WORLD WATER DAY
MARCH 2018

on the theme of
Nature for Water

Celebrated by
PAKISTAN ENGINEERING CONGRESS

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By

Engr. Tariq Rasheed Wattoo

President

PAKISTAN ENGINEERING CONGRESS

on

World Water Day, Commemoration on Saturday 31st March 2018

on the theme of "NATURE FOR WATER"

Distinguished Guests,

Members of Pakistan Engineering Congress,

Fellow Engineers, Ladies and Gentlemen!

Assalam-o-Alaikum

It gives me immense pleasure to inform that Pakistan Engineering Congress has a unique distinction of commemorating World Water Day since 2005 based on universal themes. Not only this, but the papers presented / discussed and recommendations resulting from these events have been published and disseminated complimentary by the Congress to all concerned, particularly Federal / Provincial Government Agencies.

Ladies and Gentlemen!

As you are aware, the theme of this event is **'Nature for Water'**. This seems to be a very relevant topic for Pakistan, where per capita water availability is approaching the stage of 'acute water stress'.

Water is the free gift of nature. The human beings are required to realize its immense value, make all out efforts to conserve it, use it for its socio-economic operations in a judicious manner and make out maximum benefit out of its use. Pakistan is no exception. It should have visualized importance of water for ensuring "Sustainable Economic Development" / Prosperity and "Food Security" in the context of the volume of its population, Indus Water Treaty of 1960, under which three (3) rivers namely Ravi, Sutlej & Beas, vested with India. Let us analyze whether the "Planners" displayed proper vision in building Mega, Medium and Small water reservoirs / canals; took affective steps to control flood hazards / storage of these waters, proper storage and use of rain water (i.e. harvesting rain waters), controlling water from flash floods, hill torrents etc.

Ladies and Gentlemen!

Water availability in 1951 was 5263 m^3 which now stands reduced to 915 m^3. Pakistan is now a water scarce country. The country has only 30-days water storage capacity, a dismal scenario. India has 220-days potential and is further increasing it.

Non-Construction of Dams:-

After the construction of Mangla & Tarbela Dams, the Country miserably failed to construct any major reservoir. As per the advice given by PIETER LIEFTINCK of World Bank in his study on "Water and Power Resources of West Pakistan-1968", the Country was mandated to construct at least one major water reservoir every decade. Kalabagh Dam that was to be operative in 1998 was not constructed under the utopian plea of absence of "provincial consensus". A "Technical Matter" that was to be resolved through domestic / international expertise was made a political issue. Not only Kalabagh Dam was not constructed, no other dam was built. Now belatedly, work on Dasu, Bhasha Dam etc. has been started which would take 6 years to 11 years to complete a long time indeed. In the meantime, the Country suffered huge recurring financial loss of million of rupees. Also, 30 MAF water continued to flow into the sea without being used, in energy generation, agriculture and industrial development.

Ladies and Gentlemen!

Population of the Country that was 34-million stands at the staggering figure of 207.7 million (an understated figure) and is visualized to be 399 million by 2047 rising at an abnormal / galloping growth rate of 2.4%, a catastrophic scenario. It has been characterized by "Economists' as time bomb. China has controlled its population by enacting 1-child policy. We may go for at the most 2-child policy if drought, hunger, starvation is to be avoided. It is the only sensible course to be adopted.

Ladies and Gentlemen!

The country has not only plundered surface water but has also been playing havoc in the mining of "Groundwater" to the tune of 50-MAF, which is the main source of "Agricultural" development as there is surface water shortfall of 31 MAF. In the absence of regulatory limitations, more than 1.2 million tube-wells are indiscriminately over-mining the "Groundwater" with the water table constantly declining. The aquifer is further suffering due to inadequate recharging. Water Resources specialists have identified numerous areas for recharging the aquifer.

Federal/Provincial Governments should work on groundwater recharge in depleted areas like Bari Doab, Rachna Doab, upstream of Ravi River, Fresh Water Lake needs to be established up-stream of River Ravi. Another recharging method is drilling bore holes upto ground water levels in fresh water areas through reverse function of tube wells.

Ladies and Gentlemen!

Rain water Harvesting Techniques in cities of High Rise buildings, Libraries, Museums, Universities etc. is being practiced in several countries for achieving water supply which is clean/potable and can be used in Domestic purposes, gardening, industries and Groundwater recharge. It is the best source of providing low cost decentralized water to urban and Rural House holds where safe treated water is not available. It has been

successfully implemented in NUST-Islamabad. It is being effectively practiced in Canada, India, United Kingdom, Sri Lanka, and Malaysia etc.

