 1980's when Sri Lanka started work on the accelerated Mahaweli programme, under which water of Mahaweli River is diverted to the dry zone, it was found that there had been an ancient irrigation network exactly in the manner designed by modern engineers.

The world is rapidly moving toward shortages of freshwater, both on the surface and underneath the Earth. Globally water-usage has increased fivefold in this century, and today's per-capita availability is predicted to decline by a third over the next generation. Water shortages are rapidly emerging, even in water-rich countries from the United States to China; recent droughts in South Asia and North Africa have emphasized the precarious balance between water supply and demand.

Water is a strategic asset for the countries of the South, most of whom are agro-based economies, and thrive on the optimum yield of crops. Hence water is a key factor for sustainable development.

Change in climatic cycles and rain-belts, depleting aquifers, salination and water-logging impress upon us the need to better manage the endowed resource, which is becoming a scarce element in the face of population explosion. Water as basic amenity of life, especially fresh, uncontaminated-potable water is available to a very small portion of world populace.

With changing life-styles and usage-pattern, the access to water is further getting out of the reach of the rural habitants, coastal and marine life is facing challenging scenarios, maintaining biodiversity is becoming an up-hill task, contamination by fertilizers and pesticides, dumping of municipal and industrial wastewater into rivers and lakes, solid waste deposits along river banks, and uncontrolled seepage from unsanitary landfills--all these factors are degrading freshwater-resources and imposing health risks, especially for children, the primary victims of waterborne diseases.

The need of the hour is to focus on the water-issues at a much broader level; deploy water-management plans to conserve and optimize water-resources, use water-efficient products, techniques and technologies, sensitize much needed public opinion to make the resource available to all segments of societies, impartially.

Sri Lanka being an island country, does not face a water-management crisis, though there are signs of increasing stress on water-resources and competition between users. Lower river levels and increasing salinity intrusion into the Kelani River mouth is threatening the entire water-supply to Greater Colombo, an area of 730 Sq. Km.

The government of Sri Lanka has initiated a number of steps to strengthen gainfully its water-resources management and, with help of Asian Development Bank, had sometime back, embarked upon Institutional Strengthening for Comprehensive Water-Resources Management (ISCWRM) project. It is in line with the emphasis on water-policy and institutional development and on the need for a comprehensive, water-sector approach to sustainable development. The project addresses the entire water-sector in Sri Lanka, including irrigation, water supply, hydropower, and environment aspects. It follows a five-point action-plan, which along with others include the development of integrated river-basin planning.

It will also be worth mentioning that IUCN Sri Lanka, established in 1988, has provided considerable support to national initiatives for the sustainable management of biodiversity and for enhancing local capacity for environmental management. I would also like to add that Muthurajawela Wetland Project is the largest saline coastal peat-bog of Sri Lanka and is listed as one of the 12 priority wetlands of the island due to its rich biodiversity. An ecological survey on the Muthurajawela march sanctuary has been in operation, in order to identify its critical habitats.

Although Sri Lanka is signatory to water-related global projects, much is still needed at regional level to mutually tackle the present and future challenges, and make use of each other's experiences.

I greatly value the outcome of the deliberations of this meeting, for which COMSATS has convened this august conference for furthering the cause of water-resources for sustainable development in the countries of the South. The findings of the meeting will hopefully go a long way in addressing the issues to gainful utilization of these resources in the future.

Thank you.

KEYNOTE ADDRESS BY GUEST OF HONOUR:

H.E. Mr. Lu Shu Lin
Ambassador,
Embassy of the People's Republic of China

Dr. Ishfaq Ahmad,
Dr. Hameed Ahmed Khan,
Executive Director, COMSATS,
Eminent Scientists
Ladies and Gentlemen,

It is my honour to be invited to attend the opening ceremony of COMSATS 1st meeting on Water-Resources in the South, and it's my privilege to make a speech on the occasion of its inauguration. First of all, I'd like to express my appreciation to the Executive Director, Dr. Hameed Ahmed Khan, for making such an important key-issue that is posing grave challenges to the COMSATS member countries as the theme of the conference. I'd like to take this opportunity to share with you some Chinese experiences on sustainable development of water resources.

Basic Facts and Objectives On Water-Resources

In China, total water-resources are 2.8 trillion cubic meters, freshwater resources are inadequate and unevenly distributed in both temporal and spatial scales. China's per-capita water resource is, 2400 cubic meters, only one-fourth of the world's average. Water consumption is 530 billion cubic meters; out of those, 78% is used for agricultural purposes and 22% is used for industry and human consumption. With the growth of the population and economic development, serious water-shortages have appeared not only in the arid and semi-arid areas, but also in many cities of northern China. This has become a limitation to the economic development. Moreover, some river basins of the country have been polluted to various degrees, resulting in a further decrease of water-resources utility. Therefore, it is an important strategic task for the implementation of sustainable development to rationally use and protect water-resources.

In order to solve this problem, the Chinese government put forward the general objectives for water-resources protection and sustainable utilization. The objectives are: to implement the policy of rational exploration, utilization, and comprehensive conservation of water; to strengthen the management of river-basins and lakes; to improve the management and control of water-pollution; and to vigorously maintain and improve the natural utility of water- resources and the ecological environment of basins.

Actions and Achievements On The Sustainable Development Of Water-Resources In China

Strengthening the management and development of major rivers and lakes:

The Chinese Government has strengthened the integrated development and management of major rivers and lakes. The key part of this work is to prevent flood disasters by heightening and reinforcing major dams, building flood-division areas, and realigning river-courses in major rivers and lakes, such as the middle and lower reaches of the Yangtze River, the lower reaches of the Yellow River, Huaihe River, Haihe River, Songhuajiang River, Liaohe River, and Taihu Lake. A group of important large-scale water-conservation projects have been developed to allow more effective control and bring comprehensive benefits. In order to solve the problem of water-shortages in northern China, the Chinese Government has vigorously organized the planning and construction of trans-basin water-transferring projects, conducted a scientific feasibility study of transferring water from the south to the north in the central, eastern, and western parts of China, and made preliminary preparations for the project.

Controlling Increased water-pollution in major river basins:

In order to bring water-pollution under effective control and protect the aquatic environment, beginning in 1994 the Chinese Government carried out the "Three Rivers and Three Lakes" water pollution-control project (Huaihe River, Haihe River, Liaohe River, Taihu Lake, Dianchi Lake, and Chaohu Lake). It also defined the targets for controlling the total amount of water-pollutants discharged into river basins, as well as the maximum permissible discharge amount for major cities, towns, and discharge points. Meanwhile, a deadline was set for closure or production capacity was less than 5000 tons in the Huaihe Basin. By June 30th of 1996, 1, 111 small paper mills in four provinces along the Huaihe River had been closed, reducing COD discharge by 346,000 tons, and achieving the objective of a 15% reduction in pollutants for that year.

Progress in agricultural water-conserving technology and demonstration-project construction:

The Chinese Government has organized the compilation of the "China Water-Conserving Development Programme for Irrigation Agriculture", drawn up the technology-standards suitable for national conditions for various water-conserving irrigation projects, and formulated the plan for the construction of large-scale water-conserving irrigation demonstrations at the national level. At present, the total area covered by water-conserving irrigation has reached 13.33 million hectares. Some practical water-conserving technologies have been developed and these are being used in the technical preparations for the establishment of 300 demonstration counties for water-conserving irrigation projects during the Ninth Five-Year Plan.

Promotion of drinking-water projects in poor rural areas:

In order to solve the drinking-water problems of some poor rural areas, the Chinese Government began to carry out a drinking-water project for those areas in 1990. Since 1991, 145,000 drinking-water projects have been built, 470,000 drinking-water wells have been dug, 199,000 water-collecting facilities have been established, and 174 million rural people have had the problem of inadequate drinking water resolved. With the cooperation of UNICEF, the government has carried out the Trinity project (water, environmental hygiene, and health education) and achieved preliminary progress. Moreover, the government has popularized low-cost water supply measures and sanitary toilets, and disseminated health-knowledge to farmers. With the implementation of the "Sweet Dew Project", more than 4 million people in Shaanxi Province and 3.8 million herdsmen in Inner Mongolia Autonomous Region have achieved adequate drinking-water supplies during the past 3 years. A series of drinking-water projects have also been carried out in Xinjiang, Gansu, and some other western provinces; all these have eased, to some degree, the difficulties of peasants in water-short areas.

Projects for water-resource development in western China.

The Chinese Government has greatly promoted the western water-resource development plan and carried out a number of utilization projects that focus on the central and western regions. These projects include the Xinjiang Wuluwati Reservoir project, Tibet Manla Reservoir project, Ningxia Fuyanghuang irrigation project, Gansu Changma Reservoir project, etc. These projects will play a very important role in promoting the social and economic development in central and western China, changing the poor and backward situation, improving the eco-environment, and strengthening national solidarity.

Finally, thanks again to Dr. Hameed Ahmad Khan for your kind invitation, and thank you all for listening to me.

INAUGURAL ADDRESS BY THE CHIEF GUEST

Dr. Ishfaq Ahmad
Special Advisor to the Chief Executive, Pakistan

Dr. Hameed Ahmed Khan,
Executive Director COMSATS,
Excellency, Mr. Lu Shulin, Ambassador, Peoples Republic of China,
Excellency General C. S. Weerasooriya,
High Commissioner, Democratic Socialist Republic of Sri Lanka,
Fellow Scientists,
Ladies and Gentlemen,

It is commendable that COMSATS has organized a meeting on an important subject of great current interest. I am pleased and delighted to be present at the inauguration.

The world's fresh-water resources are finite and are coming under stress because of increasing population, higher standards of living and recent global climatic change. Furthermore, they are also unevenly distributed in space and time. There is a universal awareness and concern on the availability and sustainability of water, which is a vital strategic resource. In the South; some countries have ample water resources while most suffer from its scarcity.

Life, as we know, originated from water around 3.5 billion years ago; therefore, it is no surprise that all species and ecosystems depend on it for their existence. Ninety seven and half percent of all water on earth is in the oceans, as salt water. The total fresh water is only two and a half percent. Most of this fresh water (68.7%) is in the form of snow and ice, mostly as polar icecaps and is inaccessible. Nearly 31 % is fresh underground water, major portion of it in deep aquifers; the most accessible water contained in lakes, reservoirs and rivers is only 0.26% of the total amount of fresh water or 0.007% of all water. Fresh water in rivers and streams and ground-water recharges by rains are the primary renewable resource for ecosystems and humans. In this renewable water, there is lack of sufficient and reliable data on water-availability in many areas of the world.

The total renewable water resources of the world are estimated to be 42,600 Km^3 (1995 figures). The table compares the water resources by individual continent basis. On the average, water availability per-capita was about 7,600 m^3/year in 1995, the lowest being 4,000 m^3/year for Asia, and highest 38,000 m^3/year for South America.

The ecosystem provides food, wood and other important goods and services to humanity; water having an absolute fundamental balancing functions in the natural processes. Water dissipates the solar-energy variation in space and thus acts as a buffer. It dissolves and carries nutrients to plants and living organisms, it provides chemical services, like oxygen production, carbon dioxide uptake and release of nutrients through biodegradation. Ninety percent of all living organisms live in water, because sun-light can pass through it. Thus, water not only has direct use for drinking, washing and vital input for food and energy production, etc., but it simultaneously has other functions indispensable to life and human welfare. For a holistic perspective, an integrated approach to water-development has to be taken. The past interests have mainly focused on ***Blue water,*** the water available in the streams, lakes and ground water aquifers. The available blue water is about 40,000 km^3 per year. However, water is involved in a host of complex functions, some of which have been listed earlier, in which there is no substitute for it. The water in the ecosystem may be referred to as ***Green water***; i.e. water for non-irrigated vegetation, including forests and woodlands, grasslands and rain-fed crops. ***Green water*** or soil water is estimated as 60,000 km^3 per year. It is the primary source for terrestrial ecosystem. For long-term sustainability, both ***blue water*** and ***green water*** functions have to be balanced.

Table - 1: Potential Water Availability Worldwide				
Continents	**Population in millions**	**Water Resources (in km^3/year)**	**Potential Water availability (in km^3/year)**	
			Per 1 sq.km	**Per capita**
Africa	708	4,040	134	5.7
Asia	3,403	13,508	309	4.0
Europe	685	2,900	278	4.2
North America	448	7,770	320	17
South America	315	12,030	674	38
Australia and Oceania	28.7	2,400	268	84
All Continents	5,588	42,650	316	7.6

Not so long ago, the human population was limited in size and there was no conflict between ***Blue and green water*** use, but a combination of runaway population growth and industrialization has drastically increased the requirement of water. In the previous century the world's population tripled, but human use of water multiplied six folds. Today, perhaps as much as half the world's fresh water is serving human needs. There is a need now to assess in this new century if the world can sustain this high ratio of water-use by the increasing world population.

Whenever water availability is less than water needs for societal functions and plant growth, water is said to be scarce. Water scarcity cannot be directly defined in terms of the amount of water. The climatic conditions play an important role: 1000 mm of rain per year may produce dripping environment in cold regions; the same amount of rain may, however, only produce semi-arid conditions in hot areas due to high evapotranspiration.

Renewable water-resources are not only scarce but are also highly variable in time and space. The arid and semiarid zones of the world constitute 40% of the land-mass, whereas they have only 2% of the global run-offs. Even so, some countries in the semi-arid region suffer form devastating floods in the rainy seasons. Rivers provide about 90% of renewable water; however, stable base river flow only accounts for 37% of total river flow. The rest of the flow depends primarily on the natural variation of climate.

This situation has been compounded during the past decades in many regions of the world, through development in basins where these waters originate. The anthropogenic changes in the climate caused by higher concentration of green-house gases, especially carbon dioxide, has the potential to further affect water-resources significantly. The International Panel for Climate Change (IPCC) which has the support of 3,000 scientists, including several of the world's most distinguished meteorologists, in its third Assessment Report on climate change published in July 2001. states that global warming is happening, and at a much faster rate than was expected: global temperatures are rising nearly twice as fast as previously thought. Their prediction based on computer models is that temperatures could rise by as much as 5.8^{o}C by the end of the century. The climatic models also predict that rainfall will increase in regions that already have sufficient rains, while dry regions will become even dryer, thus aggravating the crisis in dry regions.

Humanity depends on freshwater for life as well as economic activity; water is increasingly becoming a strategic commodity. Although the problems associated with water are world-wide and are required to be tackled regionally and globally; however each country in the south must develop a *comprehensive strategy for water-resource management;* elements of this comprehensive policy should include the following:

1. Resource-Estimation

Estimation of water-resources is the first step to understanding the situation facing any country; a proper and accurate estimate will determine future policy and actions.

2. Forecasting of Demand

The next step in the preparation of a comprehensive water-policy is assessing the present and future needs. In this assessment, the anticipated growth of population as well as change in living standards will be considered. Life style and population-distribution have large impact on amount of water used. Another factor which may also be considered is the anticipated effect of global climate-change.

3. Conservation and Reuse

For countries which have sufficient resources, the need may only be to conserve and, if required, reuse or reallocate water between different areas. For countries in which water is scarce, drastic measures in conservation and reuse may be required, such as recycling waste water, purifying water, water-harvesting, large storages, introduction of drip-technology in agriculture, etc. However, if conservation and reuse measures are inadequate, then investment in a whole host of modern technologies will be required.

4. Modern Technologies

Most modern technologies can be used, directly or indirectly, to solve water-problems. These include such technologies as bio-technology and genetic engineering, nuclear technology and space technology, as well as other innovative approaches like the use of solar energy, laser technology, and cloud-seeding. Space technology, such as satellite remote sensing, can determine vegetation cover, snow cover and areas under heat stress; it can also determine water seepage through channels.

Technologies like Isotope Hydrology can determine leakages in dams and map underground aquifers and aquifer recharge. Bio-technology may be used to develop plants for water cleaning and purification; genetic engineering and nuclear mutation can be used to develop plants that require less water and are suitable for drought areas. Plants that can grow in brackish water may offer an opportunity to use large tracks of saline lands. Desalination, and especially nuclear desalination, may be inevitable in the future. Breakthroughs in membrane technology are having profound effects in many areas, ranging from waste treatment to desalination. Information technology has an important role to play in water management and policy. Laser land-levelers are proving economical, as they optimize water-use in agriculture. Applications of new technologies in agricultural practices thus offer opportunities to grow more food with less water.

5. Awareness and education

Fresh water is scarce, precious, and irreplaceable. Yet this basic profound truth eludes much of humanity. Public-awareness campaigns to educate people on the importance of water and the need to conserve and reuse it should be undertaken in earnest. Participation of the public in planning and management of water-resources is essential to develop the ownership psyche. Children should be taught the worth of water at an early stage in the school. Curricula of technical courses on water-related technologies may be introduced at higher levels of education; some countries like South Africa have already started doing it.

6. Management

The developing countries are particularly lacking in the management aspect of water. For proper management, all agencies involved in water-affairs, starting from the collection of data, processing, dissemination, research and development and implementation, have to be integrated to get the desired results.

The present situation of water-scarcity is global and requires global solution, however, the situations facing most countries in the South are similar. Cooperation between countries in the South, particularly in sharing information and technology, can go some way in addressing the situation. There may be an urgent need now to setup some institutes for water research and related technology by countries in the South.

Many developing countries, including Pakistan, are undergoing industrialisation and are now faced with the full range of modern toxic pollution problems, heavy metals, acidification, persistent organic pollutants (POPs), while still struggling to deal with traditional problems of poor water-supply and lack of sanitation services. The pollution threat, man-made or natural, is particularly serious when it affects groundwater supplies. The arsenic poisoning case in Bangladesh is one such example. Ground-water reserves provide more than 50 percent of domestic supplies in most regions of the country. Water-scarcity has been exacerbated by accelerating contamination of usable water-supplies, especially in rapidly urbanising areas, gravely damaging human health. An important element of national water-policy must be the provision of safe drinking water to the population. Drinking water supplies must have the standards specified by WHO.

Water-availability, water-use efficiency and associated problems such as ground-water depletion, salinity, pollution, contamination etc. are going to be serious in the coming years. These are exemplified by the fact that close to one billion people in 40 countries are prone to famine; almost 70% of the arid lands where agriculture is vital for minimal food-production are subject to desertification. It is estimated that 30% of all the arable lands will be salinized by the year 2020 and 50% by the year 2050.

Pakistan is the fourth largest country, after China, India and USA, in terms of land under irrigation. The river Indus basin, which is the main source for this irrigation, is a semi-closed basin; it offers good opportunities for adding value to water through storage. There is no excess outflow to sea during the low-flow season, but there is excess outflow during the high-flow season. Thus, storing water and reallocating it between seasons can achieve potentially large increases in the value of water. Pakistan is blessed with large glaciers in the North; the need is to access this potential and to understand the anticipated changes in it due to global warming.

The impending crisis is severe. If we take a myopic view, we will be in trouble; however, collective and individual efforts by member COMSATS countries may go a long way in averting the crisis. There is a need to invest in the future; keep a close watch on the impact of global change, both climatic and technological. Meetings like this one organised by COMSATS, I hope, will go some way in identifying the problems and suggesting remedial measures for the sustainable development of water-resources in the South. I note that this is the first meeting on water-resources in the South. I hope that the next meeting will be more specialized, and that it will follow-up on the recommendations made in this one.

In the end, I commend COMSATS for having undertaken the initiative. I compliment Dr. Hameed Ahmed Khan, Executive Director COMSATS, and his team for taking up such an important task.

Thank You.

STATEMENT ISSUED AT THE MEETING ON WATER-RESOURCES

Management and conservation of water-resources are fast emerging as critical issues facing today's world and need to be tackled through a collective and sustained effort by all countries. Most of the countries in the South, including Pakistan, are facing serious problems of mismanagement of its precious water-resources and lack of co-ordination among various establishments dealing with water-resources research, planning and development. It is in the vital interest of Pakistan to formulate, issue and implement a "National Water Development and Management Policy" at the earliest possible time. The delegates to the COMSATS 1st Meeting on water stress the need to respond to the frequent advice by the President, General Pervez Musharraf, to formulate mechanisms for better management of the continuously depleting water-resources in Pakistan and fill the need to strictly follow water-conservation strategies, in response to recent changes in regional and global climatic patterns. It is strongly felt that South Asian countries, specially Pakistan, need to make and implement short-term, intermediate-term and long-term measures to manage sustainable water-supplies for drinking, agricultural and industrial purposes, to boost their national economy.

The long-term strategies are costly, but can be optimized from economic view point. The long term strategies, including 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 regions and provinces, need to be given top priority in order to solve the water-availability and water-quality problems. The delegates to the conference also observe that planning, development and management of Water-resources is an exclusive subject with the Federal Ministry of Water and Power; the Chief Engineering Adviser, the Pakistan Council for Research in Water-Resources (PCRWR); the Center of Excellence in Water-Resources at Lahore; Irrigation Research institute, Lahore; and the Pakistan Atomic Energy Commission (at PINSTECH), Islamabad. The Federal Ministry of Agriculture and the Federal Ministry of Planning & Development are also closely associated with the Water-Resources Development & Management issues. These organizations can contribute in determining the direction of the program, the priorities, the grouping of the subjects, and in laying down some broad guidelines for the water-resources development and management issues in Pakistan.

The participants also highlight the need to improve the existing statistics on subsurface water and glacial melts and to put in place a dependable drought-forecasting programme. The delegates also feel the need to build as many reservoirs as possible, along the major water-courses and rivers in Pakistan to tap flood-flows and conserve water for national needs. The continuity of the National Water-Quality Monitoring Programme, initiated by the Pakistan Council of Research in Water Resources (PCRWR), is to be ensured and the National Environmental Quality Standards (NEQS) should be effectively enforced. Specifically, the NEQS for drinking water should be formulated. The expert delegates strongly feel the need for introduction and use of nuclear techniques, in conjunction with classical non-nuclear techniques, for water-resources development research, water-use efficiency and water-quality evaluation.

The participants thank the COMSATS for organizing this first and highly successful meeting to bring forth problems of water-resources limitations in Pakistan and their solutions, and urge COMSATS to continue to hold water-related meetings, seminars, conferences and national / regional level training-workshops for educational and planning purposes and to create an awareness among people about the water-related issues. COMSATS is expected to constitute a high-level multi-disciplinary panel of top professionals in the water-sector, both at national level and at regional level, to help and resolve many complimentary concurrent activities in the water-sector development and management. COMSATS is also expected to take a lead in seeking perusal of recommendations and in setting the trend for implementation of suggested solutions to mitigate water-sector problems in Pakistan and in the South. COMSATS intends to hold similar water meetings on annual basis.

SUMMARY AND RECOMMENDATIONS

The COMSATS 1st Meeting on Water-Resources In the South: Present Scenario & Future Prospects

Water is likely to be one of the most critical resource issues of the developing countries. A balanced, continuous and sustainable approach is mandatory if the adverse impacts of increasing water-crises are to be avoided. There has been a long history of water-resources development and management in many countries of the South with conditions similar to Pakistan, in terms of supplies, demands, development/management strategies and socio-economic as well as socio-environmental conditions. Many international agencies are providing support in enhancement of water resources development in the South. Looking at the global water-resources, it appears that there is enough water; however, a careful study of the global water scenario reveals that 97% of this water is saline. Most of the fresh water on earth is in the form of glaciers and ice or very deep groundwater. Although, water in rivers and lakes is in substantial quantity, yet, due to rapid growth in population and slow pace of new water-resources development, the per capita water supply has decreased significantly in many of the COMSATS Member States in the South. Further, much of the fresh-water reserves in the South are being contaminated through unplanned disposal of untreated wastes into water-courses and on to ground, which is ultimately polluting the potable water reserves.

Water management and conservation are thus fast emerging as critical issues and need to be tackled through a collective and sustained effort by the affected countries. The recent drought spanning a few years period has led many governments in the South to address water-related problems rather more seriously and to formulate and reconsider the national water-policies. Pakistan is no exception. The surface water and groundwater reserves in Pakistan have been significantly depleted by the prevailing conditions of drought. This has seriously unbalanced the water supply and demand relationship in the country.

Over the past 50 years, Pakistan has seen a golden era of water-resources development. This includes successes like the Indus Basin Works, multipurpose storage dams, projects for control of water-logging and salinity, link canals, hydropower projects etc. The scientific community in Pakistan have gathered vast experience related to all facets of water-resources harnessing and development. Nevertheless, the 21st century has brought its own challenges in the water sector. This necessitates that all past programmes related to water-resources development must be critically examined so as to bring the shortfalls to the surface, in order to reshape the strategies and options for optimum development and utilization of our precious resources of water.

Pakistan has finite resource of water which is thus exhaustible. Development of additional potential will improve water-availability, but only in the short run, if additional storage facilities are developed or adequate conservation measures are taken. Major future challenge is to attain food self-sufficiency on an environmentally sustainable basis. However, without requisite water-supply, food and fiber deficits would be irrecoverable.

PURPOSE OF THE MEETING & ARRANGEMENTS

Realizing these facts, the Commission on Science and Technology for Sustainable Development in the South (COMSATS) organized a two-day (November1-2) meeting on “Water-Resources in the South: Present Scenario and Future Prospects” at its Headquarters in Islamabad. The main objectives of the meeting were three fold: firstly to evaluate the past developments of water resources in the country, in terms of success stories, achievements, failures and overlooks, secondly, to prepare the water-resources professionals to meet the challenges of the 21st century, and thirdly, to provide a platform and unique opportunity to water-resources engineers and scientists for closer working collaboration between their respective departments for water-resources research, water-resources development, planning and management, in the interest of the country and the region.

The first announcement and call for papers were prepared and circulated to the concerned national organizations, individuals and environmental NGOs in September, 2001. In addition, certain individuals were identified as experts in their fields and were requested to present lectures of national importance, related to water-crises & water-resources development, climate change, drought preparedness, isotope hydrology, agriculture and wastewater-related technology options in the South. The response was very encouraging and quite thrilling. Abstracts received were reviewed and the authors were then informed to compile papers according to a specific format. It was decided to publish the papers in the form of a compact proceedings. There was no registration fee for participation in the meeting. A token payment equivalent to US 100/- dollars was made to each speaker, upon submission of the manuscript, in order to encourage them for their participation and consideration.

The meeting was attended on both days by eminent scientists, dignitaries, members of the diplomatic community and government officials. The meeting highlighted the critical issues, in relation to the condition of water-resources in the COMSATS countries.

INAUGURATION

Dr. Ishfaq Ahmad, Special Advisor to the Chief Executive of Pakistan, inaugurated the meeting. In his inaugural address, Dr. Ishfaq Ahmad explained that global climatic changes, expanding population, rapid industrialization, pollution, are all contributing to the current stress on water resources. It is important that modern scientific tools be used, particularly the nuclear or isotope techniques in hydrology, in national projects and programmes for development of water-resources, water conservation, water pollution and water-management efforts.

The meeting was specially attended by the High Commissioner of Sri Lanka, General Weerasooriya, and the Ambassador of China Mr. Lu Shu Lin. In their keynote addresses, both dignitaries underlined the need for further strengthening the collaboration among the countries of the South and creation of mass awareness about the critical water-issues. They were appreciative of the initiative that COMSATS has taken and pledged full support for further COMSATS' mission in bringing about sustainable socio-economic development in the South.

Dr. Hameed Ahmed Khan, Executive Director COMSATS, while outlining the objectives of the meeting elaborated that COMSATS realized the criticality of water-issues in the South and, therefore, decided to hold a meeting on these, so that countries of the South can collaborate and come up with strategies to mitigate the effects of the problem.

The inauguration was followed by five technical sessions spanning two days. Well known water-experts, isotope hydrologists, climatologists, water-resources engineers, irrigation experts, water planners and environmentalists, dwelt upon the management and better utilization of water-resources to meet future challenges in the South.

PARTICIPATION

A total of 94 participants took part in the deliberations of the meeting, including 52 executives from 10 different organizations belonging to various government/semi-government departments, research establishments, universities and environmental NGOs dealing with water resources development, water management, and planning. The key organizations included the following:

- *Federal and Provincial Secretariats (GoP)*
- *Pakistan Council of Research in Water Resources (PCRWR)*
- *Irrigation and Water Department (GoP)*
- *Irrigation & Power Department (GoP)*
- *Indus River System Authority (IRSA)*
- *Federal Flood Commission (GoP)*
- *Department of Meteorology (GoP)*
- *National Agricultural Research Council (NARC)*
- *Agriculture Prices Commission (APC)*
- *National Physical Standards Laboratory (NPSL)*
- *Pakistan Atomic Energy Commission (PAEC)*
- *Pakistan Institute of Development Economics (PIDE)*
- *Sustainable Development Policy Institute (SDPI)*
- *Universities and Academic Institutes*
- *Non-Governmental Organizations (NGOs)*

TECHNICAL SESSIONS

In four (4) technical sessions of this meeting, 22 lectures were delivered on the current situation of water-availability, demand, supply, development and management in arid and semi-arid regions in the South, and with special reference to Pakistan. The scientific and technical level of all presentations was very high. These presentations covered the following key areas of concern:

- *Water-Resources Development and Management*
- *Drought Preparedness and Mitigation Management*
- *Climate-Change and Flood Control*
- *Isotope Hydrology*
- *Groundwater Pollution*
- *Marine Pollution*
- *Agriculture*
- *Water-related Technology Options and Development*

The delegates to the conference stressed the need to devise and implement the "National Water Policy". The delegates also called attention to the importance of research on water-resources and water-related issues in Pakistan. In view of the contents of various presentations and thought-provoking discussions during the meeting, the expert delegates to the meeting carefully addressed and discussed the sector-wise water-related issues / challenges faced by Pakistan. The interaction of participants was mutually beneficial and the discussions over tea-breaks were very thought provoking. The exchange of ideas generated a lot of interest among participants to know more about the water-scenarios in the South. The participants came up with proposals and solutions as to how water-resources can be best managed and utilized most efficiently. Based on these discussions and suggestions received by participants at individual level, the panel of COMSATS experts formulated a series of recommendations for future directions. These recommendations have been presented in the end of this chapter of this proceedings, for consideration by the Federal and Provincial Governments, water-related bodies, environmental NGOs and the EPAs, as well as the common citizens of Pakistan. The basic objectives of COMSATS 1st meeting on water-resources were thus adequately met.

CONCLUDING SESSION

The concluding session of the meeting was chaired by the Federal Secretary, Water and Power, Mirza Hamid Hasan. Dr. Hameed Ahmad Khan, while summing up the two-day proceedings put forward some recommendations for the consideration of the member countries and their governments. He said the governments of the region need to make policies for conservation of water-resources and should also put in place a system that forecasts droughts, assesses damages and provides relief to the affectees. He also emphasized that better understanding of global climatic changes and development of techniques to predict its effects is the need of the hour. He opined that appropriate technologies be introduced for treatment of industrial and domestic waste and for the purification of sea-water for drinking purposes. Dr. Khan, while concluding his speech, expressed gratitude to the participants for making this COMSATS initiative a success.

In his closing address, the chief guest, Mirza Hamid Hasan, Federal Secretary, Water and Power, lauded COMSATS for taking up a very important issue as the theme of the meeting and said that the government of Pakistan would extend every possible help to support this COMSATS initiative towards conserving water-resources. He emphasized that water-related issues should be tackled through collaboration of the international community, since these issues have assumed regional and global proportions. The closing session of the meeting was also addressed by the Charge d' Affaires of Syrian Arab Republic, Mr. Badi Khattab and the Deputy High Commissioner of Nigeria, Mr. T.Y. Opatola. Both dignitaries were appreciative of COMSATS; efforts to highlight problems in relation to water and called for more sustained initiatives to find solutions for these problems. The meeting ended with a vote of thanks to COMSATS for providing such a wonderful forum.

RECOMMENDATIONS

The delegates to the conference called attention to the importance of research on water-resources and water-related issues in Pakistan. In view of the contents of various presentations and thought-provoking discussions during the meeting, the expert delegates to the meeting carefully addressed and discussed the sector-wise water-related issues and challenges faced by Pakistan. Based on these discussions, and suggestions received by participants at individual level, the panel of COMSATS experts formulated the following recommendations for future directions:

DEVELOPMENT AND MANAGEMENT OF WATER-RESOURCES

- Pakistan's "National Water Development and Management Policy" should be issued at the earliest possible moment.

- Short term, intermediate term and long-term measures must be carefully sorted out and adopted to manage sustainable water-supplies for drinking purposes, as well as for agricultural purposes, to boost the agrarian economy of South Asian countries, specially Pakistan.
- Long-term strategies are costly, but can be optimized from economic viewpoint. The long-term strategies, including formulation of a regulatory framework on groundwater-abstraction, construction of large storage dams, better forecasting mechanisms for flood and drought, and resolving water-distribution problems between regions and provinces, should be given top priority to solve the water-availability and water-quality problems. Efforts should be made not to politicize projects of such national importance.
- **COMSATS** must stress the constitution of a High-Level Multi-disciplinary Group of top professionals, in the country, to help in and resolve many complimentary, concurrent activities in the watersector development and management.
- Planning, development and management of water-resources is an exclusive subject with the Federal Ministry of Water and Power, the Chief Engineering Adviser, the Pakistan Council for Research in Water Resources (PCRWR), the Center of Excellence in Water Resources at Lahore, and the Pakistan Atomic Energy Commission, Islamabad (at PINSTECH). The Federal Ministry of Agriculture and the Federal Ministry of Planning & Development are also closely associated with the issues of Water-Resources Development & Management. These organizations can contribute in determining the direction of the program, the priorities, the grouping of the subjects, and laying down broad guidelines for the water-resources development and management.
- Management/development efforts have to be seen (i) in the light of the benefits to ‘haves’ Vs “have nots”, and (ii) for giving a balance in the regional development, especially for the backward areas.
- The financial/economic aspects, like public/private expenditure, pumped groundwater vs. flow river supplies, small dams vs. large dams, burden on the farmers, traditional water-rights and the paying capacity of the users, need in-depth considerations for their complimentary planning.
- Existing statistics on subsurface water and glacial melts in South Asian countries are inadequate or faulty and, so, there is an urgent need to improve these statistics for future planning of water resources in the South.
- Shortage of water is not a major problem at the moment, but the mismanagement of water-resources is a problem of key concern.
- The storage quantum to year 2000 needs correction.
- Participatory management of water-resources, compatible with local socio-political environment must be supported.
- There is a need for sustainable and efficient management of water-projects, with emphasis on effective monitoring and evaluation systems & strategies.
- Government must pay due attention to increasing the developmental activities in the water-sector and to improve upon the deteriorating health of irrigation infrastructure.
- Farmers should be educated to better handle water-losses.
- The water-distribution systems must be geared to match water-requirements of the community and the farmers.
- Rising trends in some canal commands need to be checked.
- "Abiana" (water rates) for irrigation purposes must not be increased at all, as this will result in adverse effects on agricultural outputs since most of the farmers can not pay because they are living below the poverty line.
- Technical services and spare parts be made available to farmers, in order to sustain the use and maintenance of new technologies.
- Agricultural research is required inorder to improve water-stress resistant crop-varieties.
- Cultural practices of “Pancho” irrigation-system must be replaced by more efficient irrigation practices.
- There is a need for construction of additional storage. Pakistan has not been able to construct and add even a single reservoir into the national pool of water-reserves after Mangal Dam and Tarbela Dam. Adequately large and small storage reservoirs should be built, inorder to meet the future water-needs. Silt-control to enhance reservoir-life and water-holding capacity, should be made the essential part of dam construction. Nuclear techniques should be used to study the

mechanisms of sediment transport and deposition in large reservoirs.

- The Community, in general, and farmer associations, in particular, must be involved in watershed management programmes and water-resources development and management schemes, such as small storage dams, rain-water harvesting, especially in desert areas like Thar and Cholistan desert; and water conservation programs, such as optimization of the canal-water regulatory and distribution system for irrigation water supply.
- The mechanized, and capital, as well as energy intensive, water-saving options like drip-irrigation, trickle-irrigation need consideration for their merits and limitations, and specific applications.

DROUGHT PREPAREDNESS AND MITIGATION MANAGEMENT

- The countries in South Asia must put in place a system that forecasts droughts, assesses damages and provides relief & assistance to minimize the hardships of life.
- Short-term, intermediate term and long term measures must be adopted to mitigate the effects of drought and to manage sustainable water-supplies for drinking and agricultural purposes, in order to improve the socioeconomic status of inhabitants in arid regions in South Asia, such as the Thar desert in Pakistan.
- Among the drought-affected areas in Pakistan, the Thar desert is the most important and biggest zone vulnerable to drought. The groundwater-exploration done by different organizations in the Thar desert during the past 50 years, using geophysical and hydrological tools as well as satellite tools, should be integrated to develop a database on groundwater resources of this arid zone.
- Special research funding and grants must be provided to encourage and undertake detailed hydrological investigations in the drought-vulnerable zones, under M.Phil & Ph.D projects by university graduates.
- Future groundwater development in the arid zones should be monitored, considering the subsurface hydrogeological models. Moreover, rainwater-harvesting should be encouraged, based on research studies closely supervised by experts in universities and government institutions dealing with water-resources research, development and planning.
- For drought-stricken areas, the following mitigation and management measures have been recommended as inevitable for drought control and mitigation:

a. A dependable drought-forecasting programme must be initiated.
b. The areas vulnerable to drought must be precisely identified and the causes of drought be kept in view, before chalking out any strategy for drought-mitigation.
c. The environmental, social and economic implications of the drought events in an area be compiled, in terms of an impact assessment.
d. The early-warning system (of the order of a season or so) be improved and strengthened. In Pakistan, the responsibility for this task should be given to Pakistan Meteorological Department (PMD).
e. Use of modern and appropriate techniques, such as nuclear/ isotope techniques, should be encouraged to evaluate the history of drought in the area.
f. Adequate strategies for drought-mitigation, in terms of description of practical step-by-step processes, should be developed for identification of mitigation actions that can reduce potential drought-related impacts before the occurrence of drought event
g. The planned operations in drought-affected zones must be closely and continuously monitored.
h. Water-management should be optimized at macro and micro levels.
i. Efficient extension-services should be facilitated to farmers, in terms of selection of suitable crops, improved availability of fertilizers, better seeds, timely dissemination of information regarding canal operations, etc.
j. Post-disaster needs must be strictly kept in view and implemented.

CLIMATE-CHANGE AND FLOOD CONTROL

- There is a vital need for adequate understanding of the recent and past climatic history of snow and glacial melt in Northern Pakistan, for estimation of present and future risks of flooding at sites traversed by the Indus River. Isotope hydrological and isotope palaeoclimatic techniques should be applied for this purpose, in conjunction with classical techniques in climate science.

- There is a need to build as many reservoirs as possible along the major water courses and rivers in Pakistan, to tap flood-flows and conserve water for national needs.
- The inadequate investments in the drainage-system must be checked and rectified for future strategies.

WATER QUALITY

- The continuity of the National Water-Quality Monitoring Programme initiated by the Pakistan Council of Research in Water Resources (PCRWR) should be ensured.
- The National Environmental Quality Standards for discharge of industrial effluents and stack-emissions should be effectively enforced.
- The National Environmental Quality Standards for drinking-water should be formulated.
- There should be water-quality monitoring check-points at the confluence of polluted streams with major water-courses (rivers) and marine natural outfall zones along the coast of Pakistan.

TECHNOLOGY OPTIONS AND DEVELOPMENT

- There is a strong need for introduction and development of appropriate new technologies for water-resources research, water-use efficiency and water conservation.
- Economic treatment of industrial & domestic wastewater by conventional technology and, in some cases by commercial-scale radiation-technology, should be carried out to a level that it can be safely used for agricultural purposes as well as for domestic and municipal purposes, such as for gardening, washing of roads, cars etc. The use of nuclear desalination plants for purification of seawater for domestic use (drinking and washing purposes) and for generation of electricity may also be considered.
- Biotechnological development must be made for saline agriculture, in order to enable normal cropping operations in saline / sodic soils and in large tracts of the Indus basin and the coastal belt, where saline groundwater is available for irrigation purposes. Presently, the cost of agriculture-related bio-active products is reduced by 40 % but it is still high for routine adoption by the farmers. COMSATS must help in commercializing this new approach.
- Modern techniques, such as isotope techniques/nuclear techniques, must be used in conjunction with space technology (remote-sensing technology) and Geographic Information System (GIS) to explore and estimate water-reserves, as well as groundwater recharge mechanisms and interconnection of shallow and deep groundwater reserves etc.
- The Community must think of reviving long –forgotten old technologies for water-conservation and natural purification, such as use of pitchers.
- The laser-leveling equipment is very useful to ensure precision land-leveling. The apparatus has been indigenously fabricated by PAEC at PINSTECH, Islamabad (Pakistan), at costs 40% less than the similar imported devices. Local and regional farmers must opt for this technology to conserve water in the irrigation fields. The Government and the NGOs must take practical steps to commercialize the manufacturing, marketing, supply and access of this technology to the farmers for better results.
- The wastage of water from domestic and household activities is quite significant in the region, specially in Pakistan. Appropriate technology options may be used to conserve water. This may include technological options, for example, use of time-controlled water taps (water taps with spring-lever system), improved design of W.Cs to conserve water; and imparting education to the community for awareness of the increasing shortage of our national water-reserves and the need to conserve water for the present generation as well as for future needs.

ROLE OF COMSATS IN MANAGEMENT AND DEVELOPMENT of NATIONAL WATER-RESOURCES

The delegates of the 1st Meeting on Water-Resources appreciated the pioneering efforts of COMSATS in holding the meeting with great success in a field that is new to them. The delegates emphasized that COMSATS should take the lead in seeking dissemination of the meeting's recommendations and in setting the trend for implementation of suggested solutions to mitigate water-sector problems. The participants urged COMSATS to play an active role in targeting the following needs for water-resources development & management and water-conservation in Pakistan and in COMSATS member states:

Need for Regular Meetings and Training Workshops on Water Resources

In view of capital-intensive aspects of Water-Resource Development and the tight financial resources of the developing countries, it is imperative that great emphasis be laid on water-conservancy. The first and foremost step in this direction would be to create an awareness in the people about this issue, whereby every single man has to know how he can reduce wastage and improve conservation. This can be done through a mass orientation and training programme through all types of media, as well as practical demonstration training. By conservation in every sector of water-usage i.e. domestic, urban, industrial, agricultural and environmental improvement, Pakistan can achieve present self-sufficiency to a great extent. COMSATS must continuously hold water-related meetings, seminars, conferences and national/regional-level training workshops for the purpose of education and planning. COMSATS should also arrange similar training and orientation programmes in other member States, by mutual arrangement.

Setting up a COMSATS Experts Advisory Cell at National Level

Experience and past observations reflect that, in Pakistan (as also in other countries in the South), reliance is generally placed on advice of foreign experts in handling medium and large-scale projects. These experts generally lack local knowledge of ground-conditions, environment, demands and available capabilities and, thus, give their “unbaked” opinions, which are accepted by most funding agencies. Moreover their advice is generally subjective, i.e., their own interest. Sometimes, even the local consultants, either because of not having the related expertise, or just under local political pressures fail to be objective. It is, therefore, important to recommend that an experts-cell should be created at COMSATS, by picking experienced and qualified experts from the national water-sector.

Setting Up a COMSATS Regional Level Experts Advisory Cell

From regional view-point, it imperative that COMSATS countries set up a central pool of experts, picked from each member state, and having authority and experience in different disciplines of water-resource development and management. Their sole responsibility would be to scrutinize and check various Projects proposed in the COMSAT countries and give their expert and unbiased opinion about the viability and economics/need of each project, without being handicapped or tied to any local political or regional compulsions or the Donor-country pressure to achieve the following objectives:

I. Optimization of technical/ financial parameters for schemes in various sectors of water-resources management, to suit each country’s demands and financial resource. This would also be helpful exercise for different regions within the same country.
II. Giving a implementation priority of all medium and major schemes in various countries compatible with their overall objectives.
III. Maximum utilization of local expertise or expertise from other COMSAT countries and local men and material deployment.

MANAGEMENT OF WATER-RESOURCES IN SOUTH ASIA

*Muhammad Hanif**

SUMMARY

The South Asian Region consists of Pakistan, India, Nepal, Bhutan, Bangladesh, Sri Lanka and Maldives. The region has high altitude mountain terrain, sub–mountaineous 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 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 monsoon and during snowmelts (July- September) and the flows largely recede in 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 a 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 purpose. The total water withdrawals from surface and subsurface are estimated at 772 MAF. About 90 % of the water supplies in the region are used for agriculture and remaining for households, industry and other purposes. Canals irrigation is mostly in public sector and wells/tubewells are generally in 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 14% area. Other important crops grown in the region are coarse grains grown on area of 12.1%, pulses 10.5%, cotton 4.5%, oilseeds 4.5%, beans 3.8% and sugarcane 2.0%. The plantations as tea, coconut and rubber, although having high commercial value, are grown on considerably smaller area.

About 40 % cropped area in this region is irrigated and 60 % is dependent upon rains. Water requirements for the 8 important crop (grown on 74 % area) have been worked 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 almost the only irrigated crop. Wheat is the second largest crop grown, both under rainfed and irrigated conditions. Water requirements have been estimated at wheat 10%, coarse grains 7%, pulses 6 % and sugarcane 6 %. The water requirement for these five crops makes 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 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 although useful, there are growing concerns on building reservoirs in the countries of the region. These concerns are both national and international in character.

* Agricultural Development Commissioner, Ministry of Food, Agriculture and Livestock, Islamabad, Pakistan.

There is a growing feeling that the reservoirs result in displacement of people/farming communities, create environmental problems and on 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 net work of water structures 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, 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 indents. All these works need to be furthered. Some of countries of the region need to have a second look on their heavy dependence on mono-crop system of growing rice a water-thirsty crop.

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 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

Figure - 1: Map of South Asia

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 a large O & M cost 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.

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 Gigantic civilizations thrived and prospered in this region.

Agriculture has been the main pursuit in the region since the 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 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.

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

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% in agricultural discipline. However, Asian involvement in agriculture is 53% and South

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
SriLanka	6,463	1,888	651	0.1
Source: FAO Production Year Book, 1999.				

Asia 56%; Bhutan and Nepal have more than 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 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.

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.

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
Total	**37.19**	**60.04**	**32.30**	**12.00**	**5.42**	**28.03**	**11.90**	**10.22**	**197.10**

Table - 1.4: Water Requirements of Important Crops.

Crops	Area	Water Requirements	Total	% Share
Unit	*Million ha*	*Acre inches**	*MAF*	
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
Total	**197.1**	**29**	**1166.9**	**100**

** By Pakistan standard*

COUNTRY PROFILE

The ware 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 population of 834 inhabitants per km^{2}. 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.

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.

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 purposes. Maldives finds it extremely difficult to obtain suitable drinkable water. Three desalination plants are in operation, with a total production of 1000 m³/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.

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.

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:

- 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 reserviors 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-reserviors 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 reserviors are built, the rapid sedimentation is a big issue and calls for appropriate policy and action plans.

Groundwater

The groundwater involves aspects of quantum 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 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:

- 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.

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

Muhammad Akram Kahlown and Abdul Majeed*

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 paper takes stock of the present situation of water-resources, present needs and future requirements, 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 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 %. Since agriculture is the major user of water, therefore 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^3); below 1,000 m^3, countries begin experiencing chronic water stress (Population Action International, 1993). Table-1 gives the comparison of per-capita water-

*For Correspondence: Chairman, Pakistan Council of Research in Water Resources, No.3, St.17, F-6/2, Islamabad, Pakistan.

Table - 1: Per Capita Water-Availability in Selected Countries (m^3)

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

availability 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.

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 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

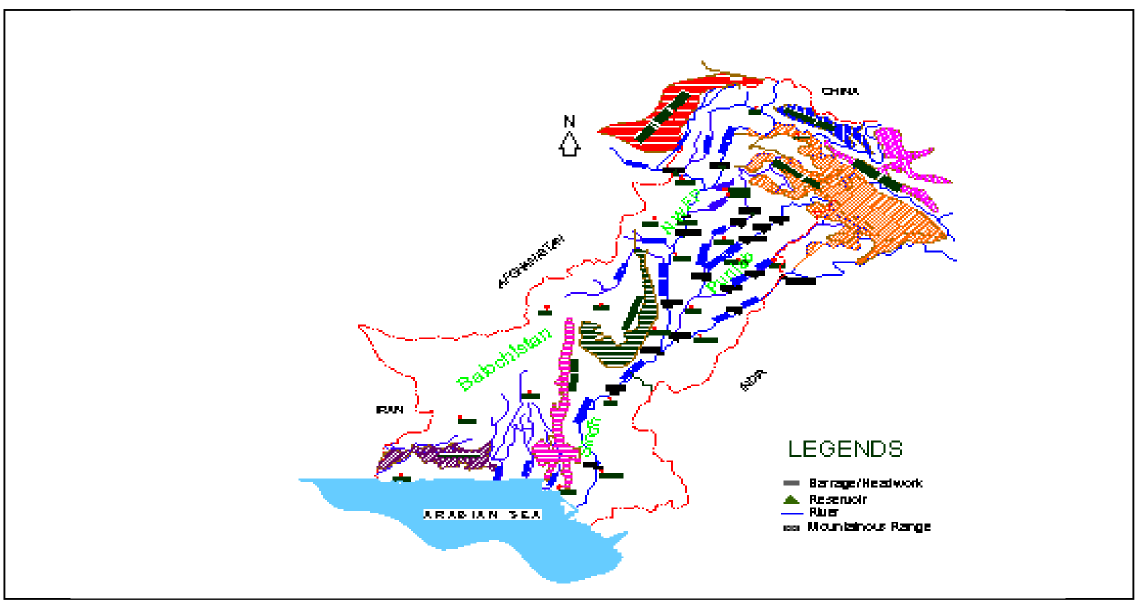


Figure - 1: Indus River System

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

	Kharif	Rabi	Total
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

Source: WAPDA and IRSA reports

about 138.7 MAF of water annually, see Table-2.

Table – 2(a)

Province	Water Development Potential (MAF)
Punjab	2.7
NWFP	7.3
Balochistan	7.86
Sindh	0.78

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

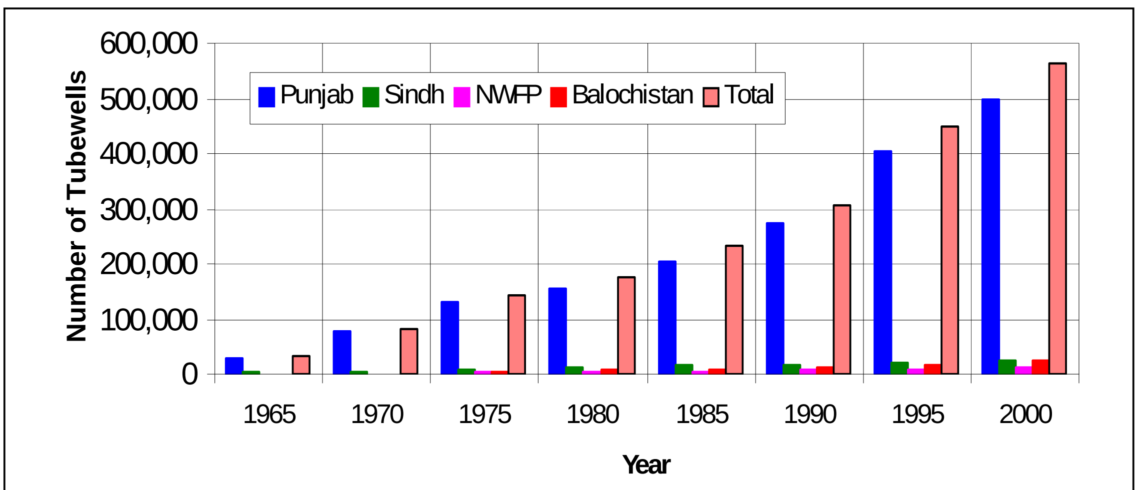


Figure- 2: Growth in Number of Tube wells

sites. Out of this, almost 60 per cent can be developed for crop production. This 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 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

Table - 3: Agricultural Water Demands (MAF)

Crops	1990	2000	2025
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
Total with Losses @70%	168.32	188.28	261.14

target, on the surface, may not look so demanding, as the country is bestowed with enough fertile 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^3 per annum. The corresponding industrial water-demand is considered negligible when compared with the domestic and agricultural demands.

Table - 4 : Water Demand for Domestic Use			
Year	**1990**	**2000**	**2025**
Population (Million)	110	140	260
Water Demand (MAF)	4.1	5.2	9.7

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^3 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 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

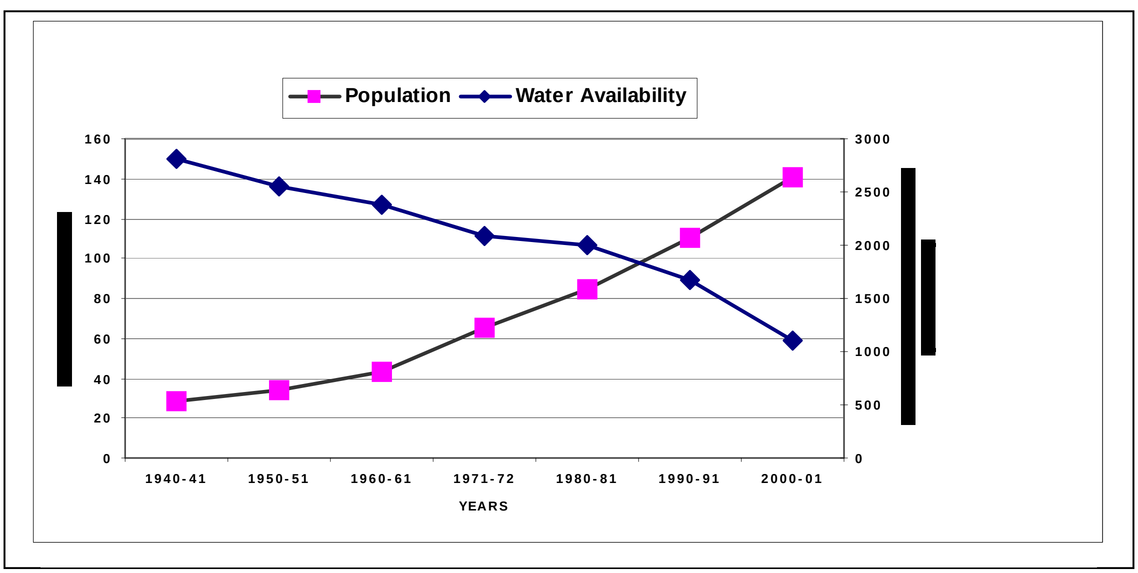
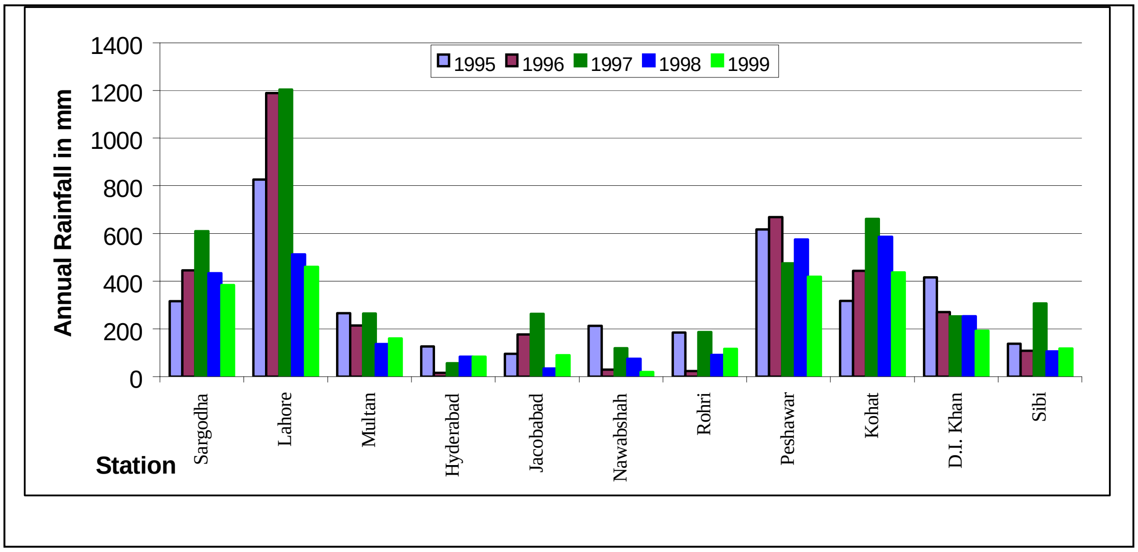


Figure - 3: Per-Capita Water-Availability

- Salt-water intrusion, due to up-welling from underlying saline aquifer
- Deteriorating performance of public tubewells, resulting in increased pumping costs

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



Source: *Pakistan Meteorological Department rainfall data*

Figure - 4. Rainfall over Irrigated Areas

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

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,

Table - 5: Reduction in Capacities of Major Reservoirs

Reservoir	Year Commissioned	Live Storage Capacity (MAF)			Decrease (%)	
		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
Total		**15.7**	**13.6**	**11.7**	**13**	**25**

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

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

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-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 groundwater-use, floods during the summer nd 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,

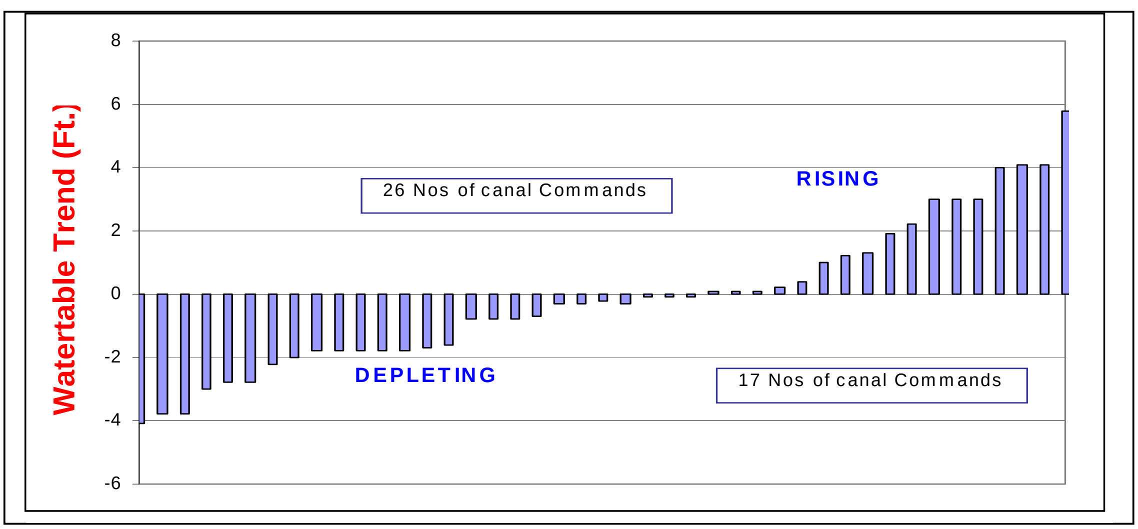


Figure-5. Water-Table Trends in Canal Commands

Table - 6: Area Under Various Water-Table Depths (% 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
Average	**13.50**	**37.40**	**49.10**

Source: SMO unpublished data

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), 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 through 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.

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)

Table - 8: Changes in Water-Quality in SCARP Areas				
		Percent Change in Water Quality		
Project	**Data Period**	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-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 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.

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.
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 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-Storages 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 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.

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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WATER-RESOURCE MANAGEMENT-STRATEGY

*Mian Hafizullah**

ABSTRACT

Water-resource pattern has been disrupted in Pakistan throughout the Indus Basin, affecting the Northern areas, Punjab and Sindh, all of which are reeling from the effects of the current drought. This, consequently, affects the country's agrarian economy and indeed the economy as a whole, since the economy is directly linked to the performance of agriculture.

The water shortages are likely to persist with the increase of population and consequent pressure on agriculture. It will be further aggravated by weather effects of elnino and lanino. This essentially calls for a proper water-management strategy. The strategy consists of short-term measures, medium-term measures and long-term measures, as below:

Short-Term Measures

1. *Ridge cultivation: Improving methods of irrigation from border to furrow. Most of the crops, including wheat, can be sown on ridges, which would save about 30% water.*

2. *Precise Land-Levelling: saves 30 to 40% of water with zero tillage, but levelling effects last for three crops only. The laser-levelling apparatus is being locally manufactured by PINSTECH at 40% cost of the imported gadget. Steps need to be taken in commercialising the manufacture and marketing of laser-levelling equipment, so that it is brought within the farmers' reach. It also improves yield-per-acre and results in better seedings and germination of crops.*

3. *Watercourse: Improve water-courses (not lining), to reduce wastages, and design rotation programmes of channels, in consultation with Agriculture Department, so that water is given to the priority areas within the Province.*

4. *Taking up, with community-participation, minor storage-schemes so as to harvest rain- water, especially in areas of Thar and Cholistan.*

5. *Timely delivery of good-quality inputs, like seed, fertiliser, pesticides, in the agricultural sector.*

6. *Improving marketing of agricultural produce.*

Medium-Term Measures

1. *Improving seed-technology, through agricultural research. Time-bound result-oriented programme of research should be undertaken, to improve seed, variety and the production. Pioneer maize-seeds and mexi-pak for wheat are the examples, in point.*

2. *Agricultural research to improve water-stress resisting varieties.*

3. *Canal Seepage**:** Indigenous research needs to be undertaken to stop the canal seepage especially in saline ground-water zone, right from the source and to re-use it.*

    a. *In Punjab Province, the re-charge to ground-water seepage is 40-42 maf, of which over 35 maf is being exploited - private tube-wells 32 maf, scarp tube-wells 3 maf.*

       In Sindh Province, the re-charge at present is about 21 maf, while pumpage by both private and scarp tube-wells is 3.5 maf.

    b. *By using proper technology, like multiple-bore tube-wells and radial tube-wells, etc, the additional potential of 12-13 maf can be exploited in Sindh and Punjab. This would be a much better alternative than stopping seepage through lining, which is very capital intensive.*

4. *Tube-well Technology needs to be standardized, in order to make it more popular in the farmers community.*

5. *Cultural practice of `Pancho' irrigation system needs to be replaced by more efficient rice-crop husbandry practices.*

* Chairman, Indus River System Authority (IRSA), Building R-3, Markaz G-7, Islamabad, Pakistan.

Long-Term Measures

Larger storages have longer gestation-period, but there is no substitute available against the large storage reservoirs. The schemes need to be prioritized, through national consensus, and then taken up under critical path, so that the effects of shortages of water can be mitigated.

Alternate Measures

Till the larger storages schemes materialize, smaller, off-farm storages could be considered, with participatory efforts of the beneficiary. These beneficiary or off-farm storages or village ponds can be excavated and maintained by beneficiaries themselves to an average depth of 4 ft. or more, wherever feasible. These could be filled during Kharif and Monsoon, with flood supplies. Even rain-water can be harvested if these ponds are suitably located. It has been estimated that about 1 lakh irrigation out-lets are there in Pakistan, covering an area of 33 million acre. On the average, 4 ft. depth of pond on an area of one acre would store 4 Acre feet of water and the grand total would come to 0.4 maf. The storages can be increased by increasing surface area of the ponds or their number, or their depth.

These ponds would be located more suitably in the base lines or unculturable wastes, so that these do not encroach upon the CCA. These ponds would be suitably lined with polythene membrance to save seepage. This alternate, although not a complete substitute of storage reservoirs, can be implemented immediately to store about 2.5 maf of water. These would be used in Rabi shortages.

1. EXISTING SITUATION

Pakistan is predominantly an agriculture country; 26% of the GDP, 70% export and 52% labour force is contributed by this sector. Inspite of favourable conditions of soils, irrigation, water and climate, the agriculture suffers from under-production, both in terms of yield per acre and production per farm worker. Yield per acre is one of the lowest in the world. It is marginally less than India and about 50% less than Egypt and other developed countries. Comparison of important crops, in terms of yield for various countries is given in **Table-1.**

Consequently the majority of farmers live at, or below, poverty line. The country is heavily dependent upon agriculture for food and fibre requirements for ever- increasing population. In order to cope with these requirements, it is essential to increase food and fibre production, not only for self-sufficiency but also to the extent of exportable surplus for earning foreign exchange. Pakistan is heavily under debt-burden; 50% of its annual production is taken away by debt-servicing and it cannot afford luxury of import of food, being itself an agricultural country.

About 90% of agricultural value-added comes from irrigated agriculture. Unfortunately, irrigation supplies have been inadequate for the last 2 years. On the average, 3ft water is provided per culturable acre for agriculture per year, according to our present diversion of water from the rivers. This is further reduced by about 48% during conveyance and so the nett delivered, below the out-let, is reduced to 1.6 ft per acre per year, which is quite inadequate for the arid and semi-arid climate of Pakistan.

Table-1: Comparison of Yields for Some Crops

	Wheat	**Rice Paddy**	**Sugar Cane**	**Cotton**	**Maize**
WORLD Average	*Kg/Hect*	*Kg/Hect*	*Kg/Hect*	*Kg/Hect*	*Kg/Hect*
	2700	3832	64694	1620	4309
China	1690	6017	-	2638	4916
USA	2441	6274	74010	1575	-
India	2510	2879	69197	903	1633
Pakistan	2018(75)	2753(72)	46963(72)	1803(+11)	1457(-34)
Iran	1687	-	-	1941	-
Mexico	3894	-	-	1600	2158
Egypt	-	8173	-	2775	-

This has to be supplemented by other sources i.e. tube-well, rain, etc. The quality of tube-well water has become questionable for many areas and has given rise to secondary salinization of soils. For proper maintenance of agricultural regime of soil, it has to be mixed with adequate quantity of canal water for use in irrigation. Rain-fall has failed for the second consecutive year and that is not a dependable source.

2. WATER-RESOURCE MANAGEMENT

Inadequate irrigation-supply is one of the major constraints in agricultural production; this essentially requires management of water-resources for optimum use and for maximising production. The irrigation supplies can be improved in two ways:

1. Exploiting new resources, i.e construction of more dams and tube-wells;

2. Conserving the existing irrigation supplies, by making a more efficient use of the available water, through reduction of undue wastage, such as seepage/leakage, overspilling and over-irrigation to crops, etc.

3. NEW RESOURCES

Dams

The former method of improving irrigation supplies is very expensive and time-consuming. It takes decades before such programme is found feasible and ready for execution. Recently, environmentalists have added a new dimension to planning of large Dams: replacement of affected Infrastructures and displacement of communities in Pakistan, is a problem in itself. Then there are apprehensions of co-basin Provinces about the fair distribution of water. Large water-development Projects have longer gestation period. Therefore, these schemes have no attraction for the private investors and have to be taken up by the Governments.

Tube-Wells

Tube-wells offer a potential, but the quality of Tube-well water has to be kept in mind. There are a number of private tube-wells in the Punjab and these are increasing at the rate of 8% per year. The quality of tube-well water has deteriorated, due to two consecutive drought years. Lowered water-table is uneconomical to pump, and further deterioration in quality is due to less re-charge and over mining. The actual operation time of private tube-wells is 6 to 8%, which makes the whole investment less economical.

Tube-wells in Sindh have a good potential, but a lot of home-work is required to tap the seepage of canal and rivers at source. Little research work has so far been done in this direction and the farmers are not ready to invest in such marginal production-schemes. At present, an estimated 50,000 tube-wells are working in Sindh Province.

In view of the above, the International Commission of the Irrigation and Drainage has stressed the needs of conservation of existing supplies on world- wide scale, as under:-

"Conservation of water-supplies is becoming increasingly important as the demand continues to increase and new sources of supply become harder to find. The time is rapidly approaching when the only additional natural water-supplies available will be those salvaged from loss through transpiration, evaporation, consumptive waste, inefficient storage and transportation practices. Principles of conservation require that full use be made of our natural water-supplies and greatest results probably can be accomplished on most irrigation projects by a reduction in amount of water lost through seepage during transportation to the farmers field".

4. CONSERVING EXISTING RESOURCES: CANAL & WATER-COURSE LINING

Lot of investment has been made at farm-gate level to check the wastage of water from the water-courses in the last two decades. More investment has been done on water-courses than on irrigation system. Tall claims of affecting water-savings equal to two Manglas could not be realised. About 38% of the total water-courses has been lined or improved.

The author conducted the study of the irrigated figures from the freshly lined water-courses and it was found that lining of water-course resulted in increase of irrigated area from 10 to 13% for about five years and, later, it would drop to the previous figures, due to deterioration and siltation of the water-course.

Next step can be to check seepage from earthen channels, which is estimated at 48% of the canal head discharges. International experts usually call this seepage as loss of water. This is not correct. In fresh ground-water area, seepage of canals, rivers and rains is a gift of Mother Nature, which has provided a water-reservoir below the feet of farmers, which can be exploited at the time of need. This seepage can be termed as “re-charge factor”. Re-use of seepage increases efficiency of our system from 35-45% to 60-70% which is highest in the world.

Of course lining of water courses and canals is recommended in saline ground-water areas, for which a lot of home work should be done to justify the heavy investment. Ponding test would be a pre-requisite for justification of lining. Another alternative can be to tap seepage, right from the source, by tube-wells or interceptor drains.

In order to optimise use of water we need to improve our irrigation practices. It is time we switch over from border to furrow irrigation, which would require 30% less water. Other irrigation practices, like sprinkler and trickle-irrigation method, affect savings of water but are much more capital-intensive and require use of energy for its operation and maintenance. Ever-increasing prices of fuel and electricity vitiate the economics of these methods of irrigation.

Less Efficiency of Input

Efficiency of fertilizer-use is only 30%, and also indiscriminate use of pesticides is poisoning our soils and sub-soil water, which calls for caution in their use. For maximising production, we need to develop seed-varieties. In late 50s, Mexi-Pak seed was imported, which doubled the production of wheat (more than 30 mands per acre) with the same farmers, same practices and same water. In Sahiwal area in Punjab, 'pioneer' maize seed has revolutionized maize production, which is now comparable to any international standard.

Timely and in adequate quantity, delivery of good-quality inputs, like seed fertilizers, pesticides, is an area which requires close monitoring.

If Nature favours us and we have a bumper crop, then its marketing is another grey area, which needs careful study in order to sustain agriculture in this country as a profitable business.

5. RECOMMENDED MEASURES

These have been given in the Short-term, Median-term and Long-term Measures in the Abstract.

EFFICIENT AND SUSTAINABLE IRRIGATION-MANAGEMENT IN PAKISTAN

*Illahi B. Shaikh**

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 rivers 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. 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.

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 Former Organizations, which are under way. This paper discusses, in detail, the irrigation-network in Pakistan and the efforts to establish Irrigation and Drainage Authorities, Former 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 rivers 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 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. It comprises 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^3 (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

* Engineering Adviser (Civil)/Secretary, Pakistan National Committee of ICID, 16-D Safdar Mansion, Blue Area, Islamabad, Pakistan.

(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^3) 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 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^3). The flow varies from year to year; the maximum was 186.79 MAF (230 BM^3) in 1959-60 and the minimum was 86 MAF (106 BM^3) 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^3). 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^3) in 1959 to about 50 MAF (62 BM^3) 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^3). 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^3) 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 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

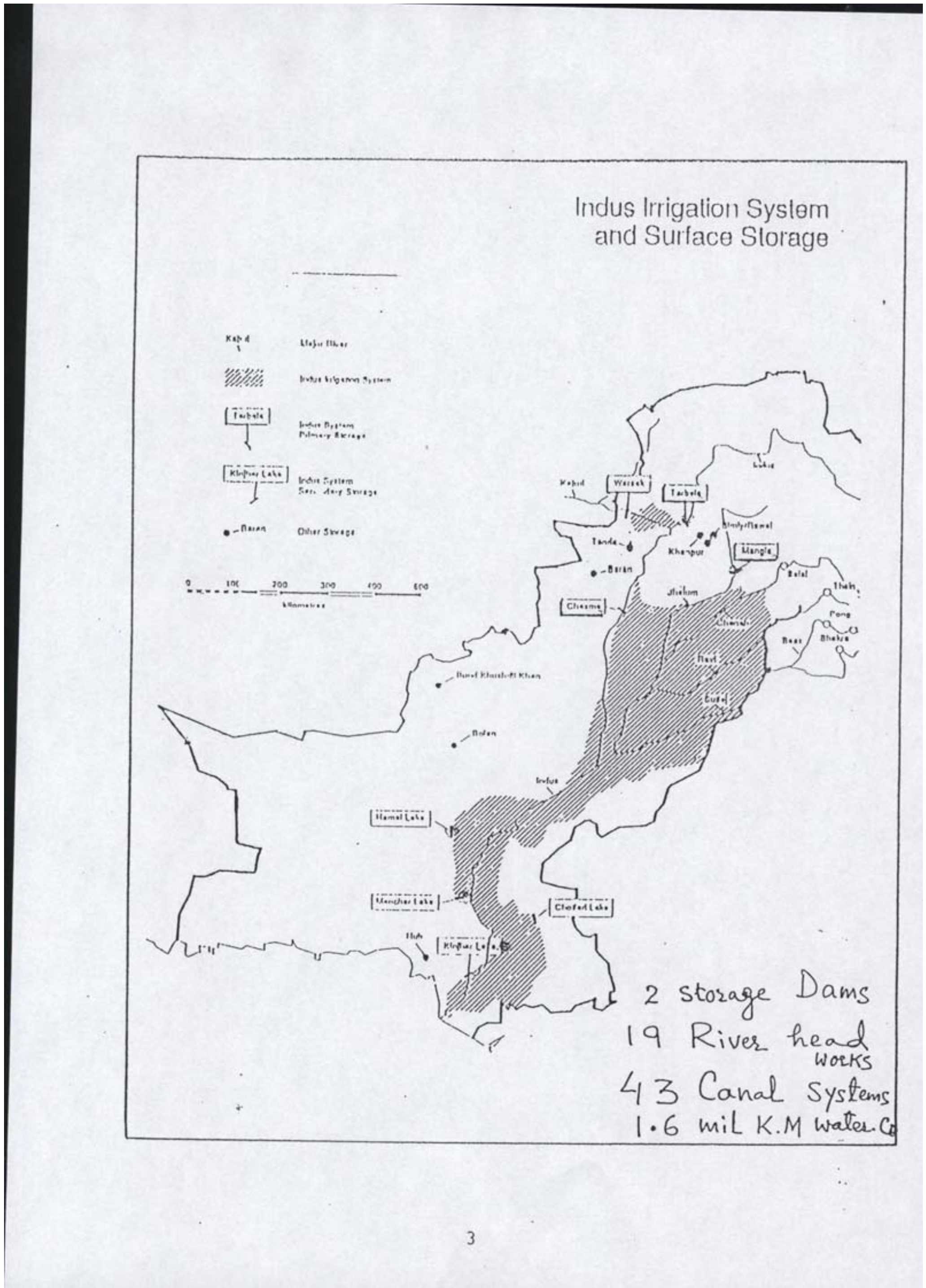

Figure - 1: Indus Irrigation-System and Surface-Storage

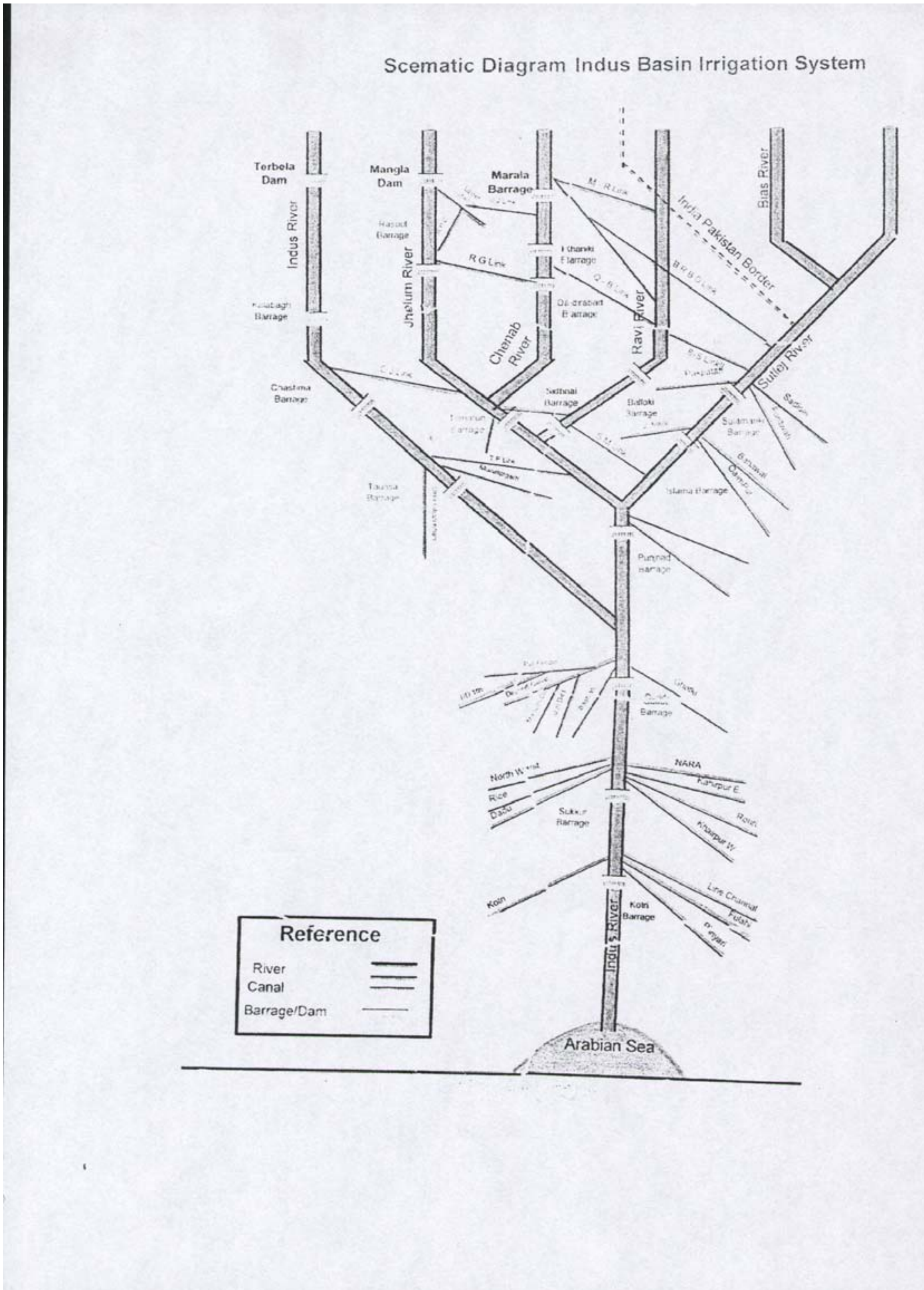

Figure - 2: Schematic Diagram Indus-Basin Irrigation-System

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;
- 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 Ortganizations (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.

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.

CONCLUSION

Owing to scarcity of water, proper management of water-resources is essential for the Agriculture Sector, which is the largest user of water 97%. 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**

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.

In this article, optimal utilization of water-resources at Mangla reservoir has been discussed, with possible options. 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 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 (MCL). 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 porition of the basin is in the form of snow. In April, May and June, the snowmelt gives to hgih sustained river flows at Mangla which normally reach their maximum in June. During the summer monsoon season, preicpitation is concentrated int eh southern and western portions fo the basin and featres intense rainstorms. It is these rainstorms, which usually gives rise to majro 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 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

* Director General, Pakistan Meteorological Department, Sector H-8/2, Islamabad, Pakistan.

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[1] and its UK Partners, in association with M/S Harza of USA, while second study was carried out alone by M/S Harza[2], in 1992.

DISCUSSION OF 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 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[1] and Partners and M/S Harza. Against this, the highest flood actually experienced at Mangla over a period of more then 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). 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[3] to the national exchequer so far.

CONCLUSION

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[4,5], 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**

ABSTRACT

Thar Desert forms the extreme southeastern part of Pakistan, covering about 50,000 km^2 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 sanddunes 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 the 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 desert extends towards Punjab Province and eastward across the Indo-Pakistan border, spreading over an area of about 200,000 km^2 (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 Thar ranges between 850,000 to 950,000 (Baanhn Beli, 90; SAZDA, 1988; Qadri, 1983). Stabilization of the sanddunes 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 living 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.

* Professor, Department of Geology, University of Karachi, Karachi, Pakistan.

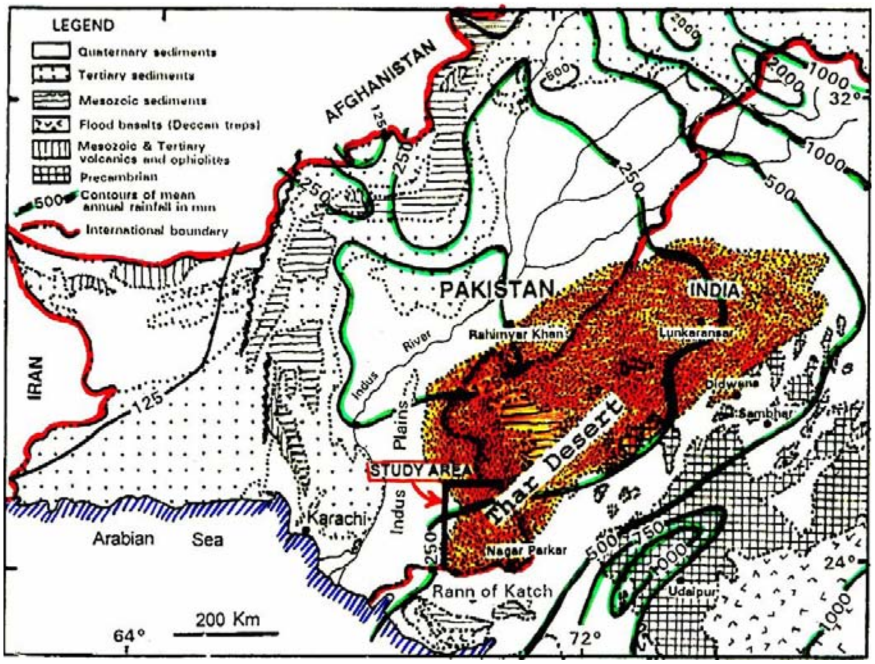


Figure 1: Index map of Pakistan showing location of study area, regional geology, contours of annual rainfall and eastward extent of the Thar Desert.

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 (Pennistum Typhoideum), Guar (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,

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

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

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 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

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

Rahimyar Khan. On the other hand, in the southeast, comparatively high annual rainfall, 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 to1929/1938 to1946 (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).

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

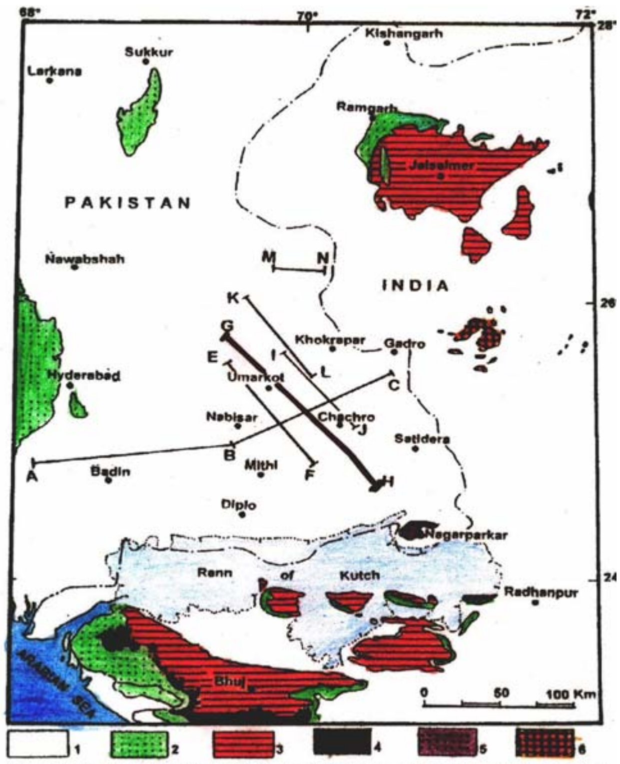


Figure - 5: Map shows general geology, locations of seismic profiles and geological cross-section. Geologic legend: 1) Quatemary sediments/Desert dune-sands, 2) Tertiary sequences, 3) Mesozoic-Jurassic sequences, 4) Lavs flows-Deccan traps, 5) Pre-Cambrian units, 6) Rhyolites-Malani beds

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-

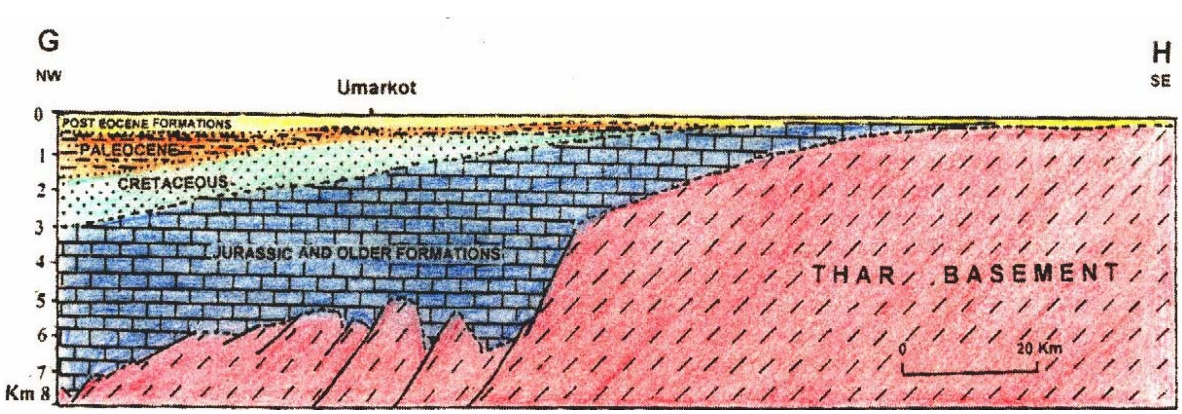


Figure 6: Geological cross-section of the Thar Rift interpreted from seismic data (after Zaigham and Ahmad, 1996).

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 Ωm, was interpreted to be a deep fissured sandstone aquifer, bearing fresh water, by Schildknecht & others (1991) under the WAPDA-BGR Groundwater Exploration Project. On the

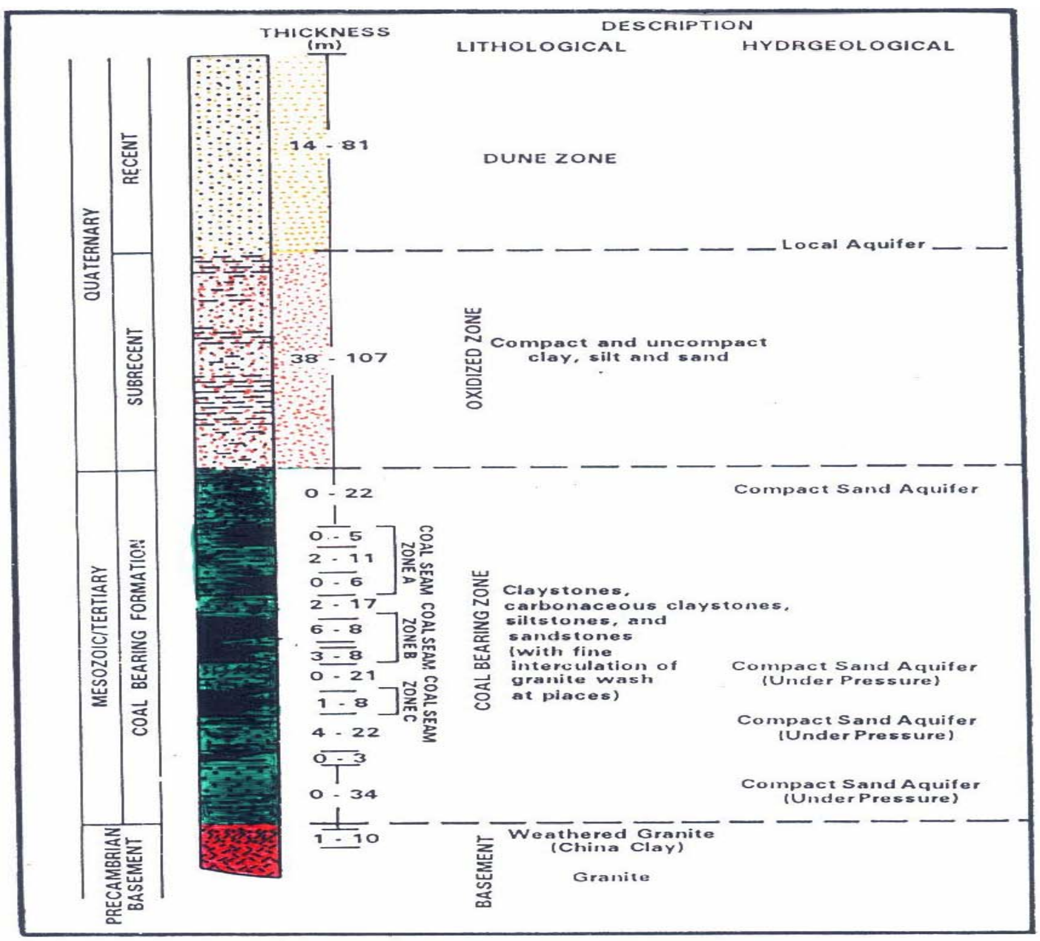


Figure 7: Generalized lithological column representing the stratigraphic units encountered in holes drilled for coal exploration and also showing hydrogeological conditions in the Thar Desert (modified after JTB, 1994).

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^2 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.
- The coal-bearing sedimentary sequence hosts a number of confined aquifers under artesian pressure, with significant yield and acceptable quality [range: 4000 - 5000 µS/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 µS/cm. The measurements of the field-conductivity indicated brackish quality of these aquifers.
- Results of pumping-test indicate nearly

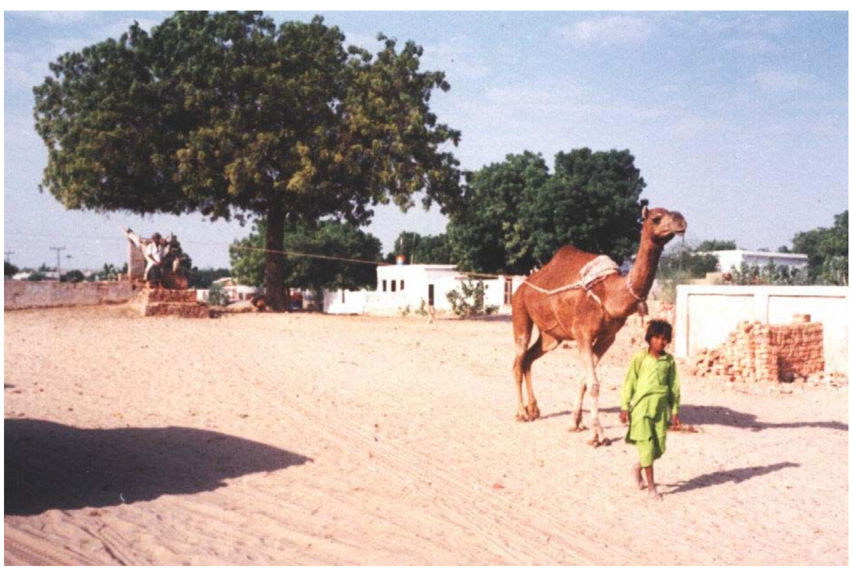


Figure 8: People of Thar Desert use camel-power to take out water from relatively deeper dug-wells.

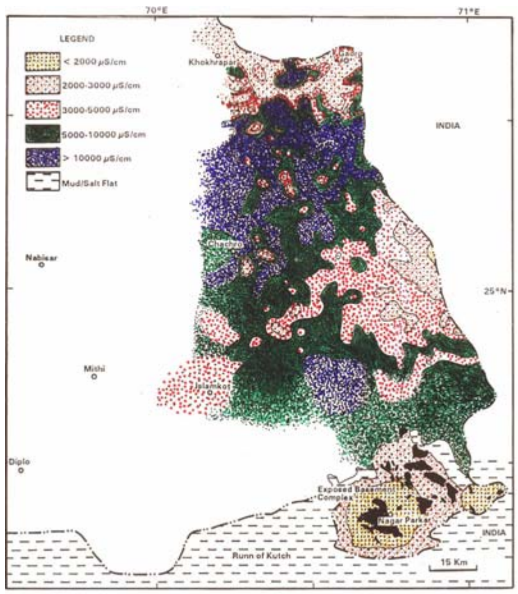


Figure 9: Distribution of electrical conductivity of groundwater in the Thar Desert. Source of data: JTB, 1994; Ploethner, 1992; GSP, 1962)

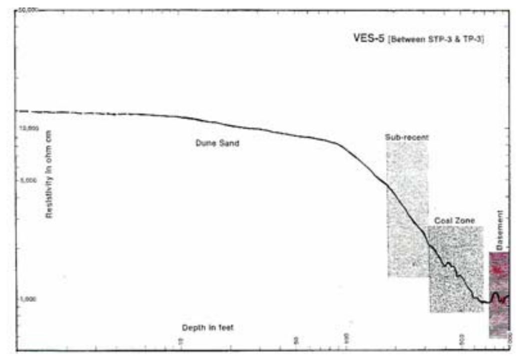


Figure 10: Deep vertical electric sounding shows layered basement indicating groundwater potential in basement units.

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 µS/cm to more than 10,000 µS/cm. Thus, under normal standard, such quality of water is unfit for human consumption, but the water with EC of 5,000 µS/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 µS/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 µS/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 µS/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 µS/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 µS/cm) indicate brackish to saline water- quality. In this area, deep sedimentary aquifers have not been explored in detail.

Occurrences of better groundwater (EC: < 2000 µs/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 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 smoothened 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.

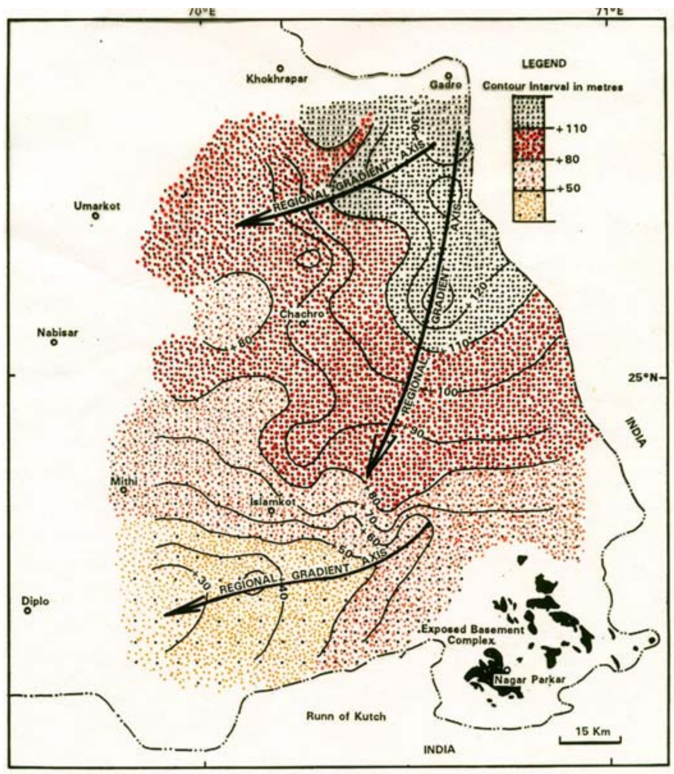


Figure 11: Map showing smoothened topography of the Thar Desert illustrating regional gradient trends which control over-all movements of water-recharge conditions

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 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.

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.

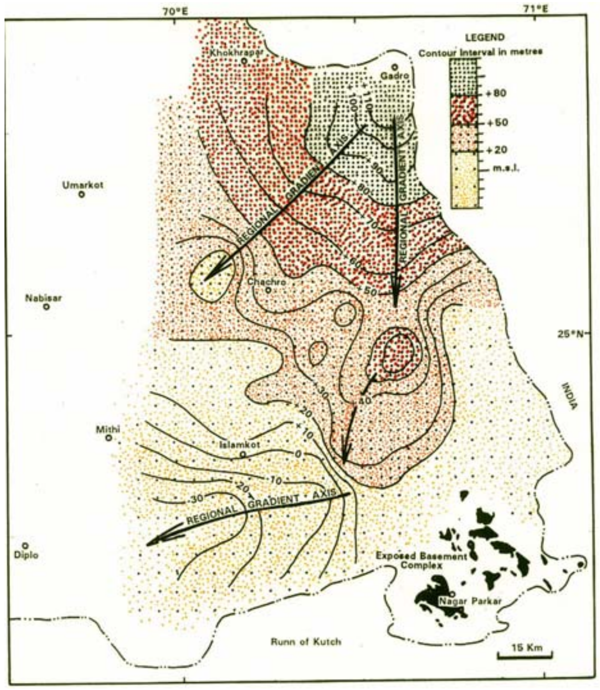


Figure 12: Subsurface configuration of top of the Oxidized Zone in Thar Desert. Arrows show major gradient trends.

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

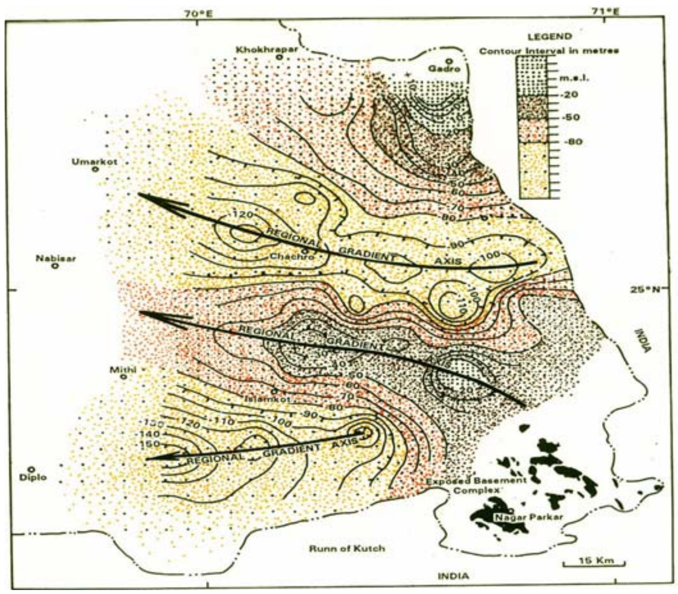


Figure 13: Subsurface configuration of top of coal-bearing formation beneath the Subrecent Oxidized Zone in the Thar Desert.

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.

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

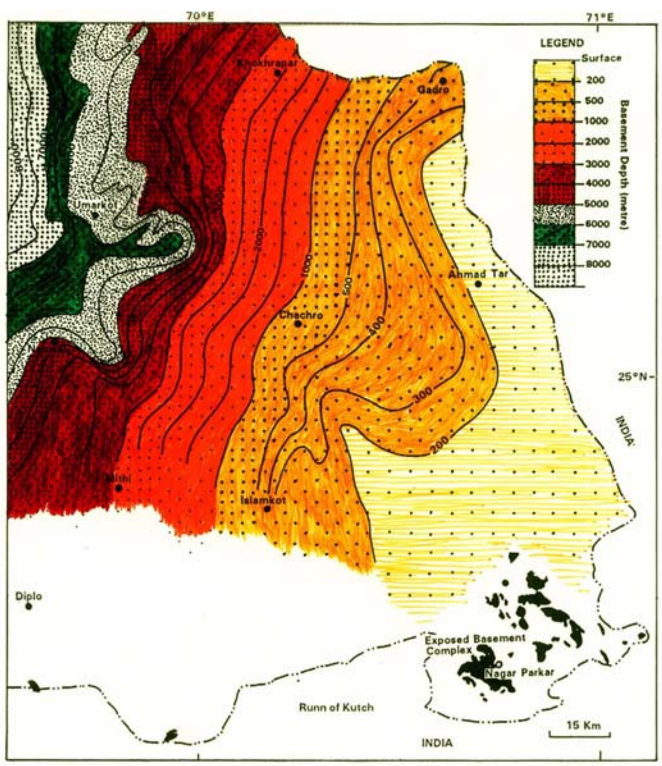


Figure 14: Thar Basement configuration analyzed from seismic, resistivity and drilling data.

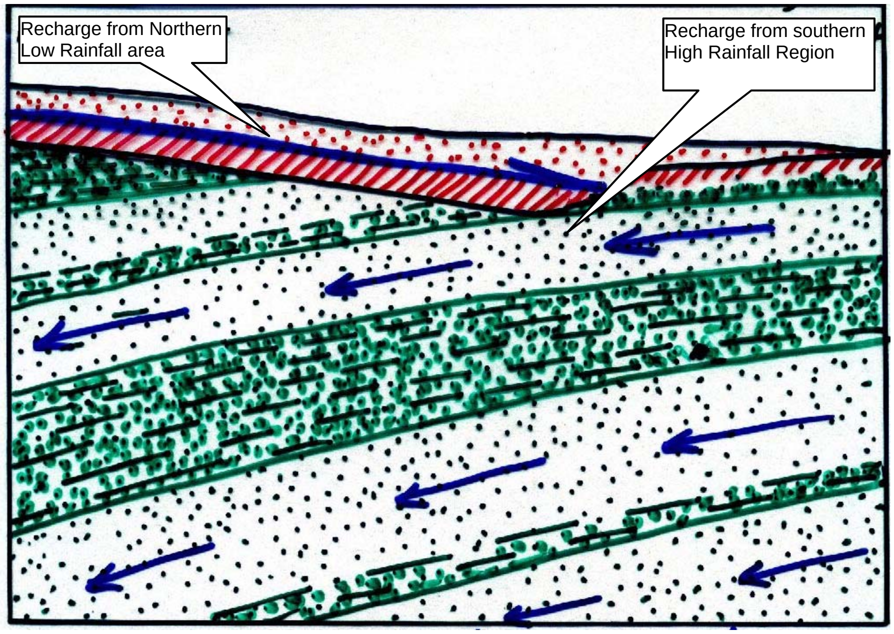


Figure 15: Schematic model shows the relationship between the regional gradients and the recharge conditions (groundwater flow) based on the rainfall conditions.

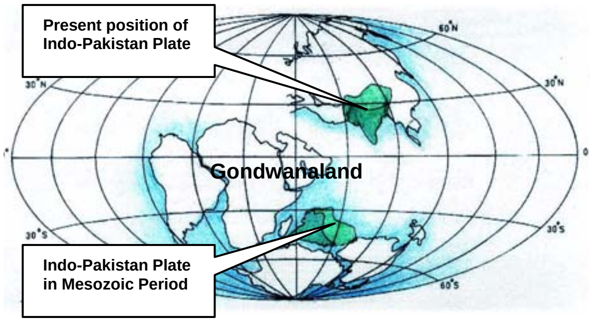
basement is deepening around Umarkot area continuously towards northwest, with an average gradient of 11.3%.

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, 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



Drifting of Indo-Pakistan

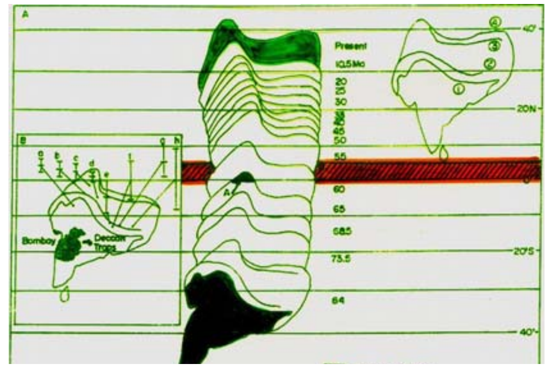


Figure 16: Left inset shows papaeo-Mesozoic position of Indo-Pakistan subcontinental plate comparing it with the present-day position. Inset on the right shows northward drifting of Indo-Pakistan plate from late-Mesozoic time to present-day.

(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, the 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 are 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 for groundwater-research activities can de-desertify the area, since Nature has already created conducive environments to stabilize dune sands, better siltification in valleys, and significantly encouraging rainfall conditions.

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FEASIBILITY OF AUGMENTING WATER-RESOURCES THROUGH SEEDING OF CLOUDS

Qamar-uz-Zaman Chaudhry & Anjum Bari*

ABSTRACT

During the recent drought conditions, which affected various parts of the country, Pakistan Meteorological Department (PMD) had initiated Cloud-Seeding Experiments from June 2000, to augment rainfall mainly over drought-hit areas of the country, In the first part of this paper. Science of Cloud Seeding has been discussed, which indicates that there are mainly two different methods of Cloud Seeding - Warm Cloud Seeding and Super-Cold Cloud Seeding. The physical basis for achieving the goal is very different from each method. For example, in warm cloud seeding, some hygroscopic seeding agents like common salt, Urea, etc. are used, whereas in the super cold cloud seeding, silver iodide or dry ice is used as seeding agent.

In the later part of the paper, equipments required for experiments have been discussed. Meteorologically equipped aircrafts, weather radars, satellite receiving equipment, synoptic weather charts and other weather-forecasting facilities are some of the main facilities required for the purpose. In the last part, results of 48 warm cloud experiments have been presented, out of which 30 were successful.

INTRODUCTION

Pakistan possesses diversified climatic conditions, ranging from hyper-arid to humid. Some areas receive meager amount of rainfall during the year, insufficient to sustain agriculture and to meet civic water-requirement. Frequent drought-occurrence is the common feature of these areas. The major drought-prone areas are located in Balochistan, Sindh, lower NWFP and Southern Punjab.

Under the directives of the chief Executive of Pakistan, received through Engineer-in-Chief, the Pakistan Meteorological Department has accepted the challenge to conduct experiments on cloud-seeding throughout the country so as to augment precipitation. The main objective of this project is to determine the feasibility of cloud-seeding in different parts of Pakistan, in order to increase rain/snowfall during both summer and winter seasons. A step forward on the way of weather-modification, the experiments on fog-dissipation and hail- suppression will also be conducted.

The science of cloud-seeding has made considerable progress since 1940. At present, research and experiments on cloud-seeding are going on in most parts of the world, using ever-advancing technologies. With the development of weather-modification science, two schools of cloud-seeding methodology emerged. One school embraced what is called the static mode of seeding, while the other favours what is called the dynamic mode of seeding. Both the static and dynamic modes of cloud-seeding will be used in Pakistan, through ground-based and airborne seeding technology.

Earlier, the Pakistan Meteorological Department had conducted cloud-seeding experiments in Balochistan, NWFP and Punjab, during 1953 to 1956, and had achieved encouraging results.

During a presentation on the subject by Engineer-In-Chief in June 2000, the Chief Executive of Pakistan approved, in principle, the undertaking of cloud-seeding experiments in Pakistan. The task was assigned to the Ministry of Defence, to conduct these experiments through Pakistan Meteorological Department, which Department accepted the challenge and availed of the services of Army Aviation and Plant Protection Department (of the Ministry of Food & Agriculture) for conducting these experiments.

On the directive of Chief Executive of Pakistan, PMD undertook the cloud-seeding Project, starting from middle of 2000, to augment summer-precipitation of warm clouds. During the first part, a total of 48 experiments were conducted. Out of these, 30 turned out to be successful and 18 failed. Four experiments failed purely due to technical problems with the aircrafts. All the results were analyzed, keeping in view the prevalent meteorological situation at the time of the experiments. Generally, areas under the

* For Correspondence: Director General, Pakistan Meteorological Department, Sector H-8/2, Islamabad, Pakistan.

influence of natural rains were avoided during the experiments. The second part of this paper would cover the cold cloud experiments from 15th December to 31st March, 2001.

BACKGROUND OF CLOUD-SEEDING IN PAKISTAN

Pakistan possesses diversified climatic conditions, mostly Arid & Semi-arid. Some areas receive meager amounts of rainfall during the year, insufficient to sustain agriculture and to meet civic water-requirement. Conditions become vulnerable to drought if two rainfall seasons fail to yield, in succession. Pakistan had its worst ever drought, starting mid 1998 to mid of this year. Partial relief has been noted after monsoon 2001, while most of the western and southern areas of the country are still under influence of this drought.

The science of cloud seeding has made considerable progress in many parts of the globe since 1940. PMD being the pioneer organization in cloud-seeding experiments had conducted these experiments as early as 1953-55.

SCIENTIFIC BASIS FOR CLOUD SEEDING

In 1946, dry ice was dropped into a stratocumulus cloud. Very quickly, the cloud was transformed into a swarm of ice crystals that grew & fell from its base, leaving behind a distinct hole in the cloud. If naturally occurring ice-forming nuclei had sufficient concentration in this cloud, they would have transformed its super-cooled liquid droplets into ice crystals themselves. In fact, the dry ice pellets counter-acted the dearth in natural nuclei by artificially creating ice-embryos. Introduction of dry ice or silver iodide in super-cooled clouds could initiate a precipitation process.

Super-cooled water droplets available in the atmosphere (clouds), and lacking ice-forming nuclei are supplemented through seeding. This seeding initiates the transformation of the super-cooled water into ice crystals, which eventually enhance the precipitation process.

Warm clouds are seeded by any hygroscopic material, such as NaCl, CaCl, NH_4NO_3, Dust particle, Urea, etc, leading to nucleation of cloud-droplets. Through collision &

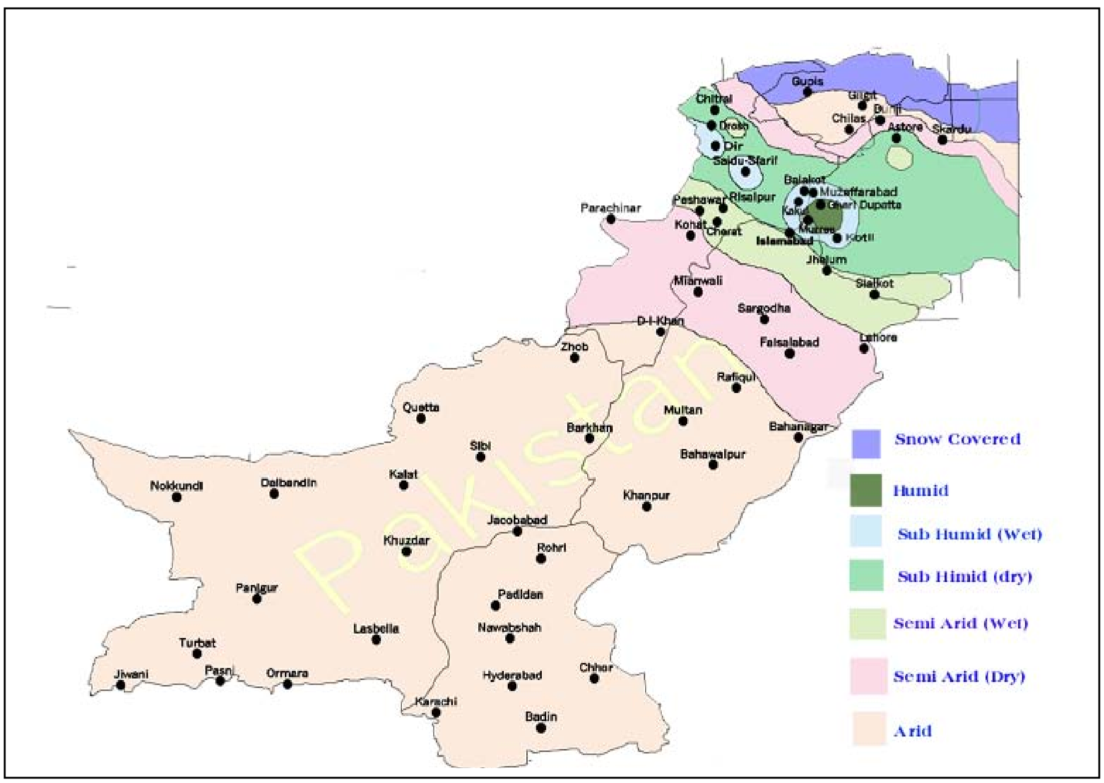

Figure – 1: Broad Agroclimatic Zones of Pakistan On Annual Basis

coalescence, the water droplets become big enough to fall onto the ground as rain.

MODES OF CLOUD-SEEDING

Two different mechanisms can disrupt the microphysical stability and lead to larger cloud particles, which in turn have greater fall-velocities and may result in precipitation:

- *One* is direct collision & coalescence (Dynamic).
- *Second* process is interaction between super-cooled water droplets & Ice crystals in the clouds (Static).

Dynamic Mode of Seeding
(*To enhance rainfall by collision & coalescences*)

The concept of dynamic seeding is a physically plausible approach that offers opportunity to increase rainfall by much larger amounts than the static one. Warm rain formation is dominated by collision and coalescence among droplets. Collision and coalescence refers to the process, in which a large drop settling through the air at a high terminal velocity overtakes a small drop with a smaller settling velocity.

Clouds most favoured to create rain by collision and coalescence of warm clouds are warm based and maritime. To enhance rainfall from warm clouds by cloud-seeding, hygroscopic particles are introduced into the cloud that is large enough to function as embryos for collision and coalescence growth.

Static Mode of Cloud-Seeding
(To increase the precipitation efficiency of Cloud/ Cloud System)

Static mode of cloud-seeding is based on the concept in which ice crystals nucleate in a water- saturated super-cooled cloud, which will grow by vapour deposition at the expense of cloud droplets. The size of cloud, time available for cloud particle growth, and vertical velocity of air, constitute significant determinants for the growth of Precipitation-sized particles.

The size of cloud is controlled largely by the amount of moisture available, temperature profile & topography of the area. Droplets with radius less than 10 micron are formed in concentrations of hundreds per cubic cm. Terminal velocity of these droplets is < 0.3 cm/sec and are called colloidally stable.

Some details of methods and result achieved are given below:

AREAS OF WEATHER MODIFICATION

1. Different Areas

- Fog dispersion
- Hail suppression
- Rain enhancement

2. Different Cloud-Seeding Agents.

- Silver Iodide
- Calcium Chloride
- Salt
- Dry Ice
- Liquid Carbon Dioxide.
- Dust

Rain-Enhancement through Cloud Seeding

1. Different Methods of Clouds Seeding

- Airborne: By using Aircraft
- Ground base: By using Generator or Rocket Technology.

2. Different Categories of Clouds

a. *Warm Clouds:*
   - Base warmer than +10 C°
   - Top warmer than + 0 C°

b. *Super-Cooled Clouds:*
   - Base & Top colder than - 0 C°

3. Types of Super-Cooled Clouds

a. Deep Stratiform Clouds.
b. Shallow Stratiform Clouds.
c. Cumuliform Clouds

METHODOLOGY FOR CLOUD-SEEDING OPERATION

- Identification of a suitable situation.
- Arrangement of an appropriate seeding agent.
- Successful transport and diffusion or direct placement of the seeding agent to the super-cooled regions of the clouds.
- Adequate time and super-cooled liquid and vapour must be available to provide precipitation-size particles.

- Eventual fall of rain on the ground in the desired location, before evaporation or being transported out of the target area.

USES OF NUMERICAL MODELS IN WEATHER MODIFICATION

Objectives: → **To evaluate Seeding potential**
→ To evaluate the Seeding experiment

- To estimate the Seed-ability of the Cloud.
- To identify the optimum location to Seed.
- Quantity of Seeding material required.
- Best time to start Seeding.
- To distinguish operational and non-operational days.

STATUS OF WEATHER-MODIFICATION EXPERIMENTS IN OTHER COUNTRIES

- *Japan* conducted Cloud Seeding of snow cloud in Central Japan for enhancing the snowfall in catchment areas of Dams in 1974 to 1997.
- *Mexico* 1997; Program for the Augmentation of rainfall in Coahuila was conducted and initial results were encouraging.
- *China* is successfully using rain enhancement techniques in their arid areas since 1990.
- *Thailand* is successfully using weather modification techniques since 1994.
- *Israel & USA*: They have done lot of research work in the field of weather modification during the last 40 years.

PREVIOUS CLOUD-SEEDING EXPERIMENTS IN PAKISTAN

Pakistan Meteorological Department Conducted Cloud Seeding Experiments from 1953 to 1956.

1. Seeding of Warm Clouds during Monsoon Season.

In Mardan district of the NWFP, in 1953 by using two aircrafts loaned for the purpose from the PAF Academy Risalpur.

In central Punjab plains and hills, from ground generator in 1954.
Repetition of the above in 1955.
Repetition of the above in 1956.

2. Seeding of Cold Clouds in the Winter Season

From the hill top behind the Meteorological Institute, Quetta, in 1955.
Repetition of the above in 1956.

RESULTS OF RECENT EXPERIMENTS

These results of 71 experiments recently conducted or shown in Tables-1 and 2. These show success rate of 65%.

ECONOMIC BENEFITS OF CLOUD SEEDING

We may conclude that so far, the experiments on warm clouds have given reasonably good results, with 30 successes out of 48 experiments i.e. 63%.

The primary motivation for cloud-seeding is the Economic Benefits associated, viz:

i) Increased hydro-Electric power and agriculture production
ii) Salinity reduction
iii) Strengthened sky industries

- A study showed that an additional 10% of ppt over the growing Season would be expected to increase from revenue by $ 10M To $ 43M.

- Another study in U.S.A showed that added rainfall of 20mm In June – July and 30 mm for June – August would increase the Economy by over 0.5 billion.

- The other direct benefit is from the augmentation of Snowfall, which results in additional stream-flow for Generation of hydro- electric power and increased irrigation water.

STATISTICS OF RESULTS

Table - 1: Phase-1 (Seeding of Warm Clouds)	
Total experiments conducted:	48
Highly successful	30
Limited success	14
Failure due to technical reasons	4

Table - 2: Phase-2 (Seeding of Cold Clouds)	
Total experiments conducted:	23
Successful	9
Limited Success	6
Failed	8

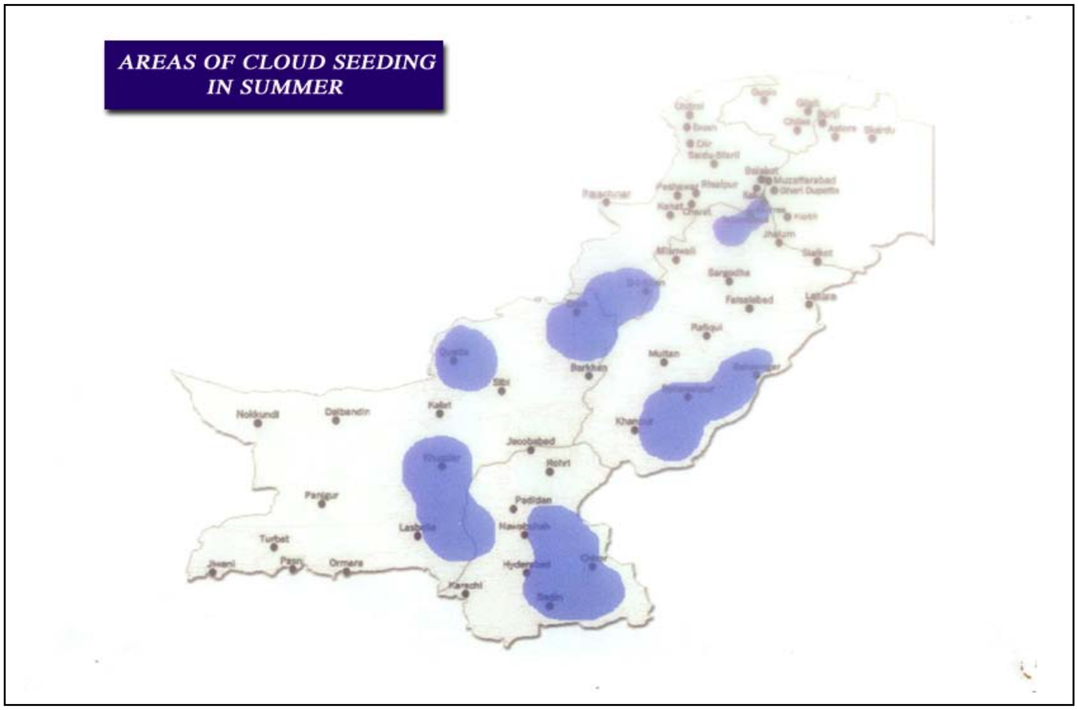

Figure - 2: Areas Covered By Cloud Seeding Experiments During Recent Drought In Summer

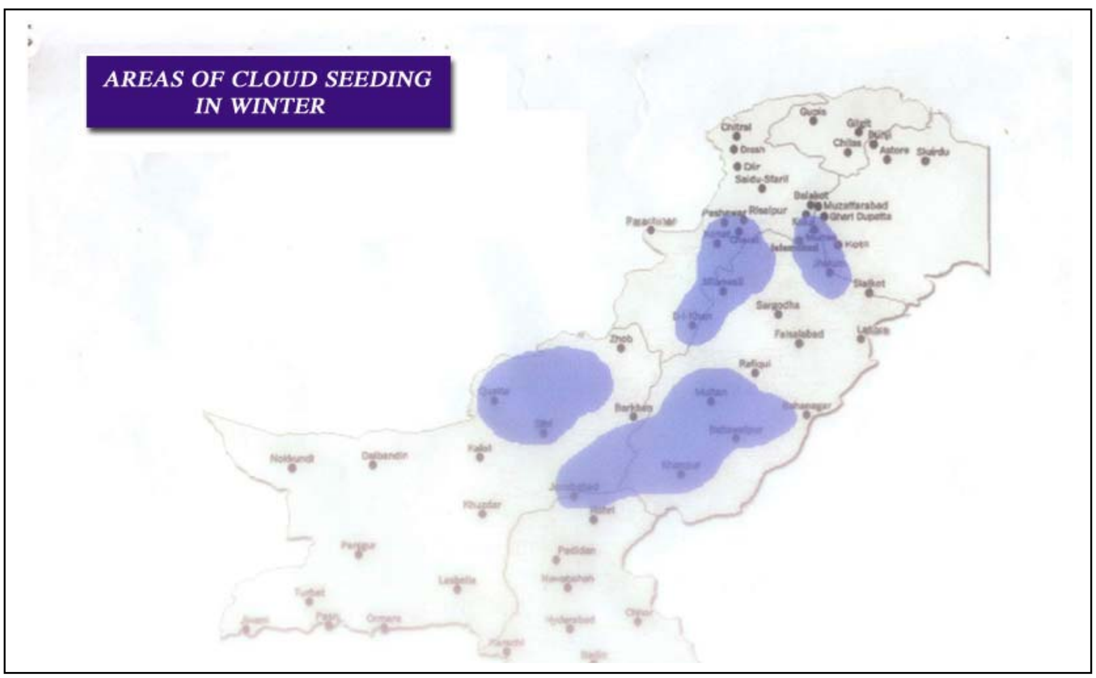

Figure - 3: Areas Covered By Cloud Seeding Experiments During Recent Drought In Winter

MATHEMATICAL MODELING OF THE UPPER-INDUS GLACIERS

*Khalid Rashid**

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 paper attempts to present the characteristics of the Upper Indus Glaciers and suggest ways to model and understand the northern areas, 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 preposition 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, I will 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.

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.

* Professor, Department of Mathematics, Quaid-i-Azam University, Islamabad, Pakistan.

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 10^{15} 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 10^{15} m^3, acquifiers 22%, lakes and rivers 0.0053% and 000345% 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. 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 recrystalize a microspcopic amount farther downslope, and other crystal disortions result in movement.

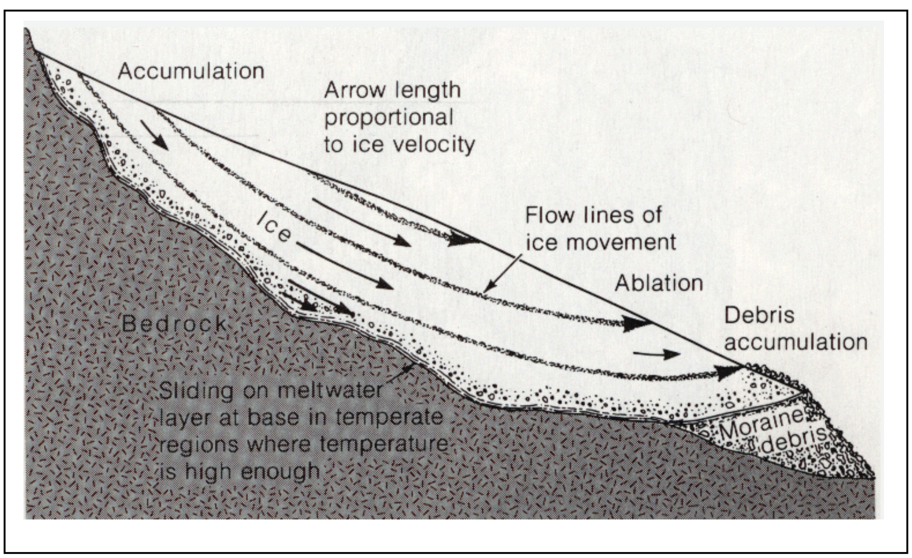

Figure-1: How ice flows in a typical valley glacier. The rate of movement decreases towards the base. If the temperature at the base is sufficiently high that the ice pressure will causing melting, the entire thickness of the glacier will start sliding along the liquid layer next to the ground (Press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

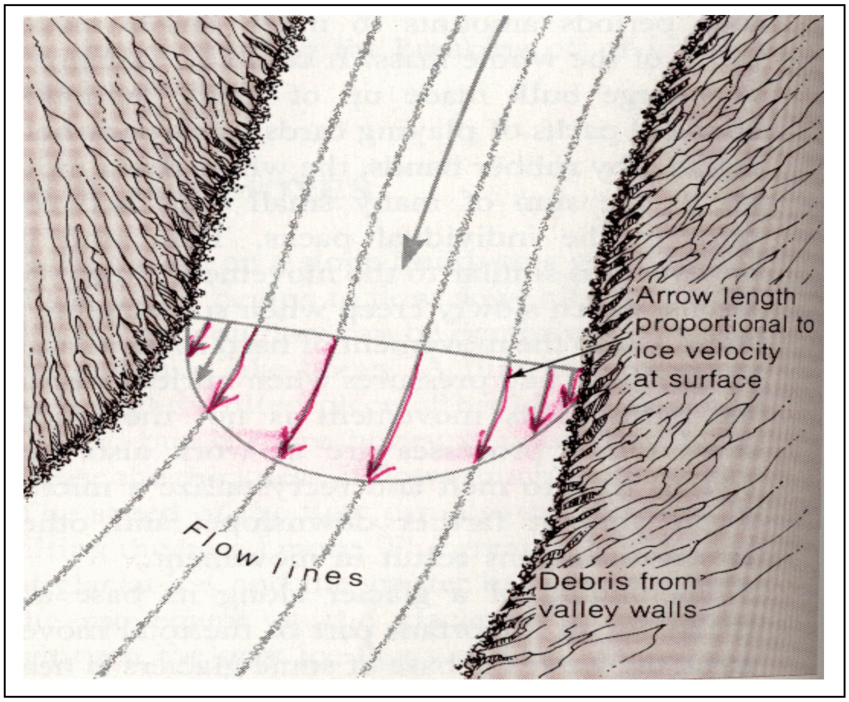

Figure-2: A Valley Glacier Moves More Rapidly At The Centre And With a Greatly Reduced Velocity Along The Valley Walls. *From (Press and Siever)*

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 that 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)

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

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 κ 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

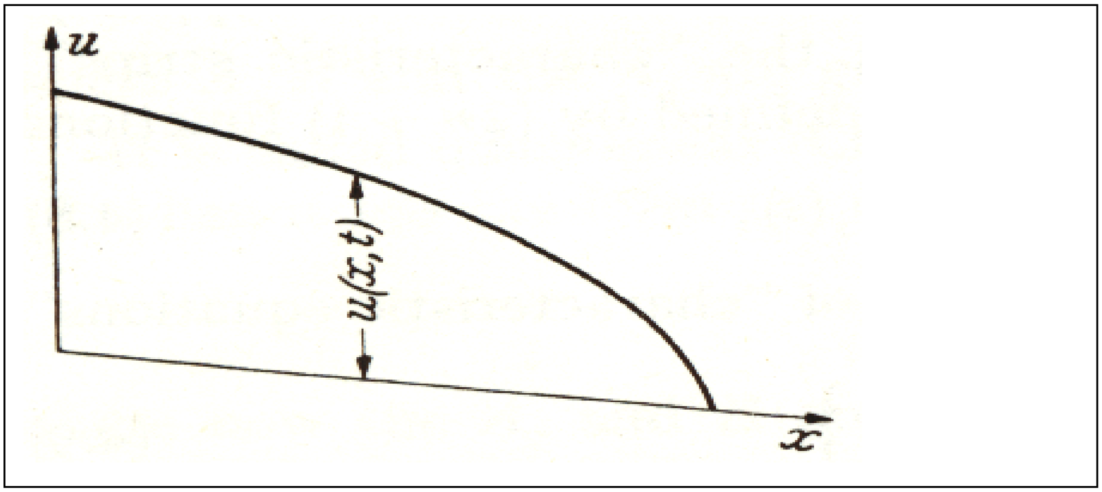

Figure-3: Longitudinal Section of a Glacier

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

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

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

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

The characteristic equations for equation (1) read

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

Their general 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:

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

where ξ and η 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).

This region has the largest concentration of peaks higher than 6000 m; the glaciarised

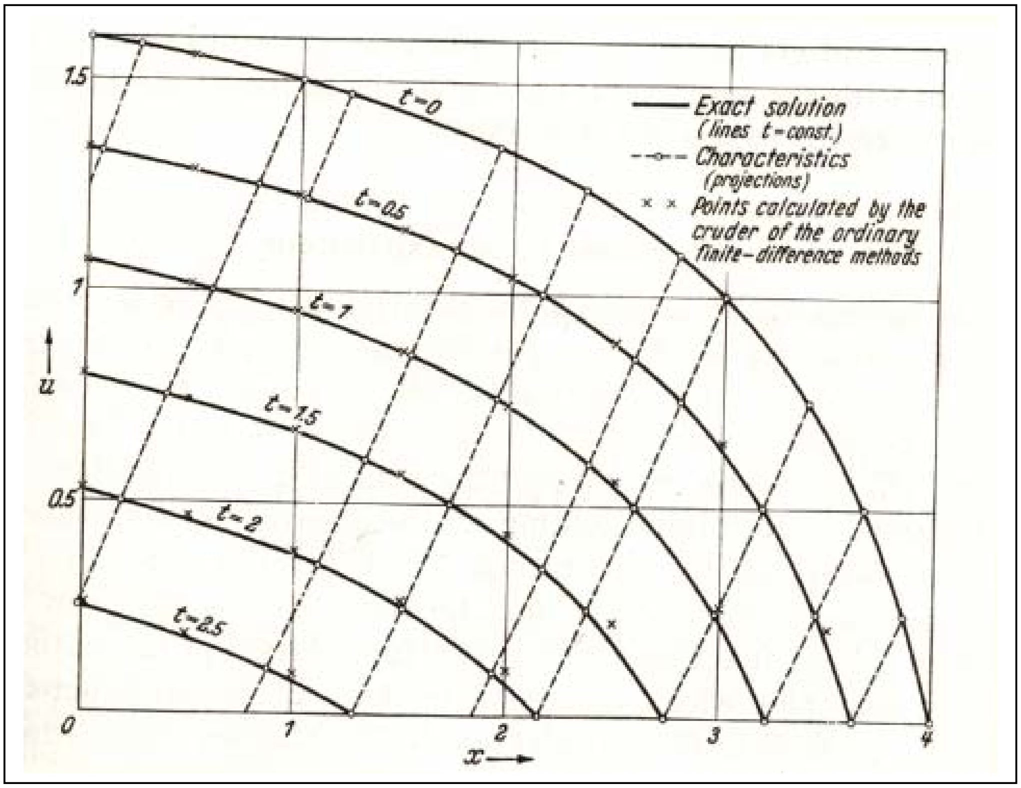

Figure-4: Profile of a Glacier at Various Times as an Example of The Integration of A First Order Partial Differential Equation

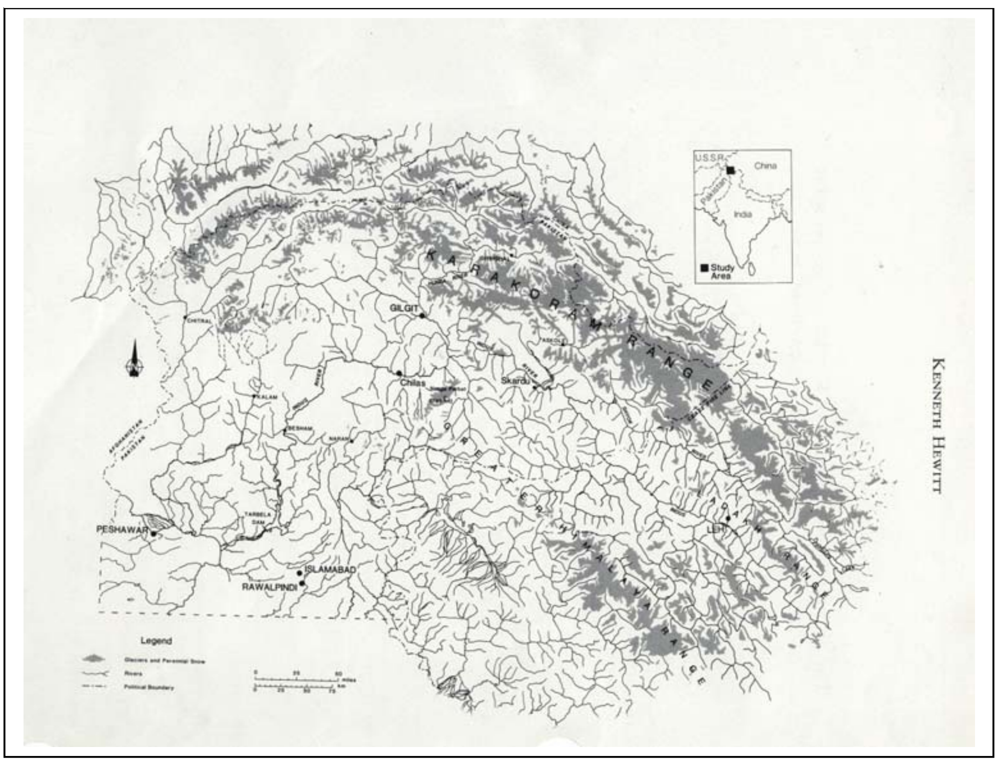

Figure-5: The Karakoram Range Showing The Extent of Perennial Snow and Ice, and The Major River Systems. *(From Hewitt 1989a)***.**

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 form 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^{O}N(Neilburger 1973).

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 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.