Ladies and Gentlemen!

Hill torrents in Pakistan drain approximately 65% of the total area of the country. There are 16 large Hill Torrents in 14-major Torrent areas. A study carried out by M/s. NESPAK, 1200 Number water conservation sites have been identified where 18690 MAF of Hill Torrents waters can be conserved and 1.409 million acres of land can be brought under cultivation. Alas, little efforts have been made to tap this valuable potential and to stem the rot of floods etc. that inflict enormous physical and financial losses.

Ladies and Gentlemen!

Pakistan with a fast-rising population cannot adequately meet its domestic agricultural and industrial water demand from surface water and ground water. Like other advanced/emerging economies it also requires proper use of its available waste water resources after their proper treatment as it needs to enhance its food/fibre production by at least 50% to ensure food security. Developed economies use approximately 70% of its waste water after its proper treatment and Pakistan should do the same.

In order to adequately meet the challenges of water shortage following projects need to be completed on Fast track basis.

1. **Diamer Basha Dam Project (6.4 MAF Storage)**

   This is now proposed to be implemented in two stages. In stage I, main Dam and appurtenant structures are going to be constructed through internal resources. PC-I Proforma for this stage is now in the final stage of approval by ECNEC.

2. **Dasu Hydropower Project (0.66 MAF Water Storage)**

   Implementation of this projects also envisaged through 2-stages. Stage 1 to develop 50% of 4320 MW Capacity (2160 MW) is already under implementation through international financing (World Bank) and internal resource mobilization through a consortium of Banks.

3. **Pattan Hydropower Project (0.06 MAF Water Storage)**

   Feasibility study of 2385 MW Pattan Hydropower Project has been already completed. For its implementation, a Chinese consortium has expressed interest on build, operate and transfer (BoT) basis under a lease of about 25-Years.

Thank you all for your patient hearing.

PAKISTAN PAINDABAD

Paper No. 142

WATER NEEDS OF CAPITAL CITIES IN PAKISTAN

Engr. Abdul Khaliq Khan

WATER NEEDS OF CAPITAL CITIES IN PAKISTAN

By

Engr. Abdul Khaliq Khan[1]

Abstract

Pakistan is one of the countries which could face severe water crises as we advance in the 21st century. Due to increased competition for water resources by domestic and industrial sectors, major cities in Pakistan are facing acute shortages of water. Most of the drinking water supply is dependent on groundwater abstractions. This has resulted in groundwater over-extraction, deteriorated water quality and extensive decline of groundwater tables.

Corporate water users increasingly perceive water scarcity, quality degradation and rain floods as direct risks whereas indirect regulatory risks arise when water becomes a shared resource with communities and ecosystems. Institutional factors, such as weak regulation and governance, are often identified as significant contributors to the manifestation of these risks.

Extreme shortage of water has already developed in Karachi and Islamabad where drinking water is now being supplied to the residents by tankers. In Quetta, the groundwater table has gone down to unworkable depths and the quality of water in the aquifers under Lahore and Peshawar cities is fast getting polluted. Gwadar is a rapidly expending city where demand for water is growing fast and the resources are limited. These issues are very important for the health and welfare of the inhabitants of all mega cities in Pakistan.

This paper discusses the drinking water issues to raise awareness, and to alert on the hovering problems so that timely actions could be taken.

General

The annual availability of fresh water on earth is 43.66 trillion m^3. With the World population at 7.55 billion people the availability per capita is about 6000 m^3. This level is considered abundant when judged by Falkenmark indicators but it is not uniformly distributed. Some countries have ample water while some have desert like conditions. The water availability of 1700 m^3/capita is threshold value below which the country is considered water stressed. The availability less than 1,000 m^3/capita would manifest water scarcity conditions in the country.

As the population in Pakistan has been growing at a fast rate with no new injection of water in the system, Pakistan entered the state of water stress in 1987 and water scarcity conditions have developed from last one decade.

---

[1] Advisor Mega Dam Projects, WAPDA

The Falkenmark indicators are very useful and widely used to examine the water stress and water scarcity situations. However they do not by themselves tell the whole story. These indices do not distinguish, for example, whether the fresh water in a country is available at the time when it is most needed say for crops or in places where it is most needed for example near towns and cities.

Access to safe drinking water is the basic human right while at the same time provision of adequate drinking water is essential for health and welfare of the people. Inadequate drinking water not only results in more sickness and death, but also causes higher health cost, lower school enrolment, low work productivity and finally leads to poverty.

In Pakistan, only 23.5% of rural population and 30% of urban population have access to safe drinking water, while every year 200,000 children die due to diarrheal diseases [Resemann (2005)].