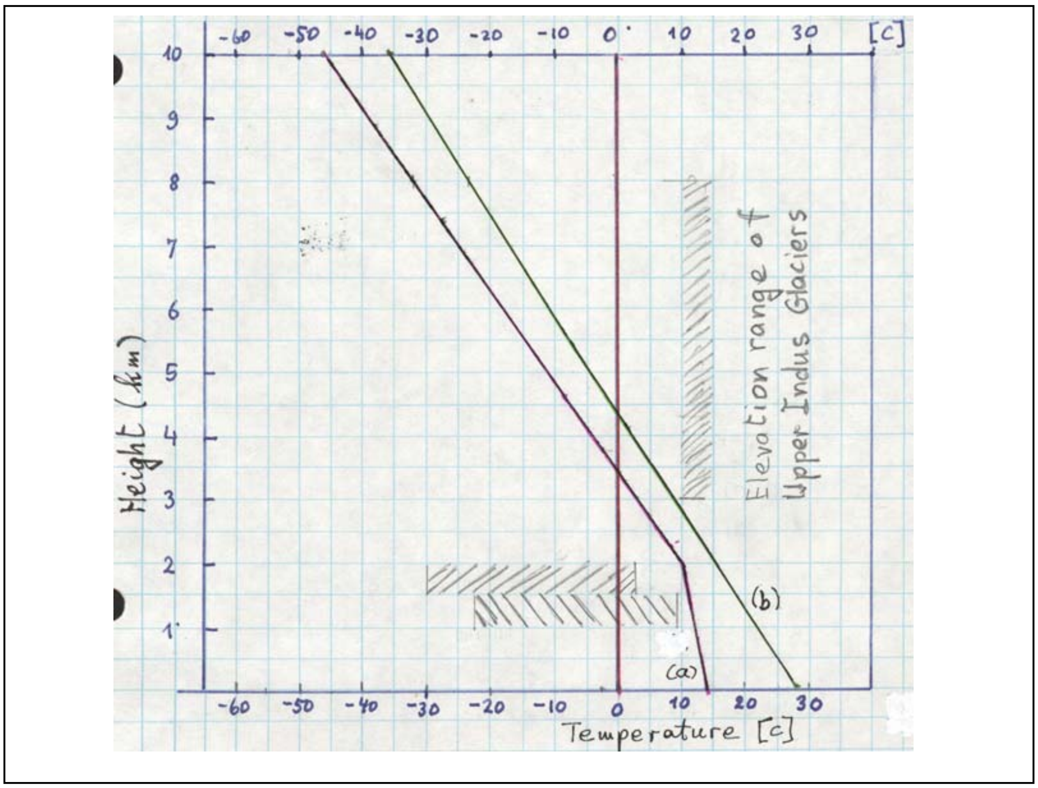

Figure-6: Temperature Variation With Height. (a) January Average. (b) July Average.[////] is the Temperature Range from 3000 to 8000 Meters Above Sea Level In July. [\\\\\] Is The Range In January.

We note that the January average temperature is below freezing at about 3000 meter above see level and in the summer month of July this is the case at about 4500 meter above see level. Large parts of UIB glaciers lie in a temperature range below freezing through the

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.

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 Miar 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 Korakorum 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

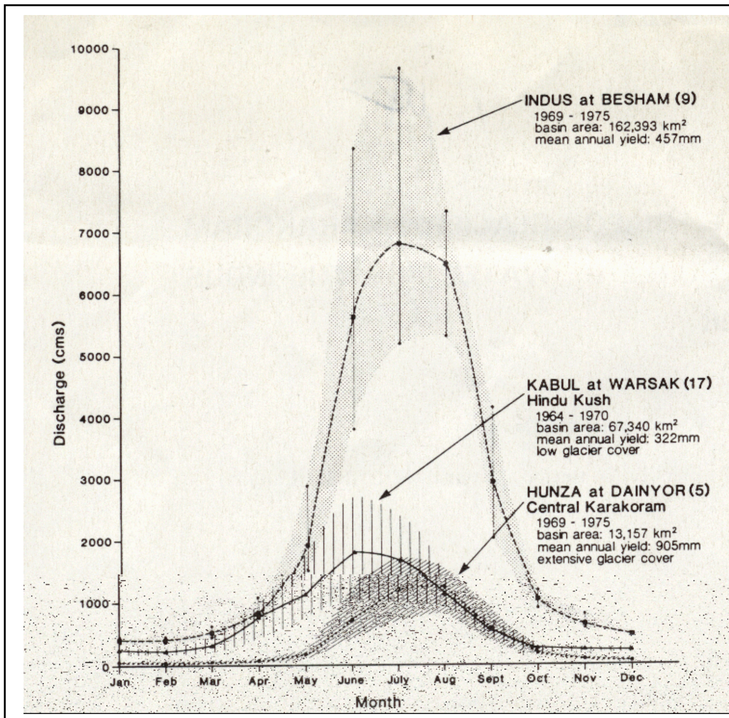

Figure-7: Hydrographs of Indus, Kabul and Hunza Rivers *(from Hewitt 1989b).*

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 the daily paper THE NEWS of 12-03-2001 carried the following story by G N Mughal. Quote. *Pakistan may use laser technology to melt glaciers. HYDERABAD. Pakistan is seriously considering the option of using laser technology to melt some of its northern areas glaciers and snow lying underneath.* End quote.

My first reaction to this story was to take it as the usual high-level rhetoric of our powerful authorities to calm the thirsty and desperate farmers. Later, when I heard from reliable sources of the seriousness with which this option was under consideration, I was truly shocked. 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^3 of ice is 333 Joules. So to melt 30 MAF(about 4.2 km^3) of ice 1.2×10^{19} Joules of energy are required. Any good CO_2 laser can have a power of 1000 kW and an efficiency of 20%. Assuming that we have excellent optics to illuminate 100 cm^2 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^2 of snow and ice cover. So artificially melting snow and ice cover is a science fiction story!

CONCLUSION 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 of 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 need to train manpower. One way to do this would be to support financially and technically, with infrastructure, M-Phil and PhD thesis 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 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 alternate users.

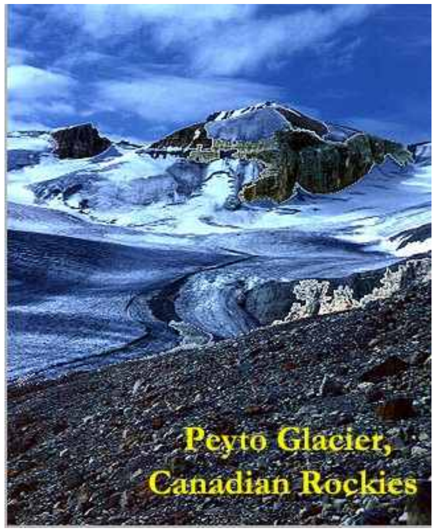

Figure - 8: Peyto Glacier, Canadian Rockies

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GLOBAL CLIMATIC CHANGE AND PAKISTAN'S WATER-RESOURCES

*Imtiaz Ahmed**

ABSTRACT

The rapid growth in the use of water in the last half century has resulted in universal awareness of the limited stocks of fresh water and, in the light of the increasing demands, the need for conservation. There is also a realisation that international climate-change may have some influence on the water availability picture of the future.

Because of its geographical location, Pakistan is mostly an arid and semiarid country. However, it is fortunate to have 3 major rivers (the Indus, Jhelum and the Chenab) flowing from the bordering region to sustain irrigation and hence agriculture. The use and development of the potential of Indus River, the major contributor (above 60%), has been central to sustaining agriculture. The Indus is basically a snow-fed river; because of global warming, the extent of snow cover is rapidly decreasing, and this may affect its base-flow. A macro-scale hydrological model for river-flow suggests that the runoff of the Indus will decrease by 27% by the year 2050.

Pakistan's population is increasing at a rate of about 2.6% p.a. and the use and demand of water is increasing faster. Additional demand for water will come from the anticipated improvements in the standard of living, through greater economic activity. Increase in industrial activity will also require additional water. Our underground water-resources are already being exploited to the maximum. Increase in sustainable water-resources in the country can be achieved through a combination of groundwater-aquifers and large and small surface-water facilities. This combination will be critical to meeting the water needs of the twenty-first century.

Incorporating realistic scenarios of water-resources is a fundamental element of sustainable development. Water-resources and climate change not only affect agriculture, but they also affect urban centres, industry and human health. Management of water-resources requires a balanced and careful review of current knowledge under a comprehensive framework.

INTRODUCTION

The recent dry years, particularly in the south of the country, and the resulting water-crisis has raised our awareness of the changing climatic conditions in the country and in our region. It has also shown our weakness in understanding and anticipating climatic problems, especially when there is little or no indication of it in our past experience. Our behaviour, for the most part, has been reactive rather than anticipatory. The crisis cannot be addressed fully in the long-term, without some understanding of the dynamics and relationship between our water-resources, the local weather, the regional weather and the global climate change.

In this paper we will try to see if there is a perceptible climatic change; if so, how will it affect our present and future water-resources.

Before we move forward, it is necessary to define the climatic region in which Pakistan is situated. Pakistan is situated in the Near East region. According to the FAO Regional Office, the Near East extends from the Atlantic Ocean (Mauritania and Morocco) in the west to Pakistan and Kyrgyzstan in the east and from Turkey and Kazakhstan in the north to Somalia in the south[1]. It falls between longitudes 17° west and 80° east and latitudes 43° north and 2° south. The Near East comprises 29 countries, with a total area of 18.5 million km^2, which is about 14% of the total area of the world. Because of the aridity prevailing in the region, the Near East is the poorest region in the world, in terms of water-resources. Irrigation covers 47.7 million hectares in the region. Pakistan alone, covering a little over 4% of the region, accounts for 33% of the irrigated areas. By adding Iran, Turkey, Iraq and Egypt, 72% of the areas under irrigation are controlled by five of the 29 countries, covering only 25% of the Near East. Pakistan and Egypt are fortunate countries because they have rivers flowing from the bordering and more humid regions, tropical Africa (the Nile) and Himalayan Asia (the Indus). Thus, Pakistan's water-resources are greatly influenced by climatic changes in its region and also in the neighbouring regions.

* Director to the Special Advisor to the Chief Executive of Pakistan, Chief Executive Secretariat No. 2, Islamabad, Pakistan.

These water-resources are also affected by climate changes in the world at large.

The question is; is there a significant change in climate of Asia, in general, and near east, in particular, to warrant such a concern?
Listed below are some of the facts that have been making headlines in recent years in Asia:

1. Lhasa, Tibet: Warmest June on record, 1998. Temperatures hovered above 77 degrees Fahrenheit for 23 days.

2. Himalayas, India: Glacial retreat at record pace. The Dokriani Barnak Glacier retreated 66 feet in 1998, despite a severe winter. The Gangorti Glacier is retreating 98 feet per year. At this rate, scientists predict the loss of all central and eastern Himalayan glaciers by 2035.

3. Tien Shan Mountains, China: Glacial ice reduced by one quarter in the past 40 years.

4. Middle East: Severe drought has affected many parts, including Iran, Iraq and Jordan. Rainfall in parts of Iran is down by 25% compared to 1999; eighteen of the country's twenty-eight provinces are suffering.

   In Iraq the Tigris and Euphrates rivers have fallen to around 20% of their average flow, with serious consequences for irrigated farming. Jordan's agricultural production has been severely damaged by two years of drought.

Most countries in Middle East are suffering the consequences of prolonged water-shortages, dating from last two years. The evidence listed above shows that the recent dry years in Pakistan were not individual events; the whole Near East region is suffering. It is also implies that whatever changes are taking place have reasons beyond the immediate zone. Before evidence of overall global change is considered, it is important to understand that to explain climate change it is important to have:

a. A picture of what happened over the whole earth, as against a single country, or region, or hemisphere;
b. Weather-data from at least several years, to allow temporal and geographic patterns to be distinguished; and
c. A perspective that encompasses all aspects of the weather.

GLOBAL CLIMATE CHANGE

The Global Temperature Increase

Globally, the 1990s were the warmest decade and 1998 the warmest year in the instrumental record, since 1861. New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century, during the past 1,000 years. Because fewer data are available, less is known about annual averages prior to 1,000 years before the present.

On the average, between 1950 and 1993[2], nighttime daily minimum air temperatures over land increased by about 0.2°C per decade. This is twice the rate of increase in daytime daily maximum air temperatures (0.1°C per decade). This has lengthened the freeze-free season in many mid- and high latitude regions. The increase in sea-surface temperature over this period is about half that of the mean land-surface air temperature. Arctic sea ice has decreased since 1973, when satellite measurements began. Since the start of the satellite record in 1979, both satellite and weather balloon measurements show that the global average temperature of the lowest 8 kilometers of the atmosphere has changed by +0.10°C ± 0.05 per decade, but the global average surface temperature has increased by +0.15 ± 0.05°C per decade. The record shows a great deal of variability; for example, most of the warming occurred during the 20th century, during two periods, 1910 to 1945 and 1976 to 2000.

The Earth may have warmed by an average of more than 1.7 degrees over the past 150 years, according to an analysis of the University of Wisconsin study of the freeze-and- thaw records for lakes and rivers in the Northern Hemisphere. Researchers found that the annual freeze of 26 bodies of water in North America, Asia and Europe shifted *later* by about 8.7 days over the last century and a half, while the spring ice break-up came an average of about 9.8 days *earlier*. The study found very strong evidence of a general warming from 1845 to 1995 in areas where there is ice cover. The change in the ice-on and ice-off days found in the study corresponds to an air temperature warming of about 1.8^{o}Cdegrees over the150-year period.

Reasons For Global Temperature Increase

(i) *Variation of Solar output*

The Sun is the primary source of energy responsible for governing both the weather and the climate of Earth. For that reason, the amount and type of energy the earth received from the Sun could alter weather and climate on the earth. Our Sun is not a constant star and variations in the energy that the Earth receives from the Sun, both in the form of total electromagnetic radiation and other types of energy, such as outflows of charged particles, are well documented. The variations in solar energy outflow are generally cyclic, with periodic times ranging from the 27-day solar rotation period, through the 11-year and 22-year solar activity periods. Solar luminosity is closely linked to sunspot activity, which waxes and wanes over a cycle that lasts 10 to 11 years, Research shows that total solar irradiance, or the total radiant power received by the Earth from the sun, was about 0.036 percent higher in 1996 than in 1986.

Meteorological and climatic data suggest that there are significant responses in the Earth's atmosphere and oceans to the variability of the Sun, in the form of drought cycles, variations in global sea-surface temperatures, etc., but the direct relation of the Earth's response to solar variations cannot be proven.

The energy received from the sun (The solar constant S) varies due to a number of reasons; these include changes in the average distance between the Earth and the Sun, the tilt of the earth and precession. The eccentricity expresses to what extent the Earth's orbit around the Sun differs from a circle. The angle of tilt of the earth's axis of rotation varies between 22° and 24.5°, with a periodicity of about 40,000 years. The maximum change in energy received from the sun S associated with variation in eccentricity is about 0.1%. The eccentricity is just one of three orbital parameters that influence seasonal and latitudinal changes in short-wave radiation reaching the Earth. Precession is another one; it is the change of direction in space of the earth's axis of rotation. The axis changes direction with a periodicity of about 22,000 years

All the above-mentioned components of the orbit vary because of the gravitational attraction between the earth and the other planets. The orbital changes are known as Milankovich orbital changes[3]. He did put forward the theory that the periodic changes of climate between glacial and interglacial are related to the orbital changes of the earth. However they are only important for climate changes on very long timescales. Hence, when modelling for short time-scales, solar constant (energy received from the sun) can be handled as a true constant.

(ii) The Greenhouse Effect

The greenhouse effect is produced as certain gases allow incoming solar radiation to pass through the Earth's atmosphere, but prevent part of the outgoing infrared radiation from the earth's surface and lower atmosphere from escaping into outer space. Greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). Major sources of greenhouse gases include the burning of fossil fuels (gas, oil, and coal), forest destruction, and agriculture. The average concentration of CO_2 was about 290 ppm (parts per million) in pre-industrial times; in 1990 it was about 350 ppm and is increasing steadily at a rate of 0.3-0.4%/yr. Since CO_2 is chemically inert, the photochemical or chemical processes in the atmosphere do not destroy it; it is either lost by transfer into the ocean or biosphere, or it builds up in the atmosphere. The concentration of methane, another greenhouse gas, has more than doubled in the same period.

To predict climate change, one must make a model of the climate. One test of the validity of predictions is the ability of the climatic models to reproduce the climate, as we see it today. Elements of the models, such as the physics and chemistry of the processes that we know or think we know, are essential to represent in the models. Therefore, the models have to embody the characteristics of the land and the oceans that serve as boundaries of the atmosphere represented in the models. Models also have to take into account the radiative characteristics of the gases that make up the atmosphere, including the key radiative gas, water vapour that is so variable throughout the atmosphere.

A number of climatic models have been developed and one of the most detailed is a General Circulation Model (GCM) developed by the Goddard Institute for Space Studies (GISS). A GCM uses extremely high-speed computers to solve the basic equations governing atmospheric motions and processes by numerical techniques. One test of the model occurred in June 1991; the Mount Pinatubo volcano erupted and sent 25 to 30 million tons of sulphur dioxide into the stratosphere. There, the sulphur dioxide reacted with water vapour to produce a long-lasting haze of sulphuric acid droplets. The GISS group inserted the new information into the model, estimated how much sunlight the Pinatubo aerosol cloud would block, and predicted that the global temperature would drop about 0.3 degree Centigrade. The predicted change actually occurred. Although these successful climate predictions are encouraging, most scientists agree that much remains to be done to improve climate models before we will be able to predict future climate in a credible manner.

(iii) EL Niño and LA Niña

El Niño phenomenon is the result of persistent higher Sea Surface Temperatures (SSTs) in the central and eastern tropical Pacific; the magnitude of the warming determines the magnitude of El Niño. In 1997, Sea Surface Temperatures recorded in some of these tropical Pacific waters were more than 5^{o}C (9^{o} F) higher than their average value. Records of past climate reveal that El Niños have been a recurring feature of the earth's climate for thousands of years; however they have now become more persistent.

El Niños are often preceded or followed by the opposite phase, dubbed La Niña, when surface temperatures in the tropical Pacific Ocean are systematically lower than the long-term average. A corresponding modulation in the general circulation of the global atmosphere – called the Southern Oscillation – is also closely allied with these ocean changes. The name, which is widely used by scientists to refer to the three together, is the El Niño-Southern Oscillation phenomenon, or ENSO.

El Niño is the warm phase of ENSO, and La Niña the cold. Both involve the tropical oceans and the atmosphere, and the exchange of energy between the ocean surface and the air above it. The ocean and the atmosphere are linked together, interactively, and each affects the other. Atmospheric winds push the ocean currents and help determine the patterns of sea surface temperature. But Sea Surface Temperatures, at the same time, help determine the force and direction of winds and atmospheric circulation, by adding heat or taking it away, chiefly by shifting the places where tropical thunderstorms preferentially occur. The warmest large-scale pool of ocean water in the world is normally found in the vicinity of Indonesia – south of China and north of Australia. El Niño shifts the location of the warm water pool over 3200 km (2000 miles) eastward. When water vapour condenses and falls as rain, the heat that was stored when the water was originally evaporated is released into the air. Because of this, the major shift in the location of tropical pacific rainfall that accompanies an El Niño alters the heating patterns of the whole atmosphere; their effects reach beyond the tropics into mid-latitude regions. In the end, winds and storm tracks and the jet stream are all perturbed, in ways that affect, to some degree, almost everyone on Earth.

When La Niña takes control, the situation changes. Areas with drier than normal or even drought conditions during El Niño, such as Indonesia, the Philippines, Australia, Southeast Asia, Hawaii, and parts of Africa, Asia and Brazil, are apt to experience heavy rains during La Niña. Meanwhile, areas that have experienced El Niño floods, such as Peru, Ecuador, Uruguay and northern Argentina in South America, parts of Africa, and southern parts of the U.S. in winter, are apt to be drier than normal during the ensuing La Niña phase. We know from past occurrences that what might be called a "mini global warming" accompanies each El Niño, with the highest air temperatures typically occurring a few months after the peak in ocean surface warming. The record-breaking and long-lasting El Niño of 1997-98 began in April of the first year and persisted until May of the next. It almost certainly contributed in establishing 1998 as the world's warmest year on record. It is estimated to have cost a staggering sum of $89 billion[4]. In addition to material losses; these weather-related events had taken an estimated 32,000 lives, while displacing 300 million people. These estimates do not include the losses incurred because of the ensuing drought in Asia.

Changes in Climate Due to Temperature Increase

(i) Effect on Rain Fall

Although the precipitation has increased by 0.5 to 1% per decade in the 20th century, over most mid- and high latitudes of the Northern Hemisphere continents, and the rainfall has increased by 0.2 to 0.3% per decade over the tropical (10°N to 10°S) land areas, rainfall has decreased over much of the Northern Hemisphere sub-tropical (10°N to 30°N) land areas during the 20th century by about 0.3% per decade (this in the region in which most of Pakistan is situated). In contrast to the Northern Hemisphere, no comparable systematic changes have been detected in broad latitudinal averages over the Southern Hemisphere. There are insufficient data to establish trends in precipitation over the oceans.

In the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century, there has been a 2 to 4% increase in the frequency of events of heavy precipitation. Increases in heavy precipitation events can arise from a number of causes, e.g., changes in atmospheric moisture, thunderstorm activity and large-scale storm activity. In most areas, there is an observed decrease in daily temperature range. Since 1950, there has been a reduction in the frequency of extreme low temperatures, with a small increase in the frequency of extreme high temperatures.

(ii) Snow Cover And Ice Extent

Satellite data show that there have been decreases of about 10% in the extent of snow cover since the late 1960s. Ground-based observations show that there is very likely to have been a reduction of about two weeks in the annual duration of lake and river ice cover in the mid- and high latitudes of the Northern Hemisphere, over the 20th century. There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century. Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15% since the 1950s. There has been a decline in Arctic sea-ice thickness of about 40% in recent decades and a considerably slower decline in winter sea-ice thickness.

It may be remembered that increase and decrease in ice-cover does not depend on winter temperature. It is the summer temperature that determines the extent of ice cover. If the summer is warm, all the accumulated ice is melted and the ice cover decreases or remains constant, however, if the summer is mild, the previous season's ice is carried over to the next season and the ice cover increases.

(iii) Sea Level Rise and Ocean Heat Content:

Tide-gauge data show that global average sea-level rose between 0.1 and 0.2 meters during the 20th century. Global Ocean heat-content has increased since the late 1950s, the period for which adequate observations of sub-surface ocean temperatures have been available. The average temperature of the Atlantic, Pacific and Indian Oceans has risen 0.06 degrees C since 1955.

EFFECT OF GLOBALWARMING ON WATER-RESOURCES

Global weather changes and water-resources are deeply inter-related. The largest source of freshwater is rain. Global climatic changes will have major effects on precipitation and runoff. In the relatively arid and semi-arid regions, modest changes in precipitation can have proportionally large impacts on water supplies. In mountainous watersheds, higher temperatures will increase the ratio of rain to snow, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid, earlier, and greater spring runoff. Because the temperature projections of climate models are less speculative than the projections of precipitation, temperature-induced shifts in the relative amounts of rain and snow and in the timing of snowmelt in mountainous areas are considered highly likely. Climate-induced changes in hydrology will affect the magnitude, frequency, and costs of extreme events, which produce the greatest economic and social costs to humans. Flooding could become more common and extreme. Recent reports of the Intergovernmental Panel on Climate Change (IPCC) suggest that a greenhouse warming is likely to increase the number of intense-precipitation days as well as flood-frequencies in northern latitudes and snowmelt-driven basins. These reports also suggest that the frequency and severity of droughts could increase in some areas, as a result of a decrease in total rainfall and more frequent dry spells.

EFFECTS OF GLOBAL WARMING IN THE ASIAN REGION

The Asian region that spans polar, temperate, and tropical climates and is home to over three billion people, is a particular concern as far as effects of global warming are concerned. As climate warms, many mountain glaciers may disappear and the northern forests may shift further north. A report by Intergovernmental Panel on Climate Change (IPCC) sponsored by UNEP predicts that the major impacts in Temperate Asia under global climate change are projected to be: large shifts of the boreal forests, the disappearance of significant portions of mountain glaciers and shortages of water supply. The most critical uncertainty in these estimates stems from the lack of credible projections of the hydrological cycle under global climate change scenarios.

The effects of climate change on the Asian monsoon and the El.Nino/Southren Osoillation (ENSO) phenomenon are among the major uncertainties in predicting the water picture in the region. The positive ENSO phase of the pattern (wet south and dry north) is promoted by warm Sea Surface Temperatures in the tropical Pacific and Indian Oceans. A rather abrupt change in the El Niño - Southern Oscillation behavior occurred around 1976/77 and the new regime has persisted. There have been relatively more frequent El Niño episodes, compared to La Niña. This behavior is highly unusual in the last 140 years (the period of instrumental record).

Although global temperature increase has occurred over the last century, clear signs of its effects appeared in the late 1970s, with the more frequent appearance of El Niños. A given explanation is that, although present, the global warming influence was, until that time insufficient to perturb the normal working of the climate system: its capacity to affect the overall behavior of the climate system was reached only after a certain threshold had been passed.

The major risk from the climate change in south Asia is increased summer precipitation intensity in temperate regions; this may increase flash-flood prone areas. Of all natural disasters, floods are the most destructive; in terms of human life they account for over 50 % fatalities (58% deaths were due to floods in the decade 1988-1997). In terms of economic loss, they account for one third. On the other hand, the arid and semi arid regions would be drier in summer, which could lead to severe droughts.

The Himalayas have a critical role in the provision of water to continental monsoon in Asia. Increased temperatures and increased seasonal variability in precipitation are expected to result in increased recession of glaciers and increasing danger from glacial lake outburst floods. A macro-scale hydrological model for river-flow suggests that the runoff of the Indus will decrease by 27% by the year 2050[5]. This implies that the availability of fresh water in Pakistan is highly venerable to climate change.

A reduction in average flow of snow-fed rivers, coupled with an increase in peak flows and sediment-yield would have major impacts on hydropower generation and agriculture. Availability of water from snow-fed rivers may increase in the short term, but decrease in the long-run. Runoff from rain-fed rivers may also change in the future. A reduction in snowmelt water will put the dry-season flow of these rivers under more stress than is the case now, especially in Pakistan where one major snow-fed river, the Indus, accounts for as much as 80 % of the normal water flow. Increased population and increasing demand in the agricultural, industrial and hydropower sectors will put additional stress on water-resources.

RIVER-FLOW DATA OF PAKISTAN

According to the global warming scenario presented earlier, the global warming should be reflected in the river-flow data of Pakistan, especially in the nineties. From the data available form 1975 to 2000[6], the following picture emerges. In the post-Tarbela era, the water diverted from the rivers to the canal system has remained constant around 104 MAF per year (128 bm^3). The fresh-water outflow to the sea may, therefore, be considered to be a good indication of the total river flow for this period. From the year 1975/76-1989/90 the average flow into the sea per year has been 34.13 MAF/year. However from the year 1990/91 to 1999/2000, this flow has been 47.88 MAF/year i.e. about 40 % greater. (Table-1) For the winter season for the same period, the average flow into the sea from the year 1975/76-1989/90 was 1.86 MAF/year. However from the year 1990/91 to 1999/2000, this flow has been 3.28 MAF/year, i.e. about 76 % greater. Although other factors may also be contributing, nevertheless the change visible in this time-frame is quite large. This increased river-flow could be taken as evidence for local effect of global warming. The global warming is expected to initially cause the river-flow to increase as the glaciers melt, then decrease as they recede. One more fact that emerges from the data listed in table-1 is that when there is an excessive amount of water in kharif season, the succeeding rabi season also has more water than usual; this increased water-availability in rabi could be due to increased rains because of local effect of greater moisture.

Table – 1: Fresh-Water Outflow to the Sea

Year	Kharif	Rabi	Total
1975-76	37.8	1.5	39.3
1976-77	64.1	5.0	69.1
1977-78	29.0	1.4	30.4
1978-79	75.0	5.6	80.6
1979-80	29.4	0.4	29.8
1980-81	18.7	1.4	20.1
1981-82	35.5	0.3	35.8
1982-83	9.4	0.3	9.7
1983-85	43.5	2.1	45.6
1984-85	25.1	0.9	26.0
1985-86	10.9	0.0	10.9
1986-87	26.7	0.2	26.9
1987-88	17.5	0.1	17.6
1988-89	44.2	8.7	52.9
1989-90	16.9	0.4	17.3
Average flow till 1990	**34.13**	**1.86**	**34.13**
1990-91	38.2	4.1	42.3
1991-92	50.1	3.2	53.3
1992-93	69.2	12.3	81.5
1993-94	28.5	0.6	29.1
1994-95	88.2	3.7	91.9
1995-96	44.8	1.6	46.4
1996-97	61.1	0.7	61.8
1997-98	16.6	3.8	20.4
1998-99	32.6	0.1	35.3
1999-00	8.7	0.1	8.8
Average for the 90's	**47.88**	**3.28**	**47.88**
Overall Average for 25 years			**39.3**

Variation of Rainfall Between 1931-90

An overall increase in rainfall of 50-150mm[7] has been observed in the monsoon belt for the period 1931-90. However, a decrease in rainfall was seen in the rest of the country. The decrease is 50-100 mm in western and northern mountains, whereas in the southeastern and central parts it is 25-50 mm. These variations are in line with the predictions made on the expected effects of global warming. Global warming is expected to cause drier south and wetter north.

Changes in El.Nino/Southern Oscillation (ENSO) also affect Asia, especially the monsoon. Based on the monsoon rainfall pattern from 1901 to 90, a strong El Niño event causes poor or below normal rainfall in Pakistan. However, when a strong El Niño year is followed by another strong El Niño year, the rains return to normal or above average. When a strong El Niño is followed by a moderate El Niño in the succeeding year, the monsoon activity is reduced. Most of the floods in Pakistan were recorded in the La Niña years (Appendix-1). The predominance of El Niño in recent years may be one of the causes of the recent dry years.

Identifying the Crisis Facing Pakistan

The persistent failure of rains in recent years has lead to persistence of droughts in most of the country. Droughts in one country or region also effects neighbouring regions that otherwise are supposed to make surplus water available for inter-basin transfers in the flood seasons. Increase in persistency of drought requires a re-examination of our assumptions, operating norms and contingency measures for existing and planned water-management measures. Droughts produce the additional burden of migration of population from neighbouring regions into lands that are already stretched to the maximum. Besides the social disruptions, there is the cost of the degradation of the natural resources due to the over-exploitation.

A United Nations report in 1997 determined each member country's ratio of water-consumption to water-availability, in order to gauge the overall pressure on its water-resources. The report predicts that moderate to high water-stress translates to consumption-levels that exceed 20 per cent of available supply. In Pakistan, this ratio has already exceeded 65 percent! Water-use in agriculture is projected to increase as our food-demand rises. World-wide, agriculture accounts for about 70 per cent of water-consumption; in Pakistan, its share is already 95%. Future projects show a 50- to 100-percent increase in demands for irrigation water by 2020.

Better management of water-resources is the key to mitigating water-scarcities in the future in the short-term, and avoiding further damage to aquatic ecosystems. More efficient use of water could dramatically expand the available resources. In the longer term, however, the looming water-crises must be addressed through hard policy-decisions that reallocate water to the most economically and socially beneficial uses. Far greater emphasis on water-efficient technologies and control of pollution is also essential. In Pakistan, about 50 per cent of irrigation-water never reaches the crop and is lost to evaporation or runoffs. However, even with measures to contain the growth of demand and use of water more efficiently, new supplies will be needed. The financial and environmental costs of tapping new supplies will be, on average, two or three times those of existing investments, because most of the low-cost, accessible water reserves have mostly been exploited.

If the problems facing Pakistan, with respect to water, were to be *short-listed'* they would constitute the following main points:

a. Resource deficit
b. Depletion of aquifers, by lowering of water-tables;
c. Wastages, in the form of runoffs;
d. Climate change;
e. Wasteful agricultural practices;
f. Water-logging and salinity;
g. Low level of awareness to importance of fresh water;
h. Water shortages in the urban areas.

Any water policy that fails to address these concerns will be piecemeal and, in the end, may aggravate the situation.

- Future development in Pakistan may be severely constrained, because we have neither the extra water nor the financial resources to shift development away from intensive irrigation and into other sectors that would create employment and generate income to import food. The present water-scarcity gives an idea of the future vulnerability of Pakistan to absolute a water-scarcity. Under all scenarios, including the most optimistic, there is a dearth of fresh water. Climate change, as a result of global warming will further constrain our resources.

- This thirst for water necessitates broad thinking and drawing up a research agenda that would address these concerns and would contribute towards agricultural productivity, sustainable use of groundwater, introduction of modern technology to expand resources, and making our agriculture more productive with less water.

- The IPCC third assessment on climate change, published in July 2001, states that global warming is happening, and at a much faster rate than was expected, global temperatures are rising nearly twice as fast as previously thought. Their prediction, based on computer models, is that temperatures could rise by as much as 5.8^{o}C by the end of the century. The report stresses that human activity is responsible for this crisis and that industrial pollution, and, in particular, green-house gases emissions are the worst offenders.

CONCLUSION

I*n conclusion*, it is generally thought that Climate change is a very slow process and the Earth has always been a temperate world. This is far from the case. The Earth has been much hotter and much colder than it is now; actually the past eight thousand years have been a period of unusually stable climate. The current atmosphere that blankets the planet helps to keep the globally averaged surface temperature up to about 15 degrees Celsius. But there is geological evidence that this figure has been down to about 7^{o}C and possibly as high as 27^{o}C[8]. Although we are currently in a not-so-cold phase of an ice age, "the Quaternary Ice Age", there is evidence from Arctic ice and palaeontological studies that the earth has heated up to as much as 12^{o}C in a span of less than a hundred years a number of times in the past.

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APPENDIX-1

La Niña (Cold) and El Niño (Warm) Episodes By Years.

The following published list of cold (La Niña) and warm (El Niño) episodes provides a season-by-season breakdown of conditions in the tropical Pacific. Intensity is classified for each event by focusing on a key region of the tropical Pacific (along the equator from 150°W to the date line). The process of classification is based on using reanalysed sea surface temperature analyses produced at the National Centers for Environmental Prediction/ Climate Prediction Center and at the United Kingdom Meteorological Office. In the following table, weak periods are designated as C- or W-, moderate strength periods as C or W, and strong periods as W+ or C+. A column has been added to the published list to identify flood or high flow years in Pakistan to establish a relationship with these events.

We should note that heavy rainfall is but one of several factors that determine whether or not a flood occurs. The spatial extent of the storm, the total amount of rain, and the rainfall rate are also important, as are the nature and condition of the terrain on which it falls. Geophysical, topographical and vegetation conditions are all involved. Because of these factors, flood records in themselves are not reliable indicators of changes in rainfall.

YEAR	JFM	AMJ	JAS	OND	
1950	C	C	C	C	Floods
1951	C			W-	
1952					
1953		W-	W-		
1954			C-	C	
1955	C	C-	C-	C+	Floods
1956	C	C	C	C-	Floods
1957		W-	W-	W	
1958	W+	W	W	W	
1959	W-				
1960					
1961					
1962					
1963			W-	W	
1964			C-	C	
1965	C-		W	W+	
1966	W	W-	W-		
1967					
1968				W-	
1969	W	W-	W-	W-	
1970	W-			C	
1971	C	C-	C-	C-	
1972		W-	W	W+	
1973	W		C-	C+	Floods
1974	C+	C	C-	C-	
1975	C-	C-	C	C+	High discharge
1976	C			W-	Floods
1977				W-	
1978	W-				Floods
1979					
1980	W-				
1981					High discharge
1982		W-	W	W+	
1983	W+	W		C-	High discharge
1984	C-	C-			
1985	C-	C-			
					Continue….

Continued from previous page					
1986			W-	W	
1987	W	W	W+	W	
1988	W		C	C+	Floods
1989	C+	C			
1990			W-	W-	
1991	W-	W-	W	W	High discharge
1992	W+	W+	W-	W-	Floods
1993	W	W	W	W	
1994			W	W	Floods
1995	W			C-	High discharge
1996	C-				High discharge
1997		W	W+	W+	
1998	W+	W	C	C	
1999	C+	C	C	C	
2000	C	C-		C-	

THE CLIMATE AND FLOOD RISK POTENTIAL OF NORTHERN AREAS OF PAKISTAN

*Shaukat Ali Awan**

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 Karakuram ranges and in the lesser Karakuram range. Floods which arise from Karakuram region pose greater problem, 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 op 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 Co-relation Co-efficient, 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 mechanism has been discussed, which are practically important because they assist m seasonal prediction of climate and flow in the Indus. Additionally, if climate warming is causing an upward Trend in winter and spring temperature 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 m 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 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

* Chief Meteorologist, Flood Forecasting Division, Pakistan Meteorology Department, Lahore , Pakistan.

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^{o} 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 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^{o}C in daily mean temperature. Daily maximum temperatures are more affected and may fall by as much as 20^{o}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.

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*
(a) Maximum Temperature													
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

Table-1 (contd.) Maximum, Minimum And Mean Temperatures													
(b) Minimum Temperature													
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
(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

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 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. 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 Karakorams, the above conclusions have some bearing on the precipitation regime of the Karakorams. 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 Karakorams. Secondly, since the Karakorams 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 Karakorams 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-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.

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	

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-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.

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

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 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 debis-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. 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.

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 *et al*
1974	14-Aug	Batura	Hunza	Cai Xiangxing *et al*
1977/78		Darkot	Yasin/Gilgit	Raschid (1995) Whiteman (1985)
1970s		Yashpur, Henzel	Gilgit	
1999	Jul?	Juj Bargo	Ghizer/Gilgit	

- 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 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^3/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 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 presence of scientific observers to record the events. However, it is clear that there are sufficient occurrences of landslide and debris-flow blockages of many rivers, 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**

ABSTRACT

The Paper describes 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, 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 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, account for 25 per cent of GDP, and employ per cent of labour force. They supply most 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 19th 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

* Additional Secretary (Technical), Punjab Irrigation & Power Department, Lahore, Pakistan.

designed capacities. The Irrigation network of the Province comprises 21canal-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 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

Table –1: Accord Allocations*

Province	Kharif (BCM)	Rabi (BCM)	Total (BCM)
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
Total	**95.14**	**45.52**	**140.66**
	+	**+**	**+**
	2.21**	**1.48****	**3.69****

*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

Province	Kharif (BCM)	Rabi (BCM)	Total (BCM)
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
Total	**81.83**	**45.23**	**127.06**

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 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
2000-2001	**13.9**	**-40.3**	**-43**	**-40.1**

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.

Box -1: Rabi Plan 1999-2000

- All non-perennial canals in cotton-zone were closed from 5th Oct., instead of 15th October.
- All perennial canals in cotton-zone were closed from 15th to 31 Oct.
- The flow-period of NP canals in rice-zone was extended from 15th Oct. to 31 Oct.
- All perennial canals in rice-zone were closed from 1st to 15th November.
- 15 days watering in non-perennial canals in the cotton-zone was released from 20th Nov. to 5th December.
- All perennial channels were run with 10% shortfall during January to 10th 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.

BOX - 2: RABI PLAN 2000 – 2001

- 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

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.

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):

BOX- 3: Canal Command Level Water-Allocation Committees

Composition:

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

Functions:

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.

Divisional Water-Allocation Committees

Composition:

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

Functions:

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.

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):

- 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 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.

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**

Table - 6: Wheat Area 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

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.

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 GW 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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DROUGHT MANAGEMENT AND PREVENTION IN PAKISTAN

*Muhammad Munir Sheikh**

ABSTRACT

Pakistan has a long latitudinal extent, and the rainfall variability during different seasons is considerably high. Some regions of the country, in each season, remain drastically dry and are vulnerable to drought. If subsequent seasons also fail to generate significant precipitation, the drought conditions are then sure to take the regions in grip. Such conditions are often seen affecting the country, specifically the southern half of the country. The country recently remained under the grip of a severe drought during the period 1998 to 2000, which disrupted the economy badly, besides human and livestock killings.

In view of the fact that the country mostly consists of arid, semiarid and even hyperarid regions, the susceptibility of different regions to become drought-stricken is always very high. Drought is a natural event and the risk associated with drought is a product of both the region's exposure and the vulnerability of society to the event. For its management and prevention, the following aspects, thus, seem essential for study:

- *Drought vulnerable areas be identified, using the meteorological data.*
- *The causes of droughts be highlighted.*
- *Possible mitigation strategies be discussed .*

It has been tried to cover the above aspects in this paper, which would help promote further investigations in the field.

INTRODUCTION

Drought, in general, means dryness due to lack of precipitation over an extended period of time. Drought has the greatest potential impact, as compared to other major disasters like floods, tropical cyclones, earthquakes, etc., as the latter are mostly of short duration and geographically limited, while drought, by contrast, affects large geographical areas often covering the whole of the countries or even parts of continents.

Frequency of drought occurrence, when compared to other disasters, was found to be 2 to 3 times less, but the killings reported were much higher when seen on the global basis, as is shown in Annexure-I. Frequency of occurrence of drought in Pakistan, on the years. Pakistan has a previous history of droughts, too, but it was recently hit by a severe long spell of drought, during the period 1998-2000. Economic, social and environmental degradation costs and losses associated with the drought were very high. The Southern parts of the country below 30°N, particularly parts of Southern Punjab, Sindh & Balochistan, were adversely affected.

Because of the long latitudinal extent of the country from 24°N to 37°N, the country has a diversified climate, which consist mostly of arid and semiarid regions, besides some hyper-arid regions, on account of the natural deserts within 25° to 30°N. There are two rainy seasons, namely winter (December to March) and summer monsoons (June to September) and two transition periods having almost insignificant rains. The rainfall pattern is highly variable. Estimated weighted precipitation over Pakistan and its provinces is shown in Annexure-II In each season, there is at least one region, which on the average, remains dry for more than 50% of the time and, even for the remaining period, rainfall is so insignificant that the region may be termed as vulnerable to drought. If the subsequent rainfall seasons also fail to generate sufficient rains, the region becomes drought-stricken. Such a situation can be predicted well before time if the monitoring and early-warning system is authentic and reliable. Drought is mostly referred to as a creeping disaster, as its effects often accumulate slowly. Consequently, forecasts of the order of atleast a season can be made and can help policy-makers at all levels in making critical management decisions.

DROUGHT-VULNERABLE AREAS

There are two marked rainfall seasons, namely winter (December to March) and summer monsoons (June to September). "April to May" and "October to November" are

* Chief Meteorologist (Rtd), 1-B, Met Colony 46, Jail Road, Lahore, Pakistan.

the transition periods. Rainfall is significantly less during these transition periods, as compared to the rainy seasons in winter and summer.

A comparison of the weighted precipitation is shown in Table-1.

Table-1: Estimated Weighted Precipitation (1961-90)

PERIOD	N.W.F.P.	PUNJAB	BALOCHISTAN	SINDH
Dec. to Mar	228.8	81.1	69.3	14.2
Jun to Sept.	252.9	260.3	64.2	137.5
Apr to May	106.5	36.5	20.1	5.5
Oct. to Nov	37.7	11.3	4.8	4.4

The table indicates high variability of rainfall in different provinces during various seasons, leaving at least some portions of the country remaining almost under stress for rains. Further, the rainfall variations in northern and southern Punjab and in Western, Central and Coastal areas of Balochistan are also very significant, as can be seen in the isohyetal maps for different seasons (Annexure III, V, VII & IX).

In order to mark drought-vulnerable areas, maps showing the driest periods, in percentage, have been prepared and annexed. (Annexure IV,VI,VIII & X). Areas remaining dry for more than 50% of the time have been termed as vulnerable to drought. Rainfall activity in different seasons over the country is discussed below.

Winter Rains

Western disturbances or the low-pressure systems, which have their origin in the Mediterranean Sea or Atlantic Ocean. travel eastwards in higher latitudes within 30° to 60° N. and are responsible for bringing rainfall in the country. On their way lie the Himalayan mountains which, because of their topography, help in extracting the moisture from the western disturbances and make the belt within 34° N to 36 receive maximum rainfall. At times, these disturbances induce secondaries in the lower latitudes (25°-30°N). These pull moisture from the Arabian Sea and produce reasonably good amount of rainfall over submontane regions in the northern parts of the country, but comparatively much less rains over Southern Punjab and over parts of Balochistan. Most parts of the central, southern and eastern parts of Sindh which do not fall within the domain of winter rains, remain dry more than 50% of the time and are termed as a zone vulnerable to drought during this season. It is here clarified that a place remaining more than 50% dry means that, out of 30 years (the period of the data), the place received zero rainfall in more than 15 years. Even during the remaining part of 30 years, the rainfall remained drastically low.(See Annexure III & IV). A comparative statement of weighted precipitation over the different provinces during the winter season is shown in Table-2.

Table – 2: Weighted Winter Precipitation

PERIOD	N.W.F.P.	PUNJAB	BALOCHISTAN	SINDH
Dec. to March.	228.8	81.1	69.3	14.2
No. of times higher than Sindh	16.1	5.7	4.9	1

The table shows drastically low precipitation over the province of Sindh which, on the average, received less rainfall by factor of 4.9, 5.7 & 16.1, less rainfall as compared to the provinces of Balochistan, Punjab and N.W.F.P.

Summer Rains

The rains during summer (June to September) are brought by the monsoonal systems coming either from the Arabian Sea, called South westerly monsoon systems, or due to the Southereasterlies bringing intense monsoon lows or depressions from the Bay of Bengal. Pattern of the normal rainfall during the season is shown in Annexure--V. This isohyetal map and the map showing the driest periods in percentage (Annexure-VI) indicates that the Southeastern parts of Balochistan and some central portions of Balochistan and a small portion of Northwest Sind, around Jacobabad, Sukkur, Rohri & Larkana, do not fall within the monsoon rains and remain more than 50% of the time dry and are vulnerable to drought. The conditions get more severe towards Southwestern Balochistan, around Dalbandin, Nokkundi, Zahidan and Jiwani. The conditions are further apt to be worsened if the transition months of October and November and that of winter ahead do not bring sufficient rains. Comparison of rainfall over the "drought-vulnerable" parts with that of the other provinces is shown in Table-3.

Table - 3: Comparative Statement Of Weighted Precipitation Over Different Provinces During(Jun. - Sep.) Summer Period (1961-90)

Period	*Punjab*	*N.W.F.P*	*Balochistan*	*Sindh*	*Average rainfall over the vulnerable areas of Balochistan**
June to Sept.	260.3	252.9	64.2	137.5	21.4
No. of times higher than Balochistan (V).	12.2	11.8	3	6.4	1

*Note: *The areas include Nokkundi, Dalbandin, Panjgur, Jiwani, Pasni, Ormara, Kalat, & Quetta.(Mean normal precipitation over these areas is given).*

Rains During April And May

The rainfall during April to May drops drastically, when compared to the rainfall during summer & winter. The comparison is shown in Tables-4 and 5.

Table-4: Comparative Statement Of Weighted Precipitation During April to May, Compared With The Rainfall During Summer (June-Sept.)

	N.W.F.P.	*Punjab*	*Balochistan*	*Sindh*
June to Sept.	252.9	260.3	64.2	137.5
April to May	106.5	36.5	20.1	5.5
Ratio	**2.3**	**7.1**	**3.2**	**2.5**

Table-5: Comparative Statement Of Weighted Precipitation During April to May Compared With The Rainfall During Winter (Dec. – March)

	N.W.F.P.	*Punjab*	*Balochistan*	*Sindh*
Dec. to March.	228.8	81.1	69.3	14.2
April to May	106.5	36.5	20.1	5.5
Ratio	**2.1**	**2.2**	**3.4**	**2.6**

Table-6: Comparative Statement Of Weighted Precipitation Over Different Provinces During April & May.(1961-90)				
Period	*Punjab*	*N.W.F.P.*	*Balochistan*	*Sindh*
April to May	106.5	36.5	20.1	5.5
No. of times higher then Sindh	**19.4**	**6.6**	**3.7**	**1**

The rainfall when compared to summer rains is considerably less in Sindh & Balochistan. Rainfall figures reflect that practically the whole of the country is almost vulnerable to drought during the period. When the position is seen in the context of the driest periods in percentage, the whole of Sindh, part of Northeast Balochistan around Sibi & Kalat, coastal areas of Balochistan and the western limb of Balochistan around Nokundi remain dry for more than 50% of the time. (See Annexure-VII & VIII). During these months, the temperatures usually are quite high. The maximum temperatures often range from 105^o F to 113 ^{o} F. Jacobabad is one of the hottest places of the world, which attained the highest temperature of 127.4 ^{o} F (53^{o}C) on June 12, 1919. Here the province of Sindh is not that suffer the drought conditions. A comparative statement, showing rainfall in different provinces during these months is given in Table-6.

The rainfall over Sindh is 1/4, 1/7 & 1/19 (approximately) of that in Balochistan, NWFP and Punjab respectively. The drought-vulnerable areas in Balochistan receive similar type of precipitation as in Sindh. If the summer rains too fail, the conditions may get aggravated. However, the drought-conditions in this region subsided considerably due to the ground-water availability in the province.

Rains During October To November

The rainfall during October to November,

Table-7: Comparative Statement of Weighted Precipitation During October to November with the Rainfall During Summer Monsoons (Jun - Sep.)				
	N.W.F.P.	*Punjab*	*Balochistan*	*Sindh*
June to Sept.	252.9	260.3	64.2	137.5
Oct. to November	37.7	11.3	4.8	4.4
Ratio	**6.7**	**23**	**13.4**	**31.3**

Table-8: Comparative Statement Of Weighted Precipitation During October To November With The Rainfall During Winter rains (Dec. - Mar)				
	N.W.F.P.	*Punjab*	*Balochistan*	*Sindh*
Dec. to March.	228.8	81.1	69.3	14.2
Oct. to November	37.7	11.3	4.8	4.4
Ratio	**6.1**	**7.2**	**14.4**	**3.2**

vulnerable to drought, as sufficient ground-water availability can reduce the impact of drought in some areas where ground-water can be exploited easily. However, the areas in Balochistan are always at risk with regard to the drought- susceptibility, as even during the subsequent months of summer monsoons (June to September), these areas are apt to which is also termed as the post-monsoon period, further drops drastically when compared to the summer monsoon and winter rains. The comparison is shown in Tables-7 and 8.

The rainfall in the post-monsoon period drops drastically in Punjab, Balochistan and Sindh. The position in southern Punjab would look more serious when rains in the northern Punjab and Southern are seen separately. Infact, half of Pakistan below 30°N remains more than 50% dry. The isohyetal map and the map showing the driest periods in percentage are shown in Annexure-IX & X. A comparative statement of precipitation over different provinces during the months of November to December (1961-90) is given in Tabel-9.

Table –9: Comparative Statement Of Weighted Precipitation Over Different Provinces During October To November (1961-90)

Period	*Punjab*	*N.W.F.P.*	*Balochistan*	*Sindh*
Oct. to Nov	11.3	37.7	4.8	4.4
Ratio	**2.6**	**8.6**	**1.1**	**1**

The pattern clearly indicates that Balochistan & Sindh received approximately 1/3 and 1/9th rainfall of Punjab and NWFP provinces, respectively.

CAUSES OF DROUGHTS

Possible underlying causes include the following:

- El-Nino & La Nina Phenomena
- Increase of atmospheric Co_2 & other greenhouse gases etc.
- El-Nino and La-Nina are the recent discoveries in the field of Meteorology. El-Nino is associated with the quasi-periodic anomalous surface-warming of the equatorial eastern and central pacific ocean, which, in turn, induces changes in weather-systems over the globe. The strongest association of El-Nino is found near the equator, with anomalous high rainfall in the central pacific and equational eastern Africa, but anomalous low rainfall in Indonesia, Pakistan, India and equational north-eastern Brazil. 1982-83 was the strongest El-Nino year and Pakistan remained devoid of any significant flood in 1983. 1997-98 was the subsequent strongest El-Nino year on record and, again, there was a significant reduction in the flooding during the monsoons of 1988. La-Nina, which is a phenomena reverse to El-Nino and is associated with the temperatures over Pacific Ocean remaining below normal, has also been found to affect the weather of Pakistan. Pakistan went under the grip of La-Nina from mid 1988 to 2000 and the country had drastically low rains during the period. These results are yet to be established to confirm linkage of El-Nino and La-Nina events to the occurrence or otherwise of rains and floods. The existing studies rely on statistical associations between time-series of El-Nino indices e.g. anomalous Sea-surface temperatures over a sizeable areas of the equatorial pacific and time series of stream flows. With an El-Nino occurrence once every 4 to 7 years and the presence of a multitude of other climatic causes of enhanced regional flooding, the requirements for a long time series of stream flows for several streams over a region is necessary for reliable statistical associations.

- It has been found that the temperatures of the region of seasonal low, developing as a semi ermanent feature over parts of Sindh, Balochistan and adjoining areas of Southern Punjab, also contribute significantly towards pulling moisture from the Arabian Sea during monsoons. Statistical evidence shows a reasonably good linkage between the temperatures of May and the monsoon rains. Such changes in temperature may be associated with the increase in CO_2 and other greenhouse gases, but these factors are yet to be established.

TYPICAL ADVERSE EFFECTS ASSOCIATED WITH THE DISASTER

Drought has often been referred to as a creeping disaster, as the affects of drought often accumulate slowly over a considerable period of time and may linger for years together after the termination of the event. Such a state of affairs often keeps the people hopeful for the good times to come soon. Further, their attachments with their homes and surroundings make them hesitant to leave their home towns. Only under inevitable circumstances, some partial migration takes place. The drought brings multitude of adverse effects in its wake, such as :-

- Killings of people and livestock due to famine.
- Diseases.
- Deterioration of nutritional status.
- Reduction in resources of drinking and irrigation-water.
- Decline in the ground-water tables, where available.
- Social disruption due to migration.
- Increased rates of inflation.
- Desertification.
- Environmental degradation, due to contamination of soil, water and atmosphere through the deaths of livestock and human beings.

MITIGATION MEASURES

A Drought-mitigation plan should have the following three primary components:-

1. Monitoring & Early-warning system.
2. Risk and impact-assessment and mitigation.
3. Post-disaster needs.

Monitoring & Early Warning System

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more. Other climatic factors (such as high temperatures, high winds and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event. Similar conditions prevailed over the drought-stricken areas in Pakistan during 1998-2000. In Pakistan, different regions are vulnerable to drought during each season; as such, authentic early warning seasonal forecasts are required to make reliable risk-assessments. Unfortunately, no country over the globe is yet self-sufficient in producing authentic and really accurate forecasts.

Pakistan Meteorological Department has a good data-collection system for developing a sound early-warning system for ascertaining the drought conditions. Meteorological data are important, but represents only a part of a comprehensive monitoring system. Other physical indicators (e.g. ground water and stream flow) must also be monitored to reflect the impacts of drought on agriculture, households, industry, energy production and on water users. Helpful technology includes soil-moisture sensors, Automated Weather-Stations, and satellite imageries, such as digital data obtained from the Advanced Very High Resolution Radiometer(AVHRR), which is transmitted from the National Oceanic and Atmospheric Administration (NOAA) Satellites. Satellite data is useful in indicting areas where deficiencies of moisture are affecting vegetation growth.

Risk Assessments And Mitigation

Once the areas are declared to be drought-stricken a Risk-Assessment Committee (RAC) should be formulated. Its responsibility should be to assess sectors, population groups, ecosystems that are most at risk and identify appropriate and reasonable mitigation-measures, to address these risks. The members of RAC and that of its working committee, formulated under the aegis of the RAC, should be composed of technical specialists representing each of the sectors, groups or ecosystems. The overall responsibility of RAC would be to make recommendations to the Disaster-cell, for taking mitigation actions.

Post-Disaster Needs

The Government must keep the following measures in view, so as to meet the post-disaster needs, which inevitably appear as consequences of a drought:-

- Measures to maintain food-security.
- Food subsidies.
- General food distribution.
- Special programmes for livestock and pastoralists .
- Complementary water and health progammes.
- Price Stabilization.
- Rehabilitation.

SUGGESTIONS AND RECOMMENDATIONS

Some suggestions and recommendations to mitigate the disasters are given below:-

Early Warning System

The drought is a creeping disaster and offers sufficient time for early warnings, of the order of a few months or a season. Droughts can be predicted very accurately if early-warnings are reliable and fully authentic. Institutions such as Pakistan Meteorological Department, which is the most suitable agency, need to be strengthened to achieve self-sufficiency in this field.

Role of Reservoirs

More and more reservoirs are required to be raised to store water during the rainy seasons. Areas vulnerable to draught need, if possible, to be linked with main acquifers through canal-links.

Anthrapogenic Activities

Deforestation, loss of vegetation due to over-grazing, etc., need to be curbed by imposing legal bindings on such activities. These and many such anthrapogenic activities have raised the global temperature over the last century by about 0.6° and the vulnerability of drought-prone areas has, presumably, further increased.

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4. W.M.O. Bulletin, Vol. 47 No.4, October, 1988.
5. Early Warning Systems for Drought Preparedness and Drought Management, WMO/t.d No.1037 W.M.O., 2000.

ANNEXURE-I

TYPE	***NO. OF EVENTS***	***NUMBER KILLED***
HURRICANE/TYPHOON	894	8,96,063
FLOODS	1358	3,04,870
FIRE	729	81,970
FAMINE	15	6,05,832
EARTHQUAKES	758	6,46,307
DROUGHT	430	13,33,728
LANDSLIDES	238	41,992
STORMS	819	54,500
EPIDEMICS	291	1,24,338

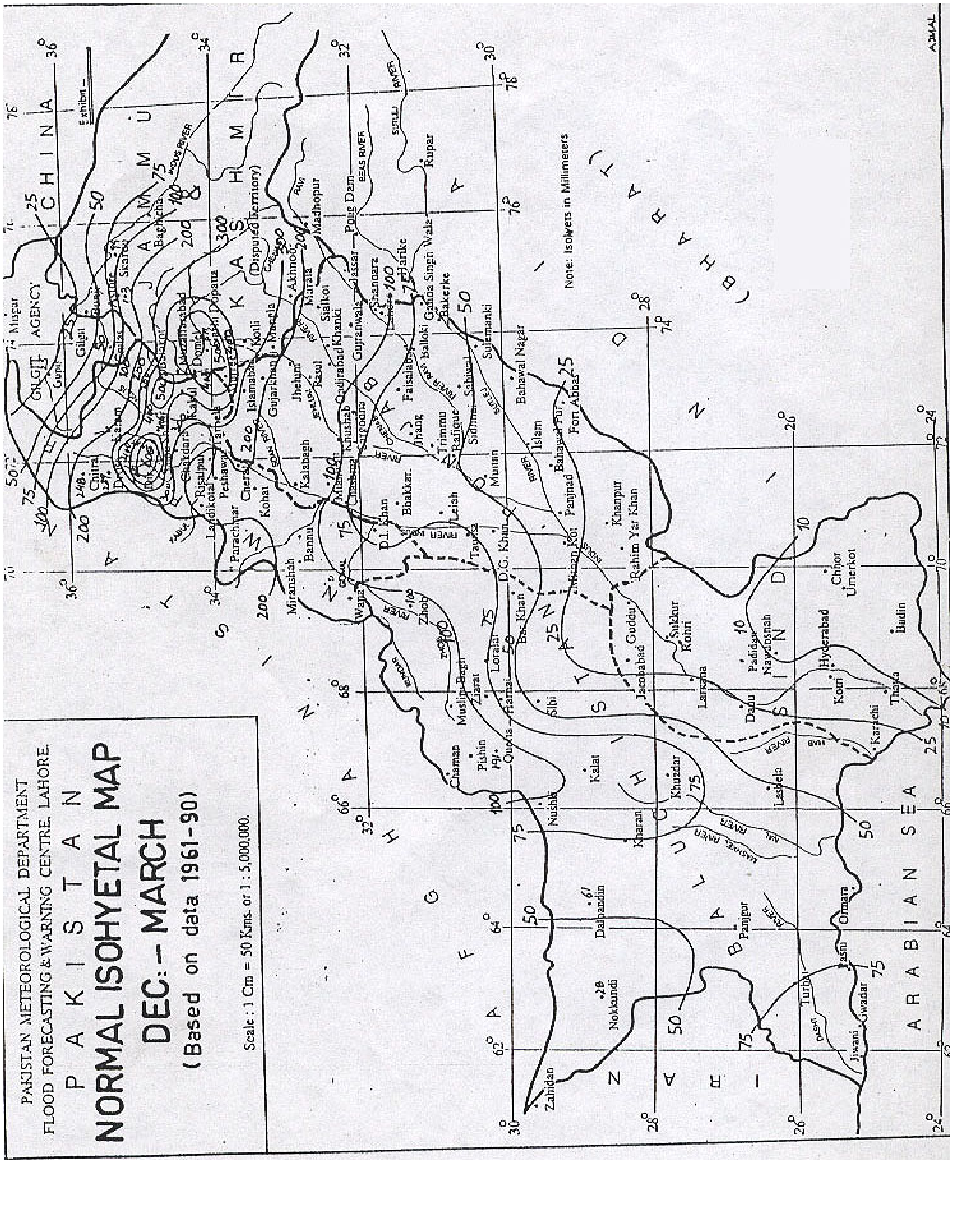
Note: The largest numbers Killed by Drought, with Hurricanes a close record.

ANNEXURE-II

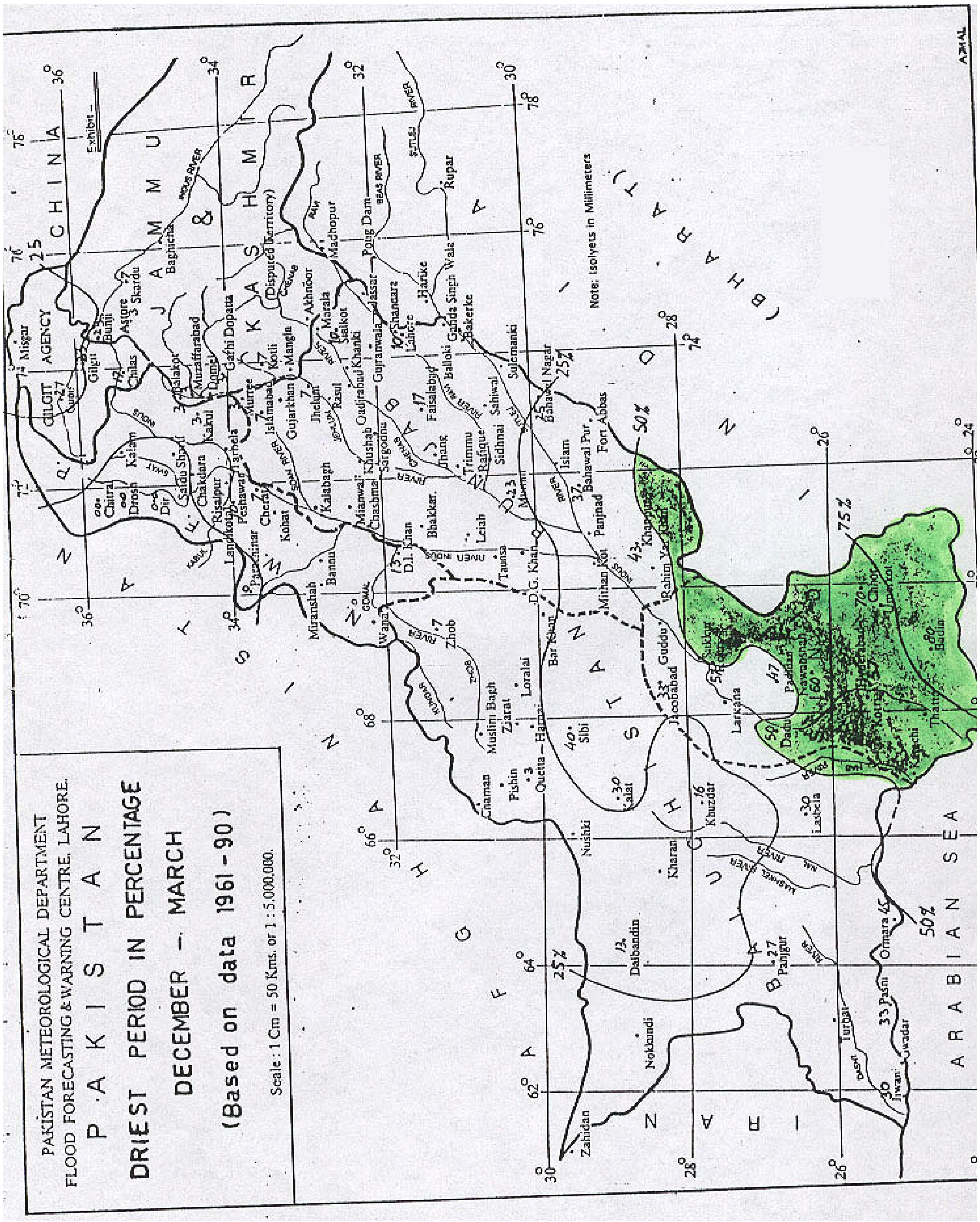
ESTIMATED WEIGHTED PRECIPITATION (IN MILLIMETERS) OVER PAKISTAN AND PROVINCES BASED ON THE NORMALS OF 1961-90

MONTH	***PAKISTAN***	***N.W.F.P.***	***PUNJAB***	***BALOCHISTAN***	***SINDH***
JANUARY	17.00	39.50	15.00	17.80	1.90
FEBRUARY	22.50	61.00	22.40	18.60	4.60
MARCH	31.00	95.30	32.00	22.00	5.10
APRIL	19.70	66.70	20.70	11.90	3.10
MAY	13.20	39.80	15.80	8.20	2.40
JUNE	14.00	27.70	24.60	5.40	10.00
JULY	62.50	95.40	108.40	28.60	56.90
AUGUST	55.40	94.00	93.60	23.00	52.40
SEPTEMBER	19.50	35.80	33.70	7.20	18.20
OCTOBER	5.70	21.10	6.40	2.10	2.40
NOVEMBER	4.90	16.60	4.90	2.70	2.00
DECEMBER	12.40	33.00	11.70	10.90	2.60
ANNUAL	**277.80**	**625.90**	**389.20**	**158.40**	**161.40**

Annexure - III



Annexure - IV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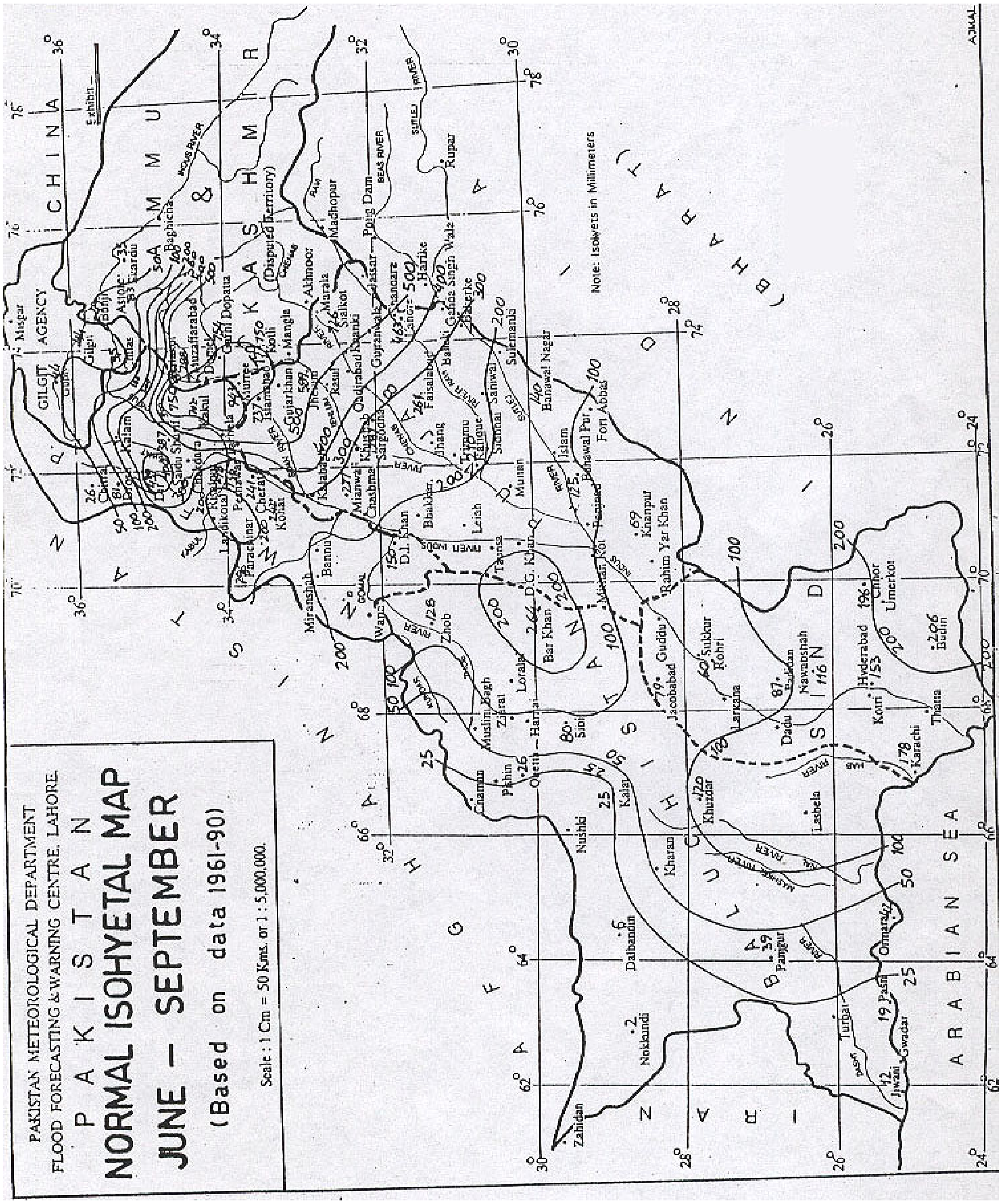
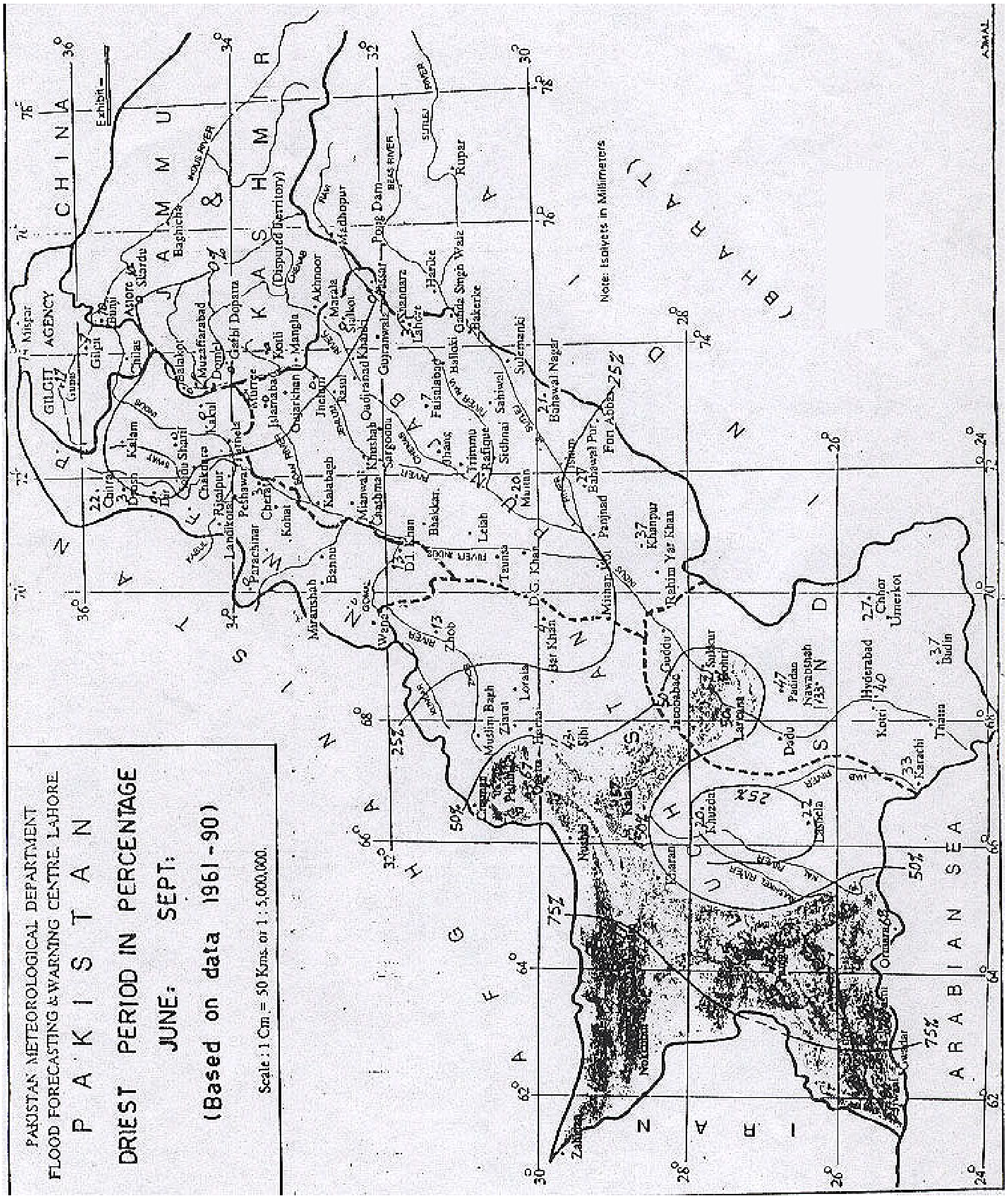
FLOOD FORECASTING & WARNING CENTRE, LAHORE.
PAKISTAN
DRIEST PERIOD IN PERCENTAGE
DECEMBER – MARCH
(Based on data 1961-90)
Scale: 1 Cm = 50 Kms. or 1 : 5,000,000.
Note: Isolyets in Millimeters
ARABIAN SEA

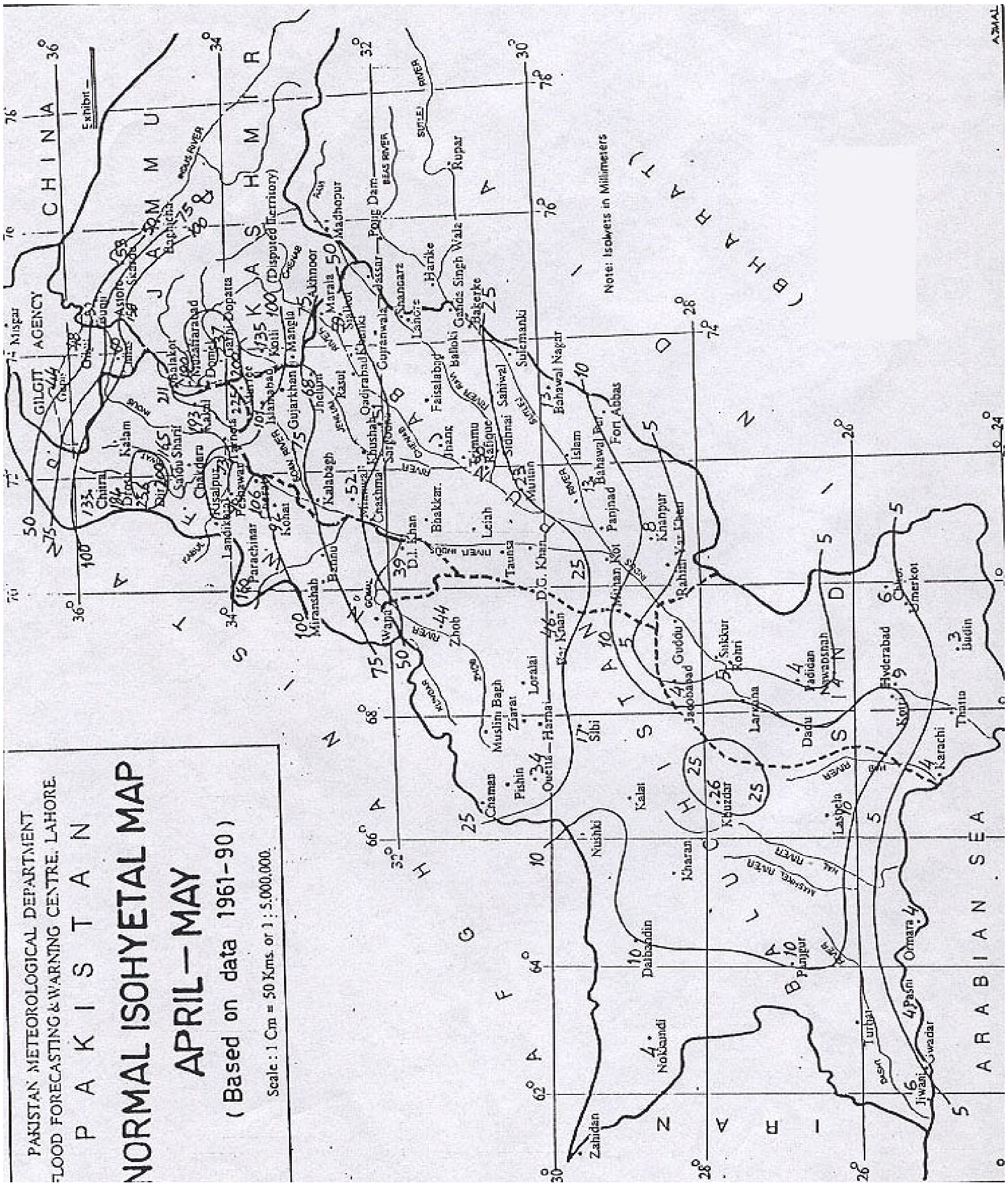
Annexure - V


PAKISTAN METEOROLOGICAL DEPARTMENT
FLOOD FORECASTING & WARNING CENTRE, LAHORE
P A K I S T A N
NORMAL ISOHYETAL MAP
JUNE – SEPTEMBER
(Based on data 1961-90)
Scale : 1 Cm = 50 Kms. or 1 : 5,000,000.
Note: Isohyets in Milimeters
ARABIAN SEA

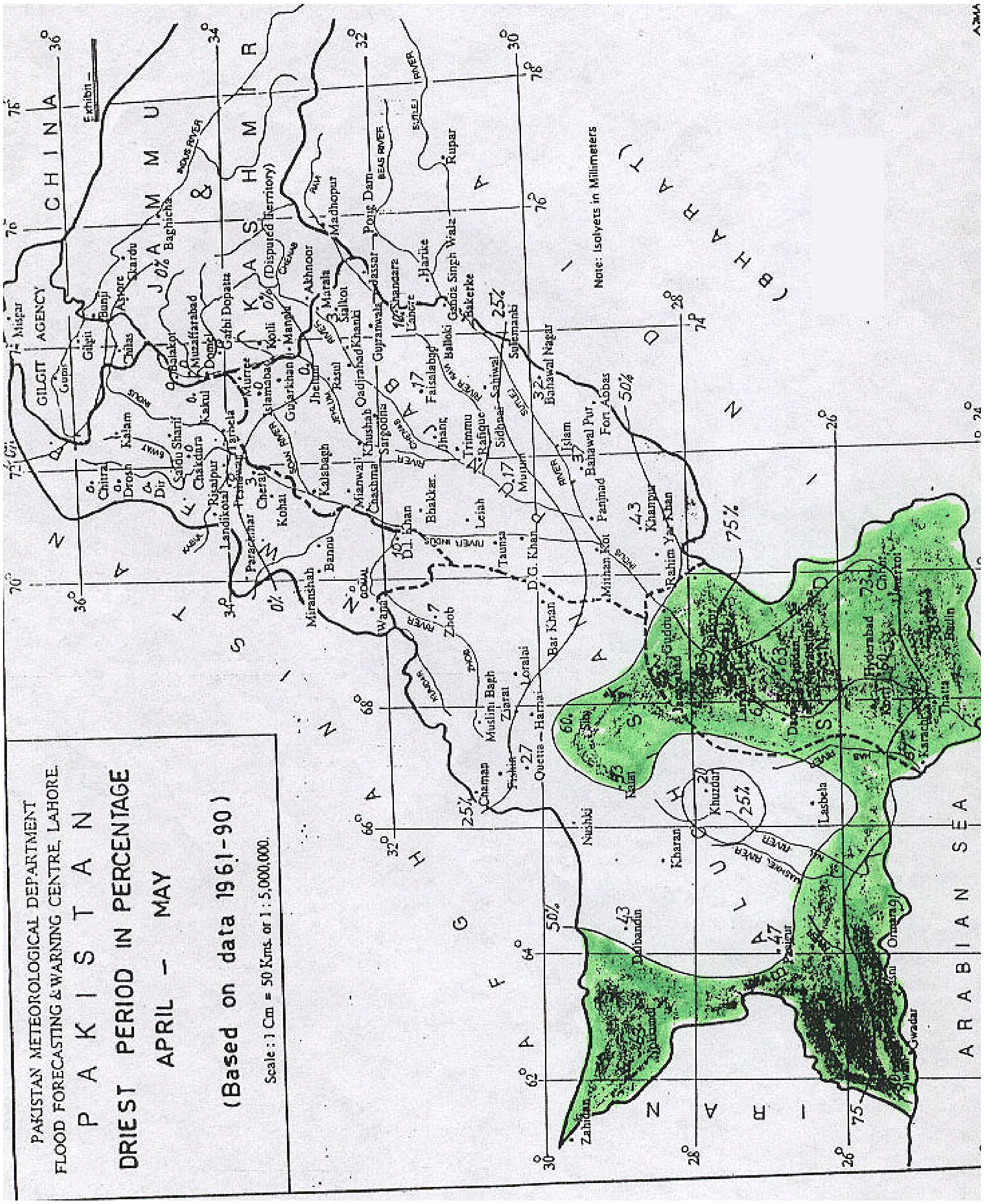
Annexure - VI


PAKISTAN METEOROLOGICAL DEPARTMENT
FLOOD FORECASTING & WARNING CENTRE, LAHORE
P A K I S T A N
DRIEST PERIOD IN PERCENTAGE
JUNE: SEPT:
(Based on data 1961-90)
Scale: 1 Cm = 50 Kms. or 1 : 5,000,000.
Note: Isolvets in Millimeters
C H I N A
A R A B I A N S E A

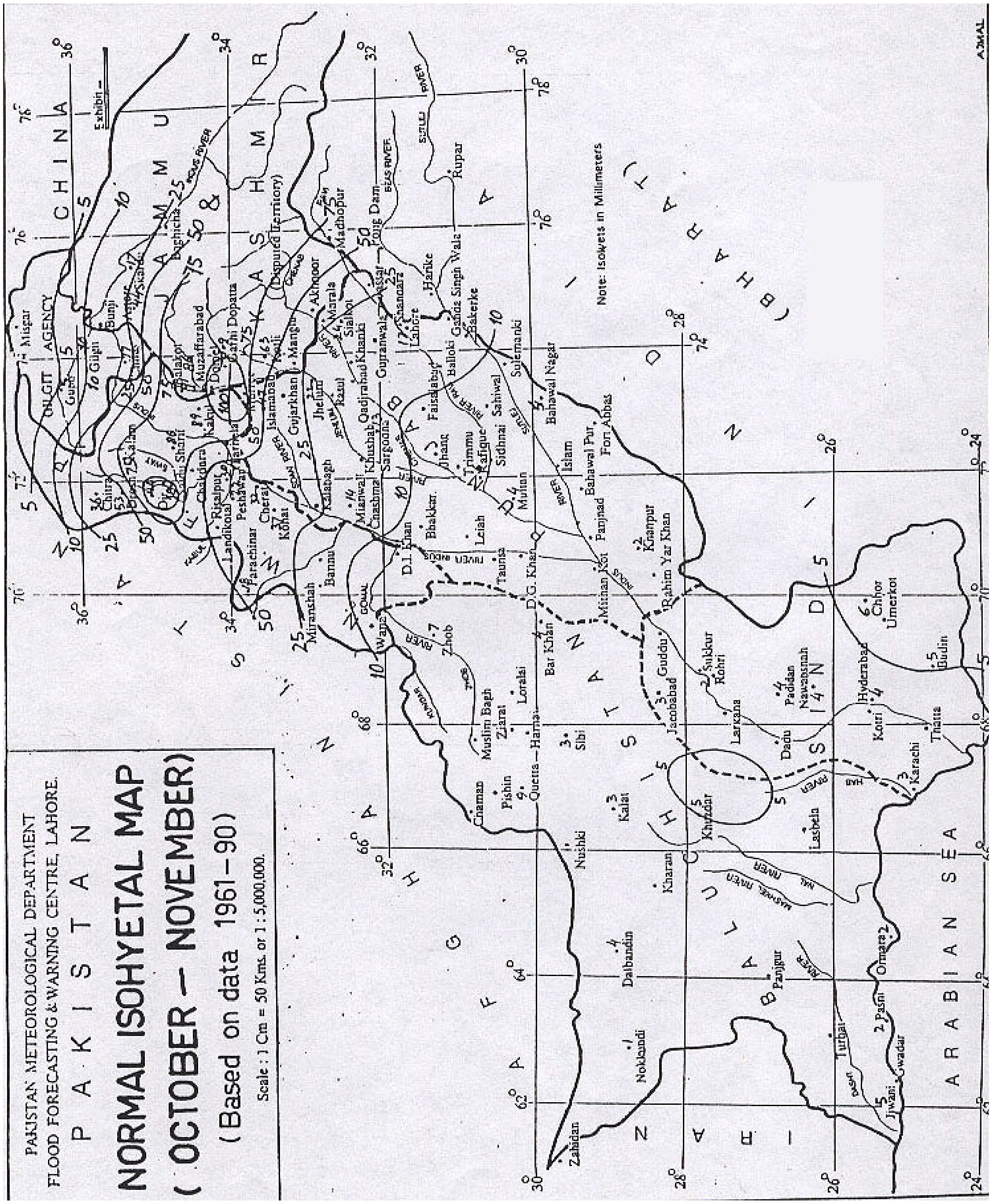
Annexure - VII



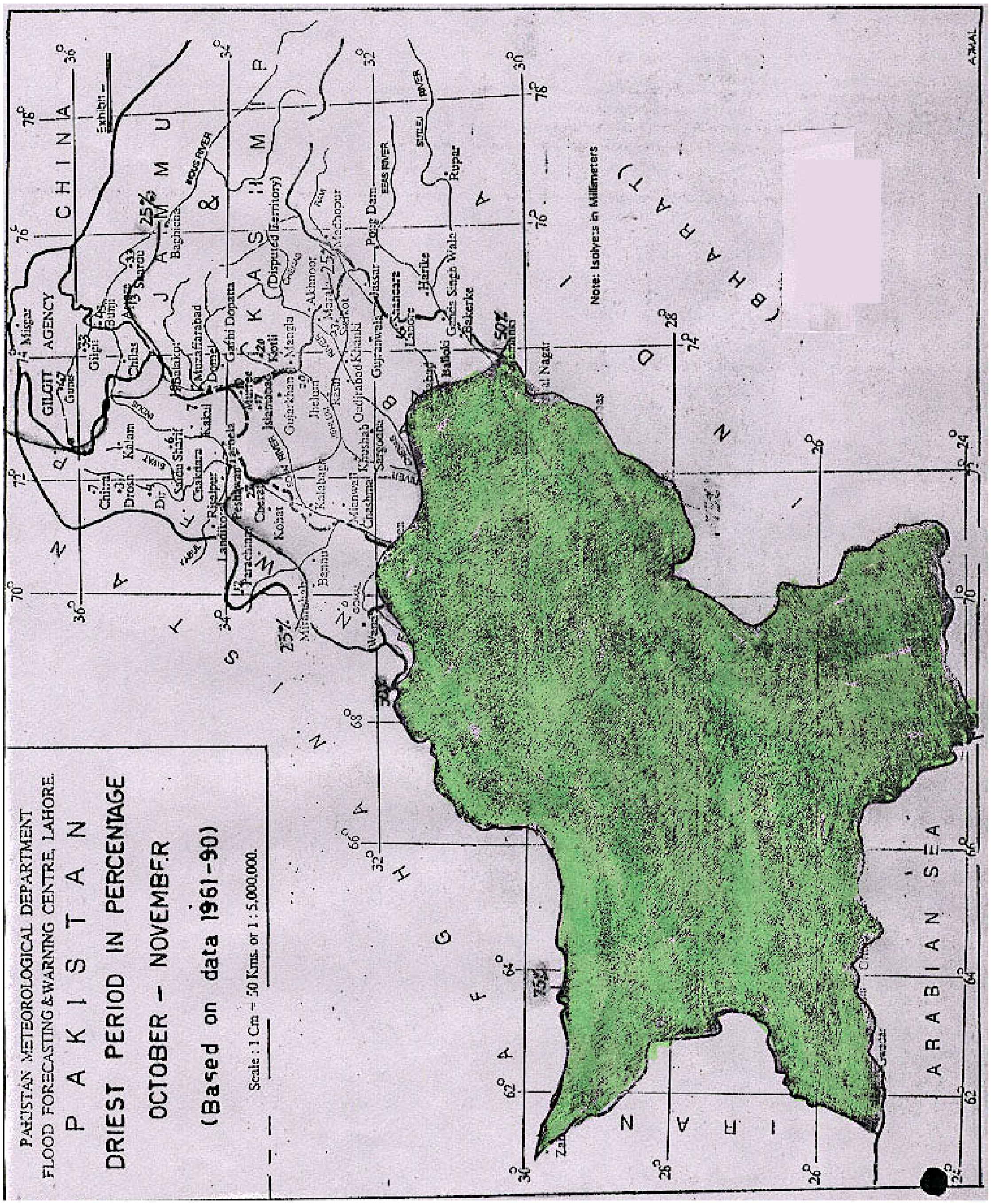
Annexure - VIII



Annexure - IX


PAKISTAN METEOROLOGICAL DEPARTMENT
FLOOD FORECASTING & WARNING CENTRE, LAHORE.
P A K I S T A N
NORMAL ISOHYETAL MAP
(OCTOBER — NOVEMBER)
(Based on data 1961–90)
Scale : 1 Cm = 50 Kms. or 1 : 5,000,000.
Note: Isohyets in Millimeters
C H I N A
A R A B I A N S E A

Annexure - X


PAKISTAN METEOROLOGICAL DEPARTMENT
FLOOD FORECASTING & WARNING CENTRE, LAHORE.
P A K I S T A N
DRIEST PERIOD IN PERCENTAGE
OCTOBER – NOVEMBER
(Based on data 1961-90)
Scale : 1 Cm = 50 Kms. or 1 : 5,000,000.
Note: Isolyers in Millimeters
C H I N A
J A M M U & K A S H M I R
(Disputed Territory)
(B H A R A T)
A F G H A N I S T A N
I R A N
A R A B I A N S E A

POLICY-DOCUMENT ON DROUGHT PREPAREDNESS & CRISIS-MANAGEMENT IN THE PROVINCE OF BALOCHISTAN

*Muhammad Ahmad Gondal**

ABSTRACT

This document was prepared to understand the framework on drought-preparedness and mitigation, along with crisis-management in the area-wise largest Province of Pakistan. Balochistan has a rich history back to the Stone Age; then, as now, people depended on natural resources of this arid region. The Government is now determined to achieve prosperity and progress for the people of Balochistan. It intends to achieve this through the optimal use of resources, new policy- initiatives, financial discipline, and balanced combination of approaches on inter-sectoral and inter-regional development. The document describes a practical step-by- step process for identifying actions that can be taken to reduce potential drought-related impacts before a drought occurs, viz.

***Step 1:** begins with making sure that the right people are brought together and supplied with adequate data to make informed and equitable decisions during the process.*

***Steps 2 and 3:** narrow the focus of the study, by identifying high-priority drought-related impacts that are relevant to the user's location or activity.*

***Step 4:** demonstrates that, in order to reduce the potential for the identified impacts to occur in the future, it is necessary to understand the underlying environmental, economic and social causes of the impacts.*

***Finally, Steps 5 & 6:** utilize all of the previous information to identify feasible, cost-effective and equitable actions that can be taken to address the identified causes. In this manner, with a few subsequent steps, true drought-vulnerabilities can be addressed that will subsequently reduce drought-related impacts and risk.*

GLOSSARY OF TERMS

Below are definitions for terms that appear within this document. Several of these terms have other definitions that are commonly used elsewhere, depending on the discipline or perspective. In this case, the definitions have been tailored to the natural hazard of drought.

Acceptable Risk: A level of vulnerability that is considered to be "acceptable", balancing factors such as cost, equity, public input, and the probability of drought.

Crisis Management: An approach for dealing with drought, where responses and actions are made during the event, with no prior planning, sometimes leading to ineffective, poorly coordinated, and untimely initiatives by individuals or governments.

Drought: A deficiency of precipitation from the accepted or "normal" that, when extended over a season or longer period of time, is insufficient to meet demands. This may result in economic, social, and environmental impacts. It should be considered a normal, recurrent feature of climate. Drought is a relative, rather than absolute condition that should be defined for each region. Each drought differs in intensity, duration, and spatial extent.

Drought Contingency-Plan: A document that identifies specific actions that can be taken before, during and after a drought, to mitigate some of the impacts and conflicts that result frequently. These actions are triggered by a monitoring system.

Hazard: A threatening event (in this case of drought, a reduction in water-supply, or an increase in water-demand) that would make supplies inadequate to meet the demand.

Drought impact: A specific effect of drought. People also tend to refer to impacts as "consequences" or "outcomes." Impacts are symptoms of vulnerability.

* Executive Director, Environment Foundation Balochistan (EFB), 2nd Floor, Firdusi Building Jinnah Road, Quetta, Balochistan, Pakistan.

*Drought-impact assessment***:** The process of looking at the magnitude and distribution of the drought's effects.

Mitigation: short-and long-term actions, programs, or policies implemented in advance of drought, or in its early stages, to reduce the degree of risk to people, property, and productive capacity.

*Preparedness***:** Pre-disaster activities designed to increase the level of readiness or improve operational capabilities for responding to a drought-emergency. Preparedness is a mitigation action.

*Response***:** Actions taken immediately before, during, or directly after a drought, to reduce impacts and improve recovery. Response-measures are an important part of drought-preparedness, but should only be one part of a more comprehensive mitigation-strategy.

*Risk***:** The potential adverse effects of drought as a product of both the frequency and severity of the hazard and corresponding vulnerability.

Risk Analysis: The process of identifying and understanding the relevant component associated with drought-risk, as well as the evolution of alternative strategies to manage that risk.

Risk Management: The opposite of crisis-management, where a proactive approach is taken, well in advance of drought, so that mitigation can reduce drought-impacts, and so relief and recovery decisions are made in a timely, coordinated, and effective manner during a drought.

Vulnerability: Characteristics of populations, activities, or the environment that make them susceptible to the effects of drought. The degree of vulnerability depends on the environmental and social characteristics of the region and is measured by the ability to anticipate, cope with, resist, and recover from drought.

Vulnerability Assessment: vulnerability-assessment provides a framework for identifying or predicting the underlying causes of drought-related impacts. Drought may only be one factor, along with other adverse social, economic, and environmental conditions that create vulnerability.

UNDERSTANDING DROUGHT

*U*nfortunately, we tend to focus on drought when it is upon us. We are then forced to react---to respond to immediate needs, to provide what are often more costly remedies, and to attempt to balance competing interests in a charged atmosphere. That is not good policy; it is not good resource-management; and it certainly adds to the public's perception that government is not doing its job when it simply reacts when crisis strikes. To the contrary, we must take a proactive approach to dealing with drought. We must anticipate the inevitable ---- that drought will come and go--- and take an approach that seeks to minimize the effects of drought when it inevitably occurs".

(Mr. James R. Lyons, Assistant Secretary of Agriculture for Natural Resources and Environment, May 1994.)

In drought management, making the transition from crisis to risk-management is difficult because little has been done to understand and address the risk associated with drought. To promote the process, this document presents a guide to assist individuals and organizations, through a process of identifying specific actions that can be taken to reduce short and long-term risks. Although based on natural-hazard theory, this is flexible enough to be tailored to any particular region or province, as a straightforward and practical tool for all drought-managers. The approach may be new to some natural-hazard managers since traditional hazard-risk assessment is often limited to comparison of the likelihood of a disaster with currency-value of potential losses or impacts. These comparisons are then used to decide whether it is economically favorable to prepare for certain disasters. This strategy, however, recognizes that impact-assessment and economic analysis only partially accomplish risk-management. To be complete, risk-management must also address issues of vulnerability and the equity of efficiency-cost, and urgency of possible actions.

Therefore, this guide focuses on identifying and ranking the priority of relevant drought-impacts, examining the underlying environmental, economic, and social causes of these impacts; and then choosing actions that will address these underlying causes. In a sense, what make this guide different and more helpful than previous methodologies is that it addresses the "whys" behind drought-impacts, which are the true causes of vulnerability, rather than specific impacts. Until now, almost all drought-responses have been reactions to the impacts. This guide provides its users the opportunity to identify mitigation-actions that can be taken to lessen vulnerability to future droughts.

STEP-1: GETTING STARTED

For this type of interdisciplinary analysis, it is essential to bring together the right group of people and supply them with adequate data to make fair, efficient, and informed decisions pertaining to drought-risk. This group's knowledge will need to encompass several aspects of environmental, economic, and social topics. Any shortfall in information or perspective could lead to results that fall far short of planning goals.

STEP-2: DROUGHT IMPACT-ASSESSMENT

Impact-assessment examines the consequence of a given event or change. For example, drought is typically associated with a number of outcomes. Drought-Impact Assessments begin by identifying direct consequences of the drought, such as reduced crop-yields, livestock losses, and reservoir-depletion. These direct outcomes can then be traced to secondary consequences (often social effects), such as the forced sale of household assets or land, dislocation, or physical and emotional stress. This initial assessment identifies drought-impacts, but does not identify the underlying reasons for these impacts, as in Box I.

Box – 1: Common Types of Drought Impacts

<u>Economic Category</u>
- Agriculture
- Industry
- Tourism and Recreation
- Energy
- Financial
- Transportation

<u>Social Category</u>
- Stress and health
- Nutrition
- Recreation
- Public Safety
- Cultural Values
- Aesthetic Values

<u>Environmental Category</u>
- Animal / Plant
- Wetland
- Water Quality

The assessment would yield a range of impacts related to the severity of drought. In addition, by highlighting past, current, and potential impacts, trends may become evident that will also be useful for planning purposes. These impacts highlight sectors, populations, or activities that are vulnerable to drought, and when evaluated with the probability of drought occurrence, identify varying levels of drought-risk.

STEP-3: RANKING THE IMPACTS

The impacts should then be ranked according to the most important impacts. To be effective and equitable, the ranking should take into consideration concerns, such as cost, area extent, trends over time, public opinion, fairness and the ability of the affected area to recover. The general public, community advisory committees, and group of relevant scientists and policy-makers can be included in the process of ranking. However, it is recommended that, as in all decision-making activities, as many groups as possible be represented for informed and equitable policy-formulation. In choosing the impacts of highest priority, it may be helpful to ask some of the following questions:

- Which impacts are important to the affected individual's or group's way of life?
- If impacts are not distributed evenly, should hard-hit groups receive greater attention?
- Is there a trend of particular impacts becoming more of a problem than others?

It may be also useful to develop some kind of matrix, as shown in Table-1 below, to help organize the information used in the decision-making.

Table – 1: Decision-Matrix for Drought-Impacts

Impacts	Cost	Equally Distributed?	Growing?	Public Priority?	Equitable Recovery?	Impact Rank

From this list of prioritized impacts, the next need is to decide which impacts should be addressed and which are too small to warrant attention in this forum. No impacts should be ignored, but they may be deferred to another forum for discussion or postponed until the impacts of higher priority have been addressed. Again, the previously mentioned concerns (urgency, equity, etc.) should be taken into account.

The result of this step is the development of a list of the impacts of highest priority that are relevant to your particular region or activity and supported by scientific researchers, policy makers, and the public. These impacts can then be investigated further (see step-4).

STEP-4: VULNERABILITY ASSESSMENT

Vulnerability-Assessment provides a framework for identifying the social, economic, and environmental causes of drought-impacts. It bridges the gap between impact-assessment and formulation of policy by directing attention to underline the causes of Vulnerability, rather than to its result, the negative impacts, which follow triggering events such as drought; for example, the direct impact of a lack of precipitation may be reduced crop-yields. The underlying cause of this vulnerability, however, may be that the farmers did not use drought-resistant seeds, either because they did not believe in their usefulness, or the costs were too high, or because of some commitment to cultural beliefs. Another example of an impact could be a farm foreclosure. The underlying cause of this vulnerability could be many things, such as small farm-size because of historical land-appropriation policies, lack of credit for diversification options, farming on marginal lands, limited knowledge of possible farming-options, a lack of local industry for off-farm supplemental income, or government politics (state, national, or international).

Therefore, for each of the identified impacts that are relevant to your application, begins asking why have (might) these impacts occurred (occur)? It is important to realize that a combination of factors might produce a given impact (i.e., environmental, economic, and social factors). It might be beneficial to make a diagram of this causal relationship in some form of a tree-diagram. Two examples are shown in Figures-1 and 2. Figure-1 demonstrates a typical agriculture example and Figure-2, a potential urban scenario. Depending on the level of analysis, this process can quickly become somewhat complicated. That is why it is necessary to have the right mix of people working on the project who have knowledge of the relevant topics. Appendix-1 lists many factors that typically make an area vulnerable to drought; these should be considered when forming your tree-diagrams.

The tree-diagrams illustrate the complexity of understanding drought impacts. The two examples provided are neither meant to be comprehensive or represent an actual location. Basically, their main purpose is to demonstrate that impacts must be examined from several perspectives in order to expose their true underlying causes. For this assessment, the lowest causes on the tree diagrams, the items in boldface of the tree diagrams will be referred to as basal causes. These basal causes are the items that have the potential to be acted upon in order to reduce the associated impact. Of course, some of these impact causes should not be or cannot be acted on for a wide variety of reasons (discussed in step-5).

STEP 5: ACTION IDENTIFICATION

Once drought-impact priorities have been set and the corresponding underlying causes of vulnerability have been exposed, it is time to identify actions that are appropriate for reducing risk of drought. In accordance with the overall goal of drought-mitigation rather than drought-response, we emphasize that mitigative actions should be identified before potential response actions.

Again it may be useful to develop some kind of a matrix (like table-2) in the decision-making. This matrix expands on the impact, of "income loss from crop failure" from the agriculture example in step-4. The matrix lists the impact, as well as the described basal causes, of the impact. From this point, begin to investigate what actions could be taken to address each of these basal causes. The following sequence of questions may be helpful in identifying potential actions:

First, Can the basal cause be mitigated (can it be modified before a drought)? If yes, then how?

Second, Can the basal cause be responded to (can it be modified, during or after a drought)? If so, then how?

Third, Is there some basal cause, or aspect of the basal cause, that cannot be modified and must be accepted as a drought-related risk for the activity or area.

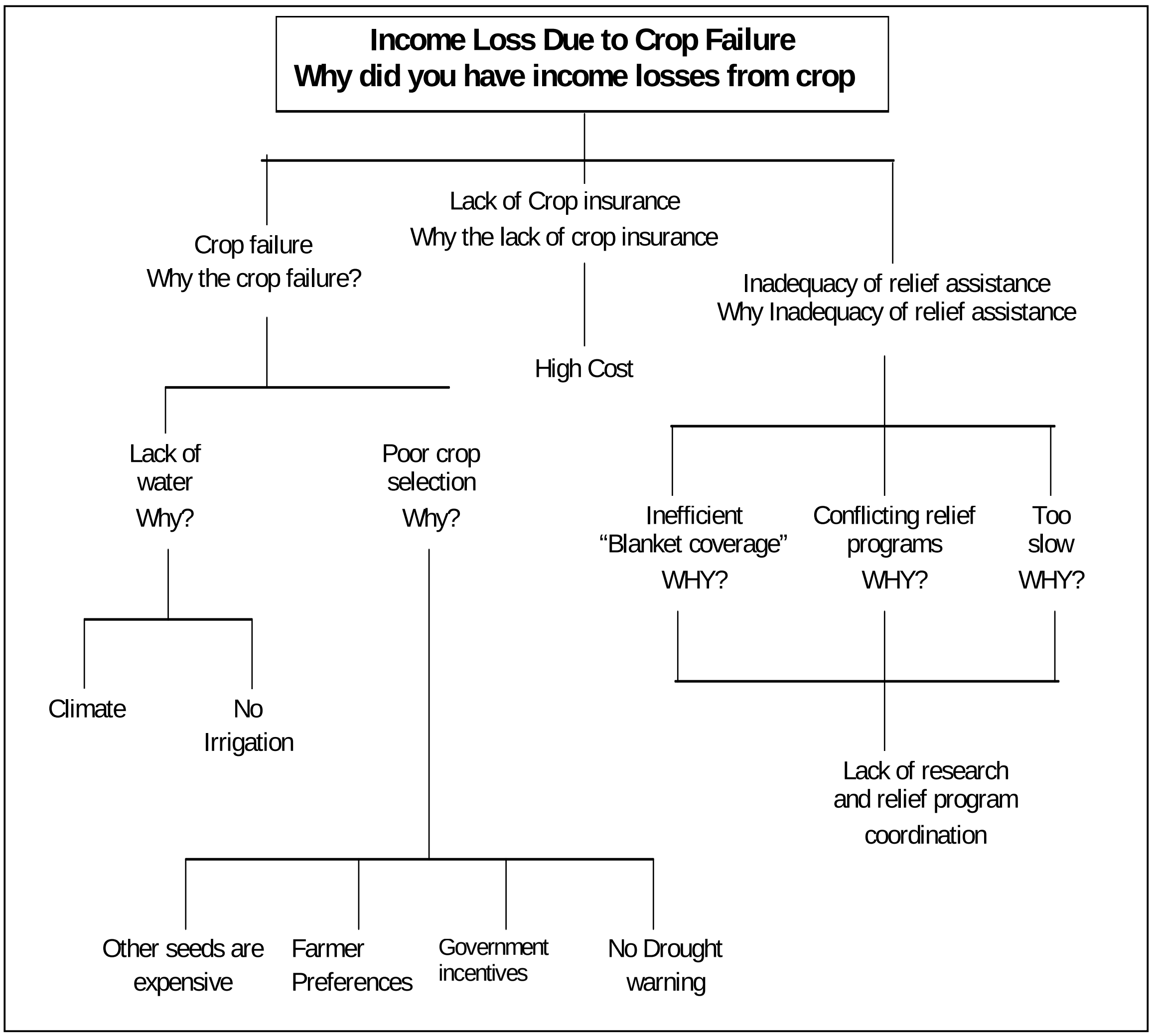


Figure - 1. An example of a simplified agricultural impact tree diagram. Notice that the boldface items represent the basal cause of the listed impact. Although these items may be broken down further, as in Appendix F, this example illustrates the vulnerability-assessment process.

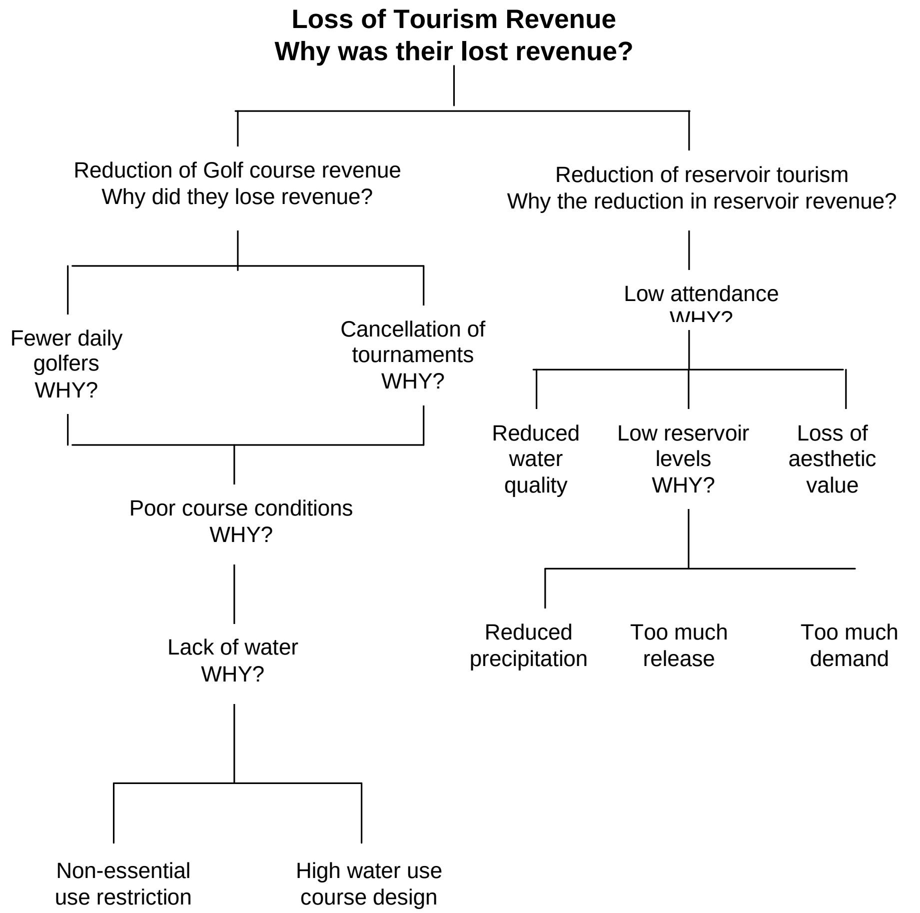


Figure 2. An example of a simplified urban impact tree diagram. Notice the boldface items represent the basal cause of the listed impact(in this case, the loss of tourism revenue). Although these items may be broken down further, as in Appendix G, this example illustrates vulnerability assessment process

Table – 2: Drought-Risk Action Identification Matrix

Impact of Drought	**Underlying causes of Vulnerability (Basal causes of the Why Questions)**	**Possible Actions**	**Mitigation (M), Response (R), or Accepted Risk (AR)**	**Feasible?**	**Effective for impact reduction?**	**Benefit / Cost?**	**Equitable?**	**To Do?**
Income loss from crop-failure	Variable climate	Weather modification	M					
		Weather monitoring	M					
	NO irrigation	Haul water during a drought	R					
		Provide Government-assistance for project	M					
	Expensive seeds	Subsidize seed sales	M					
	Farmer preferences to plant specific seeds	Conduct workshops	M					
		Conduct research	M					
		Enhance communication	M					
	Government incentives to plan specific crops	Lobby for new incentives	M					
	No drought-warning	Provide weather-monitoring	M					
		Identify “triggers”	M					
	High cost of crop-insurance	Government subsidies	R					
	Lack of research as to the efficiency of drought-relief efforts	Identify target-groups and conflicting relief-program criteria and goals	M					
	Lack of drought relief program coordination	Streamline relief application and funding	M					

STEP-6: DEVELOPING THE "TO DO" LIST

Now that the impacts, causes, and relevant potential actions have been identified, the next step is to choose which actions to take in planning your risk-reduction. This selection should be based on such concerns as feasibility, effectiveness, cost, and equity. Additionally, it will be equally important to review the impact tree-diagrams when considering which groups of actions need to be considered together. For example, if it is wanted to reduce crops-losses by promoting the use of a different type of seed, it probably wouldn't be very effective to educate farmers on the benefits of the new variety if it is too expensive for them to use, or there are high government-incentives for planting other crops.

In choosing the appropriate actions, it might be helpful to ask some of the following questions:

- What are the cost/benefit ratios?
- Which actions are deemed feasible and appropriate by the general public?
- Which actions are sensitive to the local environment (i.e., sustainable practices)?
- Are the actions addressing the right combination of causes, to adequately reduce the relevant impact?
- Are the actions addressing short-term and long-term solutions?
- Which actions would fairly represent the need of affected individuals and groups?

Again, a matrix (such as Table-2) may be useful for organizing the concerns regarding relevant actions. Once the appropriate risk-reduction actions have been chosen, they should be compiled in a comprehensive, explanatory form. It is suggested that the "To Do" list be split into actions that are to be taken now, versus those that are to be performed during, or after, a drought. In addition, it may be helpful to clarify the areas of vulnerability that have been identified as falling under the acceptable-risk categories.

This process has the potential to lead to the identification of effective and appropriate drought-risk reduction activities, rather than ad-hoc responses or un-researched mitigation plans that may have little effect on reducing drought-impact in the future.

CONCLUSION

Upon completion of Step 6, the risk consistent is finished. The user has gone through a process to identify drought impacts, vulnerabilities, and the underlying causes of those vulnerabilities. Perhaps most importantly, the user has identified a "to do" list of actions that can lead to long-term mitigation of these impacts. Drought-mitigation actions have always been difficult to identify because of the lack of systematic approaches to do so. This guide stops short of suggesting methods of implementing any of the actions identified.

The development of a drought contingency-plan provides an excellent opportunity to use this guide. In these cases, many of the people needed to complete the guide have already been assembled. In addition, completing this consistent will also provide important information useful in constructing a plan. For example, the mitigation actions identified, by using the guide, can then be included within the plan. It would also be useful for those interested in reviewing and updating any drought-plans. Completion of the analyses as part of a post-drought evaluation would be another valuable opportunity, providing information on how efforts of mitigation, response, and recovery can be improved before the next drought. Finally, because vulnerability is dynamic, it would be beneficial to periodically complete a drought-risk consistent in order to assess how vulnerability is changing and to maintain an appropriate level of preparedness.

THE CHALLENGE

After a major drought, it was important to study the causes and impacts of the event, and let us recognize that has not been met so far.

As a citizenry, we must remember the apparent lessons learned from drought and act on them to prepare for the next drought. May we urge federal governments to decide: How to coordinate drought-related programmes and how to integrate them with ongoing federal – provincial drought-programmes and the efforts of civil society.

Unless and until these basic steps are taken, this country will perhaps continue to rely on taxpayers-funded emergency relief after drought, and probably forget to prepare for the next drought.

Let us develop a National Drought Policy Statement, with preparedness as its foundation, and with a request to Honorable President Islamic Republic of Pakistan to endorse the policy through a National Drought-Preparedness Act, which may ultimately create National Drought Policy Commission.

Second, we should outline a course of action that includes a preparedness initiative, to help reduce the damages and costs of drought.

Third, we envision a federal / provincial partnership to ensure that federal drought-programmes are better coordinated, that they are better integrated with provincial and non-federal programmes, and that their services are more efficient, effective and driven by customer-needs.

It will take commitment and resolve to achieve the goals of national drought-policy. We therefore call on the Chief Executive and the Federal Government to provide sufficient resources to carry out the possible recommendations of the National Commission. Allocation of funds may be based on consideration of the costs and benefits associated with drought-preparedness, proactive mitigation and response-measures.

National Drought Policy may use the resources of the federal government to support, but not supplant nor interfere with, provincial, local tribal and personal efforts to reduce impacts of drought. The guiding principles of National Drought Policy should be:

1. Favour preparedness over relief, and incentives over regulations.

2. Set research priorities, based on the potential of research-results, to reduce drought-impacts.

3. Coordinate the delivery of federal service, through cooperation and collaboration with provincials.

This policy requires a shift from the current emphasis on drought-relief. It means that we must adopt a forward-looking stance, to reduce this nation's vulnerability to the impacts of drought. Preparedness-including drought-planning, plan-implementation, proactive mitigation, risk-management, resource stewardship, consideration of environmental concerns and public education -- must become the corner stones of national drought policy.

We believe that the primary need to prepare for drought is to develop the capability to produce a wealth of basic weather, water, soil-moisture, snow-amount and climate observations. Therefore, we should join and get access to national, regional & global climate-study centers, climatologists, universities and private institutions in order to develop the information needed for effective drought-preparedness along with strengthening or establishing federal-provincial monitoring and prediction-programmes. These programmes should provide data to all concerned weather-services and other enterprises, which may opt to devise detailed predictions, tailored to areas or individual needs. Use of remote-sensing technology may be another option, to show potential area farmers of crop-stress, so that the farmers can make more efficient irrigation-decisions.

We further believe that preparedness, including planning, plan implementation, reflection-planning, proactive mitigation measures, and public education, could well reduce the social, economic and environmental impacts of drought and the need for federal relief- expenditures in drought-stricken areas. Preparedness may lessen conflicts over competition for water during drought.

At provincial level, we are committed to establish Mitigation and Crisis Management Centre (MCMC) at Quetta. One of the biggest challenges for successful drought-planning is getting all the right groups of people to communicate effectively with one another. Three main groups will be involved:

- Climatologists and others, who shall monitor how much water is available now, and in the foreseeable future. (Monitoring Committee).
- Natural-resource managers and others who determine how lack of water is affecting various interests, such as agriculture, recreation, municipal supplies, etc (Risk Assessment Committee).
- High-level decision-makers, elected and appointed officials, who have the authority to act on information they receive about water-availability and effects of drought (Drought Task Force).
- Getting these three groups functioning is the core of a successful drought-plan which is step-5 in a general 10-step process that can be tailored to the needs of an individual district, region (a bunch of districts) or for the province.

THE 10 STEPS ARE

- Appoint a Drought Task-Force.
- Define the Purpose and Objective of the Drought-Plan.
- Seek stakeholder's participation and Resolve Conflict.
- Inventory Resources and Identify Groups at Risk.
- Develop Organizational Structure and prepare Drought-Plan.
- Integrate Science and Policy, close Institutional Gaps.
- Publicize the proposed Plan, Solicit Reactions.
- Implement the Plan.
- Develop Education Programmes.
- Post-Drought Evaluation.

The Basics of Drought Planning: A 10-Step Process

One of the biggest challenges in successful drought-planning is getting all the right groups of people to communicate effectively with one another.

Three Main Groups Need To Be Involved:

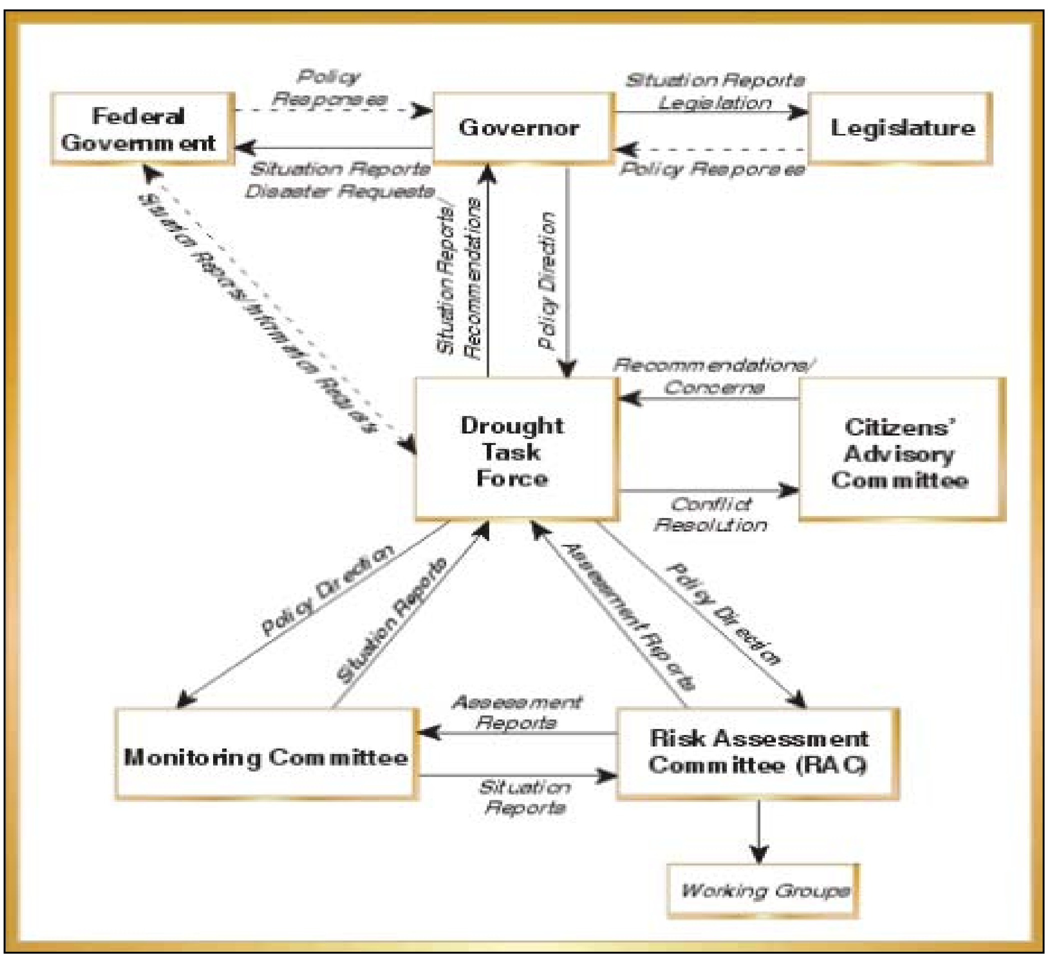
Climatologists and others who monitor how much water is available now, and in the foreseeable future. (Monitoring Committee) *natural resource managers* and others who determine how lack of water is affecting various interests, such as agriculture, recreation, municipal supplies, etc. (Risk Assessment Committee) *high-level decision makers*, often elected and appointed officials, who have the authority to act on information they receive about water-availability and drought's effects. (Drought Task Force)

Getting these three groups functioning is the core of a successful drought plan, which is step-5 in a general 10-step process that can be tailored to the needs of an individual district, province or country:

Step-1: Appoint a Drought Task Force

The drought planning process is initiated

ORGANOGRAM



through appointment of a drought task-force by the governor. The task-force has two purposes. First, it supervises and coordinates development of the plan. Second, after the plan is developed, and during times of drought when the plan is activated, the task force coordinates actions, implements mitigation and response-programs, and makes policy-recommendations to the Governor. The task-force is encouraged to oversee development of a web site that would contain information about the planning process, a copy of the plan, and current climate and water-supply information.

The task force should reflect the multidisciplinary nature of drought and its impacts, and it should include representatives of both state and federal government agencies and universities (e.g., representatives from extension, climatologists, policy specialists, and planners). A representative from the Governor's office should be a member of the task-force. Environmental and public-interest groups and others from the private sector, including industries, can be included on the task-force, and/or on sector-specific working groups of the risk-assessment committee, or an advisory council, or they can be otherwise involved, as appropriate. The actual makeup of this task-force would be highly variable between provinces, reflecting the province's political and economic character.

Depending on the nature of recent experiences with drought, the task force may find itself in the public spotlight from the outset, or it may work in relative obscurity. No matter what the initial level of public attention is, the task force needs to incorporate people who know how to conduct effective two-way communication with the public. Ideally, the task force should include or have access to public-information official who is familiar with local media's needs and preferences and a public-participation practitioner who can help establish processes that accommodate both well-funded and disadvantaged groups.

Step-2: State the Purpose and Objectives of the Drought Plan

As its first official action, the drought task force should state the general purpose for the drought-plan. State officials should consider many questions, as they define the purpose of the plan, such as the:

- Purpose and role of provincial government in drought-mitigation and response efforts;
- Scope of the plan;
- Most drought-prone areas of the province;
- Historical impacts of drought;
- Historical response to drought;
- Most vulnerable economic and social sectors;
- Role of the plan in resolving conflicts between water-users and other vulnerable groups during periods of shortage;
- Current trends (e.g., land and water use, population-growth) that may increase/ decrease vulnerability and conflicts in the future;
- Resources (human and financial) that the state is willing to commit to the planning process;
- Legal and social implications of the plan; and
- Principal environmental concerns caused by drought.

A generic statement of purpose for a plan is to reduce the impacts of drought, by identifying principal activities, groups, or regions most at risk and developing mitigation actions and programs that alter these vulnerabilities. The plan is directed towards providing government with an effective and systematic means of assessing drought-conditions, developing mitigation-actions and programs to reduce risk in advance of drought, and developing response-options that minimize economic stress, environmental losses, and social hardships during drought.

The task force should then identify the specific objectives that support the purpose of the plan. Drought-plan objectives will, of course, vary between provinces and should reflect the unique physical, environmental, socioeconomic, and political characteristics of each province. At the state level, plan objectives will place less emphasis on measures for financial assistance (traditionally a role of the federal government) than would the objectives of a national plan. Technical assistance is a common element of National agency missions. Support for educational and research programs is typically a shared responsibility of provinces and federal government. Objectives that states should consider include the following:

- Collect and analyze drought-related information in a timely and systematic manner.
- Establish criteria for declaring drought-emergencies and triggering various mitigation and response activities.

- Provide an organizational structure and delivery-system that assures information-flow between and within levels of government.
- Define the duties and responsibilities of all agencies, with respect to drought.
- Maintain a current inventory of provincial and federal programs used in assessing and responding to drought-emergencies.
- Identify drought-prone areas of the province and vulnerable economic sectors, individuals, or environments.
- Identify mitigation-actions that can be taken to address vulnerabilities and reduce impacts of drought.
- Provide a mechanism to ensure timely and accurate assessment of impacts of drought on agriculture, industry,
- Municipalities, wildlife, tourism and recreation, health, and other areas.
- Keep the public informed of current conditions and response-actions, by providing accurate, timely information to media in print and electronic form (e.g., via TV, radio and the World Wide Web).
- Establish and pursue a strategy to remove obstacles to the equitable allocation of water during shortages, and establish requirements or provide incentives to encourage water-conservation.
- Establish a set of procedures to continually evaluate and exercise the plan, and
- Periodically revise the plan so that it will stay responsive to the needs of the provinces and state.

Step-3: Seek Participation of Stakeholders and Resolve Conflicts

Social, economic, and environmental values often clash, as competition for scarce water-resources intensifies. Therefore, it is essential for task-force members to identify all citizen-groups that have a stake in drought-planning (stakeholders) and their interests. These groups must be involved early and continuously, in order to have fair representation and effective drought management and planning. Discussing concerns, early in the process, gives participants a chance to develop an understanding of one another's varying viewpoints, and to generate collaborative solutions. Although the level of involvement of these groups will vary notably from district to district, the power of public-interest groups in policy-making is considerable. In fact, these groups are likely to impede progress in the development of plans if they are not included in the process. The task-force should also protect the interests of stakeholders who may lack the financial resources to serve as their own advocates.

Public participation takes many forms. Time and money may constrain how actively the task force can solicit input from stakeholders. One way to facilitate public-participation is to establish a citizen's advisory council, as a permanent feature of the drought plan, to help the task-force keep information flowing and resolve conflicts between stakeholders. Another way is to invite stakeholders to serve on working groups of the risk-assessment committee.

Provinces should also consider whether district or regional advisory councils need to be established. These councils could bring neighbors together, to discuss their water-use issues and problems and seek collaborative solutions. At the provincial level, a representative of each district-council should be included in the membership of the provincial citizens' advisory council, to represent the interests and values of their constituencies. The provincial citizens' advisory council can then make recommendations and express concerns to the task-force, as well as respond to requests for situation-reports and updates.

Step-4: Inventory Resources and Identify Groups at Risk

An inventory of natural, biological, and human resources, including the identification of constraints that may impede the planning process, may need to be initiated by the task force. It is important to determine the vulnerability of these resources to periods of water-shortage that result from drought. The most obvious natural resource of importance is water: where is it located, how accessible is it, of what quality is it? Biological resources refer to the quantity and quality of grasslands/range lands, forests, wildlife, and so forth. Human resources include the labor needed to develop water-resources, lay pipeline, haul water and livestock feed, process complaints of citizen, provide technical assistance, and direct citizens to available services.

It is also imperative to identify constraints to the planning process and to the activation of the plan in response to a developing drought. These constraints may be physical, financial, legal, or political. The costs associated with the development of a plan must be weighed against the losses that will likely result if no plan is in place. The purpose of a drought-plan is to reduce risk and, consequently, economic, social, and environmental impacts. Generally speaking, the costs associated with the development of a provincial-level plan have been $50,000-$100,000, plus in-kind costs to provincial and federal agencies. This price-tag seems inconsequential, in comparison to the impacts associated with drought. Legal constraints can include water rights, existing public-trust laws, requirements for public water-suppliers, liability issues, and so forth.

In drought-planning, making the transition from crisis to risk-management is difficult because, historically, little has been done to understand and address the risks associated with drought. To solve this problem, areas of high risk should be identified, as should actions that can be taken, before a drought occurs, to reduce those risks. Risk is defined by both the exposure of a location to the drought-hazard and the vulnerability of that location to periods of drought-induced water-shortages. Drought is a natural event; it is important to define the exposure (i.e., frequency of drought of various intensities and duration) of various parts of the province to the drought-hazard. Some areas are likely to be more at risk than others. Vulnerability, on the other hand, is defined by social factors, such as land-use patterns, government policies, social behavior, water-use, population, economic development, diversity of economic base, cultural composition, and so forth. The drought task-force should address these issues early in the planning-process, so that they can provide more direction to the committees and working groups that will be developed under Step 5 of the planning process.

Step-5: Develop Organizational Structure and Prepare Drought-Plan

This step describes the process of establishing relevant committees to develop and write the drought-plan and develop the necessary organizational structure to carry out its responsibilities. The drought-plan should have three primary components: monitoring, risk-assessment, and mitigation, and response. It is recommended that committees be established to focus on the first two of these needs. The drought task-force can, in most instances, carry out the mitigation and response function.

These committees will have their own terms of reference, but well-established communication and information flow between committees and the task force is a necessity, to ensure effective planning.

Task Force (Mitigation and Drought Response)

It is recommended that the task force (see Step 1), working in cooperation with the monitoring and risk-assessment committees, have the knowledge and experience to understand drought-mitigation techniques, risk analysis (economic, environmental, and social aspects), and drought-related decision-making processes at all levels of government. The drought task-force, as originally defined, is composed of senior policy-makers from various state and federal agencies. The group should be in an excellent position to recommend and/or implement mitigation actions, request assistance through various federal programs, or make policy-recommendations to the legislature and governor.

Specific responsibilities of the task force at this point are to:

i. Determine mitigation and response actions for each of the principal impact-sectors, in close cooperation with the risk-assessment committee. However, the transferability of these technologies to specific situations, in other districts, needs to be evaluated further because they may not be directly transferable in some cases. Working with the risk-assessment committee, the task-force should come up with recommendations addressing drought on two different time-scales:

   - Short-term responses to implement during drought, such as voluntary water-conservation guidelines, a ready-to-roll hay hotline, streamlined administrative procedures for evaluating emergency assistance applications, and pre-produced infomercials, leading agricultural producers and citizens to information on best management practices.

   - Long-term drought mitigation projects, such as education programs to give various audiences the background they need to interpret drought news-reports or scientific drought-indices; programs to persuade people to adopt measures that enhance organic-content in soil, conserve water, and otherwise boost the resilience of natural and social systems that are vulnerable to drought.

- Assuming there is no ongoing drought, it's a good idea to publicize the recommendations of the task-force and seek public input before the plan is implemented, particularly if anything seems revolutionary or controversial.

ii. Inventory all forms of assistance available from local, provincial, and federal government during severe drought. The task-force should evaluate these programs for their ability to address short-term emergencies and long-term vulnerability to drought. Assistance should be defined very broadly, to include all forms of technical, mitigation, and relief programs available.

iii. Work with the monitoring and risk-assessment committees to establish triggers. The monitoring committee can advise the task-force on which drought and water-supply indices are most relevant for the district or region. It is helpful to establish a sequence of descriptive terms for water-supply alert levels, such as "advisory," "alert," "emergency," and "rationing" (as opposed to more generic terms such as "phase 1" and "phase 2," or sensational terms such as "disaster"). The task-force should review the terminology used by other entities (i.e., local councils, states, river-basin commissions) and choose terms that are consistent in areas where authorities may have overlapping regional responsibilities. Federal / Provincial authorities may wish to provide technical assistance or other forms of encouragement to help local water-suppliers establish triggers for different stages of rationing before a drought.

iv. Establish drought-management areas (i.e., subdivide the province or region into more conveniently sized districts, by political boundaries, shared hydrological characteristics, climatological characteristics, or other means such as drought-probability or risk). These subdivisions may be useful in drought management, since they may allow drought-stages and mitigation and response-options to be regionalized. Climatic divisions are the most commonly used subdivisions at the Federal level, but they may not be the most appropriate, given topographic features, land-use patterns, or water-use characteristics. The task-force should work closely with the monitoring committee, to understand natural boundaries as well as limitations imposed by existing data-collection systems, and with the risk-assessment committee to understand the timing of drought's effects on different economic sectors and social groups.

v. The drought task-force should develop a web site for disseminating drought-monitoring information and for letting the public know about the drought plan. Models that could be followed are web pages for the states of Texas, Montana, Pennsylvania, Oklahoma, New Mexico, South Carolina, and Nebraska.

Monitoring Committee

A reliable assessment of water-availability and its outlook for the near- and long-term is valuable information in both dry and wet periods. During drought, the value of this information increases markedly. The monitoring committee should include representatives from agencies with responsibilities for monitoring climate and water-supply. It is recommended that data and information on each of the applicable indicators (e.g., precipitation, temperature, evapotranspiration, long-range weather forecasts, soil moisture, stream flow, ground-water levels, reservoir and lake levels, and snow pack) be considered in the committee's evaluation of the water-situation and outlook for the province. The agencies responsible for collecting, analyzing and disseminating data and information will vary according to the district organizational structure and by geographic region.

The monitoring committee should meet regularly, especially in advance of the peak-demand season. Following each meeting, reports should be prepared and disseminated to the provincial drought task-force, relevant district and federal agencies, and the media. The chairperson of the monitoring committee should be a permanent member of the drought task-force. This person may be the provincial climatologist. If conditions warrant, the task force should brief the Governor about the contents of the report, including any recommendations for specific actions. It is essential for the public to receive a balanced interpretation of changing conditions. The monitoring committee should work closely with public information specialists, to keep the public well informed.

The primary objectives of the monitoring committee are to:

i. Help policy-makers adopt a workable definition of drought that could be used to phase in and phase-out levels of district, provincial and federal actions, in response to drought. It may be necessary to adopt more than one definition of drought, in identifying impacts in various economic, social, and environmental sectors. Several indices are available (Hayes, 1998), including the Standardized Precipitation Index (McKee et al., 1993; 1995), which is gaining widespread acceptance (Guttman, 1998; Hayes et al., 1999); The commonly used Palmer Drought Severity Index (Palmer, 1965) is being replaced or supplemented as a monitoring tool in many states. The trend is for USA to rely on multiple drought-indices, as indicators of impacts in various sectors. The current thought is that no single index of drought is adequate to measure the complex interrelationships between the various components of the hydrological cycle and impacts.

ii. Help the task-force establish drought-management areas (i.e., subdivide the province or region into more conveniently sized districts by political boundaries, shared hydrological characteristics, climatological characteristics, or other means such as drought-probability or risk). The monitoring committee's advice may be particularly helpful in communicating natural watershed-boundaries, as well as the limits and constraints imposed by existing data.

iii. Develop a drought-monitoring system. In USA, most states already have a good data-collection system for monitoring climate and water-supplies and identifying potential shortfalls. Responsibility for collecting, analyzing, and disseminating the data is divided between many state and federal agencies and other entities. We in Balochistan need to develop such a monitoring system, applying appropriate tools for extracting the above data. The monitoring committee's challenge is to coordinate and integrate the analysis, so that decision-makers and the public receive early warning of emerging drought-conditions. Same action should be replicated at the National level.

The province should have to develop automated weather-data networks that provide rapid access to climatic data. These networks can be invaluable in monitoring emerging and ongoing drought-conditions. Data from them can be coupled with data available from federal agencies, to provide a comprehensive monitoring of climate and water systems. Data and data-products should be disseminated on a timely basis, in printed form and electronically via the World Wide Web.

iv. Meteorological data are important but represent only one part of a comprehensive monitoring system. Other physical indicators (soil moisture, stream flow, reservoir and ground-water levels) must be monitored to reflect impacts of drought on agriculture, households, industry, energy production, and other water-users. Helpful technology includes soil-moisture sensors, automated weather-stations, and satellite data, such as digital data obtained from the Advanced Very High Resolution Radiometer (AVHRR), transmitted from a National Oceanic and Atmospheric Administration satellite, which is useful in detecting areas where moisture-deficiencies are affecting growth of vegetation. Much of this data will be integrated under the Unified Climate Access Network (UCAN).

v. Work closely with the task-force and risk-assessment committees, to determine the data needs of primary users. Developing new or modifying existing data-collection systems is most effective when the people who will be using the data are consulted early and often.

Soliciting input on expected new products, or obtaining feedback on existing products, is critical to ensuring that products meet the needs of primary users and will be used in decision-making. Training on how to use or apply products in routine decision-making is also essential.

vi. Develop and/or modify current data and information-delivery systems. People need to be warned of drought as soon as it is detected, but often they are not. Information needs to reach people, in time for them to use it in making decisions. In establishing information-channels, the monitoring committee needs to consider when people need various kinds of information. These decision-points can determine whether the information provided is used or ignored.

Risk Assessment Committee

Drought impacts cut across many sectors and across normal divisions of responsibility of district, provincial, and federal agencies. These impacts have been classified by Wilhite and Vanyarkho (2000) and are chronicled in the “Impacts” section of the NDMC’s website. Risk is the result of exposure to the drought-hazard (i.e., probability of occurrence) and societal vulnerability, represented by a combination of economic, environmental, and social factors. Therefore, to reduce vulnerability to drought, it is essential to identify the most significant impacts and assess their underlying causes.

The membership of the risk-assessment committee should represent economic sectors, social groups, and ecosystems most at risk from drought. The committee’s chairperson should be a member of the drought task-force. The most effective approach to follow in determining vulnerability to, and impacts of, drought is to create working groups under the aegis of the risk-assessment committee. The responsibility of the committee and working groups is to assess sectors, population groups, and ecosystems most at risk and identify appropriate and reasonable mitigation measures to address these risks. Working groups would be composed of technical specialists and stakeholders representing those areas referred to above. The chair of each working group, as a member of the risk-assessment committee, would report directly to the committee. Following this model, the responsibility of the committee is to direct the activities of each of the working groups and make recommendations to the drought task-force on mitigation actions.

The number of working groups will vary considerably between provinces. For instance, Colorado state in USA has identified eight impact working-groups: municipal water, wildfire protection, agricultural industry, commerce and tourism, wildlife, economic, energy loss, and health. State Idaho’s drought plan outlines the responsibilities of five subcommittees: water data, public information, agriculture, municipal supplies and water quality, and recreation and tourism. New Mexico uses four sub-groups: agricultural; drinking water, health, and energy; wildlife and wildfire protection; and tourism and economic impact. Nebraska’s drought-plan identifies two working groups: agriculture, natural resources, wildlife, tourism, and recreation; and municipal water supply, health, and energy.

A methodology for assessing and reducing the risks associated with drought has recently been completed as a result of collaboration between the NDMC and the Western Drought Coordination Council’s (WDCC) Mitigation and Response Working Group (Knutson et al., 1998) The guide focuses on identifying and assigning priorities to drought-impacts, determining their underlying causes, and choosing actions to address the underlying causes. This methodology can be employed by each of the working groups. This effort requires an interdisciplinary analysis of impacts and management options and is divided into the following six tasks:

i. Assemble the team. Select stakeholders, government planners, and others with a working knowledge of effects of drought on primary sectors, regions, and people.
ii. Evaluate the effects of past droughts. Identify how drought has affected the region, group, or ecosystem. Consult climatological records to determine the “drought of record,” the worst in recorded history, and project what would happen if a similar drought occurred in the near future, considering changes in land-use, population-growth, and development that have taken place since that drought.

iii. Rank impacts. Determine which of drought’s effects are most urgently in need of attention. Various considerations in assigning priority to these effects include cost, spatial extent, trends over time, public opinion, social equity, and the ability of the affected area to recover.

iv. Identify underlying causes. Determine those factors that are causing the highest levels of risk for various sectors, regions, and populations. For example, an unreliable source of water for municipalities in a particular region may explain the impacts that have resulted from recent droughts in that area. To reduce the potential for drought-impacts in the future, it is necessary to understand the underlying environmental, economic, and social causes of these impacts. To do this, drought-impacts must be identified and the reason for their occurrence determined.

v. Identify ways to reduce risk. Identify actions that can be taken, before drought, that will reduce risk. In the example above, taking steps to identify new or alternative sources of water (e.g., ground water) could increase resiliency to subsequent episodes of drought.

vi. Write a “to do” list. Work with the task-force to assign priority to options according to what’s likely to be the most feasible, cost-effective, and socially equitable. Implement steps to address these actions, through existing government programs or the legislative process. This process has the potential to lead to the identification of effective and appropriate drought-risk reduction activities that will reduce long-term drought impacts, rather than ad hoc responses or untested mitigation actions that may not effectively reduce the impact of future droughts.

Step-6: Integrate Science and Policy, Close Institutional Gaps

An essential aspect of the planning process is integrating the science and policy of drought-management. The policy maker’s understanding of the scientific issues and technical constraints involved in addressing problems associated with drought is often limited. Likewise, scientists generally have a poor understanding of existing policy-constraints for responding to the impacts of drought. In many cases, communication and understanding between the science and policy communities must be enhanced if the planning process is to be successful. Integration of science and policy during the planning process will also be useful in setting research-priorities and synthesizing current understanding. The drought task-force should consider various alternatives to bring these groups together and maintain a strong working relationship.

As research needs and gaps in institutional responsibility become apparent, during drought planning, the drought task force should compile a list of those deficiencies and make recommendations (on how to remedy these) to the governor and relevant agencies. For example, the monitoring committee may recommend establishing or enhancing a ground-water monitoring program. Another recommendation may be to initiate research on the development of a climate or water-supply index, to help monitor water-supplies and trigger specific actions by provincial government.

Step-7: Publicize the Proposed Plan, Solicit Reaction

If there has been good communication with the public throughout the process of establishing a drought-plan, there may already be better-than-normal awareness of drought and drought-planning by the time the task force recommends various drought mitigation and response options. Themes to emphasize in writing news releases and organizing informational meetings during and after the drought planning process could include:

- How the droughts-plan is expected to relieve impacts of drought. Stories can focus on the human dimensions of drought, such as how it affects a farm-family; on its environmental consequences, such as reduced wildlife habitat; and on its economic effects, such as the costs to a particular industry or to the provincial overall economy.

- What it will cost to implement each option, and how it will be funded.

- What changes people might be asked to make in response to different degrees of drought, such as restricted lawn-watering and car-washing, or not irrigating certain crops at certain times.

In subsequent years, it may be useful to do “drought-plan refresher” news-releases at the beginning of the most drought-sensitive season, letting people know whether there is pressure on water supplies or reason to believe that there will be shortfalls later in the season, and reminding them of the plan’s existence and history and any associated success-stories. It may be useful to refresh people’s memories, ahead of time, on circumstances that would lead to water-use restrictions.

During drought, the task-force should work with public-information professionals to keep the public well informed of the current status of water supplies, whether conditions are approaching “trigger points” that will lead to requests for voluntary or mandatory restrictions on use, and how victims of drought can access assistance. All pertinent information should also be available on the province’s drought web-site, so that the public can get information directly from the task force without having to rely on mass media.

Step-8: Implement the Plan

Once the task force and any external constituencies have agreed on the plan, the task force and/or its designated representatives should oversee implementation of both the short-term operational aspects of the plan and long-term mitigation measures. Periodic testing, evaluation, and updating of the drought-plan will help keep the plan responsive to district or provincial needs. An ongoing or operational evaluation keeps track of how societal changes, such as new technology, new research, new laws, and changes in political leadership, may affect drought-risk and the operational aspects of the drought-plan. Drought-risk may be evaluated quite frequently, while the overall drought plan may be evaluated less often. An evaluation under simulated drought conditions (i.e., drought exercise) is recommended before the drought plan is implemented and, periodically, thereafter. The virtual drought-exercise developed in association with a recent national study conducted by the U.S. Army Corps of Engineers (Werick and Whipple, 1994) is one mechanism that has been used to simulate drought-conditions and related decisions. *It is important to remember that drought planning is a process, not a discrete event.*

Long-term mitigation measures, such as implementing policies that require conjunctive use of ground and surface water, may require drafting new legislation and finding funds to support new monitoring and regulation efforts. In any case, it is essential to recognize that reducing long-term vulnerability to drought will require a sustained effort, although it may be a matter of long-term programs undertaken by a variety of agencies.

Step-9: Develop Education Programs

A broad-based education program to raise awareness of short- and long-term water-supply issues will help ensure that people know how to respond to drought when it occurs and that drought-planning does not lose ground during non-drought years. It would be useful to tailor information to the needs of specific groups (e.g., elementary and secondary education, small business, industry, homeowners and utilities). The drought task-force or participating agencies should consider developing presentations and educational materials for events, such as a water-awareness of short- and long-term water-supply issues, to help ensure that people know how to respond to drought when it occurs and that drought-planning does not lose ground during non-drought years. It would be useful to tailor information to the needs of specific groups (e.g., elementary and secondary education, small business, industry, homeowners and utilities). The drought task-force or participating agencies should consider developing presentations and educational materials for events such as a water-awareness week, community observations of Earth Day, relevant trade-shows, specialized workshops, and other gatherings that focus on natural-resource stewardship or management.

Step-10: Post-Drought Evaluation

A post-drought evaluation or audit would document and analyze the assessment and response- actions of government, non-governmental organizations, and others, and provide for a mechanism to implement recommendations for improving the system. *Without post-drought evaluations, it is difficult to learn from past successes and mistakes, because institutional memory fades.*

Post-drought evaluations should include an analysis of the climatic and environmental aspects of the drought; its economic and social consequences; the extent to which pre-drought planning was useful in mitigating impacts, in facilitating relief or assistance to stricken areas, and in post-recovery; and any other weaknesses or problems caused or not covered by the plan. *Attention must also be directed to situations in which drought-coping mechanisms worked and where societies exhibited resilience; evaluations should not focus only on those situations in which coping mechanisms failed. Evaluations of previous responses to severe drought are also a good planning aid.*

To ensure an unbiased appraisal, governments may wish to place the responsibility for evaluating drought, and *societal response to it, in the hands of capable non-governmental organizations.*

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APPENDIX-1:
VULNERABILITY CONSIDERATIONS

Water Shortage Vulnerability Continuum (by Deborah Braver, 11/97)		
	Higher Vulnerability	**Lower Vulnerability**
Meteorological	Wide Precipitation Variation	Stable Precipitation Pattern
	Lack of Data/Single Source Data	Good Long-Term Data/Multiple Source of Data
	Passive Drought "Acceptance"	Advance Warning
	Longer Duration	Shorter Duration
	Higher Severity Shortage	Lower Severity Shortage
	Sudden Change in Supply	Gradual Changes in Supply
Supply/Demand Balance or "Institutional Drought"	Single Water Source or Low Supply Reliability	Multiple Water Source or High Supply Reliability
	Low Priority Water Rights or Low Contractual Rights	Senior Water Rights or High Contractual Rights
	Water Supply at Risk from Contamination	Protected Water Supply
	Imported Water Supply(ies)	Local Supply(ies) and Locally Controlled
	Subject to Other Natural Disasters	Low Likelihood of Other Natural Disasters
Water Use Patterns	High Growth Area/High Additional Demand	Stable or Decreasing Water Demand
	High Percent Water Use Improvements Requires EARLIER Demand Management Response	Low Percent Water Use / Efficiency Improves "Slack" in System = Requires MORE Demand Management Response
	Landscape /Ag Irrigation Usual Practices OR Landscape / Ag Dependence on Precipitation	"Climate Appropriate" Plants OR Non-irrigated Agriculture / grazing
Preparedness	Wait Until Shortage is "Declared" (or beyond …)	Early Shortage Response
	Lack of Political Will	Leadership
	Ignoring Situation/Abdication Responsibility	Preparedness/ Actions to Protect Community/ Economy/ Environment
	Non-interconnected Water Supply Systems OR Non-Collaborative Approach with Neighbors	Coordination with Others (i.e., Neighboring Water, Disasters Response and Fire Agencies, Mutual Aid agreements, etc.)
	Revenue/ Rate Instability	Rate Stabilization Fund
	"Knee Jerk" Rationing	Pre-determined and Equitable Allocation Methods
	Little Public Awareness	High Community Involvement (from all social and economic sectors)

ASSESSMENT OF WATER-QUALITY

*Iqbal H. Qureshi**

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 [his 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 which conforms 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 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 (1.4×10^{12}) cubic meters[1]. 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.

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%[1]. 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

* Scientist Emeritus, House # 211-A, Street # 18, Sector F-10/2, Islamabad, Pakistan.

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[2]. 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 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^3/a in 1950 to about 1200 m^3/a in 2000 which may soon fall below 1000 m^3/a. Average annual water availability in Pakistan based on seventy years data is mentioned in table - 2[3]. 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.

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 effluents are dumped into water-bodies. Table - 3 shows the quantity of sewage generated, along with the population in 10 major cities[4]. 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 studies in April 2000 by JIAC, in collaboration with Pak.EPA, by measuring the following parameters[5]:

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[6]. 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. 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[7].

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 may 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[8]. Such water is termed as "potable water".

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[9].

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 50μm or larger. Particles greater than 1μm in diameter are generally referred as silt and settle down on standing under gravity. However particles smaller than 1μm, 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, 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 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 filter 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[10] may be used, which are given in table - V. 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[11,12]. 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 desirable amount without any adverse effects on health.

CONCLUSION

- 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.
- 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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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

(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

Table-2: Average Annual Water-Availability In Pakistan

Source	Volume of Water (bm^3)		
	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^3 in 1959 - 60 , Low: 124 bm^3 in 1974 - 75

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

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

Industries ▸ Parameters ▾	Pharmaceutical	Tannery	Silk Mill	Paper Mill	Beverages	NEQS
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

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 ($CaCO_3$)	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

EVALUATION OF WATER-QUALITY BY CHLOROPHYLL AND DISSOLVED OXYGEN

Zahid Latif, M. Azam Tasneem, Tariq Javed, Saira Butt, Muhammad Fazil, Mubarik Ali & M. Ishaq Sajjad*

ABSTRACT

This paper 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 $\delta^{18}O$ of dissolved Oxygen, like concentration, is affected primarily by three processes: air-water gas exchange, respiration and photosynthesis; $\delta^{18}O$ is analysed on isotopic ratio mass-spectrometer, after extraction of dissolved Oxygen from water-samples, followed by purification and conversion into 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 of depth for seasonal studies of physiochemical and isotopic parameters of water and dissolved Oxygen. Optimum experimental conditions for $\delta^{18}O$ 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 $\delta^{18}O$ 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 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.

Key words: Dissolved Oxygen, Chlorophyll, isotopic ratio mass spectrometer, water-quality.

INTRODUCTION

Chlorophyll 'a' is a blue-green microcrystalline solid, while Chlorophyll 'b' is 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^3, Mesotrophic lakes with 1-15 mg/m^3 and Ologotrophic lakes with 0.3-2.5 mg/m^3. 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[1,2].

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

*For Correspondence: Principal Scientific Officer, Radiation and Isotope Application Division (RIAD), PINSTECH, P.O. Nilore, Islamabad, Pakistan.

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[3].

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[4]. 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.

Humak and Tarlai Ponds

Humak and Tarlai ponds, near Islamabad, are not very big in size. These are roughly 20 m^2, 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_2 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)
$\delta^{18}O$ of dissolved Oxygen in water and $\delta^{18}O$ & $\delta^{2}H$ 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 ^{o}C.

Figure-1: Algae Is Seen On The Floor Of The Kallar Kahar Lake (Sun-Set View)

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^oC[5, 6, 7].

Spectrophotometric determination of Chlorophyll:

Spectrophometer 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.

$$\text{Chlorophyll a, mg/m}^3 = \frac{26.7\,(664_b - 665_a) \times V_1}{V_2 \times L}$$

$$\text{Pheophytin a, mg/m}^3 = \frac{26.7\,[1.7\,(665_a - 664_b) \times V_1}{V_2 \times L}$$

where:

V_1 = Volume of extract, L
V_2 = Volume of sample, m^3
L = Width of cuvitte (cm)

and

664_b, 665_a= 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 coefficent 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 dennsity 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:

a) Ca = 11.85 (OD664) - 1.54 (OD647) - 0.08 (OD 630)
b) Cb = 21.03 (OD647) - 5.43 (OD664) - 2.66 (OD 630)
c) Cc = 24.52 (OD630) - 7.60 (OD647) - 1.67 (OD 664)

where

Ca, Cb, and Cc = concentrations of chloropyhll a, b, and c, respectively, in mg/L, and
OD664, OD647, and 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:

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

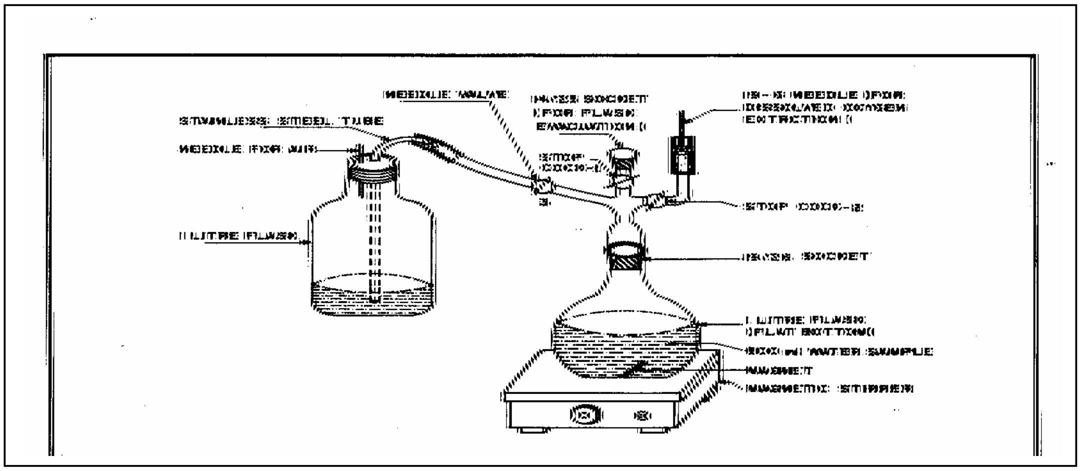

Figure - 2: Dissolved Oxygen Extraction Assembly from Water Samples

Dissolved Oxygen

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

Extraction and $\delta^{18}O$ 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.

The ampoule containing the purified dissolved aqueous Oxygen sample is attached at CO_2 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 sublimes 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 ^{18}O is analyzed on mass

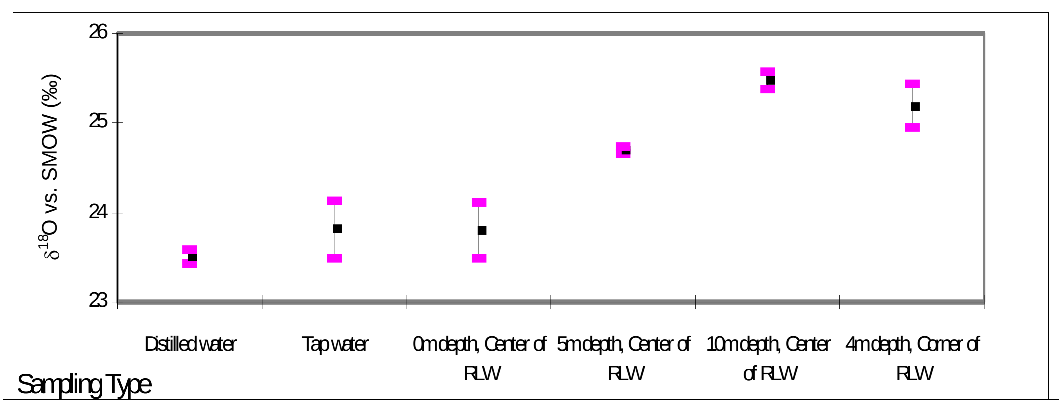

Figure-3: Precision of d18O of Dissolved Oxygen Extracted from Distilled Water, Tap Water and Rawal Lake Water (RLW) (1st Sampling, July-1998)

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

A. For extraction of dissolved O_2

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°A) heating (200°C) time	1 minute
6. Moisture removal temperature for two traps	-80°C
7. 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. For conversion of aqueous dissolved O_2 into CO_2 for $\delta^{18}O$ analysis

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°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. CO_2 sublimation time	3 minutes
7. CO_2 is purified by using	-60°C slush

spectrometer[8]. Optimum experimental conditions for $\delta^{18}O$ analysis of dissolved Oxygen of aqueous samples are described in Table-1 and the precision of $\delta^{18}O$ 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 32.2°C. $\delta^{18}O$ values of dissolved Oxygen from Rawal lake have variations from 24.15 ‰ to 29.5 ‰ and indicate that gas-exchange dominates photosynthesis and respiration[9,10] 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 $\delta^{18}O$ of dissolved Oxygen have no variations with depth. In July, dissolved Oxygen concentration decreases and $\delta^{18}O$ increases with depth. Respiration dominates over photosynthesis at 5 meters and 10 meters of depth, as dissolved Oxygen is undersaturated and $\delta^{18}O$ 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.

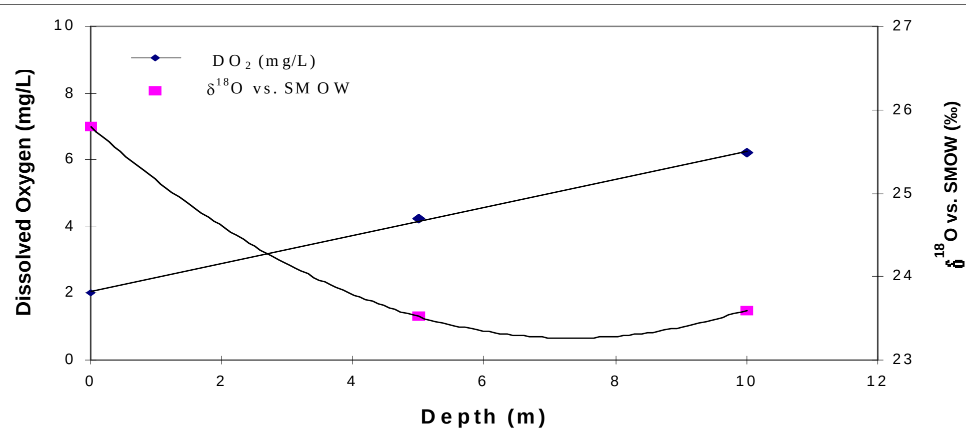

Fig. 4. Concentration and Isotopic Composition of Dissolved Oxygen at the Rawal Lake Site (1st Sampling, July-1998)

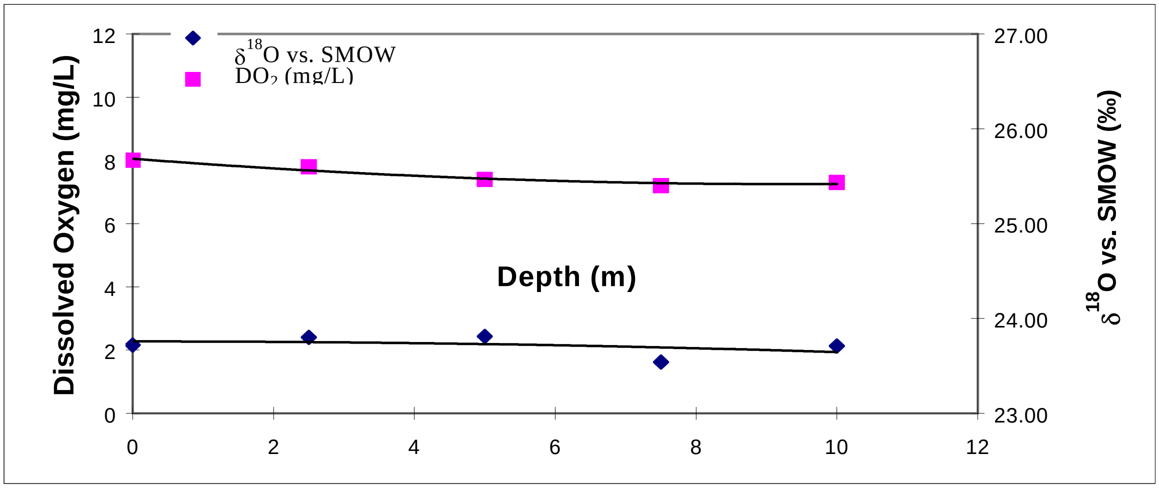

Figure-5: Concentration and Isotopic Composition of Dissolved Oxygen at the Rawal Lake Site (2nd Sampling, Dec.-1998)

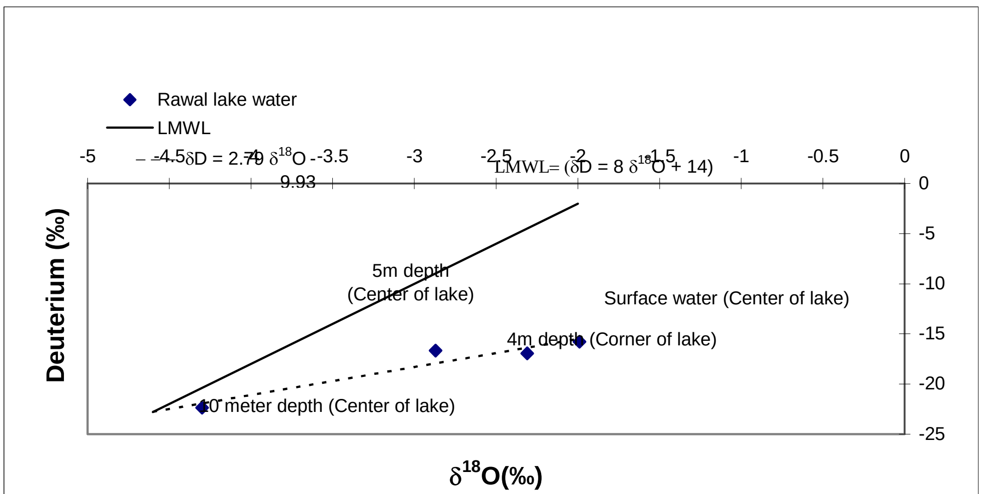

Fig. 6. Plot of $\delta^{18}O$ versus δD of Rawal Lake Water Samples (1st Sampling, July-1998)

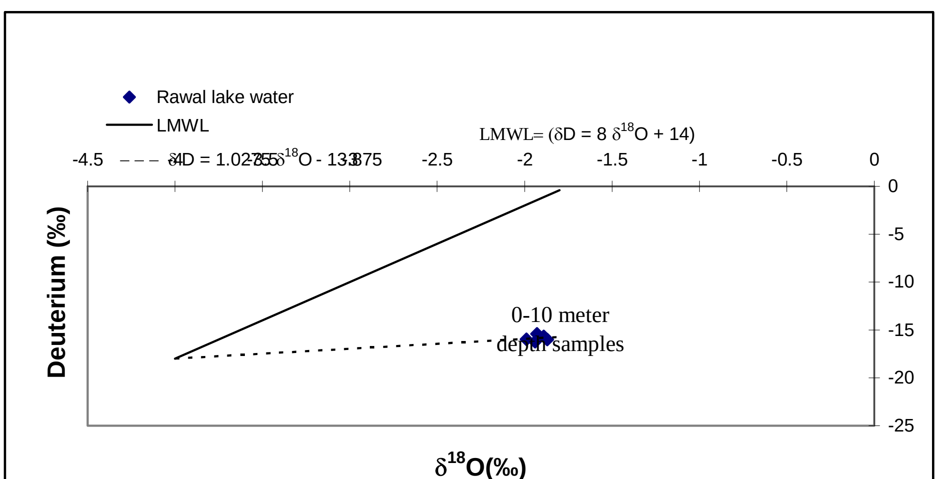

Fig. 7. Plot of $\delta^{18}O$ versus δD of Rawal Lake Water Samples (2nd Sampling, Dec.-1998)

Kalar Kahar Lake

EC varies from 3,100 μs/cm to 3,410 μs/cm. Temperature range from 15.8 ^oC to 17.7 ^oC Dissolved Oxygen concentration varies from 11.1 mg/l to 14.9 mg/l. $\delta^{18}O$ 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 mg/m^3, to 33.33 mg/m^3 as shown in Table-2. $\delta^{13}C$ value shows that inorganic carbon source is from rock sediments (Table-3). Temperature ranges from 27.30 ^oC to 32.60 ^oC at point-2 (east side), from 27.20 ^oC to 32.60 ^oC 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

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

Sampling Point	Sampling Date	Chlorophyll a in the presence of Pheophytin a (mg/m^3)	Chlorophyll a, b, c, trichromatic method (mg/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

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

Sampling Point	Sampling Date	DO_2 (mg/L)	$\delta^{18}O$ vs.SMOW (‰)	$\delta^{13}C$-CO_2 (Dissolved in water) vs. PDB (‰)	$\delta^{18}O$-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. μs/cm*	*Temp. ^OC*	*$\delta^{18}O$ vs. SMOW (‰)*	*δ^2H 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_2 (mg/L)*	*$\delta^{18}O$ vs. SMOW (‰)*	*$\delta^{13}C$-CO_2 (Dissolved in water) vs. PDB (‰)*	*$\delta^{18}O$-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

Table - 6: Chlorophyll Concentrations in Pond Water

Sampling Point	*Sampling Date*	*Chlorophyll a in the presence of pheophytin a (mg/m^3)*	*Chlorophyll a, b, c, trichromatic method (mg/m^3)*		
			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

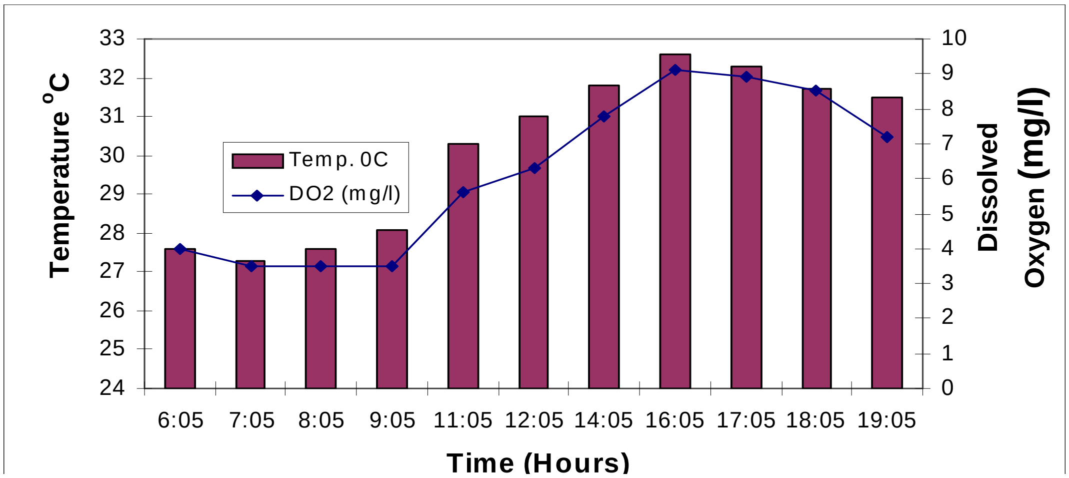

Figure - 8: Temperature and Dissolved Oxygen Behaviour in Different Day Hours at Kallar Kahar Lake (Sampling Point-2)

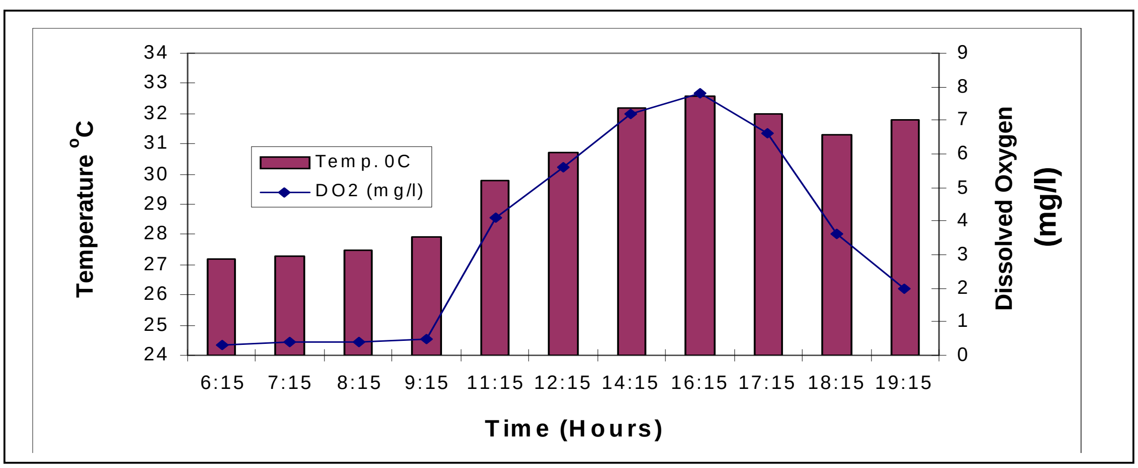

Figure - 9: Temperature and Dissolved Oxygen Behaviour in Different Day Hours at Kallar kahar Lake (Sampling Point-4)

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 μs/cm to 1,129 μs/cm. Temperature range from 8.0 ^{o}C to 15.6 ^{o}C as shown in Table-4. Dissolved Oxygen concentration has values of 8.8 mg/l to 16.2 mg/l. $\delta^{18}O$ 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 mg/m^3 in Humak pond and lowest value of 4.62 mg/m^3 in Gandaf pond (Table - 6).

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HYDROLOGICAL MODELING OF THE LAHORE-AQUIFER, USING ISOTOPIC, CHEMICAL AND NUMERICAL TECHNIQUES

Niaz Ahmad, Manzoor Ahmad, Muhammad Rafiq, Naveed Iqbal, Mubarik Ali, & Muhammad Ishaq Sajjad*

ABSTRACT

Lahore, the capital city of Punjab Province, has about 6 million population. The only water supply to the public is groundwater, pumped through tube-wells. With the increase in population, the demand of water is also increasing accordingly. Radiation and Isotope Application Division of PINSTECH is carrying out hydrological investigations of Lahore aquifer, sponsored by IAEA. For the last three years, 7 samplings have been performed on groundwater of Lahore city area. Natural isotopes of water, such as ^{18}O, deuterium and tritium, have been analysed from the collected water samples. Major and important chemical ions, such as Ca, Mg, Na, K, CO_3, HCO_3, SO_4 and Cl, have also been analysed. Hydrological data on pumping-wells and soil-characteristics has been gathered from different agencies.

A conceptual flow model was developed on Lahore aquifer and was calibrated with Visual Modflow. Hydrochemical interpretations were made with the locally developed innovative techniques and diagrams, as well. The groundwaters have been identified as calcium bicarbonate, magnesium bicarbonate and sodium bicarbonate, with the help of Multi-Rectangular Diagram (MRD). A spatial variation of groundwater-quality map has been constructed. Recharge mechanism is addressed by chemical and isotopic techniques. Both shallow and deep aquifers get significant recharge from river Ravi. Simulations have been run on dynamic depression cone, which has emerged as a result of daily abstractions of groundwater after 1960. In the vicinity of Governor House, the water level was 191 m above mean sea level (amsl) in 1989. It has been observed to have gone down to 185 m in 1998. Preliminary numerical simulations predict that the water-table will further lower to 174 m and 171 m in the years 2009 and 2019, respectively.

INTRODUCTION

Good quality potable water is a fundamental requirement for human health and survival. In third-world countries, fast growth of population, poor town-planning and industrialization are causing problems in supplying public services. Supply and sustainability of clean water stands among the most crucial problems. Lahore is the second largest city of Pakistan, covering an area of about 1000 square kilometers (NESPAK, 1991). Its population is increasing at a rapid rate of 3.7 per cent per year. In 1901 the population of Lahore was 0.203 million which, by 1990, has increased to about 5 million. At present, the population is near about 6 million. The sole supply of water to the Lahore City depends upon the abstraction of groundwater. Fast growth of population, progressive migration of people to the area and establishment of numerous industries have resulted in rapid increase in water-demand. The number of wells and, hence, the groundwater abstraction has been increasing in accordance with the growth of population. On the other hand, urbanization and industrialization has reduced the recharge, as a significant part of the land has become impermeable. With the increasing number of tubewells, the groundwater level, which used to exist at about 4.5 m below surface, started declining rapidly. A decline of 15.5 meters in water-table during 1960 to 1991 was noticed in Lahore City (Alam, 1996). At present, the water-table in the central area of the city has gone down to 28 m from the surface level (WASA, 1999). The existence of saline groundwater in the nearby areas of Raiwind and Kasur, in the south of Lahore, is a potential threat to the aquifer under the city. There is a danger of deterioration of the aquifer water-quality if the saline water finds a path to reach the city area. The flushing out of this saline water, if it once enters the aquifer, would then be nearly impossible. It is therefore, imperative to assess the mechanism of groundwater-replenishment, pollution-levels and pollution-sources, for sustainable development and conservation of these resources.

HYDROGEOLOGY

The aquifer under Lahore area is composed of unconsolidated alluvial sediments, consisting of sand, silt and clay in different proportions. The chief constituent minerals are quartz, muscovite,

*For Correspondence: Principal Engineer, Radiation and Isotope Application Division, PINSTECH, P.O. Nilore, Islamabad, Pakistan.

biotite and chlorite, in association with a small percentage of heavy minerals. The sediments have been deposited by the present and ancestral tributaries of the Indus River during Pleistocene-Recent age. The sedimentary complex has a thickness of more than 400 meters. The shifting course of the tributaries in the area has impregnated the heterogeneous character to the thick sedimentary alluvium. Therefore, the geological strata have little vertical or lateral continuity. In spite of their heterogeneity, the alluvial sediments constitute a large aquifer, which on regional basis behaves as an unconfined homogeneous aquifer (Greenman et al., 1967). The individual lenses of silt and clay do not impede the flow of groundwater, considering long-term pumping. Lahore aquifer is highly transmissive, with hydraulic conductivity variation between 25 m/day to 70 m/day. In spite of heterogeneous nature of alluvial complex, groundwater occurs under water table conditions.

SAMPLE COLLECTION AND ANALYSES

The study area comprises the city of Lahore and the adjoining areas. Locations of the sampling points are shown in Figure - 1. During the last two years, 7 samplings have been carried out in different seasons. In order to cover the maximum representation, the samples were collected from shallow and deep aquifers, and from canals, river Ravi and sewerage drains. The samples were analyzed for environmental isotopes ^{2}H, ^{3}H, ^{18}O and major chemical ions Ca, Mg, Na, K, HCO_3, CO_3, SO_4, Cl. Physico-chemical parameters like EC, pH and temperature were measured in the field.

RESULTS AND DISCUSSION

Quality Of Chemical Data

It is an imperative step, before any manipulation of chemical data, to ascertain its quality. The reliability of chemical data can be checked by computation of ionic charge-balance error (Mandel and Shiftan, 1981, and Lloyd and Heathcote, 1985). The ionic charge balance equation is defined as:

$$\text{Reaction Error} = \frac{\sum \text{cations} - \sum \text{anions}}{\sum(\text{cations} + \text{anions})} \times 100$$

In this equation, meq/l concentrations of cations and anions are used. If the reaction error of a chemical data-set is more than 10% it makes the quality of analysis questionable. In the present study, the reaction error criteria were applied to chemical analyses of each data-set. Reaction errors are shown in Figure - 2. Almost all the reaction errors are within 10% range, except 6 samples which remain within 20%. Therefore the quality of chemical data is acceptable, according to ionic charge balance criteria.

Groundwater Quality

EC of shallow aquifer (<200 feet depth) is shown in figure - 3a and it has approximately normal distribution. It varies between 250 to 4500 μS/cm. The maximum samples occur at 1200 μS/cm. On the other hand, EC of deep aquifer (300 to 600 feet depth), as shown in figure - 3b, varies between 250 to 1750 μS/cm, with maximum frequency at about 500 μS/cm. It indicates that shallow aquifer is more saline, as compared to deep aquifer. The range of EC for shallow wells is about 2.5 times higher, as compared to that of tube wells. It was also observed during sampling that a tube-well and a hand-pump only 100 feet apart had remarkable difference in EC. This difference of salinity may be due to high contribution of fresh-water recharge to the deeper aquifer from distant hills on the north, while shallow aquifer has higher contribution from local sources of canals and sewerage waters. Spatial distribution of EC is shown by figure - 4 where the radius of the circle is proportional to the EC value. This figure clearly indicates that the shallow wells (hand pumps and motor pumps) have higher values of EC than the counterpart deeper tube wells.

Frequency distributions of major chemical ions have been shown in Figure - 5. Concentrations (mg/l) of Ca, Mg, Na, HCO_3, SO_4 and Cl varies between 20 to 172, 15 to 140, 84 to 964, 140 to 1020, 80 to 672 and 55 to 550, respectively. All the ions have similar distributions except HCO_3 which indicates two populations having their modal classes at 220 and 380 mg/l, respectively. Chloride is considered as conservative anion which once it enters groundwater does not react with other ions and remains in solution form. Cl depicts the interesting behaviour of movement of groundwater in the aquifer. Spatial variation of Cl (Figure - 6) indicates higher values of shallow wells than deeper tube wells in the Bund Road and Hadiara Drain areas, while in the center of the city, Gowal Mandi and Mozang area, both shallow and deep wells show higher values of Cl. This behavior of Cl can be explained: in the south east and north east areas, the waters of shallow and deep aquifers are not mixing efficiently, while in the center of the city (Gowal Mandi, Mozang, Governor House) both shallow and deep groundwaters are mixing in substantial amounts. A three dimensional picture shown in Figure - 7 gives more clear indication of Cl variation. Groundwater from the aquifer has been abstracted heavily after 1960, to meet the increasing demand of water with growing population. It has produced a depression-cone in the center of the city, as shown in Figure 8. The areas having apex of the depression-cone and peak of Cl ion are overlapping in the center of the city. It further supports the mixing of shallow aquifer waters with the deep aquifer in the center of the city, causing deterioration in the quality of water.

Hydrochemical Classification of Groundwater

Groundwater salinity is the result of combined effect of a number of chemical ions. The major chemical ions responsible for the salinity of groundwater are calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate and chloride (Freeze and Cherry, 1979). Among these ions, some are in higher concentration as compared to others, depending upon the chemistry of source water and geochemistry of the rocks met in the way of flowing water. Groundwater samples collected from different locations may be recharged from different sources and will show dominance of particular ions, accordingly. The type of groundwater at a particular location is determined by calculating the percentages of cations and anions, using milli-equivalent per liter (meq/l) concentrations. The ions with highest percentage from cation and anion groups define the type of the groundwater. A number of graphical methods are available in the literature for hydro-chemical classification of groundwaters (Hill, 1940; Piper, 1944; Durov, 1948; Burdon and Mazloum, 1958; Lloyd, 1965 and Ahmad, 1998). Here the chemical analyses are plotted on Piper diagram, which is shown in Figure - 9. This diagram shows that Na is the dominant cation and HCO_3 is the dominant anion from the water-analyses in the study area. A small number of samples are dominant in Ca. It is difficult from this diagram to single out the pairs of dominant cations and anions together. A Multi-Rectangular Diagram developed by Ahmad (1998) takes into account the shortcomings of trilinear Piper diagram. Chemical analyses of water-samples from the study-area have also been plotted on Multi-Rectangular diagram (MRD) shown in Figure - 10. The waters emerge as calcium bicarbonate, magnesium bicarbonate, sodium bicarbonate, sodium sulfate, sodium chloride and calcium sulfate types. Out of 144 samples, 99 qualify for sodium bicarbonate, 27 for calcium bicarbonate, 6 for magnesium bicarbonate, 8 for sodium sulfate, 3 for sodium chloride and 1 for calcium sulfate categories. The waters of Indus River and its tributaries are rich in calcium bicarbonate type. Therefore, calcium bicarbonate and magnesium bicarbonate type of waters indicate fresh recharge or that the recharged water has not moved a long distance from the source area. During the movement of groundwater, the dissolved calcium exchanges with sodium present in the minerals of rock matrix. As a result, sodium becomes dominant over other cations when water covers a long distance from the source. Sodium bicarbonate type of waters may be the result of mainly ion-exchange reaction between calcium and sodium at an appreciable distance from the recharge area. Occurrence of some magnesium bicarbonate type of ground-waters indicates the presence of dolomite mineral in the reservoir formations. Chloride type of ground-waters either emerges directly from industrial activity in the area or indicates very sluggish movement of groundwater, which evolves from bicarbonate through sulfate to chloride (Chebotarev, 1955).

Hydrochemical Facies

The term hydrochemical facies is used to denote the differences in groundwater spatial quality. Generally, the groundwater facies are susceptible to geologic facies to some extent. The hydrochemical processes do not occur within sharp boundaries, rather they possess inherent transition-character within a particular area. The chemistry of groundwater evolves according to the availability of minerals and equilibrium conditions. During the movement of groundwater, its chemistry does not change abruptly until and unless it meets rocks with entirely different character. Identification of areas with a particular type of groundwater helps to manage and maintain the future supply of water. Hydrochemical facies map (Ahmad, 1998) can easily be constructed after the recognition of prevalent groundwater types with the help of MRD. Figure - 11 shows hydrochemical facies in the study area. Groundwater with a particular type is marked with a specific symbol on the map. As a result, the areas with different types of groundwater are highlighted on the map. The area under study is mainly occupied by calcium bicarbonate and sodium bicarbonate type of ground-waters. Calcium bicarbonate type of waters occur in border-areas adjacent to river Ravi and along the Lahore Canal. Other areas, which are away from the river, are occupied by sodium bicarbonate type of groundwater. Magnesium bicarbonate waters occur south east of the study area. Sodium sulfate type of waters occur towards the city, just after calcium bicarbonate type of waters.

Recharge Mechanism

The possible sources of recharge of the aquifer are: River Ravi, irrigation canals passing through the area which originate from River Chenab, and rains. Isotopic data of rivers are already available (Hussain et al., 1993) and their sampling is continued. $\delta^{18}O$ and $\delta^{2}H$ of River Ravi range from -11 to -6 ‰ and -86 to -40‰ with the mean values of -8.9‰ and -61‰, respectively. All the irrigation canals flowing through the study-area originate from the River Chenab. Their $\delta^{18}O$ ranges from -13 to -7.9‰, with mean value of -10.8‰ and $\delta^{2}H$ ranges from -86.3 to -56.2‰, with average value of -71.8 ‰. Sajjad (1991) determined the $\delta^{18}O$ and $\delta^{2}H$ indices (mean values) of river Chenab as -10 and -61‰ with high variability. The $\delta^{18}O$ and $\delta^{2}H$ indices for rain of the nearby area i.e. -5.5‰ and -32‰ have been used (Sajjad et al., 1991).

Frequency Distribution of δ18O

Frequency-histogram of $\delta^{18}O$ of deep water (Figure - 12) shows two populations. One population with modal class of about -6.5 ‰, which matches well with the index of base-flow coming from long distances; this class shows little contribution of local rains, which have $\delta^{18}O$ index of –5.5 ‰. The other population is from -9 to -7 ‰ with modal class at -8 ‰ showing significant contribution of river water. Because of significant difference in $\delta^{18}O$ values of groundwater sources, the following two-component mixing-equation roughly gives the fraction ‘f’ of river water.

$$F = \frac{\delta^{18}O_{B.F} - \delta^{18}O_{M}}{\delta^{18}O_{B.F} - \delta^{18}O_{R}}$$

where $\delta^{18}O_{M}$, $\delta^{18}O_{B.F}$ and $\delta^{18}O_{R}$ are $\delta^{18}O$ values of mixed groundwater, base-flow and river water, respectively. Using the above equation, about half of the sampling locations show 30 to 40% contribution of river water. The frequency-histogram (Figure - 13) of $\delta^{18}O$ of shallow groundwater also indicates two populations. One population is with modal class at -7.0 ‰, while the second population, which is much smaller than the first one, has modal class at -8.5‰. This distribution indicates that the groundwater-samples having major contribution from the river are much less in number, as compared to those recharged by other sources. The locations influenced by the river have greater fraction of its water, as compared to deep ones. Separation of the second population from the first one means that there is no significant mixing of river water at the locations falling in the second population and, most probably, the dominant lower end component having $\delta^{18}O$ = -7.5 ‰ is mixing with the local rains and base-flow.

Spatial Variation of $\delta^{18}O$

As the water-supply wells pump the deep groundwater from the depth of 80m to 200m and private hand-pumps/shallow motor pumps tap upper groundwater up to 50m, so the data of deep and shallow aquifers are treated separately. Considering the spatial distribution of $\delta^{18}O$ in deep water (Figure - 14), the areas having $\delta^{18}O$ <-8.0‰ show significant contribution of the river. Such areas (marked with blue filled circles) lie along the river and extend towards the Lahore Branch Canal. The area away from the river (red coloured plus symbols) having $\delta^{18}O$ > -7 ‰ clearly shows base-flow mainly recharged by the rains. A narrow belt in the center, having $\delta^{18}O$ from -8.0 to -7.0‰, indicates mixing of rain and river waters in the recharge of deep groundwater. The original $\delta^{18}O$ and $\delta^{2}H$ indices of the base-flow were estimated as -6.4‰ and -41.7‰. The local-rain index of $\delta^{18}O$ for the study area is about -5.5 ‰, which is a bit more enriched than that of base-flow mainly recharged at relatively higher altitude. Sajjad et al. (1991) found the similar values of base-flow in the North-East area of Lahore. Spatial distribution of $\delta^{18}O$ in shallow aquifer (Figure - 15) shows similar trend as in the deep aquifer, but the extent of river-dominated and rain-recharged areas towards the center of the city is relatively less. In this case, large area in the center have mixed type of water. Lateral penetration of the river-water in the shallow zone is low.

Possibly due to high hydraulic gradient

towards the center of the cone of depression, which lie in the central part of the city, the vertical component of river-water flow is dominant. It justifies the smaller contribution of river-water in shallow aquifer than that in deep aquifer in the central part. There are a few locations in the eastern part, which are also away from Lahore canal and have $\delta^{18}O$ values from -8 to -9‰, showing high contribution of canal water. These points being near BRBD canal show its large contribution in the recharge.

Study of δ^2H vs. $\delta^{18}O$

In the first and second samplings, water samples were mostly collected from WASA tubewells, tapping deep aquifer (screen: 80m to 200m) along with some private shallow pumps, obtaining water from 25 m to 50 m. Figure - 16 shows the plot of δ^2H vs. $\delta^{18}O$ for second sampling. All the points are scattered around LMWL between the river-index and rain-index. It confirms that the aquifer is recharged both by rains and the river. Some of the points being just below the LMWL show considerable evaporation-effect. In the third and onward samplings, a lot of hand-pumps were included. All the three plots of δ^2H vs. δ^8O (Figure - 17 to Figure - 19) pertaining to these samplings (No. 3 to 5) show the evaporation in the shallow aquifer. Departure of the points is not much from the LMWL, which does not show extensive evaporation. Such slopes may be obtained due to mixing of evaporated soil-water with the infiltrating rain (Clark et al, 1987). Moreover, the variation in the range of isotopic values reflects the seasonal variation in the input, which also indicate that the shallow water has sufficient recharge from local sources. The $\delta^{18}O$ of 4th sampling ranges up to -6‰, while that of 5th sampling it goes up to -5‰. It shows that contribution of local rain that might have evaporated, increased in the groundwater sampled in the 5th sampling.

Ca-Na Relationship

Calcium and sodium are two important chemical ions, which provide useful information on groundwater-recharge and movement when plotted taking the concentrations of these ions in meq/L percentages out of total cations (Ahmad, 1998). Generally, calcium bicarbonate type of waters indicate fresh recharge, or the recharged water has not moved a long distance from the source area. During the movement of groundwater, the dissolved calcium exchanges with sodium present in the minerals of soil-matrix. As a result, sodium gets dominant over other cations when water covers a long distance from the source area, which gives rise to an inverse relationship between calcium and sodium. Therefore, Ca/Na relationship parallel to isotopes has also been used to identify the recharging sources.

Relationships of Ca/Na for deep and shallow groundwater plotted in Figures - 20 and 21 confirm negative correlation. Three groups of groundwater (based on δ^8O) are represented by different symbols and colours. In case of deep water, data points of the river/canals lie at lower end with high Ca and low Na. Groundwater samples with δ^8O depleted more than -8‰, indicating major contribution from river-system (blue coloured), make a trend which starts from river points and indicates increase of Na with decrease of Ca. This trend confirms the recharge from river-system. The groundwater having δ^8O more enriched than -7‰ (mainly recharged by rainwater), lie in the upper part (high Na and low Ca) and slope of trend becomes slightly high. This type of water evolves after travelling longer distance. It seems the base-flow is mainly recharged by rainwater. The data pertaining to the middle group (mixed type of water) is scattered, showing different contributions of both the sources.

Shallow groundwater also shows similar trend of Na-Ca relationship (Figure - 21) to that of deep water, but the data-points are much more scattered, especially the samples with high δ^8O. It means that shallow groundwater is not recharged in a regular manner like deep groundwater, and various local sources are also contributing.

Modeling Of Lahore Aquifer

The whole municipal supply in the Lahore city area is groundwater. Every year new tube-wells are being installed to meet the demands of the increasing population. Presently, about 316 tube wells (2 to 4 cusecs), installed and being operated by WASA, are used for public supply. Total WASA abstraction of ground-water from the aquifer is 280 to 290 million gallons per day. Private sector is also pumping a substantial amount of water, which is estimated at 150 million gallons per day. Historical abstraction of ground-water from Lahore aquifer is shown in Figure - 22. The water-table is continuously lowering, as a result of heavy abstraction from the aquifer. In order to predict the future conditions of the water-table, a groundwater model of Lahore aquifer has been developed and has been calibrated with Visual Modflow. Visual Modflow is a computer-software, which analyses ground-water flow-dynamics. Hydrological data of WASA tube wells was used only to calibrate the model, as data on private tube wells was not accessible. Therefore, the results of the model could be considered preliminary ones and, to approach realistic values, more refined data is needed. Efforts are underway to collect all the relevant data to correct the model.

Water levels measured in November 1989 were used as initial observation heads (Figure - 23). In this figure, the hydraulic head is at 191 meter above mean sea-level (amsl) in the center of the city at Mozang and Gowal Mandi areas. Giving the required inputs, the model was run for different time-steps. The observed data of each year, from 1989 to 1998, was compared with the simulated results produced from the model. Observed data and simulated results were found in good agreement. Beyond 1998, future water-table conditions were simulated with a number of runs of the model. The water-table levels of 1998, 2009 and 2018 are shown in Figures - 24, 25 and 26, respectively. The observed water level in 1998 was at 185 meter amsl, which is predicted to lower further 12 meters to 173 meter amsl, in 2009. In 2018, the water level is predicted to go down to 170 meters amsl in the center of the city where apex of the depression-cone exists.

CONCLUSIONS

The following conclusions are drawn from the study of Lahore aquifer:

- Due to heavy abstraction of groundwater, the water table is declining rapidly and an irregular shaped depression-cone is formed in the central part of the city. If the abstraction of ground-water continues with the same pumping rate, the depression-cone will further extend south towards Kasur and Raiwind areas. The more saline and polluted waters of Kasur and Raiwind areas are the likely to intrude into the fresh aquifer under Lahore city.

- Development of chloride peak exactly at the place of depression-cone indicates that water of shallow and deep aquifer is mixing rapidly in the center of the city, while in other areas, vertical mixing is not efficient.

- Spatial variation maps of EC and Cl show that shallow aquifer is more saline, as compared to deep aquifer. Deep groundwater has generally low dissolved chemical load, indicating good quality, while shallow water is poor at most of the locations, except the areas near the river and irrigation canals.
- Stable isotopic data show that the deep groundwater in the area from the river Ravi up to the center of the city has major contribution of river-water, while at the locations far from the river it seems to be totally base-flow recharged by rains of distant area in the North-East. Groundwater showing mixed recharge from river and rains is also encountered in the intermediate area.

- The shallow groundwater at the locations near the river is mainly recharged by the river water. River influence is restricted to a smaller area, as compared to that in case of deep zone. In the other areas, different local sources like irrigation canals, sewerage drains, local rain and may be the leaking main supply-lines seem to be contributing.

- The identified compositional types of shallow, as well as deep, groundwater are mainly calcium bicarbonate (19 %) at sampling points near the river Ravi, and sodium bicarbonate (69 %) away from the river in rest of the area, indicating cation exchange process.

- Mixing of shallow and deep ground-water, especially in the center of the city reveals that the aquifer is highly vulnerable to pollution.

RECOMMENDATIONS

- As the aquifer has been found vulnerable to pollution, there is need to study the presence of any kind of pollution such as bacterial, heavy metals like arsenic, lead, chromium, mercury and anions like fluoride, nitrates, etc.
- There is an urgent need to study the temporal position of intruding saline boundary from the south. Unfortunately, if it enters into the fresh aquifer zone, it will be almost impossible to clean the aquifer from this menace. Further lowering of water-table can be stopped by;

  - Artificial recharge at the time of heavy rains;
  - Increasing water-demand be fulfilled not only from exploiting the aquifer, but also use of surface-water from canals/river should be explored
- With the advent of high speed computers, it is quite possible to study the behavior of an aquifer (flow dynamics, transport of pollutants and future predictions). Therefore, modeling of the aquifer should be included as an imperative part of exploration, and management studies. Modeling is very cost-effective, as installation of only one tube-well of about 4 cusecs discharge in Lahore costs about 3 to 4 million Pak. Rupees, while the modeling of the whole aquifer will approximately cost one million Rupees only.
- Development of a data-base is strongly recommended. At present, all data is present in the form of files and reports. Data should be in form ready for its retrieval, to be used in computer-based modeling.
- Conservation of water should be given highest priority, for sustainable utilization of these vital resources.

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FIGURES REFERRED IN THE PAPER

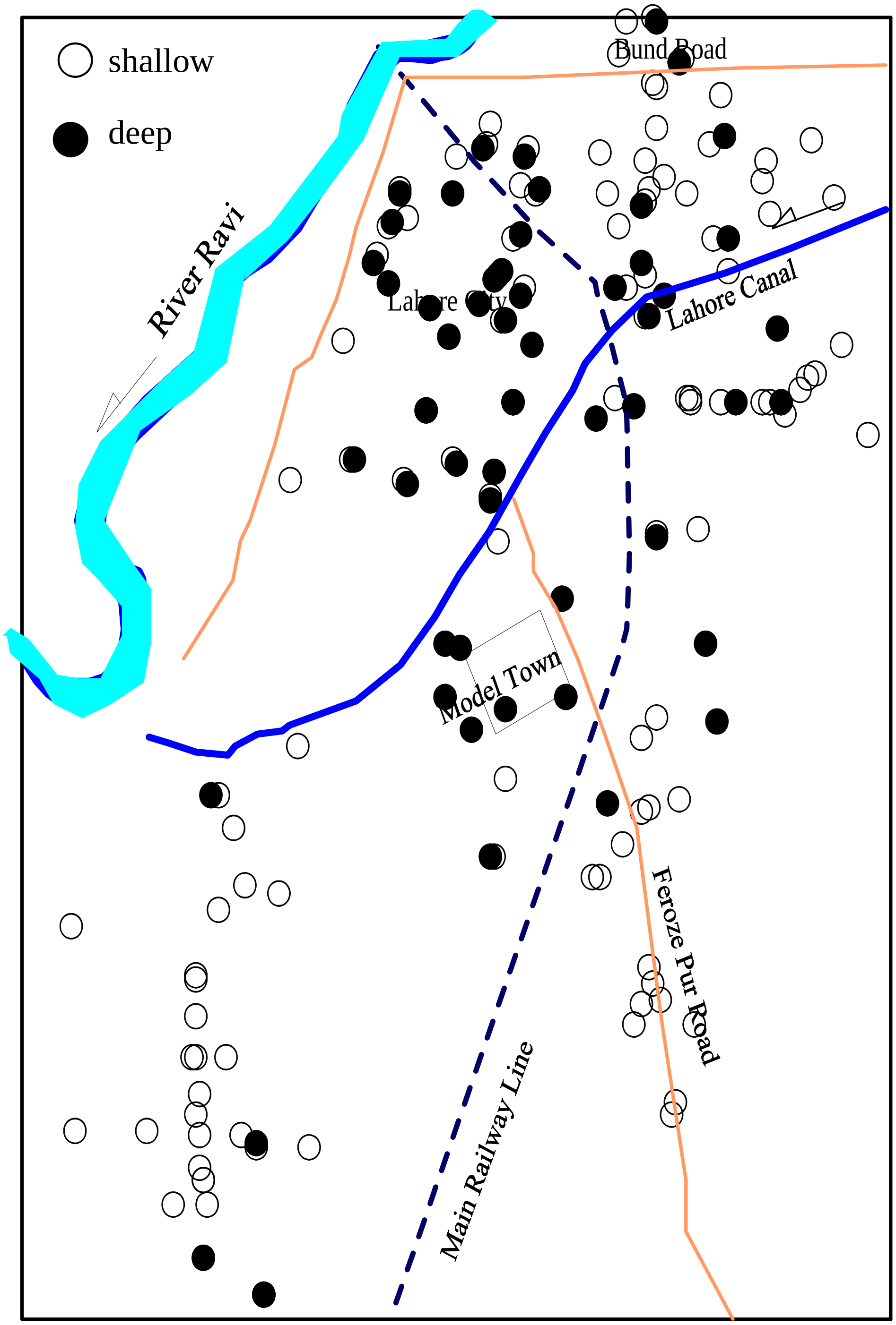

Figure – 1: Map Showing Locations of Sampling Points

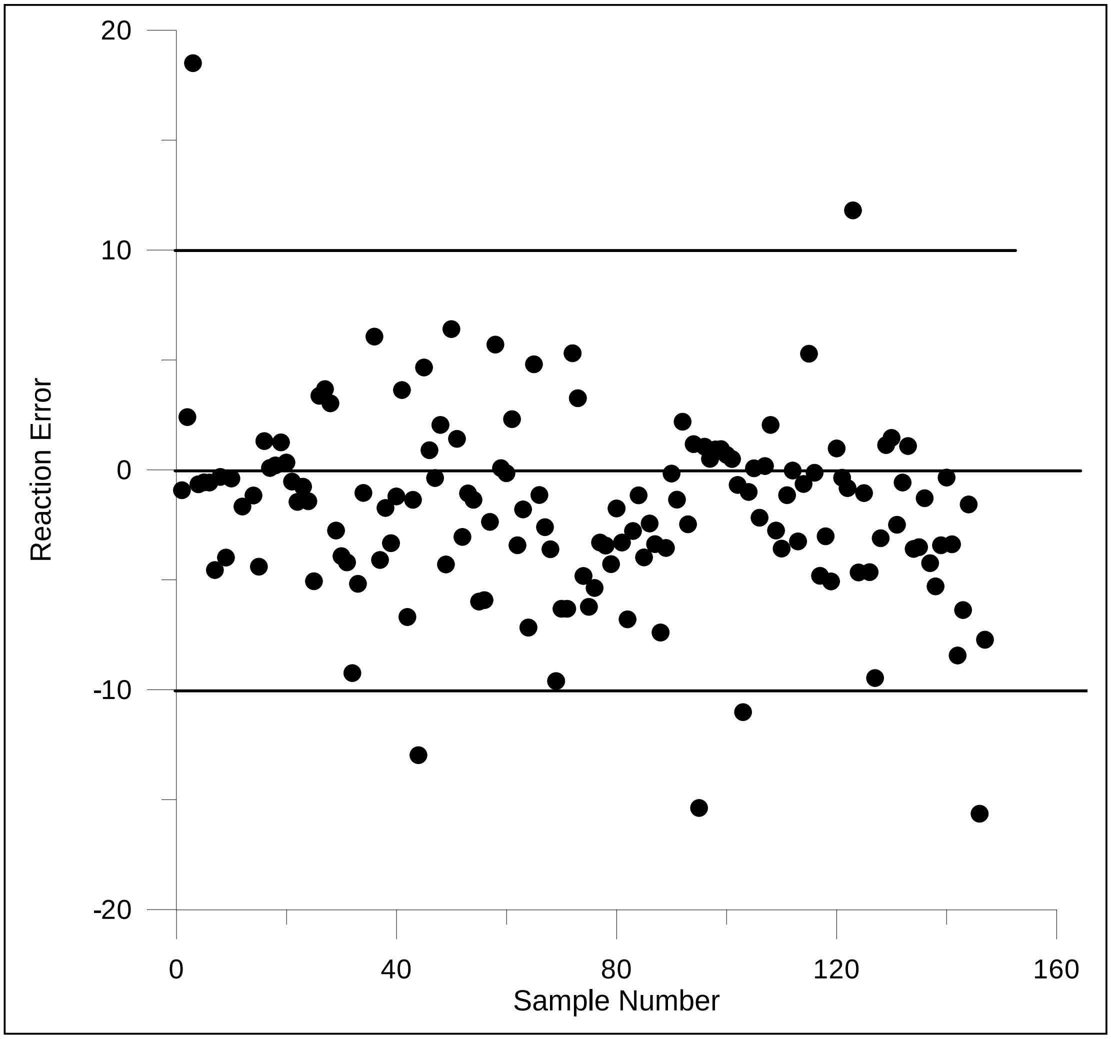

Figure – 2: Ionic Balance Reaction Error

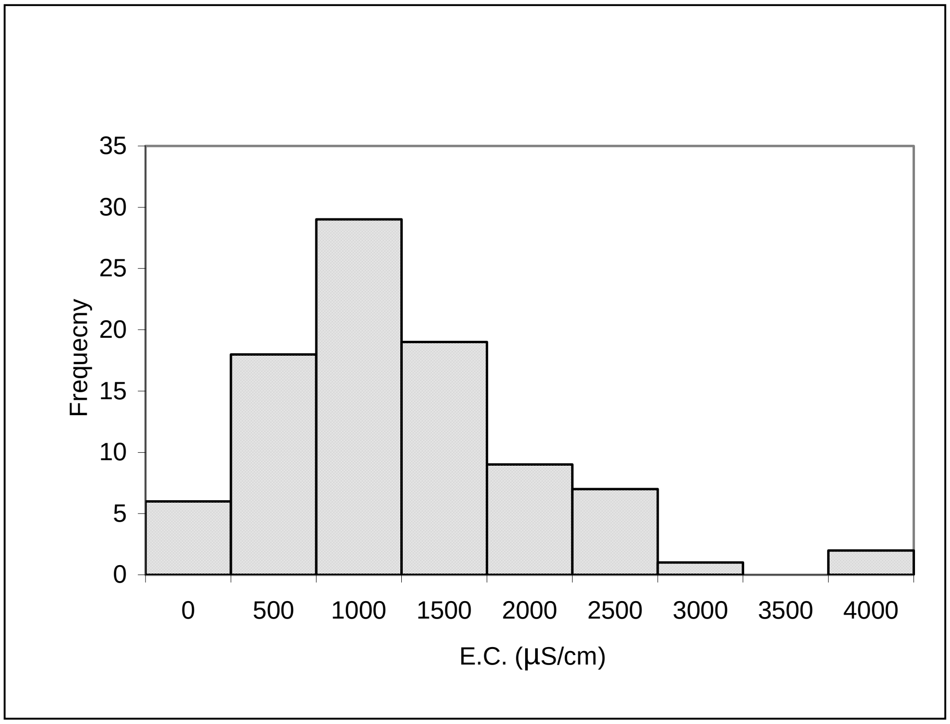

Figure – 3(a): Frequency-Histogram of Shallow Groundwater

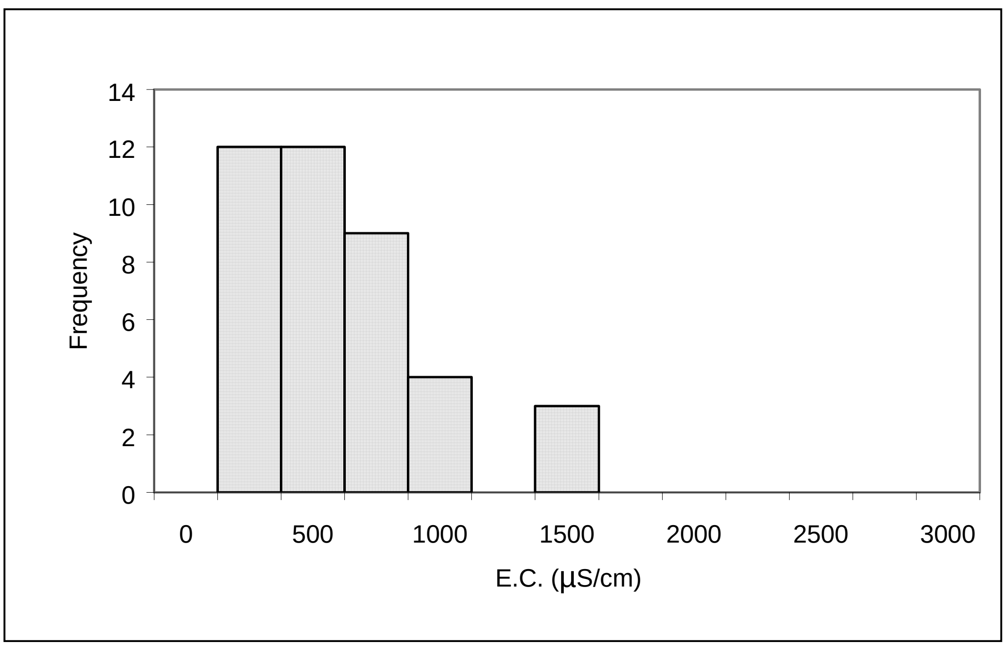

Figure - 3b: Frequency Histogram of Deep Groundwater

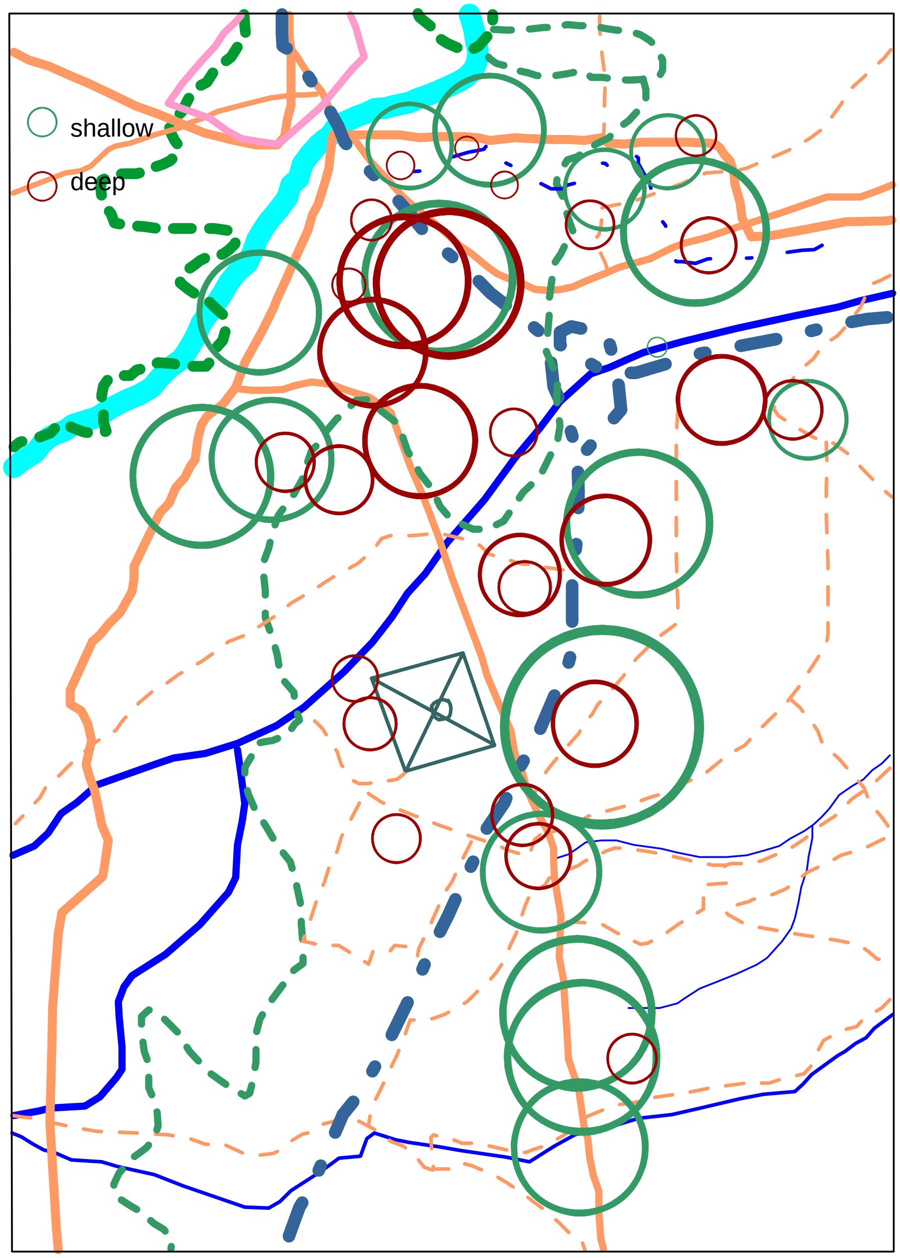

Figure – 4: Spatial Variation of EC

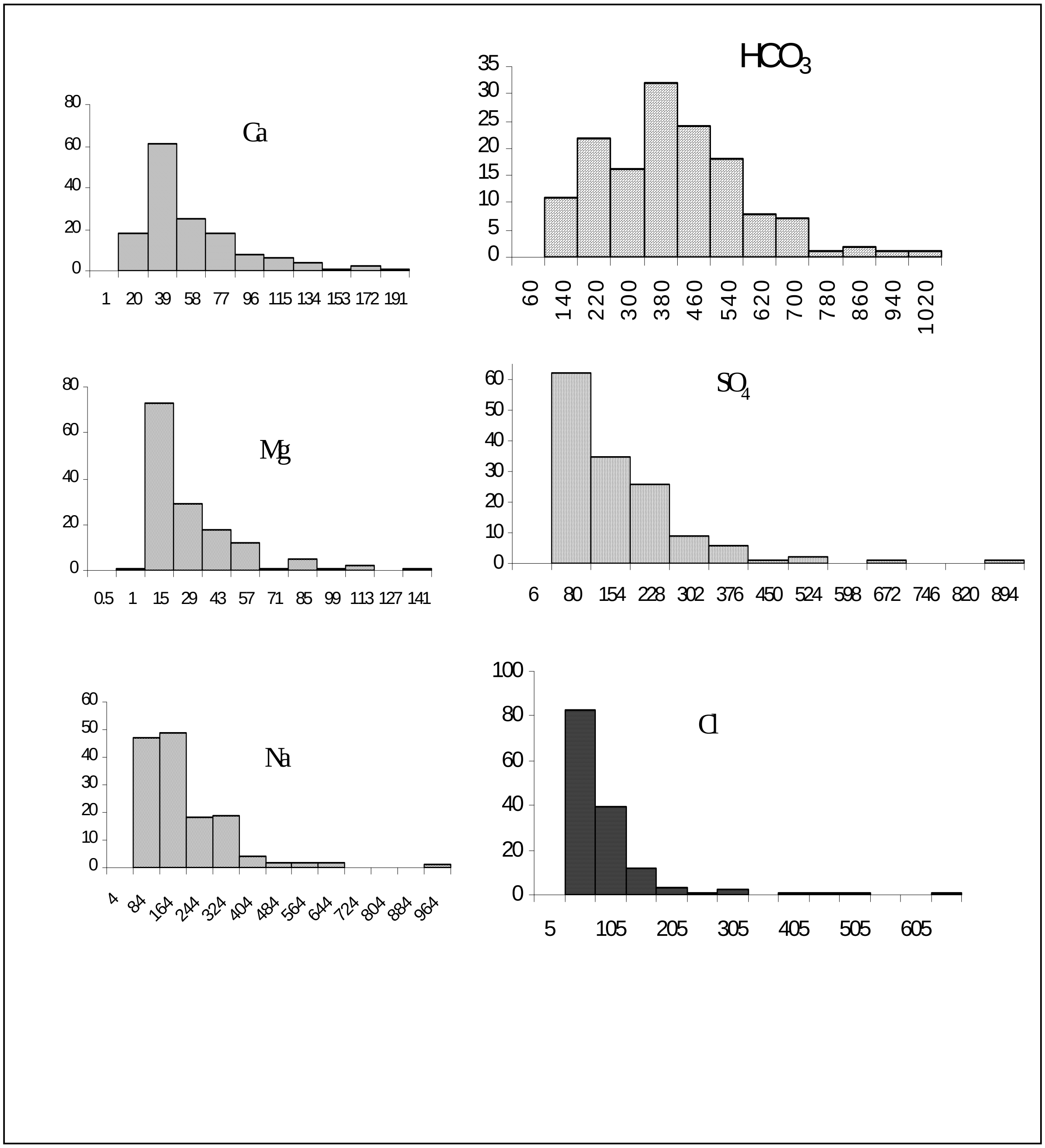

Figure – 5: Frequency-Histograms of Chemical Ions

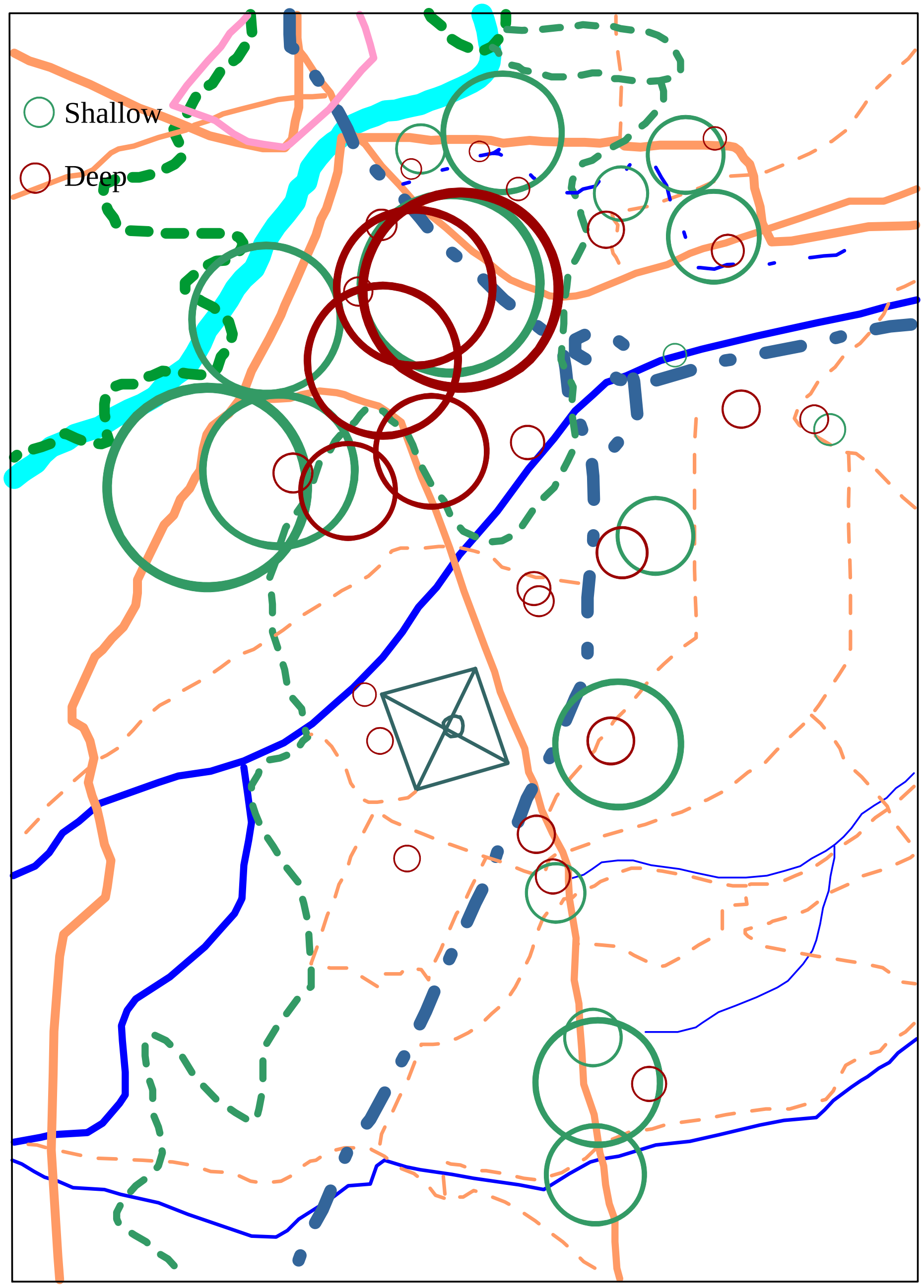

Figure – 6: Spatial Variation of Cl

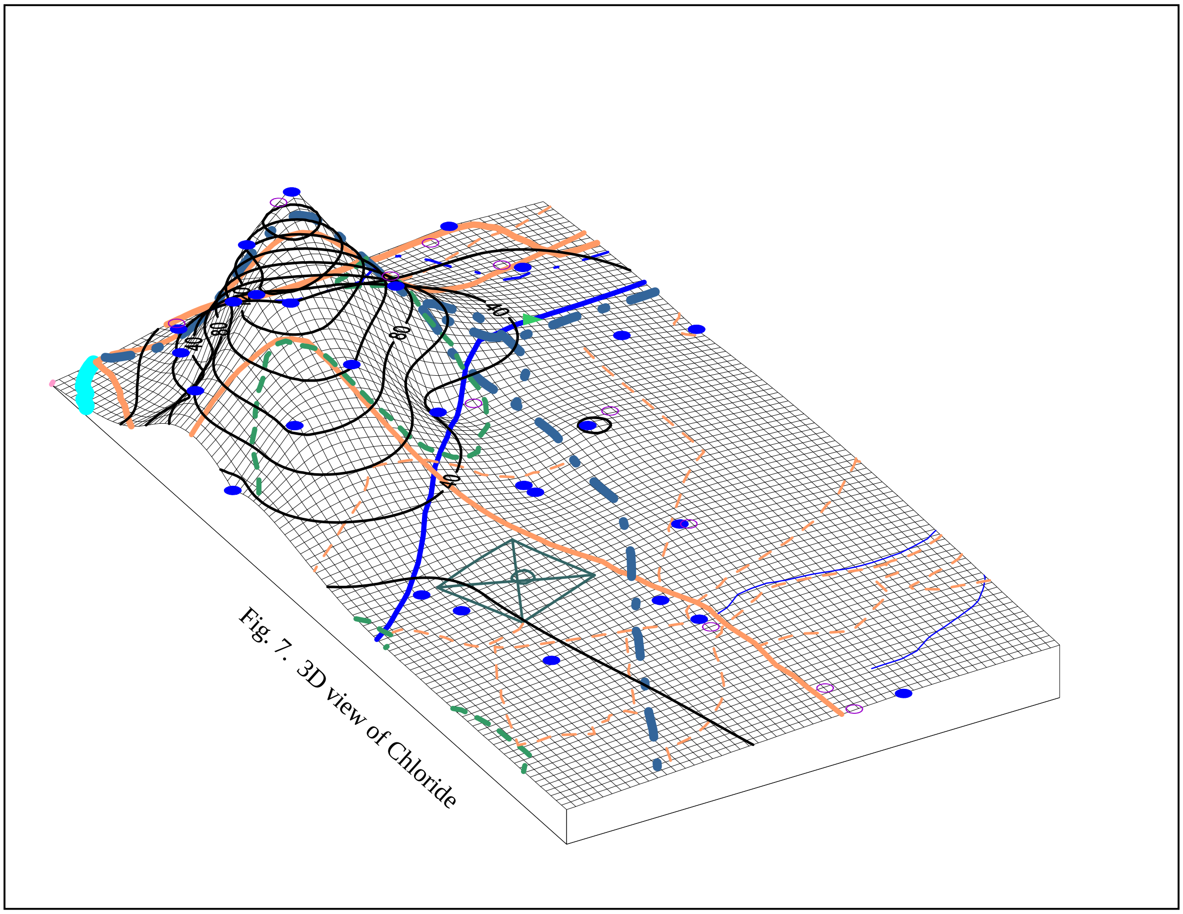

Figure – 7: 3D View of Chloride

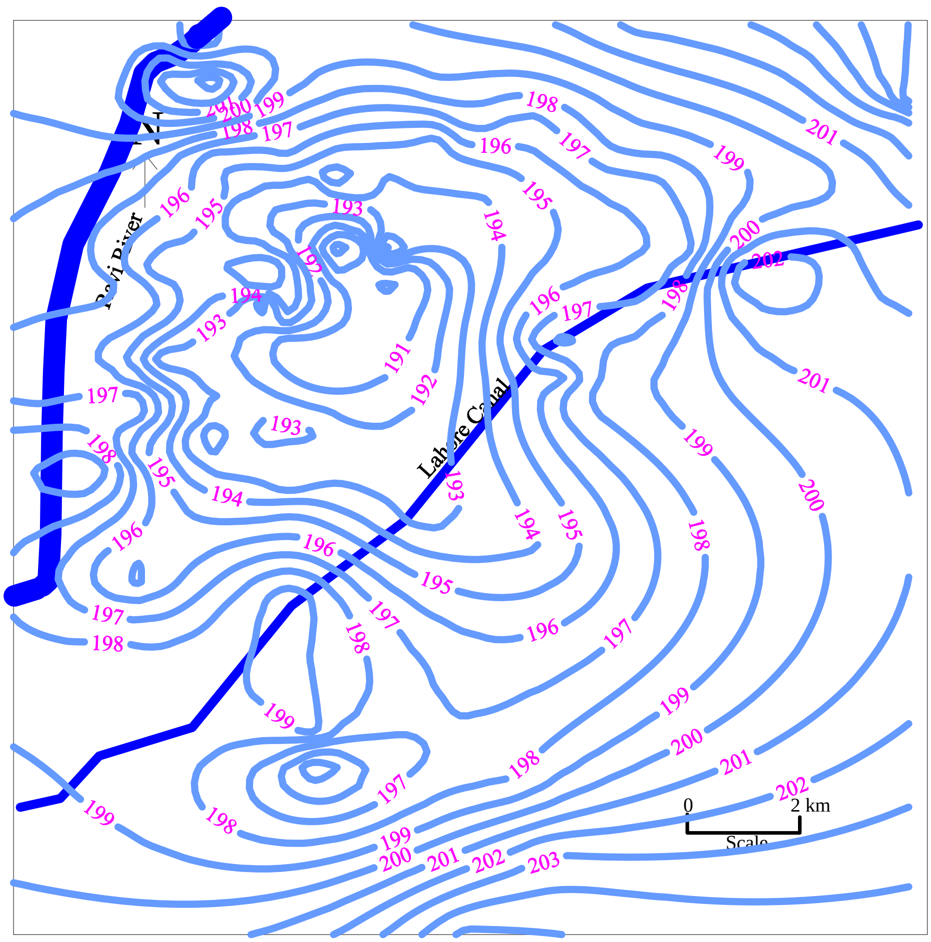

Figure – 8: Contours of Water-Level (Observations in November 1989)

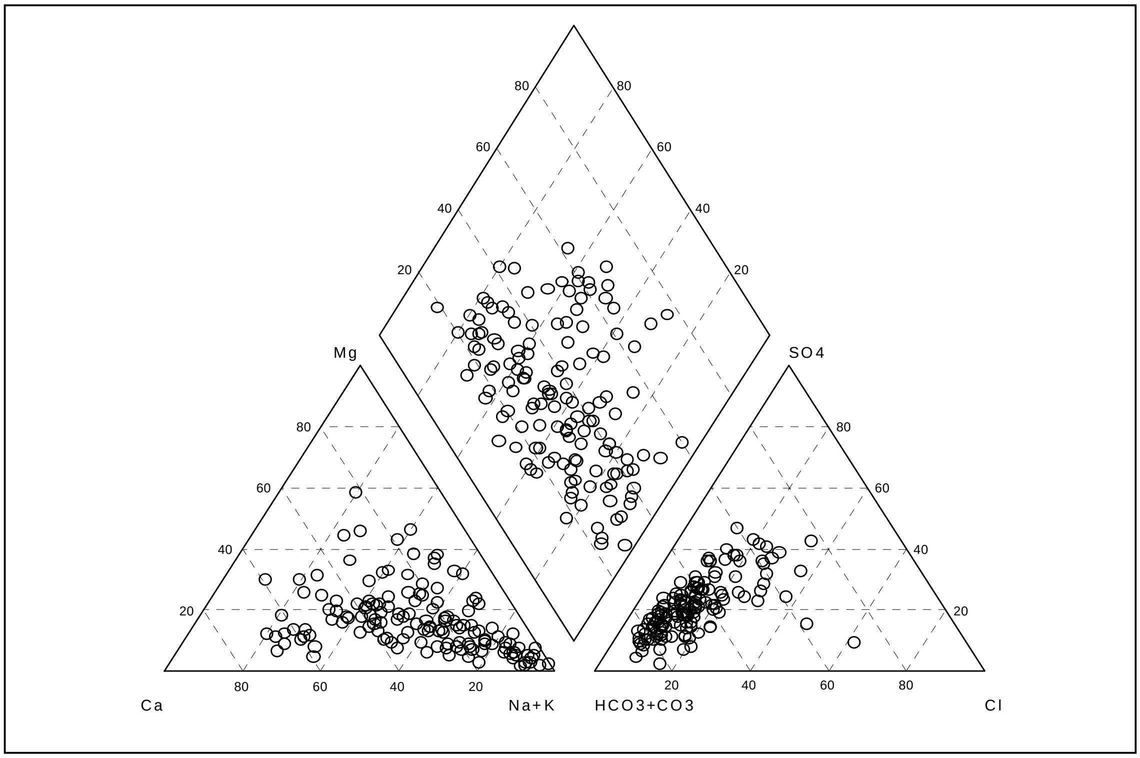

Figure – 9: Plot of Chemical Analyses on Piper-Diagram

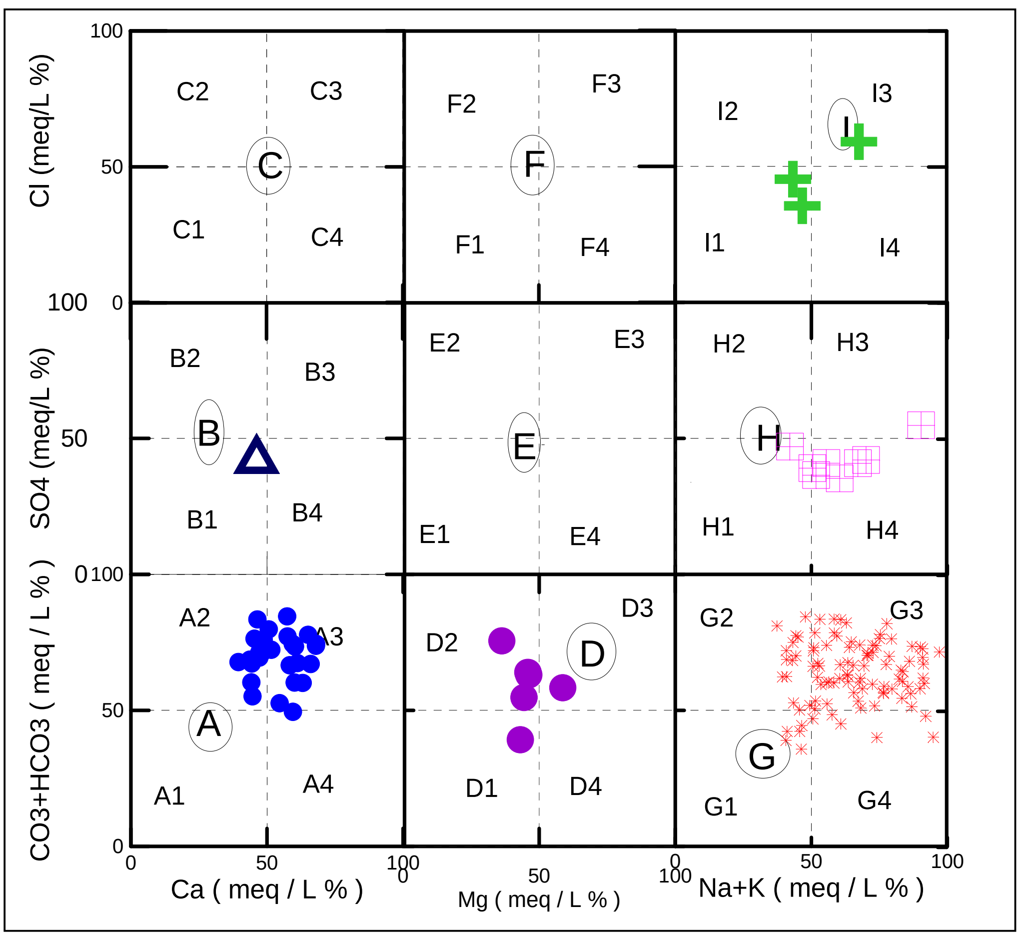

Figure – 10: Classification of Chemical Analyses by Multi-Rectangular-Diagram

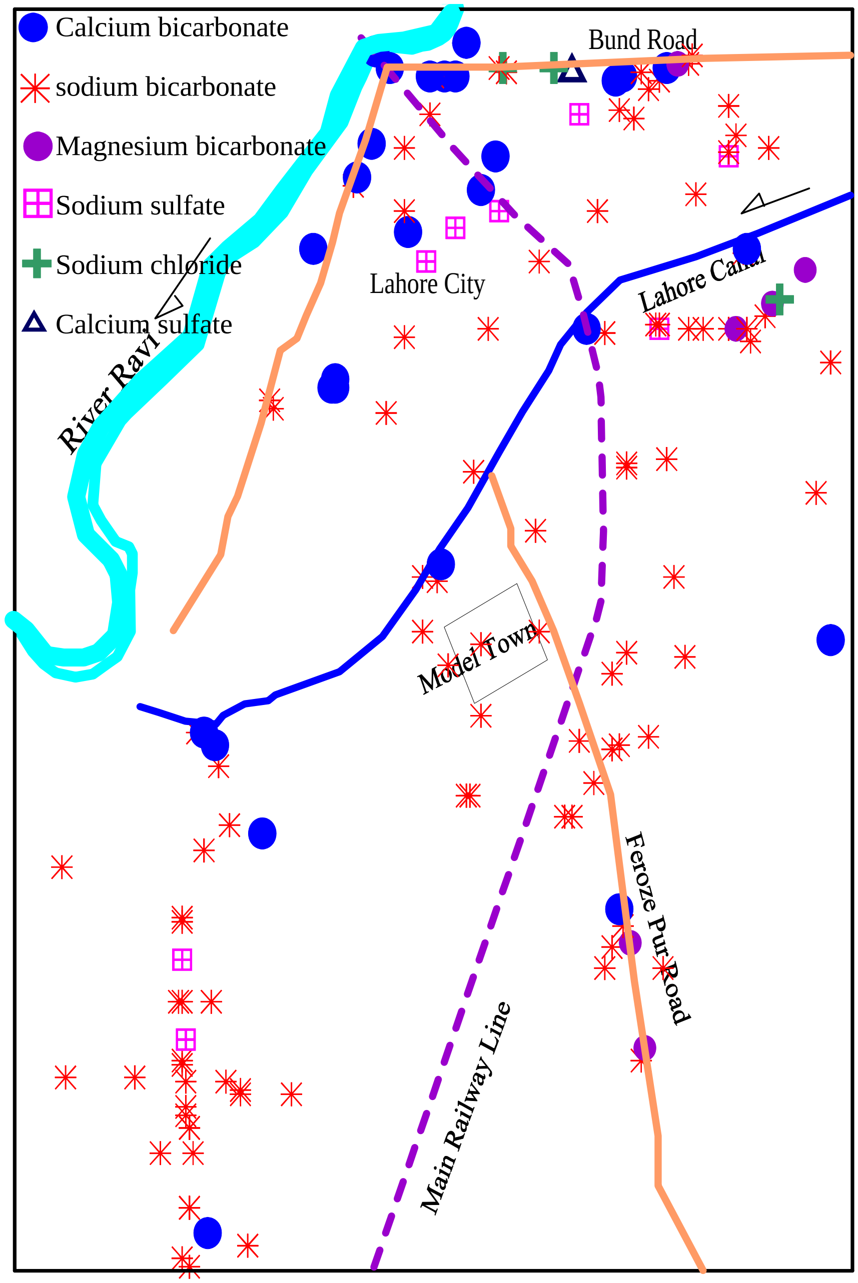

Figure – 11: Map Showing Hydro-Chemical Facies

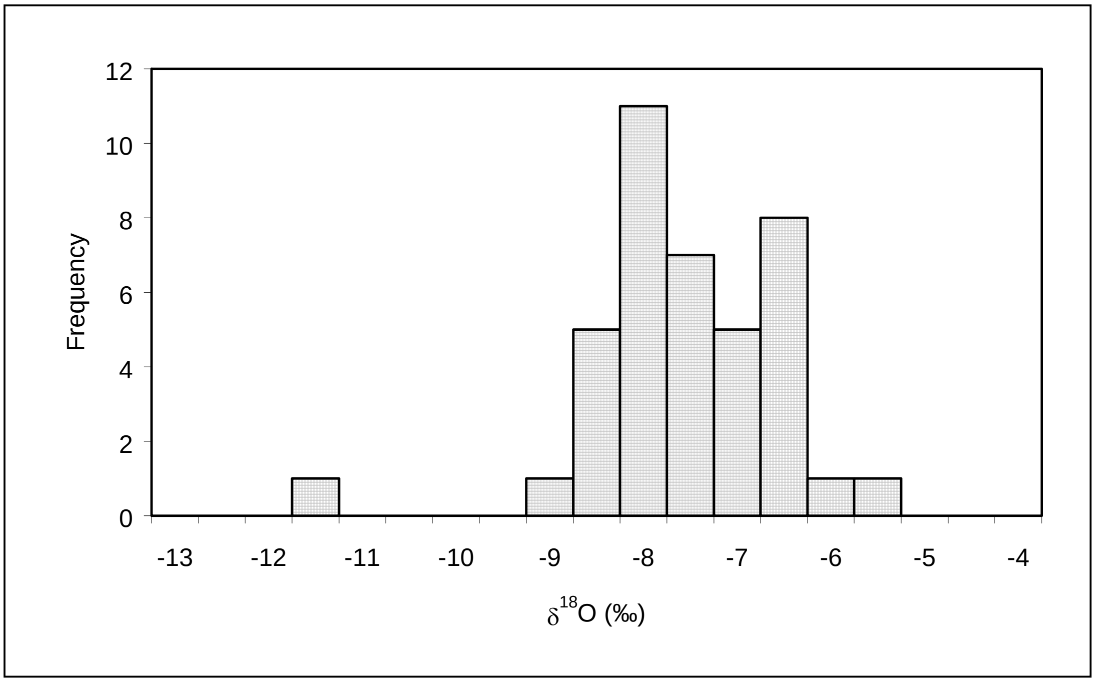

Figure – 12: Frequency-Histogram of δ^{18}O of Deep Groundwater

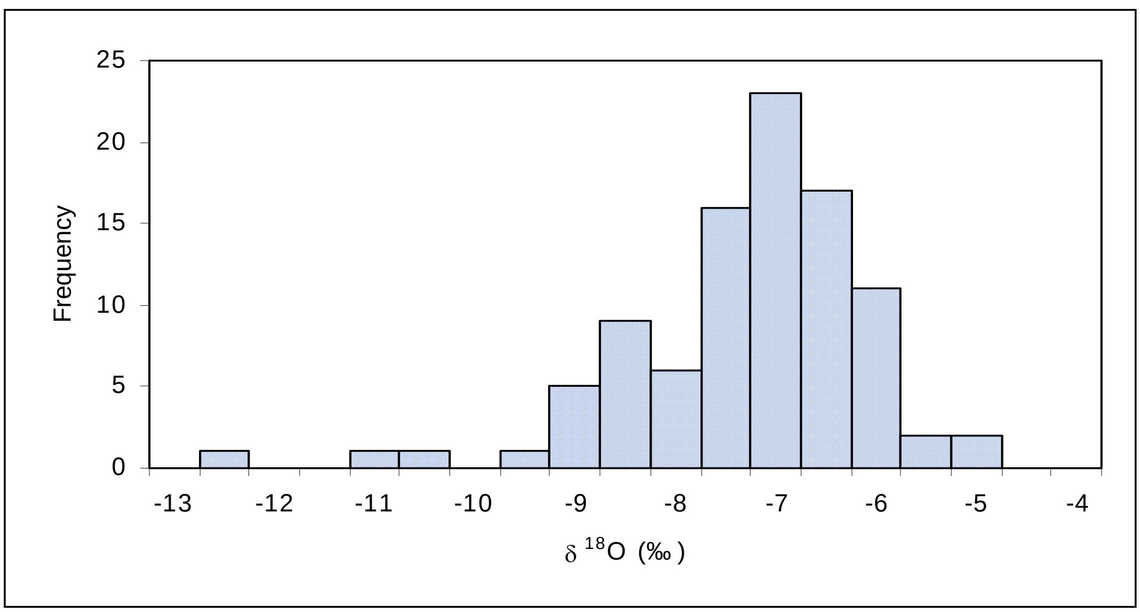

Figure – 13: Frequency-Histogram of δ^{18}O of Shallow Groundwater

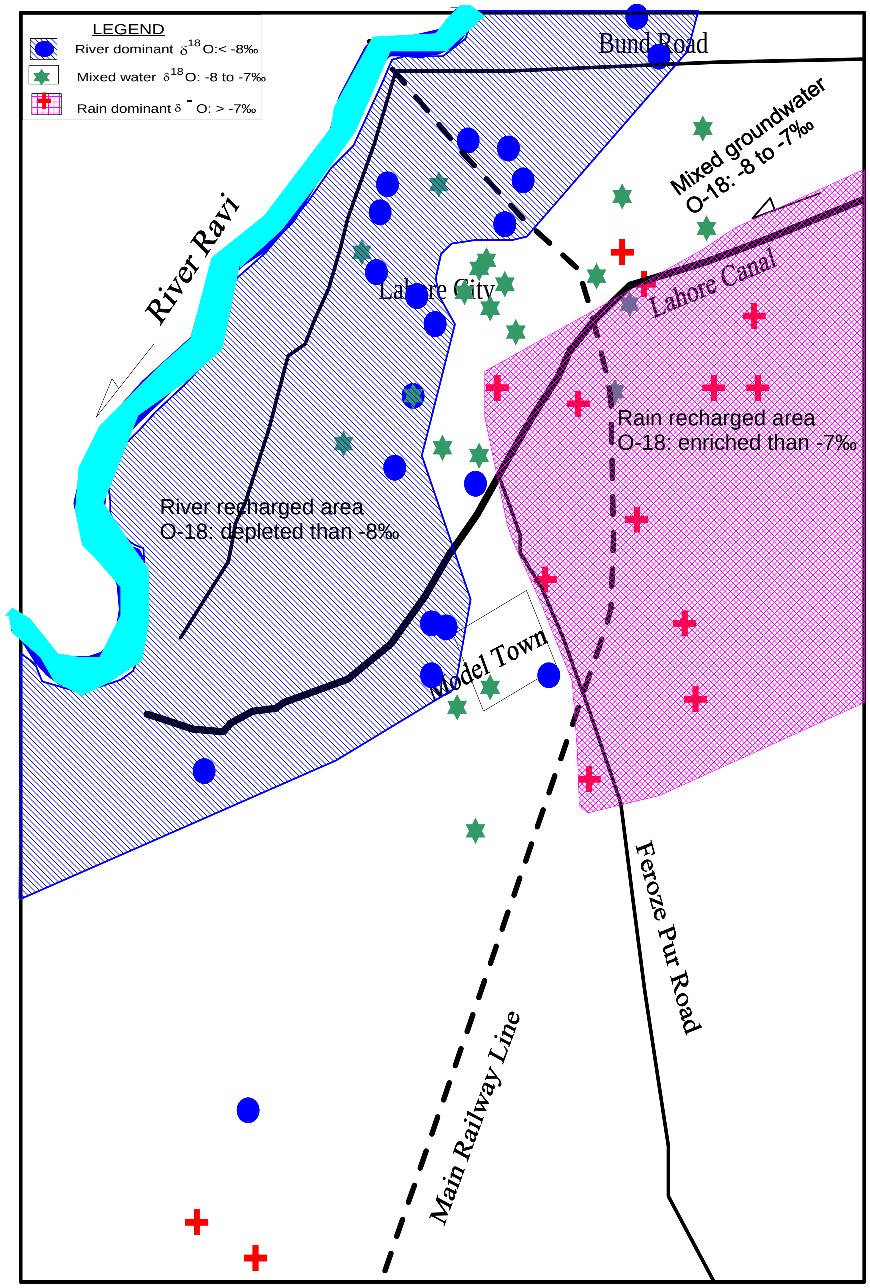

Figure – 14: Spatial Variation of $\delta^{18}O$ of Deep Groundwater

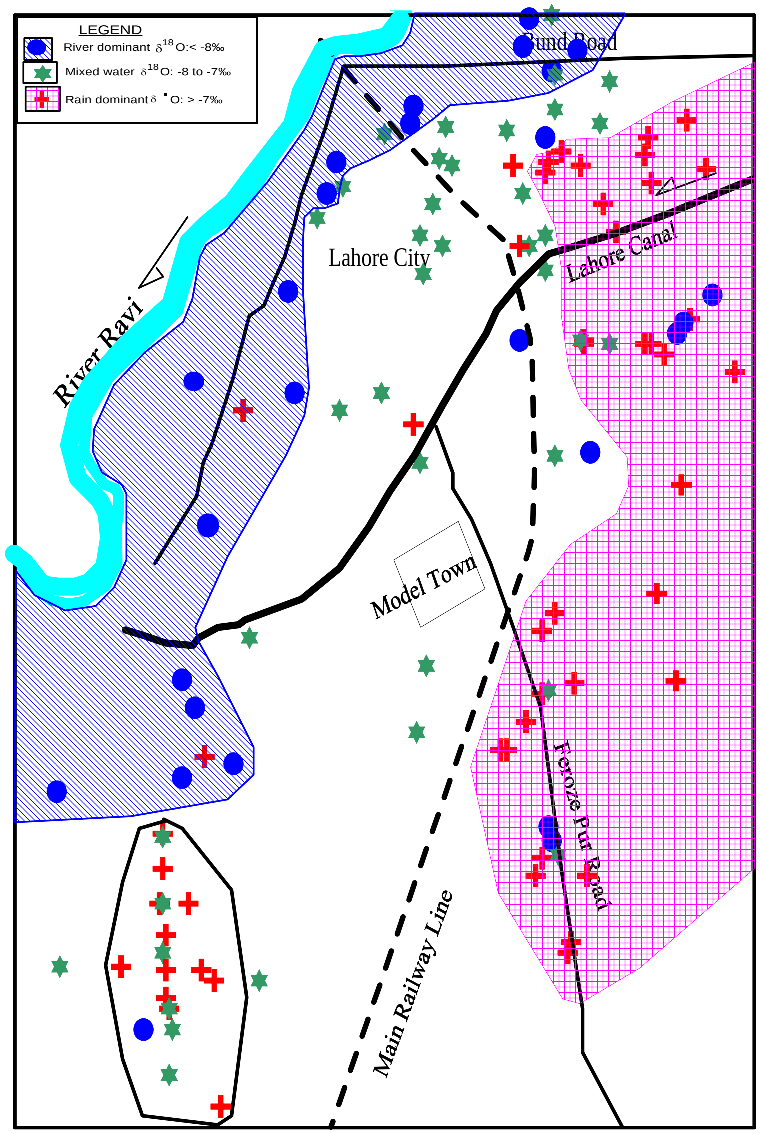

Figure – 15: Spatial Variation of $\delta^{18}O$ of Shallow Groundwater

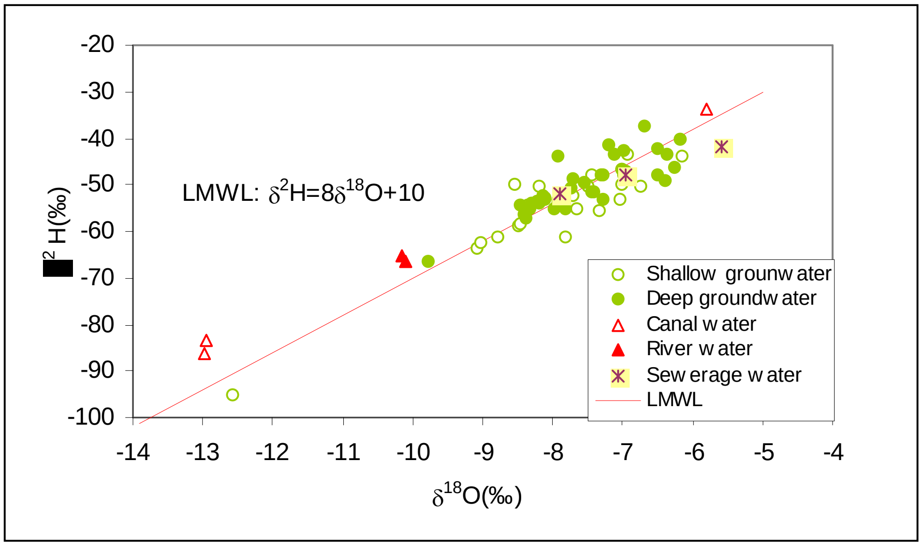

Figure – 16: Plot of δ ^{2}H vs δ^{18}O (2nd Sampling)

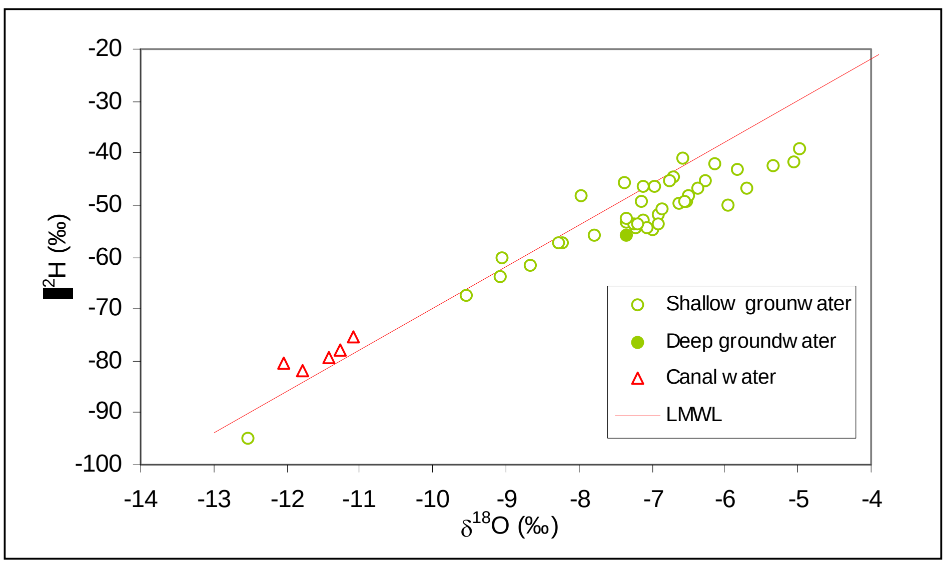

Figure – 17: Plot of δ^{2} H vs δ^{18}O (3rd Sampling)

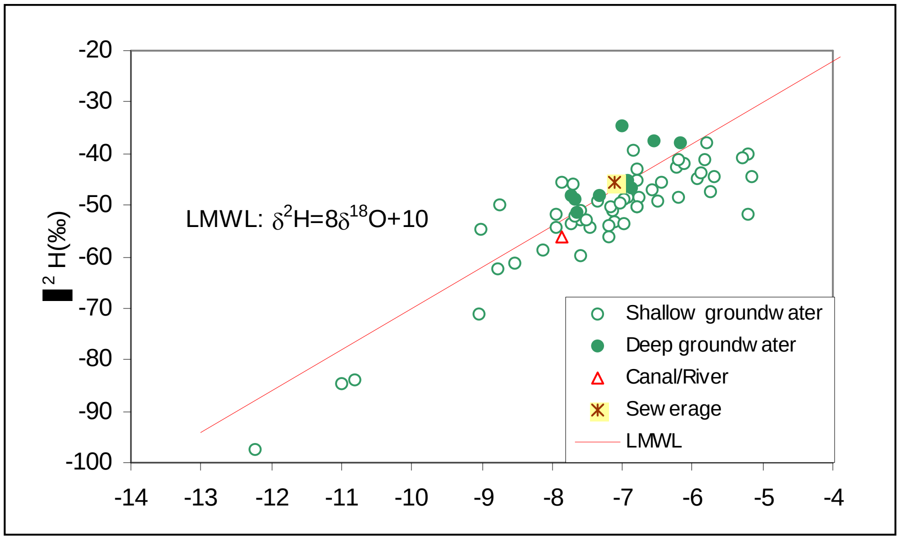

Figure – 18: Plot of δ^2H vs δ^{18}O (4th Sampling)

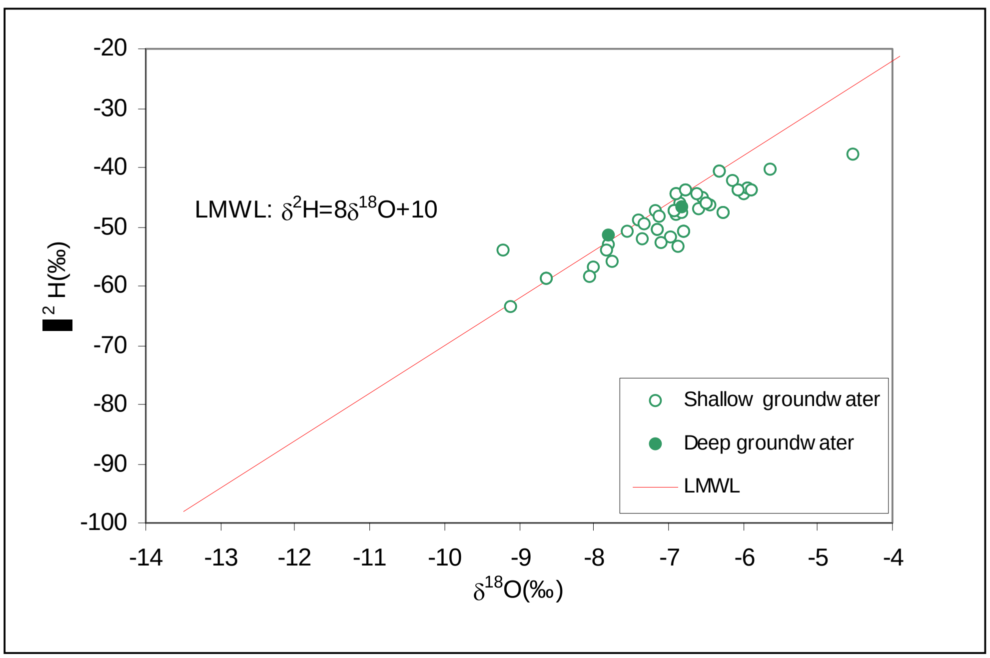

Figure – 19: Plot of δ^2H vs δ^{18}O (5th Sampling)

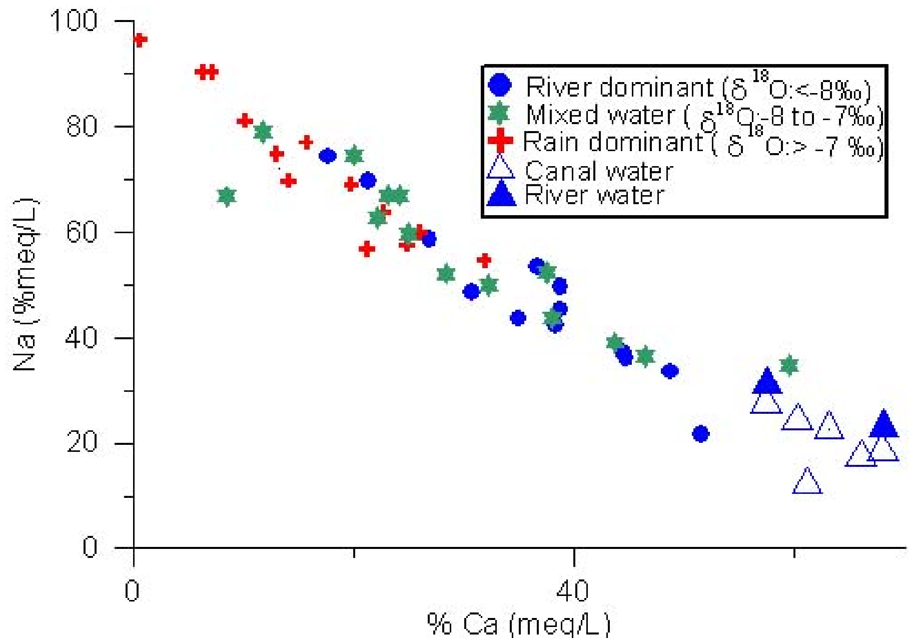

Figure – 20: Na-Ca relationship of deep groundwater

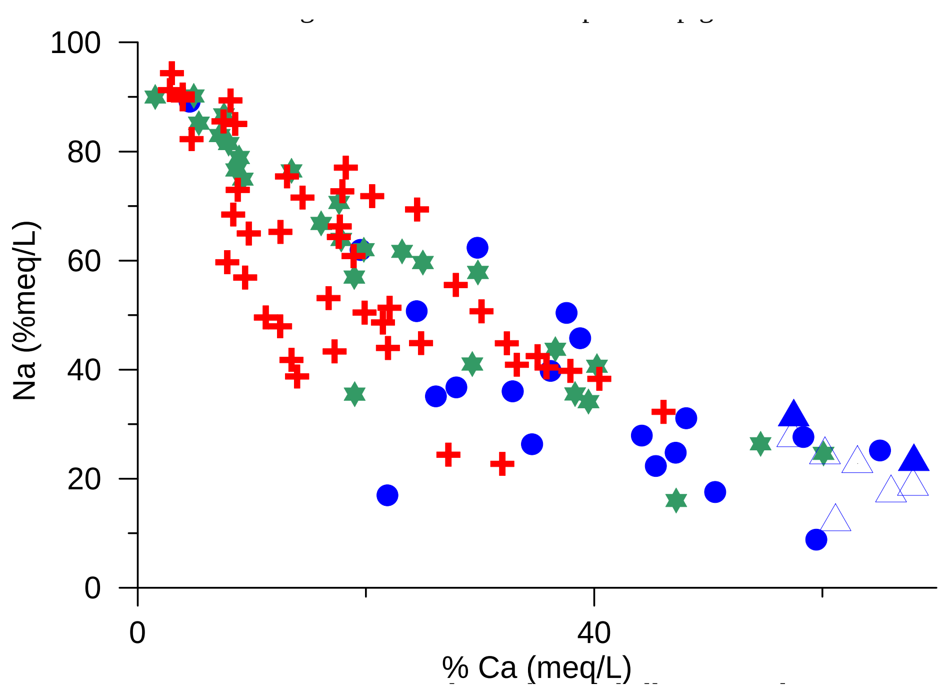

Figure – 21: Na-Ca Relationship of Shallow Groundwater

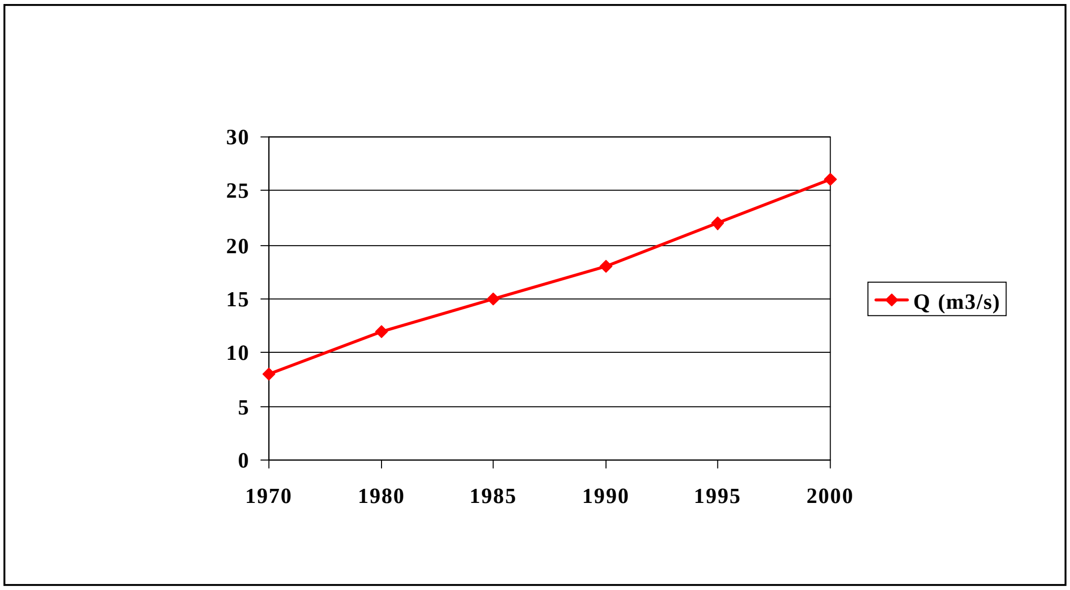

Figure - 22: Historical Abstraction of Groundwater from the Aquifer

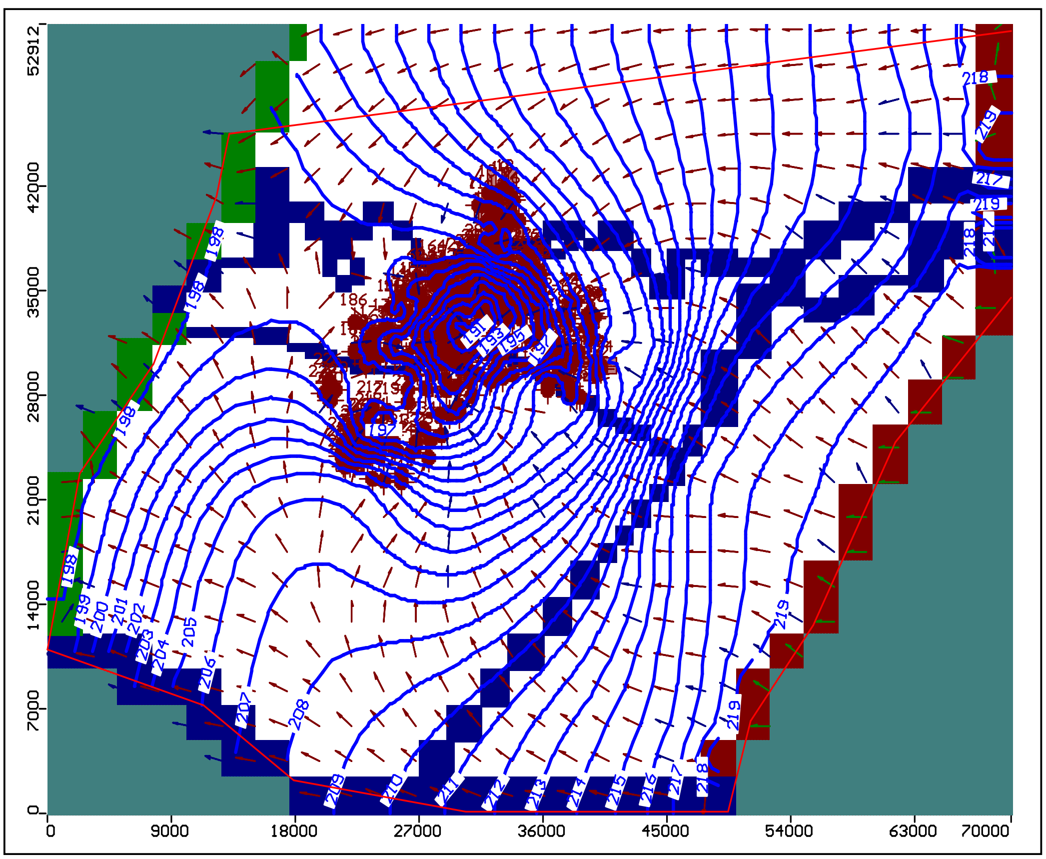

Figure - 23: Observed Contours of Water-Table (November 1989 by Visual Modflow)

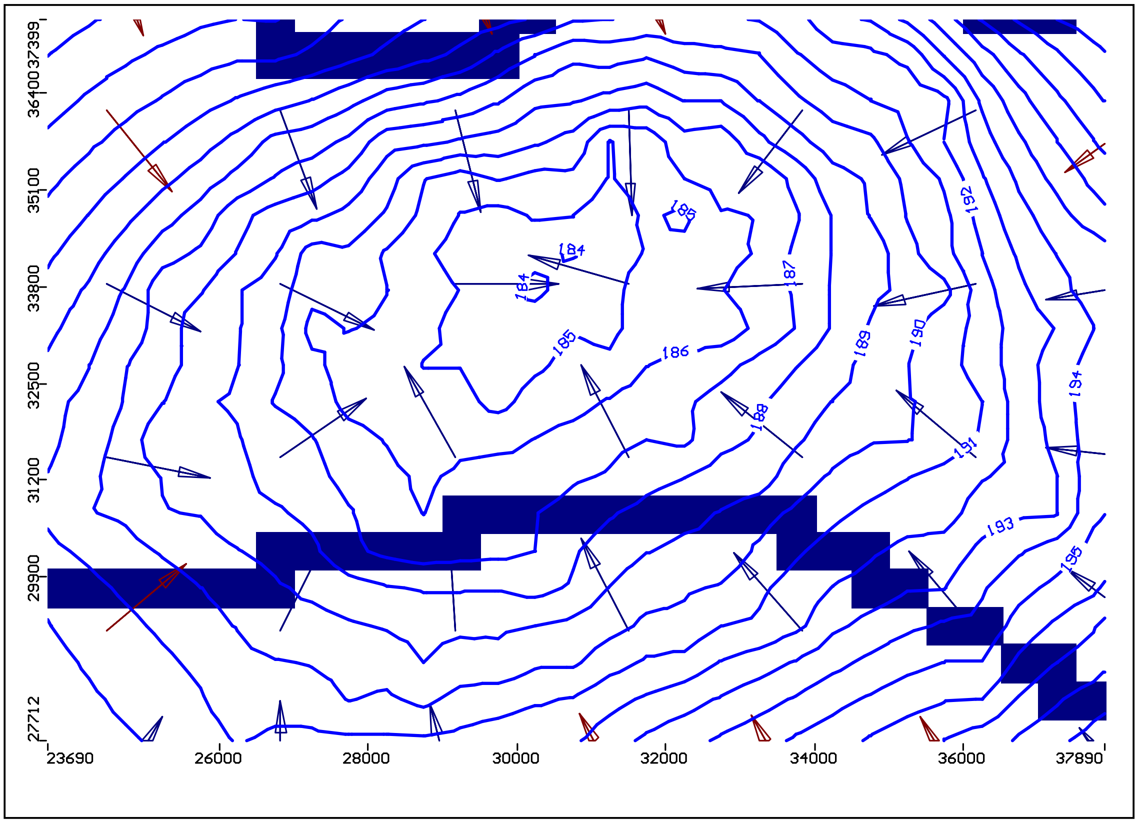

Figure - 24: Observed Water Table Contours in 1998 by Visual Modflow

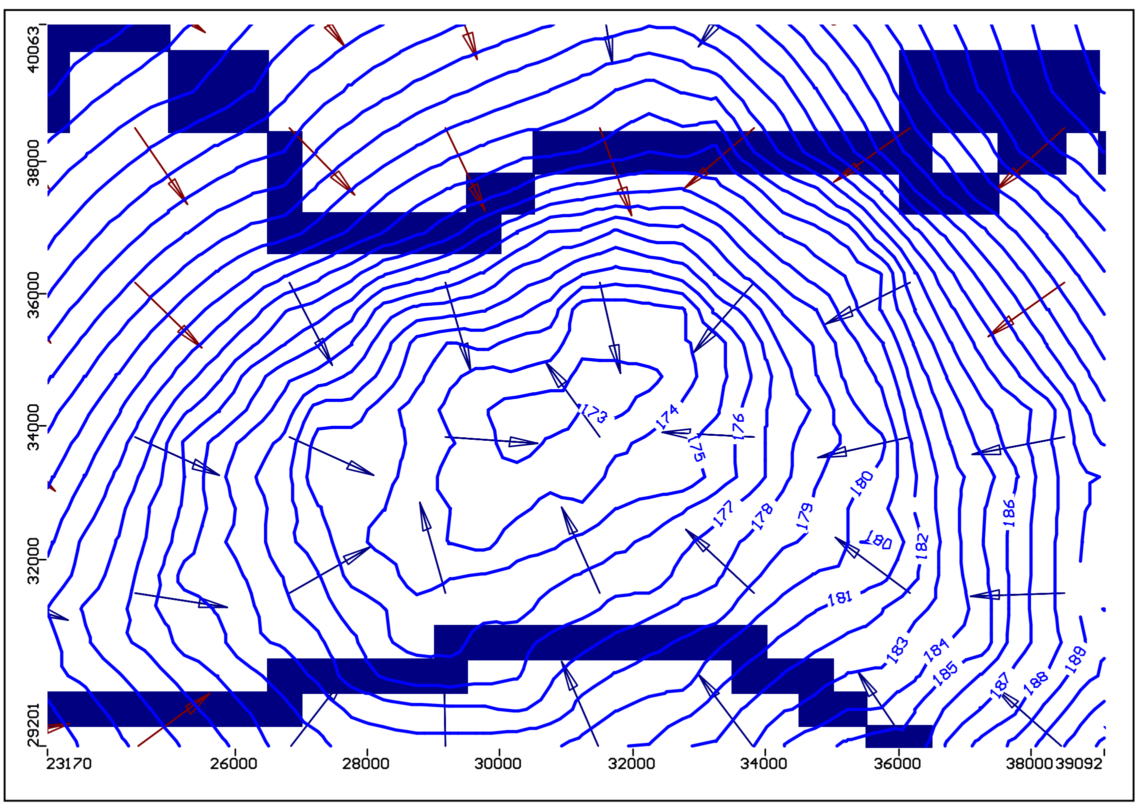

Figure - 25: Predicted Water-Table Contours in 2009 by Visual Modflow

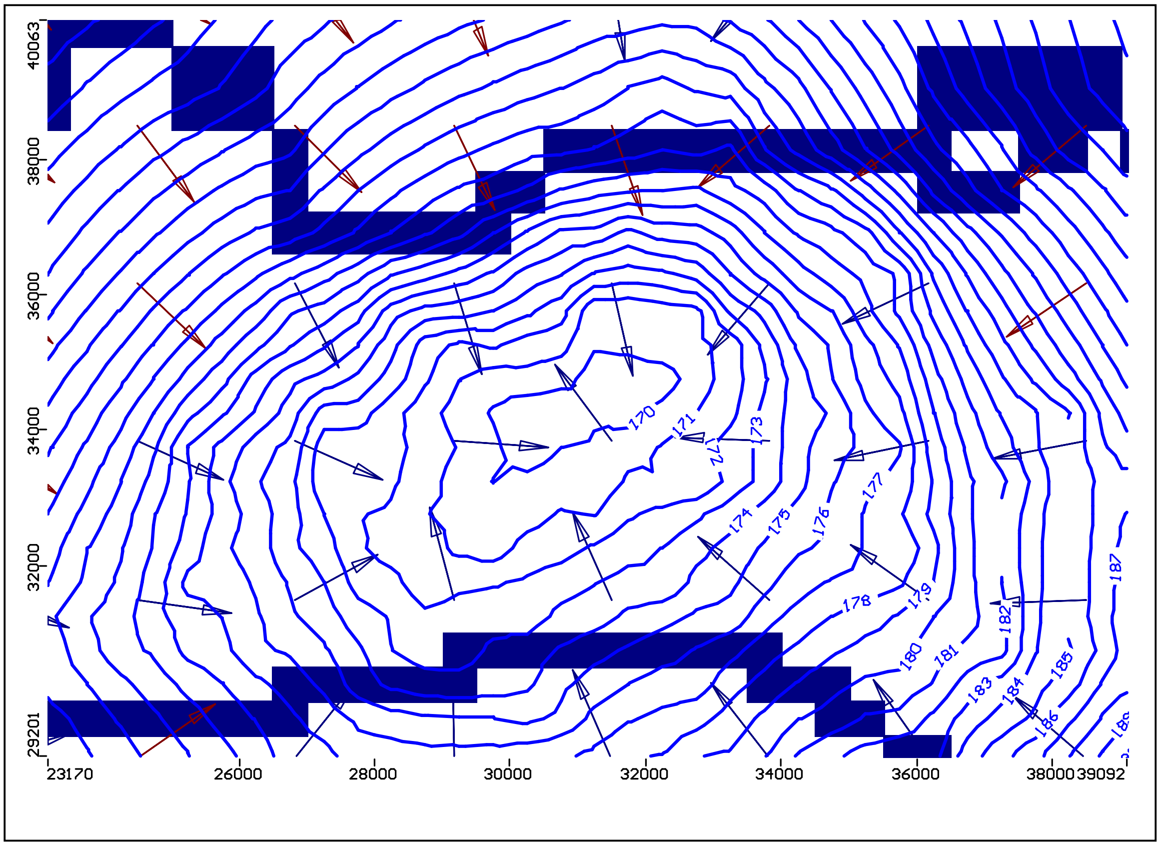

Fig. 26. Predicted Water-Table Contours in 2018 by Visual Modflow

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

A. Mashiatullah, R.M. Qureshi, N.A. Qureshi, E. Ahmad, M. A. Tasneem, M.I. Sajjad, H.A. Khan*

ABSTRACT

Potable groundwater salinity 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}O content of oxygen in the water molecule and ^{13}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}O content of oxygen in the water molecule and ^{13}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 (Figure - 1). 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 and fig 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.

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[1].

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

*For Correspondence: Principal Scientific Officer, Radiation and Isotope Application Division, PINSTECH, P.O. Nilore, Islamabad, Pakistan.

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 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}O) of the water molecule; stable isotopes of Carbon (^{13}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. Figure - 2 shows the location of various sampling points. Surface-water samples and sediment samples 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[2]. In the field, all samples were stored under cool conditions (<12^{o} 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-situe. 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

$\delta^{18}O$ values of water samples were determined by using $CO_2 - H_2O$ equilibration method. Stable inorganic carbon isotope analyses of the total dissolved inorganic carbon (TDIC) of collected water samples were determined on CO_2 gas extracted from TDIC using the routine sample preparation system by reacting 50-100 of water with 85% H_3PO_4 [3]. The stable oxygen isotope data is expressed as δ ‰ (delta per mill.) values relative to the international water standard V-SMOW (Vienna Standard Mean Ocean Water). The reproducibility of $\delta^{18}O$ measurements was better than 0.1‰ for the working standards[4]. The stable carbon isotope data is expressed as δ‰ (delta per mill.) values relative to the international carbonate standard PDB (Pee-Dee Belemnite). The reproducibility of $\delta^{13}C$ measurements was better than 0.1‰ for the working standards. HCO_3^-, Cl^- and SO_4^{-2} were determined by titrimetric. Methods[5].

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. HCO_3^{-1}, Cl^-, SO_4^{-2}), and isotopic ($\delta^{13}C$, $\delta^{18}O$ and $\delta^{2}H$) investigations of surface-water and groundwater in Coastal Karachi-Pakistan. Tables-1.1 through 1.4 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)[6]. The following stable isotope indices of precipitation in Karachi were, therefore, used for interpretation purposes:

Long Term Weighted Means:
$\delta^{18}O$ (water): - 3.93 ± 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- 1.1). The Indus River waters have electrical conductivity values below 500 μS/cm and salinity below 1ppt. The SO_4^{-2} 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:

$\delta^{13}C$ (TDIC): + 1.7 ‰ PDB (n=1)
$\delta^{18}O$ (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-1.1. 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 μS/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. HCO_3^- concentrations are moderate. Both the Cl^- and SO_4^{-2} concentrations in the lake water are around ~ 300 ppm.

The stable carbon isotope index ($\delta^{13}C_{TDIC}$) 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-1.2 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:

$\delta^{18}O$ (Layari River Water): -5 to -2.7 ‰ V-SMOW (n=5)
$\delta^{13}C$ (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 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 Cl^- (3291 ppm) and 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 Cl^- and 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 $\delta^{13}C_{TDIC}$ and $\delta^{18}O$ (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 $\delta^{18}O$ 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:

$\delta^{18}O$ (Malir River Water): -4.9 to -4.6 ‰ V-SMOW (n=2)
$\delta^{13}C$ (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 Cl^- (971 ppm) and SO_4^{-2} (230 ppm) are found in the downstream 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-1.3 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^- contents of seawater off Karachi coast are in the range of 21,578 to 25,230 ppm, while the SO_4^{-2} concentrations are in the range of 2076 to 2210 ppm. The stable carbon isotope contents ($\delta^{13}C_{TDIC}$) 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 $\delta^{13}C_{TDIC}$ value of + 0.8 ‰ PDB corresponds to relatively non-polluted seawater along north-west coast of Karachi. The lowest $\delta^{13}C_{TDIC}$ 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:

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

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

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

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 - 1.4a and 1.4b 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 concentration of HCO_3^- (356 - 514 ppm, n=4), Cl^- (82 - 169 ppm, n=4) and SO4-2 (38-117 ppm, n=4) in shallow groundwater is very reasonable.

The mean chemical concentrations of Cl-, SO_4^{-2} and HCO_3^- in shallow groundwater are as follows:

Mean Cl^- (Shallow Groundwater): 132.8 ± 36.5 ppm (n=4)
Mean SO_4^{-2} (Shallow Groundwater): 63.3 ± 36.7 ppm (n=4)
Mean HCO_3^- (Shallow Groundwater): 423 ± 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:

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

The mean stable isotope content of 18O and 13C in shallow groundwater is as follows:

Mean $\delta^{18}O$ (Shallow Groundwater): -5.9 ± 0.32 ‰ V-SMOW (n=8)
Mean $\delta^{13}C$ (TDIC-Shallow Groundwater): -10.1± 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 Cl- (range: 1480 - 6034 ppm) and SO_4^{-2} (range: 144 - 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^- (3291 ppm each well) and SO_4^{-2} (132 - 445 ppm). The mean chemical concentrations of Cl^-, SO_4^{-2} and HCO_3^- in shallow mixed deep groundwater are as follows:

Mean Cl^- (Deep Groundwater): 2169.2 ± 1828.0 ppm (n=9)
Mean SO_4^{-2} (Deep Groundwater): 458.4 ± 691.4 ppm (n=9)
Mean HCO_3^- (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^{18}O (Deep Groundwater): - 6.2 to -4.2 ‰ V-SMOW (n=10)
δ^{13}C (TDIC - Deep Groundwater): -13.2 to -0.3 ‰ PDB (n=10)

The mean stable isotope content of ^{18}O in shallow mixed deep groundwater is as follows:

Mean δ^{18}O (Deep Groundwater): -5.3± 0.7‰ V-SMOW (n=10)
Mean δ^{13}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 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 δ^{18}O value of ~ +1 ‰ V-SMOW and a chloride content of ~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 δ^{18}O in polluted river waters is ~ 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}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 δ^{18}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 (δ^{34}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 δ^{18}O value of -4.3 ‰ V-SMOW and excessively high values of aqueous chloride and sulfate. One of the samples No. G-006 has δ^{13}C (TDIC) value of -0.3 ‰, PDB which is very close to the δ13C (TDIC) value for seawater. The other two wells No. G-012 and G-014 have δ^{13}C (TDIC) values of -10.4‰ PDB ‰ PDB and -13.2‰ PDB.

Similar depleted δ13C values have been reported for deep saline groundwater tapped from confined aquifer in the coastal zone of Orissa- India[7]. 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 SO_4^{-2} (in milligrams per liter, log scale) are plotted against SO_4^{-2}/Cl^- ratios (in milliequivalents per liter, log scale) for all analyzed water-samples (Figure - 3). It is obvious that shallow groundwater and deep groundwater plot along two distinct lines.

This is further justified by demonstrating the trend of Cl^- concentrations (in ppm, log scale) versus $\delta^{18}O$ 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[8]. It may be realized from Figure-4 that the extrapolated or forecast trend for shallow groundwater samples (with low 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 SO_4^{-2} and Cl^- contents and enriched $\delta^{18}O$ 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.

CONCLUSION

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 on 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 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 little and scattered data-points. More representative sampling is thus required to be performed during the next sampling phase.

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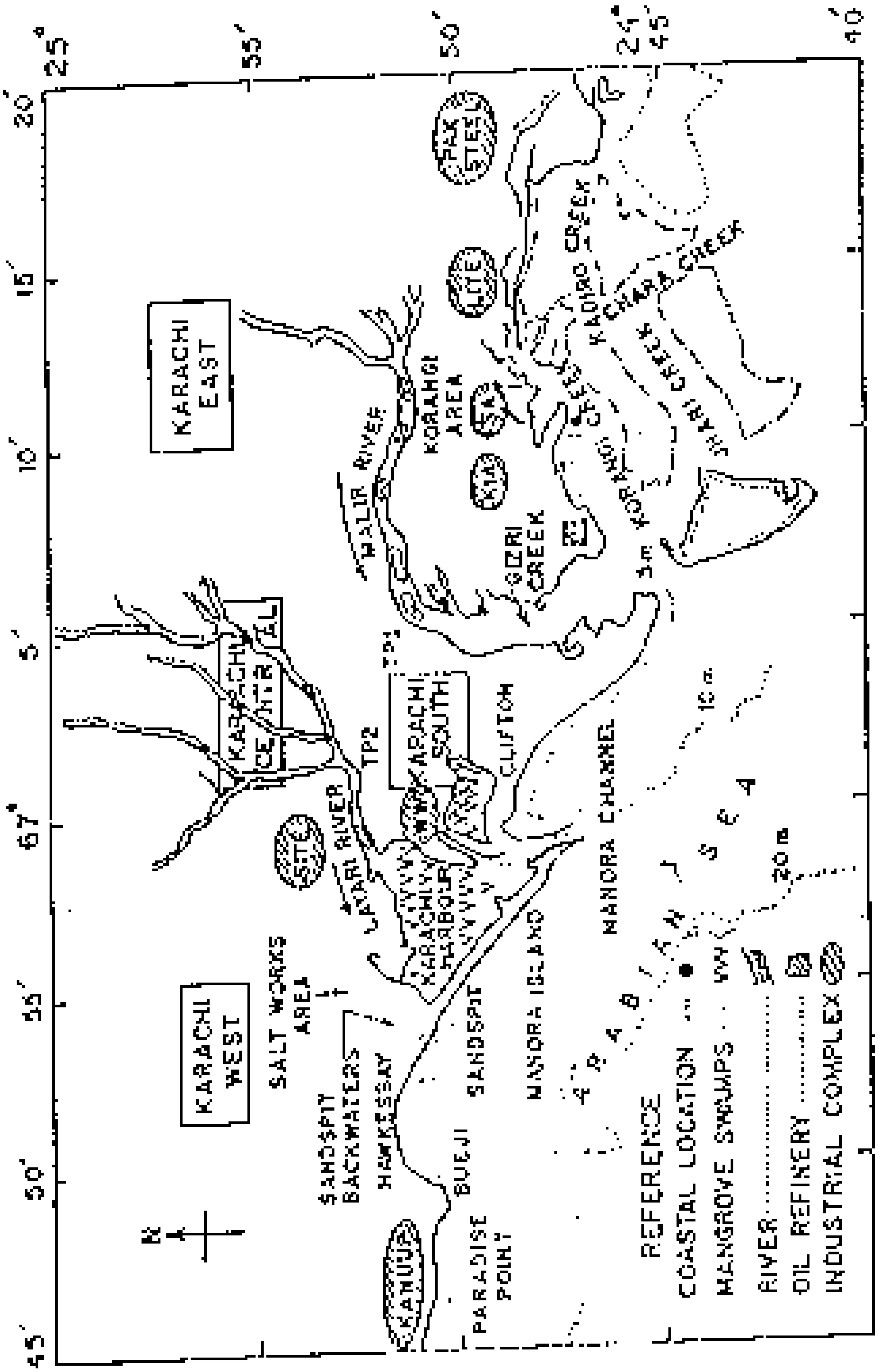

Figure – 1: Map of Karachi (Sources of Pollution, Drainage, Coastline)

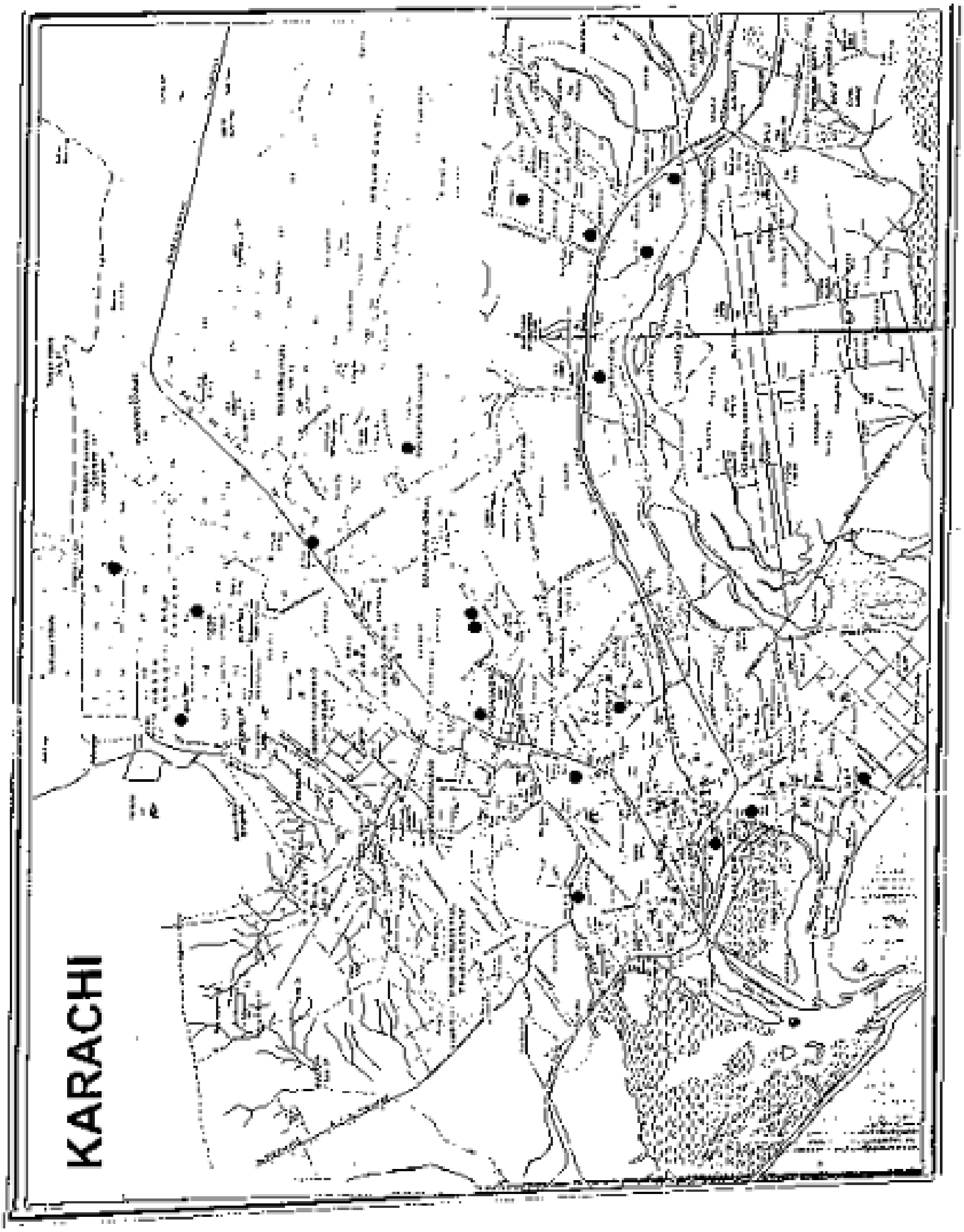

Figure – 2: Map of Karachi Metropolis Showing Location of Sampling Points

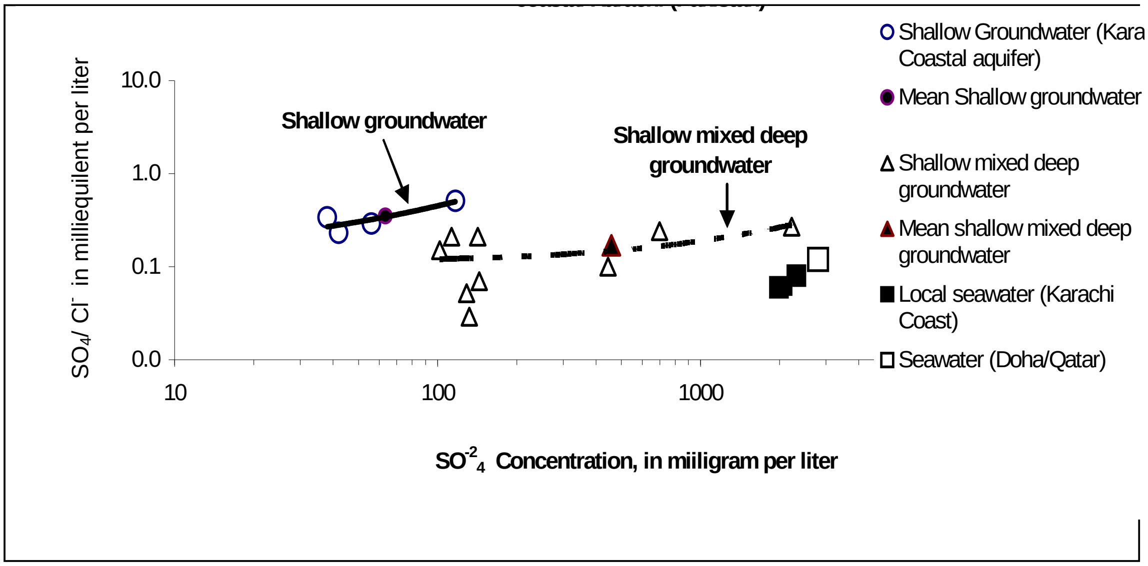

Figure – 3: Graph of SO^{-2}_4/Cl^- Ratio and SO^{-2}_4 Concentration in Shallow and Deep Groundwater, Coastal Karachi (Pakistan)

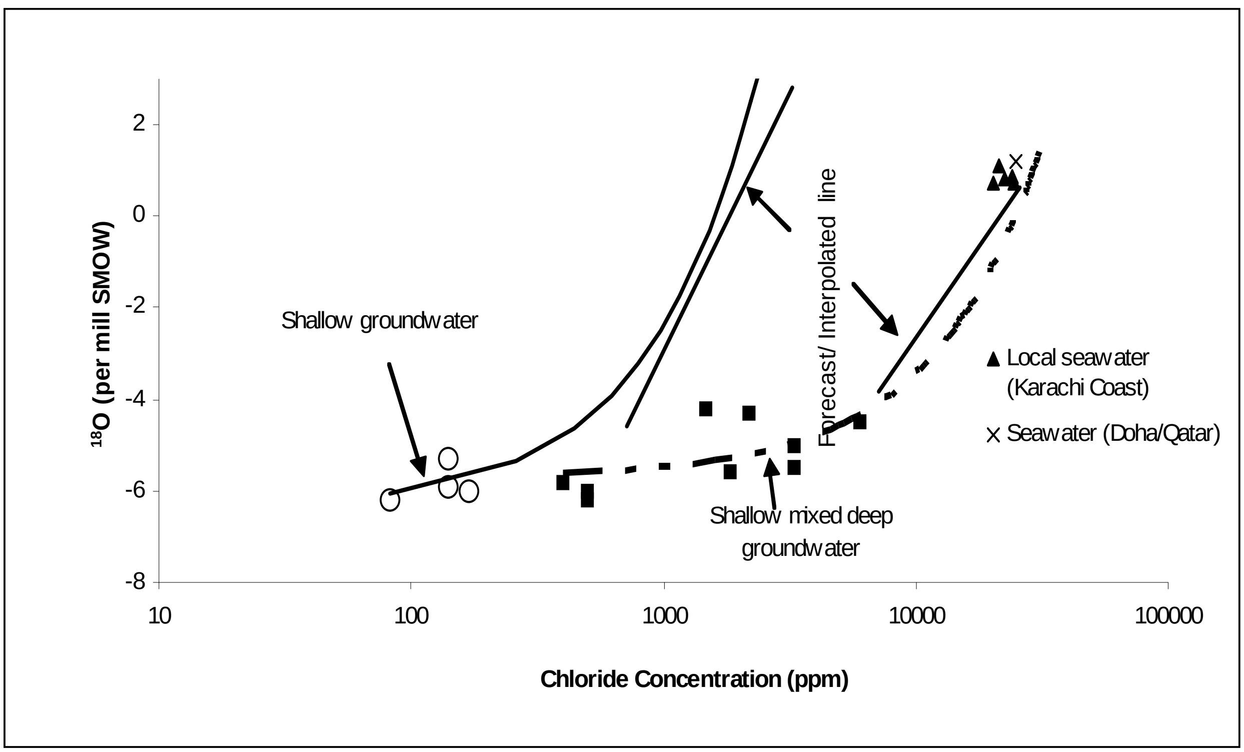

Figure - 4: Chloride Versus ^{18}O Trend Line for Shallow and Shallow Mixed Deep Groundwater, Coastal Karachi (Pakistan)

Table - 2.1 : Physico-Chemical and Stable Isotope Analysis of Potable Surface Water (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. (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	$\delta^{13}C$TDIC(‰V-PDB)	$\delta^{18}O$(‰V-SMOW)	
Indus River															
G-005	Indus water	---	7.6	0.48	36	24.7	-49	8.3	0	---	---	86	1.7	-8.2	
Hab Dam															
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

Table-2.2 : 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. (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^{-3} (ppm)	Cl- (ppm)	SO^{-2}_4 (ppm)	δ ^{13}C-TDIC (‰ V PDB)	δ ^{18}O (‰ V -SMOW)
Layari River														
S-022	New Karachi near Yousaf Ghoth	25^o-00'-48" 67^o-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^o-55'-70" 67^o-05'-28"	7.8	3.7	54	26.5	-345	0.6	3	---	---	---	-7.2	-5.3
S-020	Teen Hatti	24^o-53'-63" 67^o-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^o-52'-75" 67^o-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^o-52'-46" 66^o-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^o-52'-31" 67^o-08'-31"	6.9	1.6	75	23.7	-198	0.2	1	462	201	65	-1.4	-4.9
S-015	Bridge between Mahmooda bad and Korangi	24^o-51'-07" 67^o-05'-63"	7.7	3.2	97	21.6	-25	3.4	3.5	---	---	---	---	---
S-014	Quyyum Abad Ghizri Area	24-^{o}49'-44" 67^o-05'-52"	7.9	3.4	98	23.4	-310	24	5	486	971	230	-8.7	-4.6

Note: "---" Not determined

Table 2.3: 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. (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	$\delta\ ^{13}C$-TDIC (‰ PDB)	$\delta\ ^{18}O$ (‰ 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

Note: "---" Not Determined

Table 2.4(a): Physico-Chemical and Stable Isotope Analysis of Shallow Groundwater (Coastal Karachi)

Sample Information				Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Location/ collection point	Geographical location (Lat/Long)	Approx Depth (meter)	pH	EC (mS/cm)	Turbidity (NTU)	Temp (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	$\delta\ ^{13}C$-TDIC (‰ PDB)	$\delta\ ^{18}O$ (‰ V - SMOW)
A: Shallow groundwater															
A-I: Hand pump															
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
A-II: Dug well															
G-003	Mill Area Liaquat Abad (R_L)	---	15	7.4	1.8	56	29.2	-4	---	1	356	140	56	-5.5	-5.3
A-III: Bores/Pumping wells															
G-004	Garden Zoo Area (R_L)	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_M)	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_L)	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

C *Close to coast*
R_M *Close to Layari River*
R_L *Close to Malir River*
--- *Not determined*

Table – 2.4(b): Physio-Chemical, and Stable Isotope Analysis of Shallow Mixed Deep Groundwater (Coastal Karachi)

Sample Information				Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Location /collection point	Geographical location (Lat/Long)	Approx .Depth (meter)	pH	EC (mS/cm)	Turbidity (NTU)	Temp (^{o}C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^{-}_{3} (ppm)	Cl^{-} (ppm)	SO^{-2}_{4} (ppm)	$\delta\ ^{13}C$-TDIC (‰ V-PDB)	$\delta\ ^{18}O$ (‰ 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_M)	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_L)	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 Ghoth (R_L)	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

C *Close to coast*
R_M *Close to Layari River*
R_L *Close to Malir River*
--- *Not determined*

CONTRIBUTIONS OF PAKISTAN IN THE IAEA/RCA/UNDP REGIONAL PROJECT ON MANAGEMENT OF MARINE COASTAL ENVIRONMENT AND ITS POLLUTION

(RAS/8/083)

*Riffat M. Qureshi**

ABSTRACT

The International Atomic Energy Agency (IAEA), Vienna, launched a five-years (duration: 1998 – 2002) Joint Project on "Better Management of the Environment and Industrial Growth Through Isotopes and Radiation Technology (RAS/97/030)" in co-operation with the RCA (Regional Co-operative Agreement) office, Vienna, and United Nations Development Programme (UNDP). The Marine Sub-project entitled "Management of Marine Coastal Environment and its Pollution (RAS/8/083)" is "Output 1.2" of this joint project.

Pakistan is very actively participating in activities of the IAEA/RCA/UNDP Marine Sub-Project that were planned in two Project-Formulation Meetings (PFMs) held at Manila, Philippines, during 1998. In Pakistan, various activities of the national marine-pollution project are being administered by the nuclear institute namely, Pakistan Institute of Nuclear Science and Technology (PINSTECH), in collaboration with national end-user institutions. To-date, Pakistan has significantly contributed in this project, both at national level and at RCA regional level. This paper highlights the progress and some accomplishments of Pakistan, up to the year 2001, for marine-pollution studies related to the IAEA/RCA regional marine sub-project.

OUTLINE OF MARINE COASTAL ENVIRONMENT OF PAKISTAN

The coast of Pakistan is about 960 km long and borders the Arabian Sea. It extends from the border of India near Rann of Katch in the South-East, to the border of Iran near Gwader in the North-west (Figure-1). The territorial coastal zone of Pakistan is 23,820 sq. km, while the 'Exclusive Economic Zone' (EEZ) of Pakistan's territorial marine waters is about 240,000 sq km. Administratively, the coast of Pakistan is divided into a 745 km long strip, called the Baluchistan/Makran coast, and a 215 km long strip, called the Sindh coast. The Balochistan coast has small towns with a population of about one million. Due to lack of industry and population, the Balochistan coast is relatively free of pollution. The coastal belt of Balochistan, specially the Makran coastal belt, is one of the eight ecological zones that are the most backward and non-productive areas of Pakistan. The Sindh coast consists of the Indus River Delta and Pakistan's largest population and industrial center namely, the Metropolitan Karachi. In contrast to the Balochistan coast, very serious problems of environmental pollution exist along the Sindh Coast (mainly along Karachi coast and Indus Delta zone). With the exception of Karachi metropolis, most of the coastal areas of Pakistan are sparsely inhabited. The coastal zone supports both living and non-living resources, which annually contribute to the national economy. Further, the mangrove ecosystem of the Indus deltaic region is also of significant economic as well as of scientific interest to Pakistan. The mangrove habitat supports the spawning and breeding grounds of commercially important shrimps as well as 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.

There are a number of environmental issues in the coastal zone of Pakistan and, amongst these, the disposal of domestic wastes and industrial effluent, causing marine pollution problems along the urban centers, are the most significant. The pollution problems have arisen mainly from the indiscriminate discharge of effluent, from industrial and agricultural sources, and disposal of untreated liquid and solid wastes, generated from domestic sources, into the coastal environment. In addition, the coastal developmental activities involving man-made alterations of the coastal environment have also accelerated the impacts of pollution, leading to the deterioration of quality of coastal environmental, depletion of coastal resources, public health risks and loss of bio-diversity. The coastal city of Karachi has an estimated population of 13 million, and is the biggest

* Chief Scientific Officer, Radiation and Isotope Application Division (RIAD), PINSTECH, P.O. Nilore, Islamabad, Pakistan.

trade & economic center of Pakistan, with more than 6,000 small and large industrial units. The sewage waste generation in Karachi is some more than 300 m gal /day, out of which 40% is domestic waste and 60% is industrial waste. This waste is dumped into the Karachi sea, via Malir river (Ghizri-Korangi Creek area), Layari river (Manora Channel/Karachi Harbour area) and small waste-drains mainly along Clifton Coast and Korangi Coast (Figure-2). The other coastal areas having industrial-pollution problems are Hub Coast, through Hub Industrial Estate, and Gadani Coast, through industries based in Gadani area. The heavy metals, persistent organic pollutants, air pollution and oil pollution are the more significant factors. There is very little information available on the impacts of persistent organic pollutants in the coastal areas of Pakistan although, their presence is noticeable particularly in solid-wastes disposal. The heavy metals in the coastal waters of Karachi are being accumulated in the sediments and marine organisms, particularly those resident in the polluted areas. The accumulation of eight heavy metals (As, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn) in the resident fauna from polluted coastal areas of Karachi has been reported. The heavy metals are being accumulated in considerably higher concentrations in marine organisms of the polluted localities. The accumulation of five heavy metals (Cu, Co, Mn, Zn, and Fe) in the resident fauna from Gharo, Bakran and Korangi Creeks in considerably higher concentrations has been reported in marine organisms comprising resident fauna of fishes including edible fishes, shrimps, some benthic organisms (bivalves and barnacles) from these areas. The concentrations of iron and zinc were found to be higher than the corresponding values for Mn, Cu and Co.

Oil pollution appears to be of some concern along the Pakistan coast. Sources of oil-pollution include effluent discharges from two oil refineries, mechanized fishing boats and the cleaning of bilges and tank-washing by the large number of merchant vessels, as well as oil-tankers that pass through the EEZ of Pakistan yearly (2500 oil tankers carry 33 million tons of crude oil, ICZM report, 1994). As a consequence, tar balls (residues of weathered oil at sea) are commonly found on beaches. The recent case of oil-spill (4 June, 1998) from the ship R.V. Yashica, abandoned about 304 km south-west of Karachi (approximately 112 km south of Pasni), which was carrying 1500 tons of furnace oil.

The problem of Harmful Algal Blooms (HABs) in Pakistan is very recent. It is not that it was not occurring in the past, but we were not in fact taking notice of it, due to lack of information of its occurrence and absence of HAB alarm network. However, in the last few years several incidences of mass-mortality of fishes have been recorded in the marine coastal environment of Pakistan. Type and origin of bloom observed at specific sites along the coast varies: it may be generated locally or may have originated at some distant location and then moved by coastal currents. Factors that trigger Harmful Algal Blooms are also yet unknown. Likewise, spatial origins of blooms are presently unknown in this area. Increasing frequency and intensity of harmful algal blooms in the region and their concomitant adverse socioeconomic impacts pose a major problem in affected countries. Developing countries, like Pakistan, are especially vulnerable to the effects of toxic bloom and red tide outbreaks, because of lack of information on how to cope with red tides, and insufficient scientific and managerial expertise in this field. The toxic algal bloom appears usually once or twice in every year in this region, and cause mass mortality among fishes. *Prorocentrum minimum* bloom was observed in Gwadar Bay, which was the main factor for the poisoning of fish (Rabbani, 1990). The bloom occurred in 1987 in east Gwadar bay, a semi-enclosed shallow coastal body of highly productive water, on west coast of Pakistan. This bloom lasted for about a week that is why it was possible for the scientists to take samples and analyze them.

Over the past twenty years or so, toxic algal blooms have increased around the world in their frequency, magnitude and geographic extent, as well as in their resulting effects. It is also observed that unusual mortality of fish in the Arabian Sea has increased in last few years, which ultimately adversely affects fish-marketing and fisheries industry and is of increasing public concern. Though potential "*Red Tide'* forming organisms like *Gonialax* (Saifullah, 1973, 1978), *Noctiluca scintillans* (Saifullah, 1990), *Phaeocystis* (Chaghtai, 1997) & *Peridinium* (Hassan, 1973) have been reported by several workers, in recent incidences (Year: 1999 - 2000) of red tide in Pakistan's coastal waters where wild fish population were hit by this phenomenon including Rough tooth & Bottle nose Dolphins, Speckled Siderial Moray, File fish and Parrot fishes, baleen whale was also found dead. During this period, water-samples showed the bloom forming concentrations of *Gymnodinium* and *Noctiluca species*. In order to minimize the damage to public health, aquaculture and marine ecosystem, a comprehensive monitoring system is essential.

IAEA/RCA/UNDP MARINE SUB-PROJECT *(RAS/8/083)*

Regional Scenario

The IAEA (International Atomic Energy Agency), Vienna, in co-operation with the RCA (Regional Co-operative Agreement) office, Vienna, and the UNDP (United Nations Development Programme) has launched a Joint UNDP/IAEA/RCA Project (RAS/97/030) on "*Better Management of the Environment and Industrial Growth Through Isotopes and Radiation Technology (1998 – 2002)"*. The Joint Project 'RAS/97/030' has five outputs; the Marine Sub-project entitled *Management of the Marine Coastal Environment and its Pollution (RAS/8/083)* is designated as output 1.2 of this Project The UNDP has funded the Marine Sub-project under the project RAS/8/080, while the RCA Member States fund the Marine Sub-project in its initial phase under the project RAS/8/083. The IAEA funds the Marine Sub-project under the combined projects: RAS 8/076, RAS 8/082 & RAS 8/084. The Australian Nuclear Science and Technology Organization (ANSTO) and the Philippines Nuclear Research Institute (PNRI) are potentially funding the project-activities. Australia is also acting as the Lead Country for this project, assisted by India. The RCA Member States have to perform field and laboratory activities for the respective national marine sub-project, through in-kind contributions and national collaborative arrangements among end-user institutions.

Various activities of the IAEA/RCA/UNDP Marine Sub-project were decided in two Project-Formulation Meetings (PFMs) held at Philippines Nuclear Research Institute (PNRI)-Manila, Philippines (23-27 Feb., 1998 and 30 Nov. - 04 Dec. 1998). National Coordinators from various RCA Member States attended the PFM and discussed availability of in-kind financial resources, national collaborative arrangements, training requirements, as well as needs for RCA regional collaboration and inputs required from IAEA to properly execute project-activities along the RCA national coastal marine environments. The Marine Sub-project was thus designed to:

a. Accomplish the following four tasks along the RCA national marine coastal environment:

   i *Establishment of a National Database on Marine Radioactivity;*
   ii *Establishment of Levels, Behaviour and Fate of Radioactive and Non-radioactive Pollutants in the Marine Water and Food web, through Nuclear and Conventional Techniques*
   iii *Application of Nuclear and Modelling Techniques to Sustainable Development in the Coastal Zone*
   iv *Evaluation of Harmful Algal Bloom (Red Tide) Concerns, along the Coast, through Application of Nuclear Techniques*

b. Hold training events and mid-term review meetings, in Marine Sub-project Lead Countries (Australia, India, Philippines) and Regional Resource Units/Participating RCA Member States, for project specific activities (Pakistan, China, Thailand, Philippines, Malaysia, Australia & India) to assist the participating RCA Member States in South Asia to adequately perform project-activities

c. Organize execution of national marine pollution project related specific activities, through collaborative in-kind arrangements at national level involving the National Atomic Energy Authorities and the national/regional End-user institutions.

The project document for the marine sub-project was finally compiled, updated by the Lead Country Coordinator: Dr. Peter Airy (ANSTO/Australia), and distributed to the designated RCA national coordinators of the marine sub-project.

National Scenario

Following the two PFMs held at PNRI-Manila (1998), Pakistan is very actively participating in the IAEA/RCA Marine Sub-Project. Various activities of the national marine pollution project are being administered by the Pakistan Atomic Energy Commission (PAEC), in collaboration with the national end-user institutions of this project and according to the programme set-forth by the Lead Country Coordinator (Dr. Peter Airy, *ANSTO/Australia)*.

Under the charter of the IAEA/RCA/UNDP Marine Sub-project RAS/8/083, the national nuclear institute viz. PINSTECH, Islamabad, initiated essential field and laboratory activities in collaboration with other key end-user institutions. PAEC has designated the following officials to co-ordinate Pakistan's National Marine Sub-project activities among National End-User institutions:

RCA National Coordinator
Director, International Affairs and Training
Pakistan Atomic Energy Commission (PAEC)
P.O. Box 1114, Islamabad, Pakistan
Phone: 92-51-9201862
Fax: 92-51-4908

RCA National Project Counterpart
Director General
Pakistan Institute of Nuclear Science & Technology (PINSTECH)
P.O. Nilore, Islamabad, Pakistan
Telephone: 92- 51- 2207201
Fax No.: 92- 51- 9290275

RCA National Sub-Project Coordinator
Dr. Riffat Mahmood Qureshi
Head, Environment Research Group, Radiation and Isotope Applications Division (RIAD),
Pakistan Institute of Nuclear Science & Technology (PINSTECH)
P.O. Nilore, Islamabad, Pakistan
Telephone: 92- 51- 2207228 and 9290231- 7 (Extension: 3433)
Fax: 92- 51- 9290275
Email: riffat@pinstech.org.pk

At the national level, essential infrastructure and scientific facilities exist at the nuclear institute and potential end-user institutions. The Pakistan Institute of Nuclear Science and Technology (PINSTECH) has well-established capabilities for application of both stable isotope (^{13}C, ^{15}N, ^{34}S, ^{2}H, ^{18}O) & radioactive isotope (^{3}H, ^{14}C, ^{137}Cs, ^{90}Sr) techniques, as well as nuclear related analytical techniques (NAA, ICP, XRF, AA etc.) for study of the four components/tasks of the marine pollution project. Development of facilities for measurement of natural levels of radionuclides, such as ^{210}Po, ^{210}Pb, $^{239+240}Pu$, are underway. Based on this, the IAEA has recognized PINSTECH as a Regional Resource Unit (RRU) for the Component-II (Fate & Behaviour of Pollutants/ Contaminant Transport) of the IAEA/RCA Marine Sub-project, to help participating RCA member states in the development and application of stable isotope methods and the Direct $^{14}CO_2$ Absorption Technique for ^{14}C dating for the identification of pollution source terms and for isotope analysis of marine environment samples. Field sampling equipment, as well as analytical facilities for organic pollutant analysis (HPLC, G.C.) and biological analysis, are also available at the potential national end-user institutions of the marine project, such as the NIO-Karachi, PN, CEMB-Karachi University, HEJ-Karachi University, MFD (GoP)-Karachi, MSA and KFHA, KPT etc. It is worth mentioning that Pakistan Navy (PN), National Institute of Oceanography (NIO)-Karachi, and the Center of Excellence in Marine Biology (CEMB), Karachi University, Karachi are very strongly supporting execution of various national activities of this project through in-kind contributions.

NATIONAL PLAN OF ACTIVITIES

Development of Collaboration Among End-User Institutions

The National Coordinator of the IAEA/RCA marine sub-project made successful efforts to strengthen collaboration between National Nuclear Institute [PINSTECH/ Pakistan Atomic Energy Commission (PAEC)] and the end-users of the national marine-sub-project to mobilize local resources for accomplishment of research-plans in view of the activities of the Marine Sub-project. The following End-User Institutions indicated their willingness to participate in the field and laboratory activities of the national marine pollution project:

KFHA:	Karachi Fisheries Harbour Authority, Karachi
FCS:	Fishermen Co-operative Society Ltd. (Karachi)
KPT:	Karachi Port Trust -Karachi
KU	University of Karachi, Karachi
CEMB:	Center of Excellence in Marine Biology
DoG:	Department of Genetics (Karachi University)
HEJ:	Hussain Ebrahim Jamal Institute of Chemistry
MEL:	Mangrove Ecosystem Laboratory (Department of Botany)
MFD:	Marine Fisheries Department, Government of Pakistan -Karachi
MSA:	Maritime Security Agency Karachi
NGO:	Non Governmental Organizations
WWF:	World Wildlife Fund for Nature (Pakistan Office-Karachi)
IUCN:	International Union for Conservation of Nature & Natural Environment (Karachi Office)
NIO:	National Institute of Oceanography (Karachi)

PAEC: Pakistan Atomic Energy Commission (Islamabad):

PINSTECH: Pakistan Institute of Nuclear Science & Technology, (Islamabad)

- *RIAD:* Radiation & Isotope Application Division (PINSTECH)
- *HPD:* Health Physics Division (PINSTECH)
- *KNPC:* Karachi Nuclear Power Complex (Karachi)
- *HPD:* Health Physics Division (KNPC)

PAK-EPA: Pakistan Environmental Protection Agency (Islamabad)
EPA-Sindh Province
EPA-Balochistan Province

PN: Pakistan Navy, Naval Headquarters, Islamabad

- PN Dockyard Lab: Pakistan Naval Dockyard Laboratory, Karachi
- *MA & EC:* Directorate of Maritime Affairs & Environmental Control (Naval Headquarters, Islamabad)
- *MPCD:* Marine Pollution Control Department (Karachi)

ZSD: Zoological Survey Department of Pakistan (Karachi Office)

Planning Meeting of National End-User Institutions

PINSTECH organized a meeting of the representatives of above mentioned key end-user institutions for the Marine Sub-project at the National Institute of Oceanography, from 2-3 June, 2000, to formulate national plan of activities for marine pollution studies along the coast of Pakistan, in relation to the Marine Sub-project. The meeting was attended by 35 representatives belonging to 21 different government and non-government organizations involved in the management of coastal areas.

The following objectives were accomplished at the planning meeting:

- Review of progress made to-date on execution of various field & laboratory activities and studies, participation in IAEA/RCA sponsored training fellowship programmes, hosting of RCA Review Meetings and RCA Regional Training Courses in Pakistan, in line with the Pakistan's National Marine Pollution Project.

- Dissemination of up-to-date information received from the IAEA/RCA Office-Vienna to end-user institutions on various components of the IAEA/RCA/UNDP Marine Sub-project (RAS/8/083).

- Evaluation of available in-kind resources & future requirements by collaborating end-user institutions for proper execution of field and laboratory activities, in view of tasks as defined in the Pakistan's National Marine Pollution Project Proposal, and handle any shortcomings through in-kind arrangements, IAEA/RCA expert missions and/or training fellowships & available funds for supplies.

- Organization of suitable work plan, time schedule / protocols and field teams for execution of field-sampling trips (tentatively during Fall 2000 and Summer 2001/2002) along selective locations of Pakistan Coast (mainly in the vicinity of developing harbours and fish concentration centers, such as: *Indus Delta, Karachi Coast, Damb Sonmiani, Miani Hor, Ormara, Kalmat Khor, Pasni, Gwader, Gwater and Jiwani (Ref. Figure-1)* for collection of shallow seawater samples (mainly within 30 meter depth line, and a few samples from deeper depths within the Exclusive Economic Zone (EEZ) limits of Arabian Sea along Pakistan Coast, sea-bottom sediment samples, sea-bottom sediment core samples, marine biota samples (fish, crabs, mussels, seaweeds, mangroves etc.), as well as, transportation of marine samples to concerned end-user institution laboratories for chemical, biological, radioactive and non-radioactive isotopic analysis.

Representatives of participating institutions presented a 15-20 minutes duration seminar on their interest / level of participation in specific components of the National Marine Pollution Project, work plan, existing experience, field & laboratory facilities available at institute/department, requirement of collaboration from participating end-user institutions for sampling/analysis, baseline data available at participating department for a specific component of project. At the National Planning Meeting, the participating end-user institutions agreed to collaborate for accomplishment of marine pollution studies along the coast of Pakistan, under a National Marine Project Title: *'Application of Nuclear Techniques For Management of Marine Coastal Environment And Its Pollution In Pakistan*. It was further agreed to accomplish various tasks of the national marine project under the following four components, in line with the IAEA/RCA/UNDP Marine Sub-project RAS/8/083:

Component-I:	*Establishment of marine radioactivity database for the coast of Pakistan, with special reference to Karachi coast and Indus delta*
Component-II:	*Establishment of levels, behaviour and fate of radioactive and non-radioactive pollutants in the marine water and food web, through nuclear and conventional techniques*
Component-II A:	*Baseline studies of chemical pollution inventory in the mangrove ecosystem off the Pakistan coast*
Component-II B:	*Isotopic and chemical investigations of pollution inventory in marine water and sediments, with special reference to the mangrove ecosystem off Pakistan coast*
Component-II C:	*Environmental isotope content of marine food web in selective estuarine and near-shore shelf ecosystems off the Pakistan coast*
Component-III:	*Application of nuclear and modeling techniques to sustainable development along Karachi Coast and Gwadar Coast*
Component-IV:	*Baseline studies on harmful algal bloom concerns, in coastal marine environment of Pakistan*

Various activities and tasks involved in the four components of National Marine Pollution Project were discussed in the planning meeting. Discussion were also made on designation of field-sampling and laboratory-analysis teams and related task-distribution among participating end-user institutions. The participant from Pakistan Navy (Dockyard Laboratory-Karachi) indicated its serious concerns on heavy corrosion problems to naval vessels and structures in the Karachi Harbour, mainly due to marine pollution and activities of sulfate-reducing bacteria (SRB). The laboratory has requested to probe the problem through national collaborative arrangements. Likewise, the participants from CEMB-Karachi University indicated the need to study the Harmful Algal Bloom Concerns along the Coast of Pakistan, with special reference to the Karachi Coast.

Projections of Work Plan

In order to accomplish tasks related to the four components of the National Marine Pollution Project, and those identified by the representatives of the participating end-user institutions, specifically, the Pakistan Navy and the Center of Excellence in Marine Biology-Karachi University, it was decided to carry out specific field-sampling activities at selective locations along the coast of Pakistan at least twice: once during Fall 2000 (*Calm sea period*), and then again in Summer 2001/2002 (*rough sea period*). The main study-sites of interest include the following:

Sindh Coast:	*Indus River Delta, Karachi Coast, Damb Sonmiani*
Balochistan Coast::	*Miani Hor (Coastal Lake), Ormara, Kalmat Khor (Coastal Lake), Pasni, Gwader, Gwater and Jiwani*

Table-1 (annexed at the end of the paper) highlights tentative marine sampling activities along the coast of Pakistan, in terms of proposed participation of end-user and institutions for in-kind provision of facilities for sample collection, manpower & transport and logistics for the sampling team, etc., as well as the type and amount of samples to be collected at each location. The key elements of tentative work-plan off Pakistan coast during the period 2000 - 2002 are summarized in the following section.

1. **Year 2000**

   a. Representative collection of water, sediment and biota samples for chemical, stable isotope, radioactivity and biological analysis along the coast of Pakistan during (winter monsoon period, calm sea conditions).
   b. Sampling of HAB Cyst/sediment Core samples at specific locations along the coast of Pakistan, for biological analysis and sediment core dating.
   c. Participation in the IAEA/RCA Training Workshops/Meetings/Activities related to marine sub-project
   d. Preparation of Interim reports for presentation at the IAEA/RCA Meetings and publication.

2. **Year 2001 & 2002**

   a. Representative collection of water, sediment and biota samples for chemical, isotopic and biological analysis along the coast of Pakistan during Fall 2001/2002 (Summer monsoon period, rough sea conditions).
   b. Sampling of HAB Cyst/sediment Core samples at specific locations along the coast of Pakistan for biological analysis and dating.
   c. Strengthening the establishment of Harmful Algal Bloom Network along the Coast of Pakistan and Training of Fishermen for Alert Network Activities
   d. Study of Coastal Sediment Erosion at selective marine sites, using nuclear techniques (using ^{137}Cs Isotopes etc.)
   e. Modeling of pollution transport in Karachi Harbour and associated sea-environment, using chemical analysis and tracer data.
   f. Establishment of HAB Analysis Laboratory at NIO-Karachi and Organization of National/Regional Training Workshop for the HAB Component, in Collaboration with IAEA/RCA.
   g. Organization of National/Regional Training Workshop for Computer Modeling of contaminated estuarine environments/quality evaluations, Interpretation of data & computer modeling.
   h. Participation in the IAEA/RCA Training Workshops/Meetings related to the marine sub-project
   i. Preparation of Interim and final reports.
   j. Publication of research findings for each component of the National Plan of Activities.

In addition, upon request from an RCA Member State, Pakistan will provide service analysis (being an RRU for the marine sub-project RAS/8/083) for stable isotope (O-18, H-2, C-13, S-34, N-15) analysis (by mass spectrometry) and C-14 analysis (by LSC and CO_2 Absorption Technique) and H-3 analysis (by LSC and Electrolysis Enrichment Technique) at the nuclear institute (PINSTECH).

UPDATES ON ACCOMPLISHMENTS OF NATIONAL MARINE PROJECT RELATED FIELD AND LABORATORY ACTIVITIES

Component-I: Establishment of a Regional Database on Marine Radioactivity

Organization of the 1st IAEA/RCA Review Meeting (ASPAMARD):

PINSTECH/PAEC organized the 1st IAEA/RCA Review Meeting to Analyze Regional Database on Marine Radioactivity (RCA) in Islamabad from 12 to 14 April, 1999, to assess the current status of marine radioactivity database, to identify gaps in the database and to plan how the gaps might be filled. Thirteen (13) participants from twelve (12) RCA member states (Australia, Bangladesh, China, Republic of Korea, India, Indonesia, Malaysia, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam) and three (3) observers from national end-user institutions attended the meeting. The deliberations of the meeting consisted of four (4) Technical Sessions. A full report of the Meeting has been issued [IAEA, 1999].

Pakistan's Marine Radioactivity Database:

Water and sediment samples collected by PINSTECH designated field-team from polluted Layari & Malir River downstream (pre-outfall), Ghizri Creek, Layari River outfall in Karachi harbour, Karachi Harbour/Manora Channel Mains, as well as from open sea (South-East Coast and North-West Coast) within the 10m depth contour. The samples were analyzed at HPD/PINSTECH for a range of natural radionuclides (^{40}K, ^{60}Co, ^{137}Cs, ^{226}Ra, ^{228}Ra), using a Hyperpure Germanium (HPGe) Gamma Spectrometer. In addition, radioactivity data of selective fish-flesh samples and sediment samples was obtained from Health Physics Division, Karachi Nuclear Power Plant (KANUUP). Results are summarized in Table-2, vis-à-vis comparison with IAEA radioactivity Reference Materials for similar matices. No artificial radionuclides (e.g. ^{60}Co, ^{137}Cs and ^{134}Cs) were detected in both water and sediment samples at any of these locations. The activity of ^{226}Ra in coastal river sediments is found to be below its limit of detection (<18.35 $Bqkg^{-1}$).

Component-II: Determination of the Levels, Behaviour and Fate of Radioactive and Non-Radioactive Pollutants in the Environment Through Isotope and Nuclear Techniques:

Stable Carbon Isotope Analysis of Marine Environment Samples:

Stable carbon isotope analysis ($\delta^{13}C$) of total dissolved inorganic carbon (TDIC), seaweeds, mangroves, animal shells and sea-bottom sediments was made to quantify the flow /transport of carbon from Layari River Outfall Zone and Malir River outfall Zone (Ghizri-Korangi Creek) in to the Karachi sea environment, with special reference to the impact of mangrove ecosystem on marine pollution. $\delta^{13}C$ (TDIC) values enabled identification of areas of high pollution inventory, in shallow off-shore waters of Karachi coast (within 20 m sea depth line). This study indicated that stable carbon isotopes can be used as a dynamic tracer for the study of pollution-transport in marine environment.

Application of Environmental $\delta^{18}O$ (water) and $\delta^{34}S$ (Aqueous Sulfate) as Tracers of Pollution Transport:

In the year 1999-2000, preliminary investigations were made to explore the potential and suitability of stable isotopes of oxygen ($\delta^{18}O$) in water molecule, and sulfur isotopes ($\delta^{34}S$) in aqueous sulfate, for use as pollution tracers. Selective water-samples collected during low-tide conditions from various locations, in Manora Channel/ Karachi Harbour, Layari River, Ghizri Korangi Creek and the Karachi Sea, were analyzed for $\delta^{18}O$ (water) and $\delta^{34}S$ (aqueous sulfate). Using the chemical as well as isotope balance equation for mixing of two water bodies (two-component mixing system), the polluted mixture of sea water and Layari river water/Layari River Outfall Zone water, across a mixing profile opposite KPT Shipyard in Karachi Harbour area, was analyzed to identify the % contribution of: inorganic pollution, inorganic carbon coming from Layari River and Layari River Outfall Zone, as well as the amount of Layari River water in the mixture (Table-3). Results indicate that, within the measuring precision limits for oxygen isotopes, $\delta^{18}O$ (water) can be used to as a reliable tool to identify the amount of water coming from either of the water-sources (sea or polluted river or outfall zone) for modelling purposes (application for Component-III of the Marine Sub-project). Results on $\delta^{34}S$ (aqueous sulfate) also gave a good clue to the input percentages of sulfur from the polluted Layari river. However, the applicability of both these isotopes is restricted to narrow navigational channels and backwater zones.

Use of Mangrove Tree Rings as Indicators of Pollution Inventories:

Studies were also made to identify the potential of Mangrove Tree Rings as qualitative tracers of pollution-inventory in polluted zones off Karachi Coast. Mangrove tree rings, pertaining to a profile of trees (growth age band: Years: 1918 – 1996) collected from Manora Channel Backwaters (Layari River Outfall Zone) and a profile of trees collected from Korangi Creek/South-east coast of Karachi/industrial area (growth age band: Years: 1948 – 1996), were analyzed for $\delta^{13}C$. Tree ring were separated with a fine chisel, freeze dried, grounded in a Whiley™ Grinding Mill, combusted in a modified Parr™ Oxygen Combustion bomb for conversion into CO_2 gas, and analysed for stable carbon isotope ratios ($\delta^{13}C$ per mil. PDB), using a gas-source mass spectrometer. Results indicate that $\delta^{13}C$ values of mangrove tree-rings grown in Korangi Creek area are depleted by about 1 to 1.5 per mill in ^{13}C, as compared to mangroves grown in the polluted outfall zone of Layari river outfall zone in Manora channel. This signifies the impact of industrial pollution (in addition to domestic waste) drained by the Malir River in to Ghizri/ Korangi Creek, in contrast to mainly domestic wastes drained by the Layari river. Work is in progress.

Component-III: Application of Nuclear and Modelling Techniques to Sustainable Development in the Coastal Zone

Two manuals containing details on subroutines and use of two-dimensional and three-dimensional "Finite Element Models" for Environmental Modelling Using the "RMA Suit" (evaluation of flow/quality in estuaries and streams), along with related programmes on computer CD & Floppies as obtained through participation in the Regional Training Course (RCA) held at the Water Research Laboratory, University of New South Wales, Australia (16-20 Nov., 1998), were provided to an End-user institution (NIO-Karachi) for installation / testing of software and routine analysis of field data to be obtained through activities under national programme for marine pollution studies.

Component-IV: Application of Nuclear Techniques to Address Red Tide (Harmful Algal Bloom) Concerns

Field Sampling:

During November - December, 2000, PINSTECH field-team performed coastal marine sampling trip along the entire 960 km long coastal strip of Pakistan and collected 28 shallow off-shore sediment cores (25 -35 cm depth), as well as 11 net samples of marine phytoplankton for identification of HAB Cyst and dominant diatoms, dinoflagellates & Siliflagellates by CEMB-Karachi University and NIO-Karachi and radiometric dating at PINSTECH; also 111 seawater samples for stable isotope analysis of H, O in seawater, C (total dissolved inorganic carbon) at PINSTECH.

Cyst Identification:

To-date, out of 28 sediment cores, only 7 cores (25 % of the total sediment core samples) have been analyzed by a researcher from CEMB-Karachi University for cyst identification, etc., initially at CEMB-Karachi University, Pakistan, and then at the University Marine Biological Station, Millport, Isle of Cumbrae, Scotland, United Kingdom, and Marine Science Institute, University of Philippines, Quezon City, Philippines. In six sea sediment-cores, only diatom shells, dinoflagellate organism and pollens, and some cysts of different non-toxic dinoflagellates were detected. Only one sediment-core (No. GW1) collected off Gawadar Coast (along coastal strip of Balochistan Province) has clearly indicated presence of Toxic/Harmful Algal Species namely: *Pyrodenium Bahamense* and *Protoperidinium sp*. at a depth of 2 cm (Chaghtai and Qureshi, 2001). The Scanning Electron Micrographs of these cores were obtained for record. This finding is quite important, as mass mortality of fish has been reported previously along Gawadar coast. Researchers from NIO-Karachi independently performed field-studies for measurement of seasonal variations in some key physical parameters in marine sediment-cores collected during July-October, 2000 and February-April, 2001 off Sindh coast and Balochistan coast. IAEA/RCA has awarded training fellowships to two researchers from key end-user institutions in Pakistan.

Training Fellowship:

IAEA/RCA Office Vienna awarded Training Fellowships to two researchers from end-user institutions in Pakistan for laboratory-oriented training in the field of Harmful Algal Bloom Concerns.

i. Ms. Furqana Khalid Chaghtai (IAEA Fellowship Code: Pak/01012RV), Research Officer, Center of Excellence in Marine Biology-Karachi University, Karachi, completed 2-weeks training in Cyst identification at the Marine Science Institute, University of Philippines, Quezon City, Philippines, during June, 2001, under supervision of Dr. Rhodora Azanza. This researcher is responsible for identification of HAB Cyst in all marine sediment samples off the Pakistan coast for the IAEA/RCA Marine Sub-project.

ii. Ms. Hina Saeed Baig (IAEA Fellowship Code: Pak/01013R), Research Officer, National Institute of Oceanography (NIO), Karachi, completed 6 weeks training in the field of Radionuclides and Radiation in Aquatic Biology, with special reference to Receptor Binding Assay (RBA) Technique at the Philippines Nuclear Research Institute (PNRI), Quezon City, Philippines, starting on 2 November, 2001. Ms. Hina Saeed Baig is now preparing for establishment of the RBA Laboratory at the National Institute of Oceanography-Karachi. IAEA/RCA has provided some minor supplies & accessories to NIO for this purpose.

RRU ACTIVITIES

PINSTECH/Pakistan is an IAEA/RCA designated Regional Resource Unit (RRU) for the Component-II of RCA/IAEA Marine Sub-project (RAS/8/083) for provision of training, and environmental isotope-analysis of marine water, sediment and biota samples. The Environment Research Group of the Radiation and Isotope Applications Division (RIAD) at Pakistan Institute of Nuclear Science & Technology (PINSTECH) organized the IAEA/RCA Regional Training Course on Application of Stable Isotope and Direct $^{14}CO_2$ Absorption Techniques in the Analysis of Marine Pollutants, held at Islamabad & Karachi from 04 to 13 October, 1999. The main objective of Training Course was to train RCA participants for determination of the levels, behaviour and fate of radioactive and non-radioactive pollutants in the marine environment, mainly through isotope or nuclear techniques. The deliberations of the Training Course consisted of rigorous lecture-sessions as well as laboratory & field practical demonstrations. A total of fifteen (15) participants from Eight (8) RCA Member States (China, Indonesia, Malaysia, Pakistan, Philippines, Sri Lanka, Thailand, Viet Nam) and four (4) observers from end-user institutions in Pakistan [NIO-Karachi, Pakistan Navy, CEMB-Karachi University, KNPC-Karachi] participated in the training course. Lectures were delivered by three (3) IAEA/RCA Experts from Australia (Mr. Ronald Szymczak, ANSTO, Sydney, Prof. Allan Chivas , School of Geosciences, Wollongong University and Dr. Stewart Walker, Chemistry Centre, East Perth) and a number of local experts (from national end-user institutions, Islamabad/Karachi). At RIAD/PINSTECH, Islamabad, the participants were trained in laboratory sample-preparation techniques for stable isotope analysis of H, O, C, S and N by Gas Source Mass Spectrometry, as well as C-14 determinations in marine water, sediment and biota samples, using the novel Direct $^{14}CO_2$ Absorption Technique (developed by Dr. Riffat Qureshi, PINSTECH) and Liquid Scintillation Spectrometry. At the National Institute of Oceanography (NIO), Karachi, the participants were trained for marine organic pollutant analysis, using the conventional HPLC and G.C. techniques. The field-demonstrations for in-situ physiochemical measurements and collection of sea-water, sediments and biota samples were performed at Karachi-sea, using Survey Boats and Oceanographic Research Vessel named: SV Behr Paima provided by the Pakistan Navy. Copies of course-material (lectures & laboratory sample preparation & measuring procedures) were distributed among the participants.

CONCLUSION

Initial field and laboratory studies along the coast of Pakistan for the IAEA/RCA Marine Sub-project RAS/8/083 are very encouraging. Stable isotopes of carbon, oxygen and hydrogen have been potentially used to trace transport of pollution in shallow marine waters off the Pakistan coast, specially, the Karachi coast. Environmental radioactive isotope contents of Uranium series radionuclides: ^{40}K, ^{137}Cs, ^{90}Sr are determined in selective marine samples (water, sediment and biota). Toxic cysts of *Pyrodinium bahamens* and *Protoperidinium sp.* have been identified in a sediment core from Gwadar.

Pakistan has also contributed, at the regional level, by hosting the RCA Review Meeting in Islamabad for Component-I and a Regional Training Course for Component-II in Islamabad/Karachi, in collaboration with Pakistan Navy and NIO-Karachi.

The key end-user institutions of the marine sub-project, namely: Pakistan Navy, Karachi Port Trust and the National Institute of Oceanography, Karachi, have significantly contributed in the accomplishment of field-sampling activities. However, there is a dire need for further collaboration at national level and provision of in-kind contribution from end-user institutions for timely completion of various activities of the national marine pollution project.

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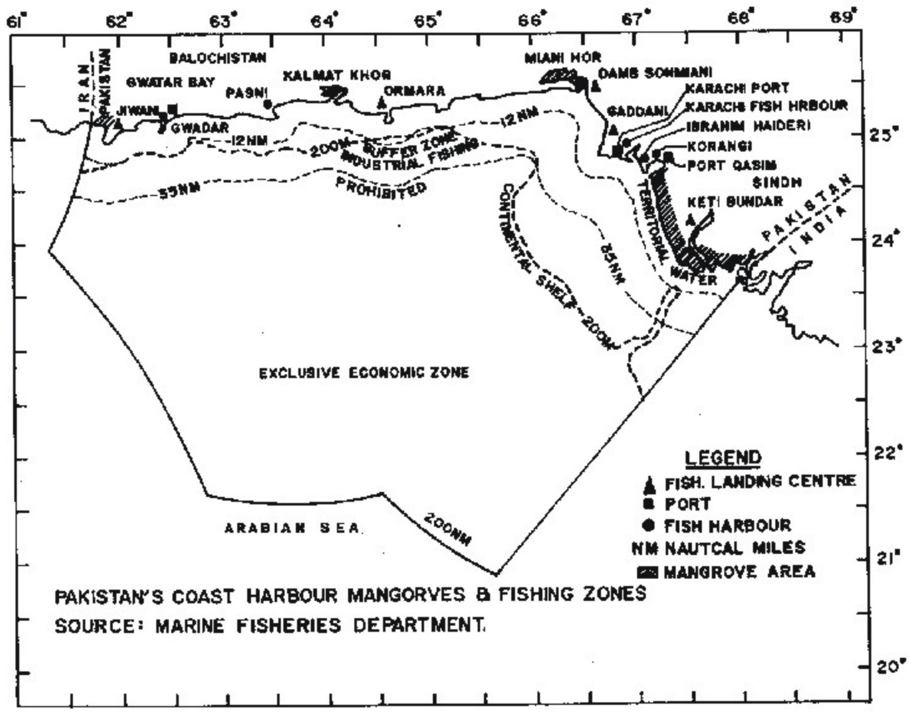

Figure – 1: Pakistan's Coast Harbour Mangorves & Fishing Zones

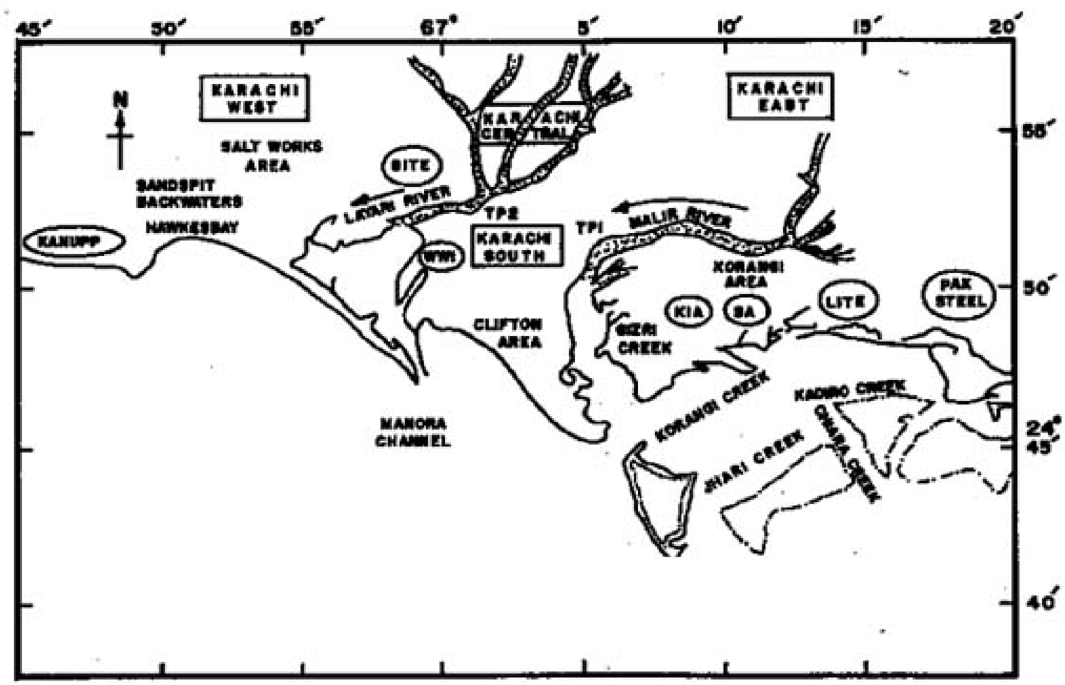

Figure – 2: Coastal Map of Karachi Showing Location of Industrial Sites and Drainage Course of Polluted Rivers into Karachi Sea

Table – 1: Details of Tentative Sampling (Types and Amount) Off Pakistan Coast

SAMPLE MATRIX	ANALYSIS TYPE	QUANTITY	SAMPLE PER Marine SITE
WATER	Isotopes:		
	O-18 and H-2 (water)	50 ml	5-15
	C-13 (TDIC)	1 Liter	5-15
	O-18 & S-34 (Sulfate)	100 ml	5-15
	H-3 (Tritium)	1 Liter	5-15
	C-14 (TDIC)	100 -250 Liters	3-5
	Low Level Radioactivity	100 -250 Liters	2-5
	Chemistry:		
	Major Ions	1 Liter	4-10
	Toxic Metals	500 ml	4-10
	Pesticides	100 -250 Liters	2-5
	PAHC	100 -250 Liters	2-5
	TDOC	100 -250 Liters	2-5
	Biological:		
	Coliform (Fecal & Total)	250 ml	5- 30 (in duplicate)
	HAB Species	100 ml	5-10
	Net Samples of Phytoplankton	Variable size	3-5
SEDIMENTS	Isotopes:		
	C-13 (TSIC)	100 gram	5-10
	C-13 (TSOC)	100 gram	5-10
	O-18 and S-34 (Sulfate)	100 gram	5-10
	N-15	100 gram	5-10
	Low Level Radioactivity	1 kg	2-5
	Chemistry:		
	Toxic Metals	250 - 500 gram	4-10
	Pesticides	500- 1000 gram	4-10
	PAHC	500 -1000 gram	4-10
	Biological:		
	HABs Cyst on Sediment Cores	50 – 75 cm long cores	5-10
Mollusks/ Shells	Isotopes		
	C-13	10 gram	3 -5 samples per specie
	O-18	10 gram	
FISH	Isotopes, Chemistry:		
	C-13 , N-15, Toxic Metals	1-2 kg Fish	3 -5
	Low Level Radioactivity	3-5 kg Fish	3-5
	Biological:		
	HABs Toxin	3-5 kg Fish	3-5
MUSSELS	Isotopes, Chemistry:		
	C-13 , N-15, Toxic Metals	500 grams	3-5
	Biological:		3-5
	HABs Toxin	2 kg Mussels	3-5
CRABS	Isotopes, Chemistry:		
	C-13 , N-15, Toxic Metals	1/2 kg	3-5
	Biological:		3-5
	HABs Toxin	3-5 kg Crabs	3-5
MANGROVES	Isotopes, Chemistry:		
	C-13 , N-15, Toxic Metals	1-2 Cores per tree	5-10 (2 samples per specie)
SEAWEEDS	Isotopes, Chemistry:		
	C-13 , N-15, Toxic Metals	200 grams per specie	3 – 5 species

Table-2: Average Radioactivity concentration in sediment (Bq kg^{-1}) & water (Bq l^{-1}) samples off Karachi Coast, Pakistan

[For sediments Limit of detection (LOD), for ^{226}Ra = 18.35, ^{228}Ra = 9.6 Bq/Kg, ^{137}Cs = 1.6], [for water Limit of detection (LOD), for ^{226}Ra = 1.62, ^{228}Ra = 1.4 Bq/Kg, ^{137}Cs = 0.32, ^{40}K = 10.96]

LOCATION	SEDIMENT				WATER
	Ra-226 (Bq/Kg)	**Ra-228 (Bq/Kg)**	**K-40 (Bq/Kg)**	**Gross Activity (Gamma) Counts/Sec/Kg**	**K-40 (Bq/l)**
Layari River Outfall Area (Pre-Harbour outfall Zone)	*<18.35*	*14.28± 3.72*	*125.00± 28.60*	*59.39 ± 5.28*	<10.96
Layari River Outfall Area (Karachi Harbour Backwaters)	53.84 (n = 1)	20.46 ± 5.94	520.91± 112.96	74.65± 13.08	36.00 ± 17.23
Karachi Harbour Mains	<18.35	24.54 ± 4.94	522.65± 143.68	105.66± 11.88	65.34 ± 4.38
KPT Shipyard/ Kaemari Fish Harbour Channel	24.23 ± 5.97	22.37 ± 6.72	373.36± 11.05	105.66± 11.88	27.20 ± 16.97
Manora Channel Mains	29.18	21.8 ± 5.1	512.62± 188.06	72.46± 31.61	61.41 ± 2.54
Karachi Sea, South-East Coast	28.89	20.80 ± 5.77	780.36± 126.58	108.02± 25.26	61.41 ± 2.54
Karachi Sea, North-West Coast	45.91± 23.72	30.77 ± 6.88	384.99± 148.6	75.89± 18.49	16 ± 16.84

Table-3: Mixing Characteristics of Layari River water with Seawater in Layari River Outfall Zone across a mixing profile in Karachi Harbour using a two component chemical and isotope balance equation (Mixing Profile opposite Shipyard)

Sample Code	Profile Description	E.C. (mS/cm)	$\delta^{13}C$ per mill. (PDB)	$\delta^{18}O$ per mill. SMOW	EC Based % Contribution of Inorganic Pollution from		$\delta^{13}C$ Based Contribution of Carbon from Layari Outfall	$\delta^{18}O$ Based % Contribution of Water Layari River
					Pure Layari River	Layari Outfall Zone		
K5	Arabian Sea, Manora Channel Break Waters	55.6	-0.88	-0.08	-	-	-	-
K1	Layari River (At Gulistan Colony, Mirza Adam Khan Road, Near Tanga Stand, Middle of Layari Channel, 1230 hrs.)	2.6	-5.9	-6.67	-	-	-	-
K2	Layari River Outfall Zone	36	-10.22	-1.79	-	-	-	-
K25	Prior to apparent mixing boundary of Layari Channel in harbour near Shipyard	53	-4.42	0.13	4.9	13.3	37.9	1
K26	Prior to apparent mixing boundary of Layari Channel in harbour near Shipyard	52.8	-5.64	-0.22	5.3	14.3	24.2	2
K27	At apparent Mixing boundary of Layari Channel in harbour near Shipyard	53.8	-9.72	-1.24	3.4	9.18	94.7	17
K29	Extreme of Layari Channel in harbour near Butti in front of shipyard	45.6	-8.6	-1.76	18.9	49	82.7	25

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

Riffat M. Qureshi, A. Mashiatullah, M. Fazil, E. Ahmad, H.A. Khan, M. I. Sajjad*

ABSTRACT

Environmentally by stable carbon isotope ratios ($\delta^{13}C$ ‰ 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. $\delta^{13}C$ values of TDIC were measured, using gas-source mass spectrometry. Significantly depleted $\delta^{13}C_{TDIC}$ 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 $\delta^{13}C_{TDIC}$ 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[1-4]. 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[7-9]. Stable carbon isotope ratios ($\delta^{13}C$ per mill PDB) of total dissolved inorganic carbon (TDIC) have been used as potential indicators of seawater-quality off the Karachi coast[8]. 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 $^{13}C/^{12}C$ 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}C, with respect to inorganic carbon. Marine and land plants have different $\delta\ ^{13}C$ 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, CO_2 from effluents of domestic sewage has ^{13}C values much lower than the natural dissolved CO_2 in marine environment and ^{13}C potentially could be used as a pollution tracer. The general spectrum of $\delta\ ^{13}C$ 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

* Chief Scientific Officer, Radiation and Isotope Application Division (RIAD), PINSTECH, P.O. Nilore, Islamabad, Pakistan.

environmental stable carbon isotope technique to establish a pollution-scenario of shallow marine coastal environment of Pakistan.

supports the spawning and breeding grounds of commercially important shrimps as well as for a variety of other fishes. In the absence of

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

Carbon Pool	$\delta^{13}C$ ‰ PDB
Atmospheric CO_2	- 9 to - 6
Soil 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 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 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[9].

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 ($\delta^{13}C$) of total dissolved inorganic carbon (TDIC). The samples were immediately spiked with 0.1M $HgCl_2$ 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. Physiochemical 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[5,6]. Seawater sample (~250 ml) was reacted with 85% pure H_3PO_4 acid to liberate CO_2 gas from TDIC in a vacuum line. The moisture in the evolved CO_2 gas was condensed in a U-trap held at -80 ^oC, using freon-liquid nitrogen slush. Residual moisture in the evolved CO_2 gas was condensed in a subsequent U-trap, held at liquid nitrogen temperature (-196 ^oC). When the reaction was completed, the first U-trap was closed and the temperature of the second U-trap was raised to -80 ^oC with “freon-liquid nitrogen slush” to evaporate and expand the sample 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 δ *(delta)* ‰ *(per mil)* values relative to the international carbonate standard, namely, PDB *(Pee-Dee Belemnite):*

$$\delta = \{(R_S - R_{St}) / R_{St}\} \times 1000$$

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

RESULTS AND DISCUSSION

Unpolluted seawaters have $\delta^{13}C_{TDIC}$ 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 $\delta^{13}C_{TDIC}$ contents for the marine coastal waters collected off the Baluchistan Coast. $\delta^{13}C_{TDIC}$ 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 $\delta^{13}C_{TDIC}$ are observed in shallow seawater collected off Jiawani Coast and Ormara Coast, whereas the negative values of $\delta^{13}C_{TDIC}$ 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 $\delta^{13}C_{TDIC}$ 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 $\delta^{13}C_{TDIC}$ contents between -2.6 to -0.6 ‰ PDB. The shift in $\delta^{13}C_{TDIC}$ contents of clean seawater towards more negative values is indicative of input of ^{13}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 $\delta^{13}C_{TDIC}$ contents are observed in the mangrove ecosystem along Sonmiani Coast and Jiawani Coast. The values of $\delta^{13}C_{TDIC}$ tend to enrich in the direction of relatively clean seawater as we move out of the mangrove ecosystem. The higher depletions in $\delta^{13}C_{TDIC}$ values of seawater in Sonmiani Bay and along Jiwani Coast are thus attributed to the influx of carbon from the adjacent mangrove ecosystem ($\delta^{13}C_{mangrove\ leaves}$ ~ -26 ‰ PDB). This means that the ^{13}C depleted CO_2 is being produced by the decay of mangrove-leaf litter and is then incorporated into the TDIC pool of seawater as HCO_3^{-1}. Further, depletion in $^{13}C_{TDIC}$ 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

Table-2: Summary Of Physiochemical And Stable Carbon Isotope Analysis (C_{TDIC}) In Seawater And Polluted Drains Along Baluchistan Coast (Pakistan)

Coastal location in Baluchistan Province (n= total samples) [Lat/Long]	*Physiochemical parameters*			*Stable carbon isotope analysis*
	pH	***E.C. (mS)***	***Salinity (ppt)***	***δ^{13} C_{TDIC} (‰ PDB)***
Jiwani (n=7) *[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)
Gwadar (n=9) *[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)
Pasni (n=5) *[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)
Ormara (n=5) *[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)
Sonmiani Bay (n=7) *[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)

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 $\delta^{13}C_{TDIC}$ contents for the marine coastal waters collected from selective sites off the Sindh coast (Pakistan). As expected, $\delta^{13}C_{TDIC}$ 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 $\delta^{13}C_{TDIC}$ 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.

CONCLUSIONS:

In general, this study concludes that:

a. 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

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)**	**$\delta^{13}C_{TDIC}$ (‰ PDB)**
Karachi Coast (n=31), [N 24- 47-53, E 66-59-77 to N 24-48-42, E67-17-18]				
Manora Channel (n=11)	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)
Clifton -Marina Club Coast (n=7)	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)
Ghizri-Korangi Coast (n=8)	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)
North-west Coast (n=7)	ND*	53.4 - 55.8	39 - 40	Clean Sea: +0.4 ** (n=1) Populated Coast: -5.3 to +0.3 (n=6)
Indus Delta (n=6) *[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)

ND = Not Determined
* *Seawater samples from shallow marine environment opposite coastal dwellings*
** *Seawater sample off Paradise Point, North West Coast of Karachi*

seawater from domestic and industrial sources as also from the mangrove ecosystems.

b. The shallow marine environment along the Baluchistan Coast is relatively much less polluted, as compared to the Sindh Coast

c. Ormara Coast is the least polluted marine site of the developed zone along Baluchistan coast.

d. The North-West Coast of Karachi is the least polluted marine site off Karachi city coast

e. The most depleted $\delta^{13}C_{TDIC}$ values of seawater in Sonmiani Bay and Jiawani Bay are due to the impact of mangrove ecosystem.

f. Extremely depleted $\delta^{13}C_{TDIC}$ 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.

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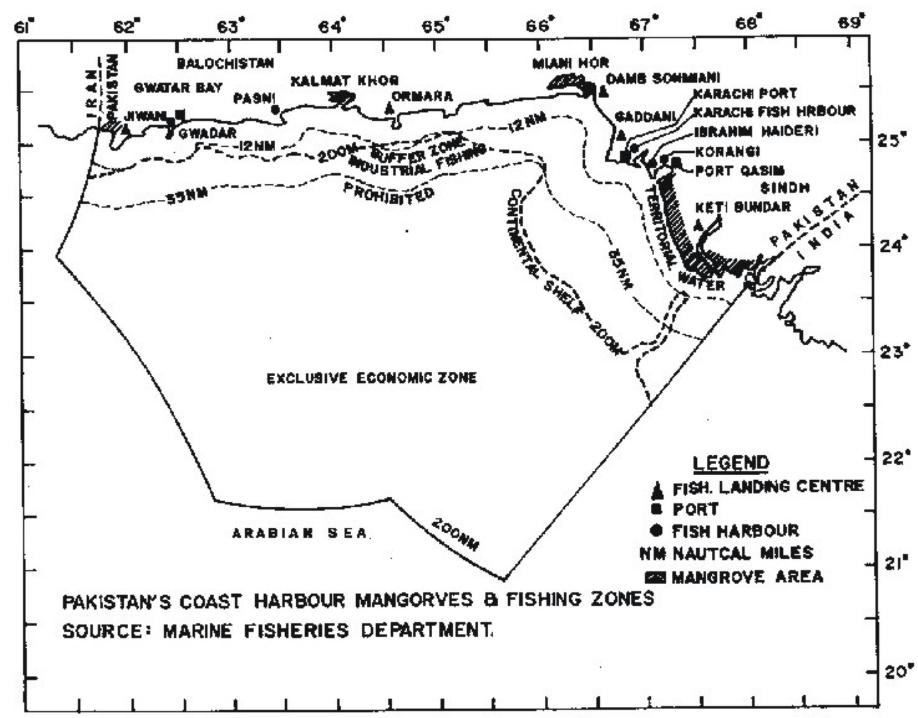

Figure – 1: Pakistan’s Coast Harbour Mangorves & Fishing Zones

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

Javed Akhter, Shafeeq Ahmed & Kauser A. Malik*

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 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).

Pakistan is located between longitude 61^o and 76^{o}E and latitude of 24^o and 37^{o}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^{o}C and maximum upto 53^{o}C. The winter is fairly cool, with an average temperature of 20^{o}C and minimum down to –2 ^{o}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,

*For Correspondence: Pr. Geologist, Nuclear Institute for Agriculture & Biology (NIAB), P.O.Box 128, Faisalabad, Pakistan.

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

Continents/subcontinents	x 10^6 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
Total	**954.922**

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

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.

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

(Area in Million Hectares).

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%)**

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. Additonally, 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 funds required render the approach difficult to practice.

Table-4: Salt Tolerant Limits (Root Zone Salinity Causing 50% Yield Reduction) Of Different Plants *(From Silver Jubilee Of Niab).*					
Species	**EC(dSm^{-1})**	**Species**	**EC (dSm^{-1})**	**Species**	**EC (dSm^{-1})**
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 striaticalyx	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		

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

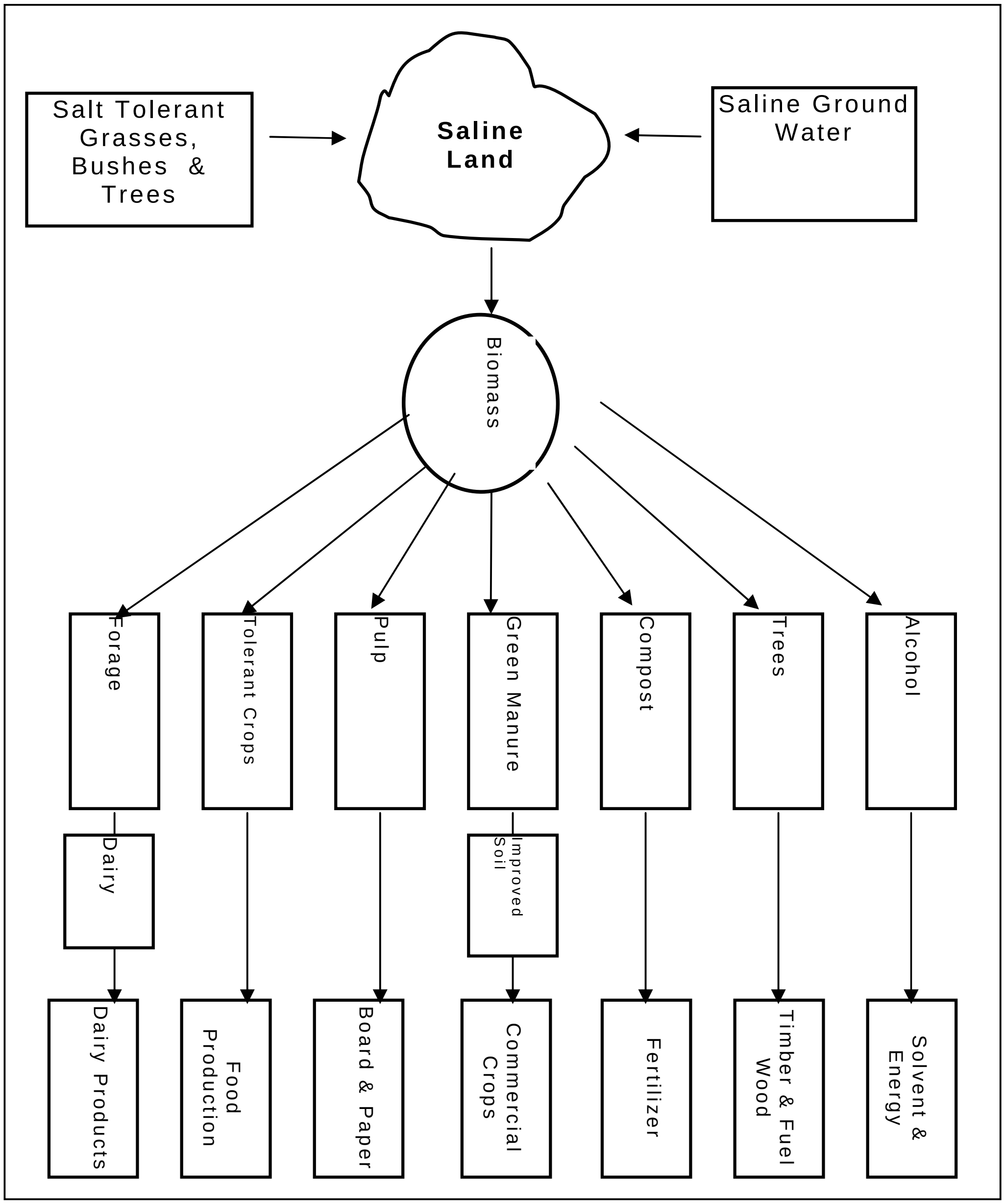

Figure-1: A Schematic Presentation of Biological Approach.

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 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

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	gKg^{-1}	550	520	570	
Silt	gKg^{-1}	230	250	250	
Clay	gKg^{-1}	220	230	180	
Textural Class	Sandy clay loam				
	$KgKg^{-1}$	0.155	0.151	0.153	
Available Water Bulk density	Mgm^{-3}	1.62	1.73	1.68	
Porosity	%	38.9	34.6	36.5	
Stability index		31.9	18.6	32.6	
Hydraulic permeability	mmd^{-1}	0.35	0.25	0.44	
(b) Chemical Properties		**Soil**			**IW**
EC_e	dSm^{-1}	22	22.2	12.5	1.4
pH		10.4	10.5	10.4	7.6
OM	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

D1=0-20 cm, D2=40-60 cm,D3= 80-100 cm, EC_e= Electrical conductivity

OM= Organic matter, SAR= Sodium adsorption ratio, adj= Adujusted

ESP= Exchangeable sodium percentage, RSC= Residual sodium carbonate

IW= Irrigation water used.

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^{o}7 E and latitude 31^{o}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

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

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 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($kgkg^{-1}$) =Soil moisture at 0.03MPa(FC) - Soil moisture at 1.5MPa(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 (Ci) 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

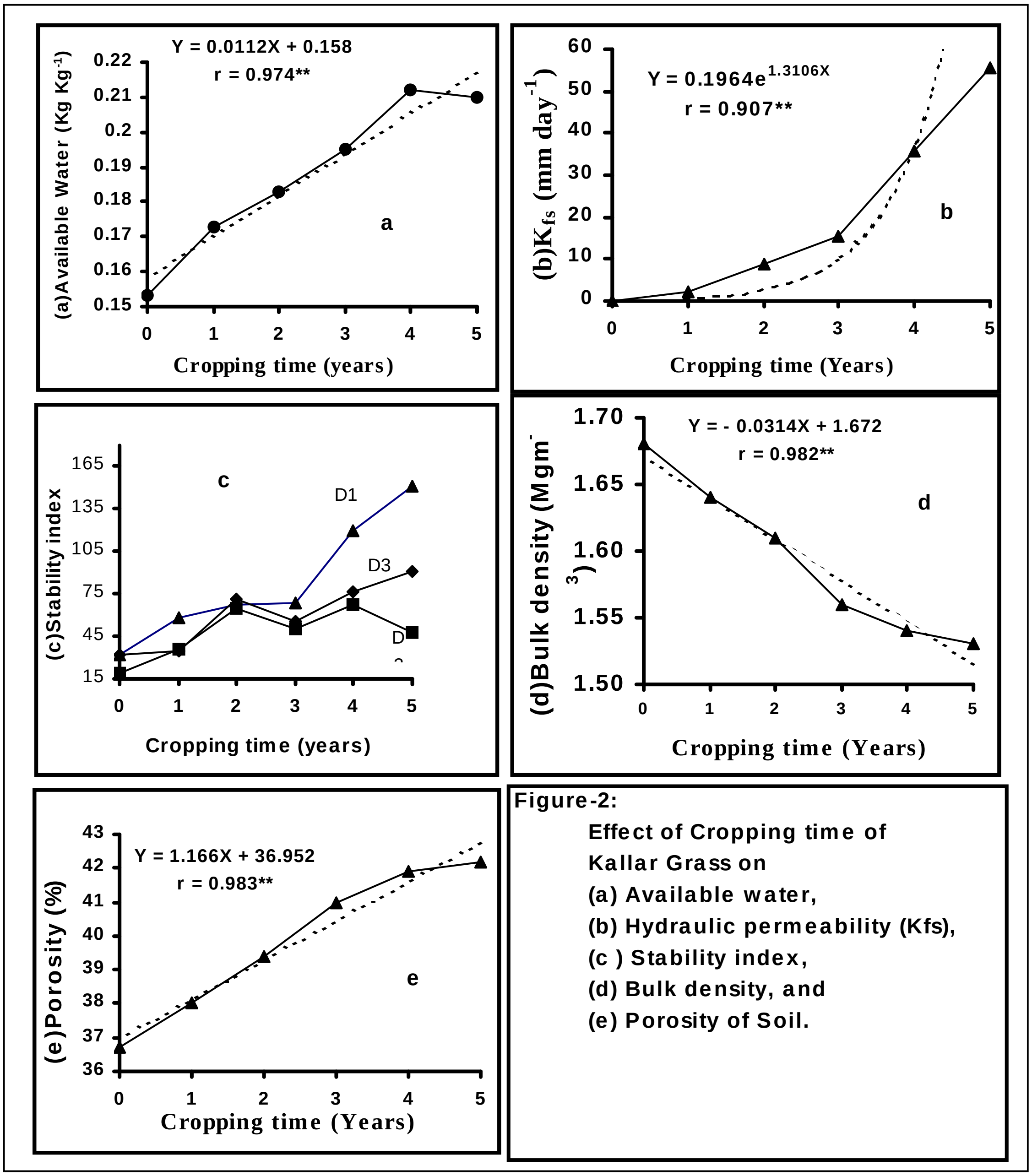

Figure-2:
Effect of Cropping time of Kallar Grass on
(a) Available water,
(b) Hydraulic permeability (Kfs),
(c) Stability index,
(d) Bulk density, and
(e) Porosity of Soil.

compared with uncropped practice system (To).

The amount of available water (AW) for plants increased (statistically) after growing kallar 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 $KgKg^{-1}$, (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 mmd^{-1} was obtained in T5 and minimum value of 0.35 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 mmd^{-1} was highly significant at $p \leq 0.01$ 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 To. 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 T4, T3, T2 and T1 over To, respectively. The soil porosity increased in a proportional pattern by increasing the growing period (Fig. 2e). The increasing rate of soil porosity (average of 1.166 $\%year^{-1}$) 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 To. The maximum reduction of 87.3% was observed in T5, followed by 79.9, 83.6, 64.6 and 41.8 % reduction after 4, 3, 2 and 1 year in T4, T3, T2 and T1, respectively, as compared with To. The regression analysis showed that EC_e exponentially ($lnEC_e$ = 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 (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 To. 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).

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 (lnSAR=4.926-0.343T) as the growing time was increased (Figure-3c). The reduction-rate of SAR 0.343 $meqL^{-1}year^{-1}$ 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 gkg^{-1} was found after 5 years and 2.0 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 (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 gkg^{-1} $year^{-1}$ because of growth of kallar grass compared with uncropped soil.

Characterization of clay fraction of uncropped soil under investigation revealed micacious-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 (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 (RIS=20.017 - 1.880T) significantly at $p \leq 0.05$ with r = 0.977*.

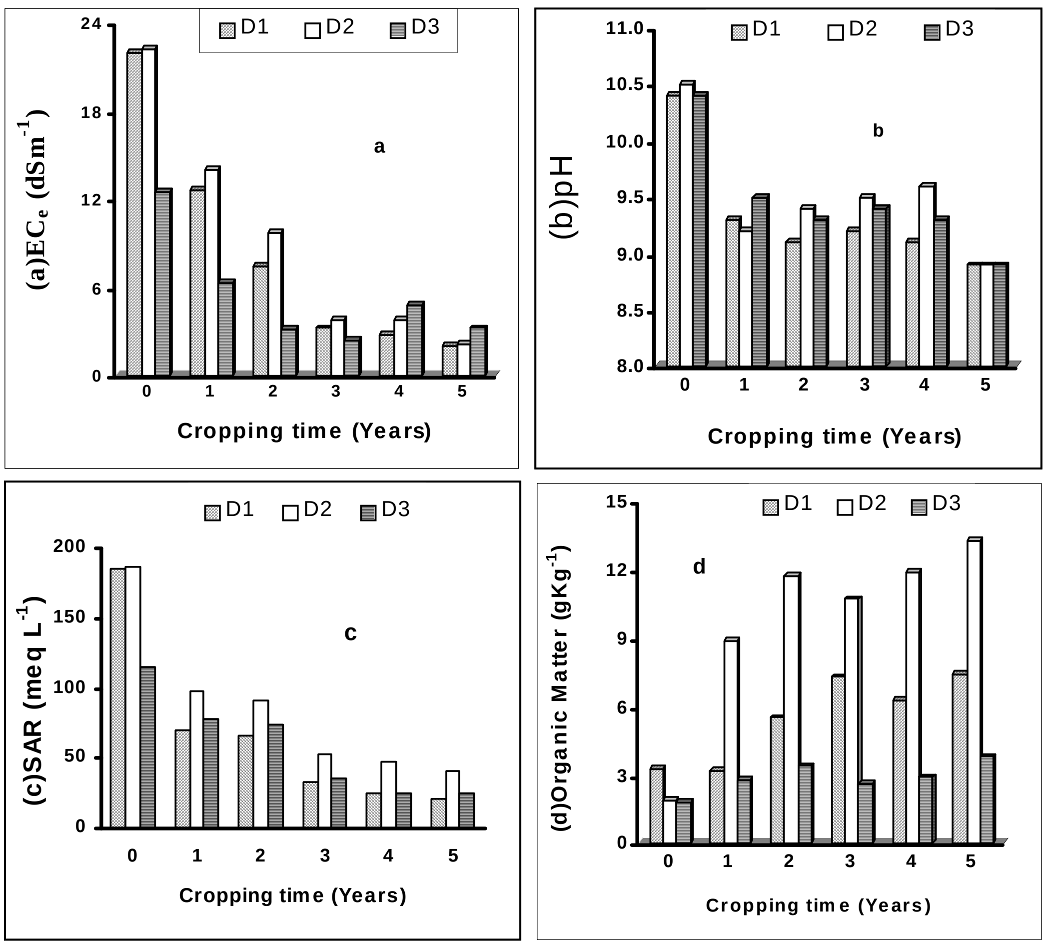

Figure-3: Comparsion of (a) ECe (b) pH (c) SAR (d) Organic Matter of Soil at Depths

D1 (0-20cm),
D2 (40-60cm) and
D3 (80-100cm) as a function of cropping time of kallar grass.

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 significant ($r = 0.989^*$ at $p \leq 0.05$) effect on kaolinite, with decrease rate of 1.153 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 and1.16 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 (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 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, Kfs, 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 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 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**

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 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 are 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)]

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 REQUIRE-MENTS OF WATER

All living things (i.e. zoological and botanical) cannot 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, since the

* Scientist Emeritus, Pakistan Institute of Engineering & Applied Sciences (PIEAS), P O Nilore, Islamabad, Pakistan.

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.

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 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 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_{th}.

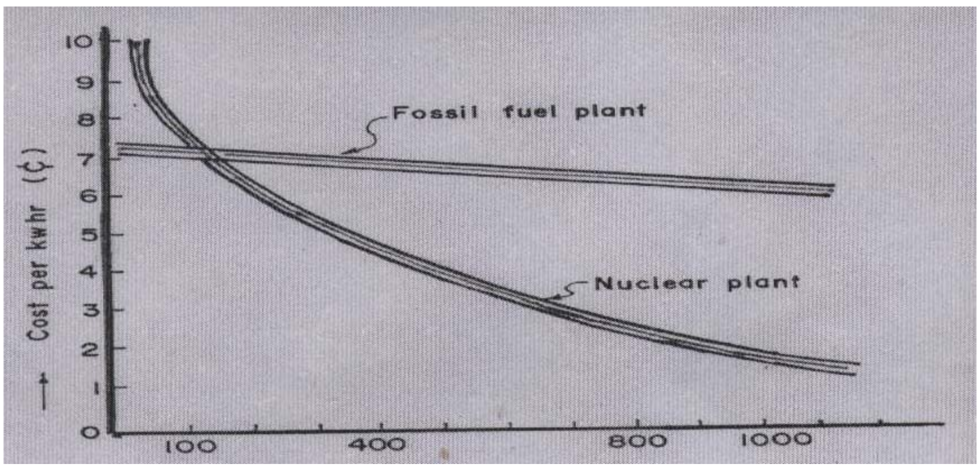


Figure - 1: Nuclear Plant-Size to Energy-Cost Ratio

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 tob) produce electrical energy, lower-quality steamc) 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.

   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.

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.

- 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

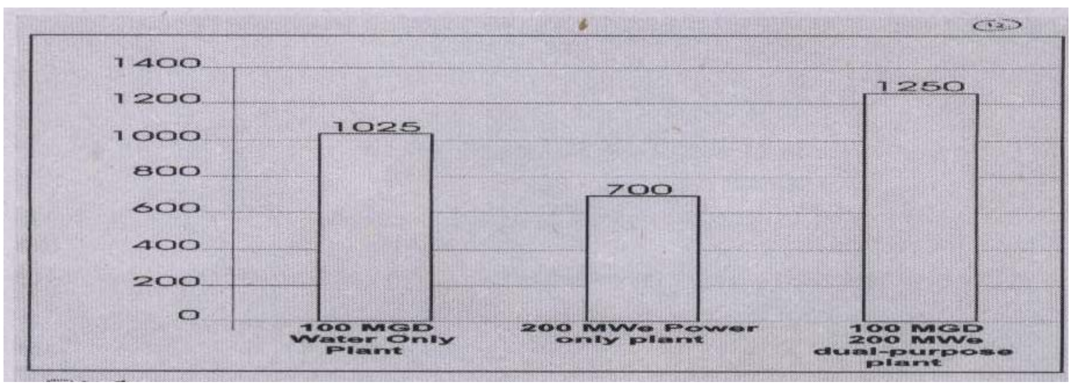


Figure - 2: Thermal Energy Requirements for Three Plants Using Water-Cooled Reactors

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)

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.

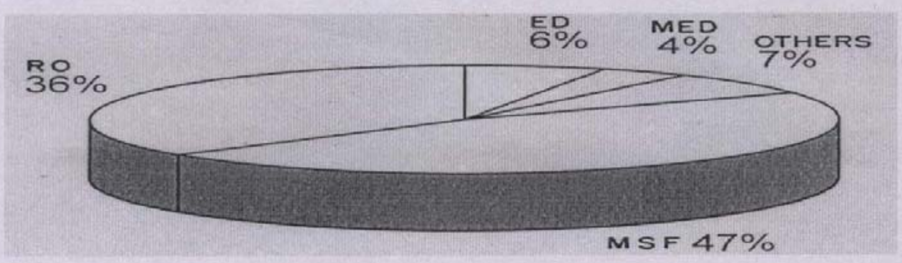


Fig. 3 (a)

Desalination plants with the capacity greater than 100 m^3/d using various technologies.

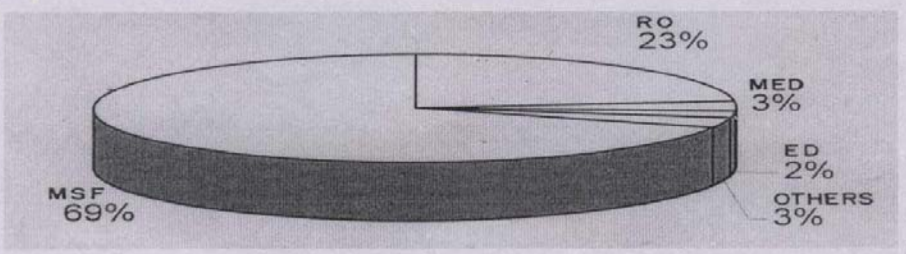
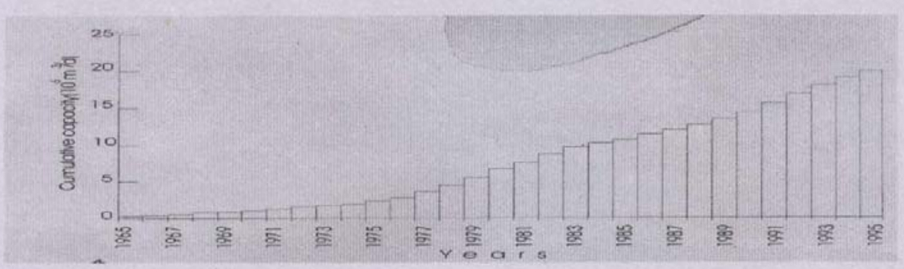


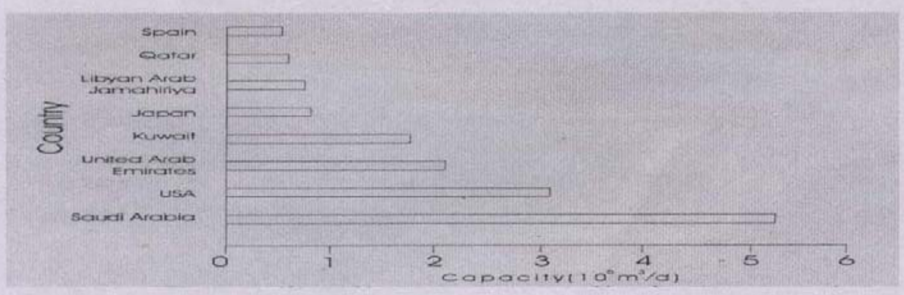
Fig. 3 (b)

Desalination plants with the capacity greater than 4000 m^3/d using various technologies.



Total installed desalination capacity

Fig. 4 (a)



Desalination capacity by country

Fig. 4 (b)

Figure – 3(a) & 3(b) and 4(a) & 4(b)

Table -1: Some Salient Characteristics Of Commercial Desalination Process

Process	Characteristics					
	Possible Unit Size m^3/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

Table - 2:World's 10 Largest Seawater Desalination Plants

Sr. No.	Name of the Plant, Capacity and Desalination Technique.		
1	Al Jobail, Saudi Arabia	1,173,000 m^3/d (310 mgd)	46 MSF Units 15RO Units
2	Jebel Ali Dubai	869,000 m^3/d (230 mgd)	28 MSF Units
3	Taweelah Dubai	806,000 m^3/d 213 mgd)	16 MSF Units
4	DohaKuwait	695,000 m^3/d (184 mgd)	23 MSF Units
5	Az-Zour South Kuwait	482,000 m^3/d (mgd)	16 MSF Units
6	Shuaiba, Saudi Arabia	454,000.m^3/d (120 mgd)	10 MSF Units
7	Al Khobar, Saudi a Arabia	450,000 m^3/d (119 mgd)	18 MSF Units
8	Jeddah Saudia Arabia	420,000 m^3/d (111mgd)	18 MSF Units 10 RO Units
9	Umm Al Nar Abu Dhabi	400,000 m^3/d (106 mgd)	16 MSF Units
10	Yanbu Saudia Arabia	382,000 m^3/d (101 mgd)	9 MSF Units 15 RO Units

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:

$$C_a = {}_{CE}\, E_a + {}_{CW}\, W_a$$

${}_{CE}$ = Cost per KWhr of electricity
E_a = KWhr produced per year
${}^{C}{}_{W}$ = Cost per m^3 of water
W_a = M^3 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

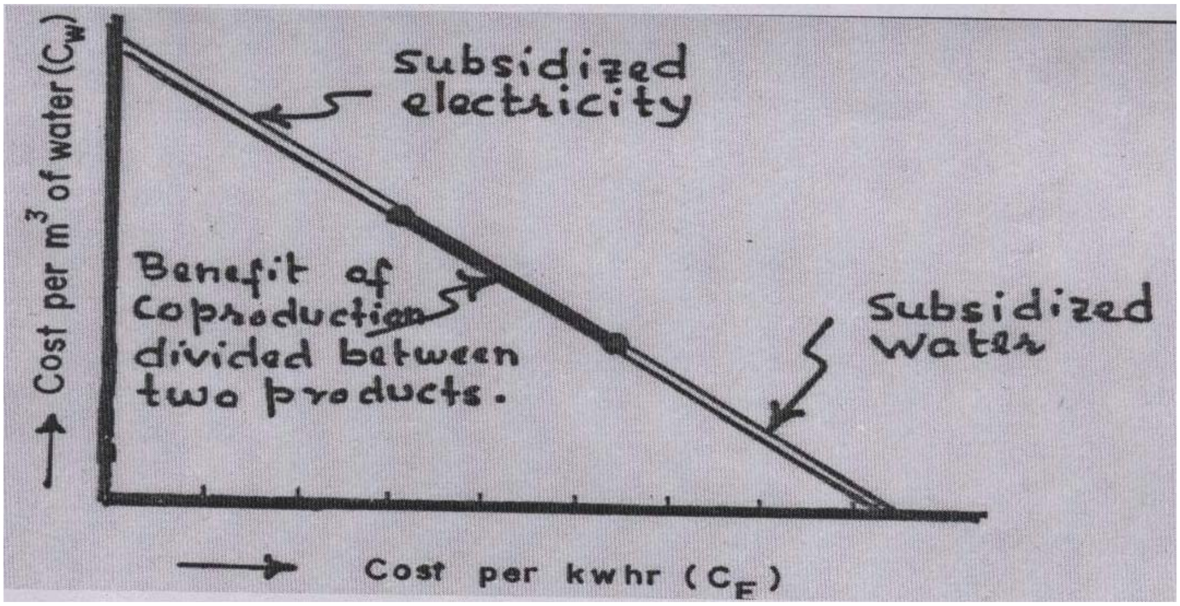


Figure - 5: Allocation of Cost to Water and Power.

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

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

Cost allocated to power $= C_D \dfrac{C_P}{(C_P - C_W)}$

.... This is smaller than Cp

Cost allocated to water $= C_D \dfrac{C_W}{(C_P - C_W)}$

.... This is smaller than C_W

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**

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 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 reserve of fresh water adds 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.

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

* Consultant, Institute of Business Administration & Technology, China Chowk, Islamabad, Pakistan

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 millenium 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.

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 from 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?

CONCLUSION

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!

CONCLUDING REMARKS

Dr. Hameed Ahmed Khan
Executive Director
Commission on Science and Technology
For Sustainable Development in the South
(COMSATS)

Honourable Chief Guest,
Mirza Hamid Hasan Sahib,
Federal Secretary for Water & Power
H.E. Badi Khattab, Charge'd Affairs
of Syria
H.E. T.Y. Opatola
Deputy High Commissioner of Nigeria
The Excellencies,
Distinguished Guests,
Eminent Scientists,
Participants,
Ladies & Gentlemen

It is with a deep sense of satisfaction and gratitude to Almighty Allah that we have had a very fruitful and technically sound discussion in this meeting on "Water Resources in the South: Present Scenario and Future Prospects". It has been a great privilege for me and the COMSATS to have acted as hosts of this meeting.

As far as the deliberations of this two-day meeting are concerned, 22 presentations were made on the following subjects: (i) Management and Uses of Water-Resources (ii) Climate-Change, Flood Control, and Drought Management (iii) Water Quality and (iv) Use of Saline-Water and Wastewater-Treatment Technology. 52 delegates including 22 speakers attended the forum. The scientific and technical standard of all the presentations were very high. I believe, the purpose of discussing the various national and regional issues of Water resources, and its management from national and regional point of view, during this meeting has been served to a large extent.

In the inaugural and key note address by Dr. Ishfaq Ahmed (the Special Advisor to the Chief Executive of Pakistan) pointed out that management of water-resources and its conservation are fast emerging as critical issues facing today's world, especially the developing-countries, and are needed to be tackled collectively and through a sustained effort by all countries. He said, global climatic changes, growing population, rapid industrialization, unplanned disposal of untreated wastes into the aquatic systems, are all contributing to the current stress on water-resources. It is important that modern scientific technologies, particularly, the nuclear desalination technique and isotope hydrology-techniques be used for better management and conservation of water resources in the South Asia.

H.E. General C.S. Weerasooriya, High Commissioner of Sri Lanka elaborated the water-resources situation in Sri Lanka and explained that his country is facing stress on its water resources, despite the fact that Sri Lanka is a water-rich country. He opined that problems like water-logging, salinity, scarcity of clean water can only be tacked if collaborative approach is adopted and awareness is created among the people about the significance of the issues.

The Chinese Ambassador, H.E. Lu Shu Lin gave a detailed account of the water resources and their status in China. He said that China, like other countries in the region, also faces drought-like conditions in its northern areas and is trying to mange it by working out strategies like standard trans-basin water-transfer from the South and Central China to the North. He also shared the view that burgeoning population and pollution are resulting in the degradation of water-resources. Excellency Lu Shu Lin lauded the efforts of the COMSATS in taking up such an important issue as the main subject of the meeting.

COMMENTS / VIEWS

H.Es The Ambassadors / High Commissioners/ Representatives of The Member Countries of COMSATS

In the concluding session, distinguished guests and the representatives of the COMSATS member states also expressed their valuable comments on the deliberations of the COMSATS 1st Meeting on Water Resources in the South and the status of water-related issues from national and regional point of view.

Speaking on the occasion, *H.E.* T.Y. Opatola, the Deputy High Commissioner for Nigeria said that there were no problems of water-resources in Nigeria; rather it has managerial problems. He was of the opinion that the participants of the COMSATS 1st Meeting on Water Resources have put forth excellent recommendations to resolve the water-resource related issues by formulating and managing comprehensive resource- plans. He was also of the view that these recommendations are useful for Nigeria as well, and that he will forward these suggestions to the Nigerian government.

H.E. Badi Khattab, the Charge'd Affairs of Syria also addressed the gathering. He was of the view that that the water-resources problems in Syria are more or less similar to those in Pakistan and there is dire need to conserve water. He stated that today we are using much more water than we did in the past; the water consumption has multiplied due to up-gradation of the standards of living and as we need more water for dish cleaning, car washing, and for frequent bathing and watering of gardens and lawns, etc. Water is divine. Mr. Badi expressed his concern and further asserted, “Even the ministries of defense in most of the developed and under-developed countries are apprehensive of the water-resource scenario. The water resources have attained special geo-strategic importance as the enemies tend to control the water resources and the water-flow channels. The water reserves are being continuously depleted due to the fact that drought cycle follows every 3-4 years of rainy seasons. It necessitates to make people aware of the growing water crises and to pay special attention to educate the community through academic institutions. COMSATS, is a good platform to address this core issue of agricultural and economic concern”. *H.E.* Badi Khattab appreciated the efforts of COMSATS in organizing the meeting on water-resources in a highly professional manner and assured that Syria will strengthen its ties with COMSATS to learn from the experiences of Pakistan in water resource management.

VOTE OF THANKS - PARTICIPANTS

Mr. Muhammad Ahmad Gondal
(EBF, Balohistan)

It is indeed a great privilege and honour for me to thank Dr. Hameed Ahmed Khan, Executive Director COMSATS, for organizing this 1st Meeting on “Present Scenario and Future Prospects of Water Resources in the South”. On behalf of the participants, let me also thank the members of the Organizing Committee of this meeting for their excellent coordination, and also thank all the participants and speakers. I congratulate them for their dedication and for their hectic efforts to make this event a success.

Further, on behalf of the participants and on my own behalf, I would like to thank the chief guest, Mirza Hamid Hasan, Federal Secretary for Water & Power, Government of Pakistan for sparing his valuable time to grace this occasion. Finally, I assure COMSATS that the participants will make use of the knowledge and expertise gained through this meeting for the progress & development of water-resources. We hope that our recommendations will be given due attention and consideration by the Government of Pakistan.

Thank you.

VOTE OF THANKS

Dr. Hameed Ahmed Khan
Executive Director – COMSATS

Honourable Chief Guest,
Excellencies,
Distinguished Guests,
Ladies and Gentlemen,

It has been a matter of great personal satisfaction for me to be a part of this gathering of the elite scientists and technologists of international fame. I believe that COMSATS' 1st meeting on Water-Resources in the South: Present Scenario and Future Prospects, has proved to be the right step forward in initiating a thought provoking series of such meetings on the subject water resources.

I believe that scientists, technologists, researchers, and experts from all fields of water-resources related institutions attended the meeting, and the presentations made here were of the highest standard. The conventional as well as latest trends of water-resource management came under discussion. This meeting on water-resources brought in useful recommendations for effective utilization and management of water-resources in the countries of the South and due emphasis was laid on the need for a regional approach by the developing countries. This indeed is in line with COMSATS' mission and objectives, and I may thank you all for guiding us with your suggestions and expert opinions. You may kindly note that we, at COMSATS, are in the process of finalizing our 5-year strategic plan, and I am sure that the discussions of this meeting will have an important bearing on formulation of this plan.

My special thanks are to the Chief Guests of the meeting, Dr. Ishfaq Ahmad and Mr. Hamid Hassan who took out time from their hectic schedules to grace this occasion. I am indeed very grateful to the Excellencies, the Ambassadors and the representatives of COMSATS member countries, who graced this occasion with their presence. I would also like to express my gratitude to all the speakers/presenters, without whose contributions this meeting would not have been possible. I cannot help mentioning the role of the participants of the meeting, whose useful contributions, in the form of healthy discussions, made this event all the more interesting and informative.

I would be doing an injustice if I do not mention the names of Mr. Tajammul Hussain and Mr. Salman Malik, whose untiring efforts made this meeting a very successful event. Last but not the least, I also take this opportunity to thank all the employees of the COMSATS, all of whom made invaluable contributions in their respective capacities.

I thank you all once again, and God bless you all.

SUMMARY OF CONCLUDING ADDRESS

Mr. Mirza Hamid Hasan
Federal Secretary,
Ministry of Water and Power
Government of Pakistan

The concluding session of the meeting was chaired by Mirza Hamid Hasan, Federal Secretary for Water and Power, Government of Pakistan.

In his closing address, Mirza Hamid Hasan appreciated the comments made by *H.E.* Badi Khattab, the Charge d' Affaires of Syrian Arab Republic, *H.E.* T.Y. Opatola, the Deputy High Commissioner of Nigeria and by the other participants. Speaking on the occasion, he said that drastic changes in the global climate have affected the scenarios of water-resources in many regions of the world and that Pakistan is no exception. He added “In our country, we are facing sever drought-like conditions for the last three years. The Government of Pakistan is taking serious measures. We are adopting short and long-term strategies to meet the situation and are formulating policies for conservation of water-resources and are putting in place a system that forecasts droughts, assesses damages and provides relief to the affectees. The time has come for us to act fast and to re-frame and devise our strategies in the most efficient way.

A number of projects are planned for water-resource management in the ‘Vision-2025’. Of these, the key projects are related to the issues of *Access to Clean Water* and *Optimal Use of Water-Resources for Agriculture*. The future threat to Pakistan emanates from increase in population and resultantly enhanced food-requirements, imbalancing the demand and supply of water. About 235 MAF of water is required, which is not possible under the prevailing conditions. We must identify key-measures to strengthen, develop, manage and conserve our water-reserves”. Mr. Hamid also underlined the need to give priority to the flood-prevention issue.

Mirza Hamid Hasan congratulated the organizers for arranging purposeful meeting of national and regional importance. He appreciated the efforts of the COMSATS for gathering key researchers and learned scholars of the field at one forum, who discussed the problem of water-resource in great detail and formulated far-reaching recommendations. He urged further refinements of these recommendations for submission to the government.

He said that the government of Pakistan would extend every possible help to support the initiative of the COMSATS in conserving water- resources in Pakistan and in the other member-states of the COMSATS. He emphasized that issues related to water-resources should be tackled in collaboration with international community, since these issues have assumed global and regional significance.

LIST OF PARTICIPANTS

Federal and Provincial Secretariat (Pakistan)

1. Mr. Illahi B. Shaikh
Engineering Adviser (Civil) &
Secretary,
Pakistan National Committee of ICID
16-D, Safdar Mansion, Blue Area
Islamabad, Pakistan
Tel 051-9201705
Fax 051-9221805

2. Dr. Muhammad Hanif
Agricultural Development Commissioner
Ministry of Food, Agriculture and
Livestock
Islamabad, Pakistan
Tel 051-9201718
Fax 051-9221246
adcmmifal@hotmail.com

3. Dr. Imtiaz Ahmed
Director
Special Advisor To the Chief Executive
of Islamic Republic of Pakistan
Chief Executive Secretariat No. 2,
Islamabad, Pakistan
Tel 051-9213283
Fax 051-9213289

4. Mr. M. Alamgir
Ministry of Industries and Production
House No. 20/2-E, G-10/1
Islamabad, Pakistan
Tel 051-2290501

Pakistan Council of Research in Water Resources (PCRWR)

5. Dr. Muhammad Akram Kahlown
Chairman
Pakistan Council of Research in Water
Resources (PCRWR)
H. No.3, Street No.17,
F-6/2 Islamabad, Pakistan
Email: pcrwr@isb.comsats.net.pk
Tel 051-9218984
Fax 051-9218939

6. Mr. Muhammad Azam
Pakistan Council of Research in Water
Resources (PCRWR)
H. No.3 & 5, Street No.17,
F-6/2 Islamabad, Pakistan
Tel 051-92189987
pcrwr@isb.comsats.net.pk

Irrigation and Water Department

7. Mr. Javed Majeed
Secretary
Irrigation and Water Department
Old Anar Kali, Opp. Punjab Public
Library
Lahore, Pakistan
Tel 042-9212117 - 8
Fax 042-9212116

8. Mr. Sardar Fazal Abbas Makin
Secretary
Irrigation and Water Department
Civil Secretariat
Peshawar, Pakistan
Tel 091-9210845
Fax 091-9210874

9. Mr. Abdus Salam Khan
Secretary
Irrigation and Water Department
Civil Secretariat, Zarghoon Road
Block 7, Quetta, Pakistan
Tel 081-9201074
Fax 081-9202157

10. Mr. M. Idrees Rajput
Secretary
Irrigation and Water Department Sindh
Secretariat
Karachi, Pakistan
Tel 042-9211445
Fax 042-9211447

Irrigation Department (GoP)

11. Mr. Allah Baksh Baloch
Chief Engineer
Irrigation Department
Warsak Road, Kababian
Peshawar, Pakistan
Tel 091-9212116

Irrigation & Power Department (GoP)

12. Mr. Ch. Mazhar Ali
Advisor
Irrigation & Power Department
Government of the Punjab
Lahore, Pakistan
Tel 042-5759247 & 9212098

13. Mr. Shafqat Masood
Project Director
Punjab Private Sector, Groundwater Development
Project Management Unit - I
I & P Department , Govt of Punjab,
Lahore, Pakistan

14. Mr. Jaffar Kabir Ansari
Chief Engineer
Irrigation Research Institute
Lahore, Pakistan

15. Dr. Mushtaq Ahmed
PSO / HRD (Material Division)
National Physical and Standards Laboratory
(NPSL) 16, H-9
Islamabad, Pakistan
Tel 4446280
Fax 4434826

16. Mr. Riazuddin Abro
Officer-In-Charge
Solar Energy Research Center (SERC)
P.O.Box 356,
Hyderabad, Pakistan
Tel 0221-614596

17. Mr. Asrar ul Haq
Additional Secretary (Technical)
Punjab Irrigation & Power Department,
Old Anarkali
Lahore, Pakistan
Tel 041-9212123 -24

18. Mr. Muhammad Bashir Khawaja
Irrigation and Power Department
Sariab Road
Quetta, Pakistan
Tel 081-9211190

Indus River System Authority (IRSA)

19. Mr. Nassar Ali Rajput
Member, Federal IRSA
Islamabad, Pakistan

20. Mr. Noor Muhammad Baloch
Member (Sindh) / Chairman
Indus River System Authority (IRSA)
Govt. of Pakistan,
Block R-3, Sitara Market
G-7 Markaz,
Islamabad, Pakistan
Tel 051-2202975-76
Fax 051-9202081

21. Mr. Aslam Saleem
Member (NWFP)
Indus River System Authority (IRSA)
Govt. of Pakistan,
Block R-3, Sitara Market
G-7 Markaz,
Islamabad, Pakistan
Tel 051-2202971
Fax 051-9202081

22. Mr. Mian Hafiz Ullah
Chairman
Indus River System Authority (IRSA)
Building R-3, Markaz G-7,
Islamabad, Pakistan
Fax 9201282

23. Mr. Amanullah
Indus River System Authority (IRSA)
Govt. of Pakistan,
Block R-3 Sitara Market
G-7 Markaz,
Islamabad, Pakistan
Tel 051-9201282 & 9221049

Federal Flood Commission

24. Mr. Javed Bokhary
Federal Flood Commission
Ministry of Water and Power,
16-D, East Blue Area
Islamabad, Pakistan
Tel 051-9219385

Meteorology Department (GoP)

25. Dr. Qamar-uz-Zaman Chaudhry
Director General
Pakistan Meteorological Department
Sector H-8/2,
Islamabad, Pakistan

26. Mr. Shaukat Ali Awan
Chief Meteorologist
Flood Forecasting Division
Pakistan Meteorology Department
Lahore, Pakistan

27. Mr. Muhammad Munir Sheikh
Chief Meteorologist (Retd)
1-B, Met Colony 46, Jail road,
Lahore, Pakistan

28. Mr. Zia-ud-Din Khan
Pakistan Meteorological Department
Sector H-8/2,
Islamabad, Pakistan
Tel 051-9257316
zias2pk@yahoo.com

29. Mr. Mahmood Hussnain
Pakistan Meteorological Department
Sector H-8/2,
Islamabad, Pakistan
Tel 051-9257317-18
mahmoodhusnain@hotmail.com

30. Mr. Azmat Hayat Khan
Pakistan Meteorological Department
Sector H-8/2,
Islamabad, Pakistan
Tel 051-9257317-18
pmisbacis@paknet.com.pk

31. Mr. Anjum Bari
Pakistan Meteorological Department
Sector H-8/2,
Islamabad, Pakistan
Tel 051-9257313

National Agricultural Research Council (NARC)

32. Dr. Zahid Hussain
CSO
Head, Water Resources Research Institute (WRRI),
National Agricultural Research Council (NARC),
Islamabad, Pakistan
Tel 051-9255022
Fax 051-9255074
wrri@wr-narc.isb.sdnpk.org

33. Dr. Shahid Ahmad
CSO, Natural Resources (NR)
Natural Resources Division,
National Agricultural Research Council (NARC),
P.O. Box 1031
Islamabad, Pakistan
Tel 051-9202136
Fax 051-9202968
shahidwr@isb.paknet.com.pk

34. Dr. Azra Qureshi
National Agricultural Research Council (NARC),
Islamabad, Pakistan
Tel 051-9255217

35. Engr. Muhammad Yasin
Head Irrigation and Water Management,
Water Resources Research Institute (WRRI)
National Agricultural Research Council (NARC),
Islamabad, Pakistan
Tel 051-9255022
Fax 051-9255074
wrri@wr-narc.isb.sdnpk.org

36. Dr. M Munir Ahmed
Senior Engineer /
Program leader
Salinity and Water Management
Water Resources Research Institute (WRRI),
National Agricultural Research Council (NARC),
P.O. Box N.I.H 45500
Park Road,
Islamabad, Pakistan
Tel 051-9255012, Ext 3083
Fax 051-9255074
munir61@yahoo.com

37. Mr.P.M. Moshabbir
Senior Engineer /TSO to M(NR)
Natural Resources Division
National Agricultural Research Council (NARC), P.O. Box 1031
Islamabad, Pakistan
Tel 051-9203070 - 75, Ext 2320
Fax 051-9202968
pmm909@hotmail.com

38. Dr. Muhammad Aslam
National Agricultural Research Council (NARC),
P.O. Box 1031
Islamabad, Pakistan
Tel 051-9255024
aslam@pnut-nare.sdnpk.org

39. Dr. M. Sharif Zia
National Agricultural Research Council (NARC),
P.O. Box 1031
Islamabad, Pakistan
Tel 051-9255218

Agriculture Prices Commission

40. Mr. Muhammad Ijaz Ahmed
Assistant Chief,
Agriculture Prices Commission,
G-8 Markaz
Islamabad, Pakistan
Tel 051-9261291-97

41. Mr. M.B. Malik
Chief (FPD)
Agriculture Prices Commission,
G-8 Markaz
Islamabad, Pakistan
Tel 051-9261284
Fax 051-9261290

National Physical Standards Laboratory (NPSL)

42. Dr. Muhammad Ahmad
National Physics Standards Laboratory (NPSL)
19, Sector H-9,
Islamabad, Pakistan
Tel 051-4446280
npsllab@isb.net.pk

Pakistan Atomic Energy Commission (PAEC)

43. Dr. I.H. Qureshi
Scientist Emeritus
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
(Res.) House # 24, St-18
Sector F-10/2
Islamabad, Pakistan

44. Dr. Inam-ur-Rahman
Pakistan Institute of Nuclear Science and Technology
Pakistan Institute of Nuclear Science and Technology
(PINSTECH), P.O. Nilore
Islamabad, Pakista

45. Dr. M. Mohsin Iqbal
Director
Nuclear Institute for Agriculture & Biology (NIAB)
P.O. Box 128
Jhang Road
Faisalabad, Pakistan
Tel 041-654210, 051-654221-30
Fax 041-654213
niab@fsd.paknet.com.pk

46. Dr. M. Afzal Sheikh
Head, Nuclear Physics Division
Pakistan Institute of Nuclear Science and Technology
(PINSTECH), P.O. Nilore
Islamabad, Pakistan
Tel 051-2207278
Fax 051-9290275

47. Mr. Nazir Ahmad Chughtai
Chief Scientific Officer
Head NMD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore Islamabad
riffat@pinstech.org.pk

48. Mr. Shujaat Ahmad
Head, Nuclear Chemistry Division
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-2207272
Fax 051-9290275
Shujaat@pinstech.org.pk

49. Dr. Salman Ahmed
Chief Scientific Officer
Head SSDL, Health Physics Division
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
riffat@pinstech.org.pk

50. Mr. Muhammad Farooq
Chief Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
riffat@pinstech.org.pk

51. Dr. Riffat M. Qureshi
Chief Scientific Officer
Head, Environment Research Group, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
riffat@pinstech.org.pk

52. Mr. Azam Tasneem
Pr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH)
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3435
Fax 051-9290275
azam@pinstech.org.pk

53. Mr. Muhammad Aslam
Pr. Scientific Officer
Health Physics Division
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3
Fax 051-9290275

54. Mr. Javed Akhter
Pr. Geologist
Nuclear Institute for Agriculture & Biology (NIAB), P.O. Box 128
Jhang Road
Faisalabad, Pakistan
Tel 041-654221-30
Fax 041-654213
niab@fsdpaknet.com.pk

55. Dr. Nasir Khalid
Pr. Scientific Officer, NCD
Pakistan Institute of Nuclear Science and Technology (PINSTECH)
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 4102
Fax 051-9290275

56. Dr. Shafiq Ahmed Mujahid
Pr. Scientific Officer
Radiation Physics Division
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-2207269
Fax 051-9290275
Sampinstech.org.pk

57. Mr. Mubarik Ali
Principal Geologist, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231, Ext. 3415
Fax 051-9290275
mubarik@pinstech.org.pk

58. Mr. Shahid Riaz Khan
Head Scientific Information Division
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290258 and 051-9290231, Ext. 3415
Fax 051-9290275
Srkhan@pinstech.org.pk

59. Dr. Niaz Ahmad
Pr. Geologist, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
chandoor@isb.comsats.net.pk

60. Mr. Azhar Mashiatullah
Pr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH)
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3433
Fax 051-9290275
Azhar@pinstech.org.pk

61. Mr. Zahid. Latif
Pr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3438
Fax 051-9290275
Zlatif@brain.net.pk

62. Mr. Muhammad Fazil
Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3415
Fax 051-9290275

63. Mr. Waheed Akram
Pr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 4436
Fax 051-9290275
Waheedpins@yahoo.com

64. Mr. Jameel A. Tariq
Pr. Geologist, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 4436
Fax 051-9290275
Manzoor@pinst.org.pk

65. Mr. Tariq Javed
Sr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3438
Fax 051-9290275

66. Mr. Ashiq Hussain Dogar
Radiation Physics Division
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore, Islamabad, Pakistan
Tel 051-2207269
Fax 051-9290275
dogar@pinstech.org.pk

67. Mr. Naveed Iqbal
Sr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 4442
Fax 051-9290275
manzoor@pinstech.org.pk

68. Mr. Maaz
Sr. Scientific Officer, RIAD
Pakistan Institute of Nuclear Science and Technology (PINSTECH),
P.O. Nilore
Islamabad, Pakistan
Tel 051-9290231-6, Ext. 3435
Fax 051-9290275
azhar@pinstech.org.pk

COMSATS Institute of Information Technology (CIIT)

69. Dr. M. Azim
COMSATS Institute of Information Technology (CIIT)
Islamabad, Pakistan
Tel 051-9201739

70. Mr. Nadeem-ud-Din Qureshi
COMSATS Institute of Information Technology (CIIT)
Islamabad, Pakistan
Tel 051-9201739

Hydrocarbon Development Institute of Pakistan (HDIP)

71. Dr. Asrar M. Khan
Hydrocarbon Development Institute of Pakistan (HDIP)
230 Nazim-ud-din Road
F-7/4, Islamabad, Pakistan
Tel 051-9290367
Fax 051-9204902

Pakistan Institute of Development Economics (PIDE)

72. Dr. M. Ghaffar Chaudhry
Joint Director PIDE
Quaid-i-Azam University Campus
Islamabad, Pakistan
Tel 051- 9211859
Fax 051-9206610

Sustainable Development Policy Institute (SDPI)

73. Ms. Foqia Sadiq Khan
SDPI
P.O. 2342
Islamabad, Pakistan
Tel 051-2278134
Fax 051-2278135
foqia@sdpi.org

Universities and Academic Institutes

74. Dr. Niaz Ahmed
Department of Irrigation and Drainage
University of Agriculture
Faisalabad, Pakistan
Tel 041-649858
Niaz@fsd.comsats.net.pk

75. Prof. Dr. Muhammad Latif
Director
Centre of Excellence in Water Resource Engineering
University of Engineering and Technology (UET)
G.T. Road
Lahore, Pakistan
Tel 042-6822558
Fax 042-6822024
center@xcess.net.pk

76. Dr. M. Iqbal Qureshi
Dean Student Affairs
GIK Institute of Engg. Science & Technology
Topi 23460,
Distt Sawabi (NWFP), Pakistan
Tel 093-71858 , 71881
Fax 0938-71877
miq@giki.edu.pk

77. Dr. Nayyer Alam Zaigham
Department of Geology
University of Karachi
Karachi, Pakistan
zaigham@gerrys.net
zaigham@geol.ku.edu.pk

78. Dr. Khalid Rashid
Deptt. of Mathematics
Quaid-i-Azam University
Islamabad, Pakistan
Tel 051-2280587
astrophy@comsats.net.pk

79. Dr. Mushtaq Ahmad Ch.
Professor & Dean,
Faculty of Crop & Food Sciences
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-9290153, 051-9290151-2
Fax 051-9290160

80. Dr. Shahbaz Ahmad Warraich
Professor,
Department of Agronomy
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-9290151-2
Fax 051-9290160

81. Dr. Safdar Ali
Associate Professor,
Soil & Water Resources
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-4457060
Fax 051-9290160
asafdar@brain.net.pk

82. Dr. M.I. Lone
Associate Professor, Soil & Water Resources
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-9290151-2, Ext. 30
Fax 051-9290160
loneuaar@yahoo.com

83. Dr. M. Ashraf
Associate Professor,
Department of Agronomy
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-9290151-2, Ext. 135
Fax 051-9290160

84. Mr. Tahir Husain Chattha
Student of Ph.D. in Soil Science
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-4457060
Fax 051-9290160
asafdar@brain.net.pk

85. Mr. Riffat Hayat
C/o Dr. Safdar Ali
Ph.D Student (Soil Science)
University of Arid Agriculture
Shamas Abad, Rawalpindi, Pakistan
Tel 051-4457060
Fax 051-9290160
asafdar@brain.net.pk

Consultants

86. Mr. B.A. Shakir
Designmen Consulting Engineers
(Pvt.) Ltd
Block-9, 1st Floor, West Rizwan Plaza,
Jinnah Avenue, Blue Area,
Islamabad, Pakistan
Te 051-2277105, 2827203, 2828577,
Fax 2829891
najib@isb.comsats.net.pk

87. Mr. M. H. Siddiqui
Consultant
Irrigation & Power Department
Government of the Punjab
Lahore, Pakistan

Consumer Right Commission

88. Mr. Asif Zaman Khan
Consumer Right Commission,
(Pakistan)
266, Street 37, G-9/1
Islamabad, Pakistan
Tel 051-2853616

Non Governmental Organizations (NGOs)

89. Mr. Muhammad Ahmad Gondal
Executive Director
Environment Foundation Balochistan
(EFB)
2nd Floor, Firdusi Building Jinnah Road
Quetta, Balochistan
Fax: (81) 836349 821312

90. Mr. Isa Daudpota
Consultant
IBADAT University
China Chowk,
Islamabad, Pakistan
daudpota@ibadat.edu.pk

91. Mr. Uzair Ahmad Syed
World Wildlife Fund for Nature (WWF)
60-Bazar Road, G-6/4
Islamabad, Pakistan
Tel 051-2829456
amwwfisd@apollonet.pk

Print Media

92. Mr. G. Ali Rai
The Frontier Post
413-Melody
Islamabad, Pakistan

93. Mr. Khawar Aziz
Online News Network
F-8/1, Islamabad, Pakistan

94. Mr. Ikram-ul-Haq
Business Recorder
Islamabad, Pakistan

COMSATS 1ST MEETING ON WATER-RESOURCES IN THE SOUTH: PRESENT SCENARIO AND FUTURE PROSPECTS

List of Participating Organizations

- Federal and Provincial Secretariats (GoP)
- Pakistan Council of Research in Water Resources (PCRWR)
- Irrigation and Water Department (GoP)
- Irrigation Department (Govt. of NWFP)
- COMSATS Institute of Information Technology (CIIT)
- Irrigation & Power Department (GoP)
- Indus River System Authority (IRSA)
- Federal Flood Commission (GoP)
- Meteorology Department (GoP)
- National Agricultural Research Council (NARC)
- Agriculture Prices Commission (APC)
- National Physical Standards Laboratory (NPSL)
- Pakistan Atomic Energy Commission (PAEC)
- Hydrocarbon Development Institute of Pakistan (HDIP)
- Pakistan Institute of Development Economics (PIDE)
- Sustainable Development Policy Institute (SDPI)
- Universities and Academic Institutes
- Consultants
- Consumer Right Commission (CRC)
- Non Governmental Organizations (NGOs)
- Print Media