After years of observations and a decade of integrative research and other initiatives, water scientists are totally convinced that world-wide and particularly in Pakistan the fresh water systems are in a precarious state. Mismanagement, overuse and climate change pose long-term threats to human well-being and evaluating and responding to those threats constitutes a major challenge to both researchers and managers.

Water and Sustainable Development

Pakistan is one of the countries which could face severe food and water crises as we advance in the 21st century. Due to increased competition for water resources by domestic and industrial sectors, major cities in Pakistan (see Fig-1) are already facing acute shortages of water. This has resulted in groundwater over-extraction, deteriorated water quality and extensive decline of groundwater tables.



Figure-1: Map showing Major Cities of Pakistan

Sustainability of water resources is a matter of great concern for Pakistan.A three days International Conference on “Water and Sustainable Development” was organized by Riphah International University in Islamabad in June, 2015.

The conference concluded with **Islamabad Water Declaration** which is a set of core recommendations to institutions and individuals focused on science, governance, management and decision-making relevant to water resources in Pakistan.

There are 28 recommendations on the agenda of Islamabad Water Declaration. The following six items refer particularly to the water supply & management needs of mega cities in Pakistan;-

1) National Water Policy may be given top priority and finalized by Planning Commission on fast track basis. The policy must reflect the implementation strategy and resource mechanism along-with respective responsibilities and the accountability mechanism.

2) A detailed map of drinking water quality in Pakistan should be prepared with special emphasis on major pollutants, sources of pollution and the consequent health problems. Chemical contaminants, such as fertilizers, pesticides and herbicides must also be included in hazards of chemicals in water from various sources.

3) Environmental protection laws must be enforced properly and effectively and those held responsible should be held accountable for polluting water resources.

4) Out of the 225 wetland sites, in Pakistan many have been identified as a resource that remains mostly untapped. Ways and means need to be developed to utilize the ones identified in ensuring water security.

5) Water wastage should be strictly monitored and prevented. Awareness program may be launched for mass awareness for protecting the precious commodity i.e. “Water” at various levels starting from schools.

6) A comprehensive Water Information System be developed to collect, analyze and disseminate information on; water resources, water uses and water management.

Islamabad

Present population of Islamabad is 1.76 million which is likely to increase to 4.44 million by 2050. The city population is growing at a rate of about 5.5% per year which is aggravating the water shortage.

The main sources of water for Islamabad are, the reservoirs built at Simly and Khanpur and a few tubewells, as water aquifer in the capital territory is shallow and scattered.

The cumulative water production from these sources is maximum 84 million gallons per day (MGD). The average demand is 176 MGD, while water shortage of 106 MGD, confronts most of the time of the year. The position in neighboring Rawalpindi city and cantonment with a population of 2 millions is equally bad as it is solely dependent on Rawal Lake and sharing with CDA supplies from Khanpur Dam.

The Federal Cabinet in 2004, instructed CDA to find out long-term solutions of water shortage to help catalyze the development process in the city of Islamabad. The study of following sources was focused upon;

1. Indus River – Upstream of Tarbela Dam
2. Jhelum River – Upstream of Mangla Dam

The Consultants studied seven locations for abstraction of water and twelve route options for conduction of water up to Islamabad. Conduction of water from Tarbela Lake was found most optimal choice to meet present demand which is 200 MGD and the future requirement for twin cities on long term basis. The supply channel/pipeline can off-take from Tarbela reservoir near Haripur and traverse along road to Taxila and onward to Islamabad. The maximum reservoir level at Tarbela is 1550 ft which is too low and shall require at least 75 ft pumping lift to access Islamabad residents. The project will cost about $ 1.2 billions.

The Council of Common Interest (CCI) in June 2011 has approved the water allocation of 215 MGD for Phase-1 of the project.

Dotara Dam

While the water supply from Indus River will take long time, a feasibility study for the supply of water, by gravity, from Haro River to Islamabad & Rawalpindi has also been proposed. In this connection a dam is to be constructed on Haro River near Dotara village, about 66km upstream of Khanpur Dam. The bed level of Haro River at this site is about 2,632 ft (802 m). With a 400 ft (122 m) high dam, the maximum reservoir level would be around 3,000 ft (915 m) leaving 32 ft of free board. Dotara Dam being located on a higher elevation can meet by gravity the present and future water supply requirements of Rawalpindi & Islamabad. The lower pond of Dotara Scheme is at El. 2000 while the sectorial population of Islamabad is located below the level. A layout plan & longitudinal profile of water supply from Dotara Dam to Islamabad are shown in Fig-2& 3 respectively.

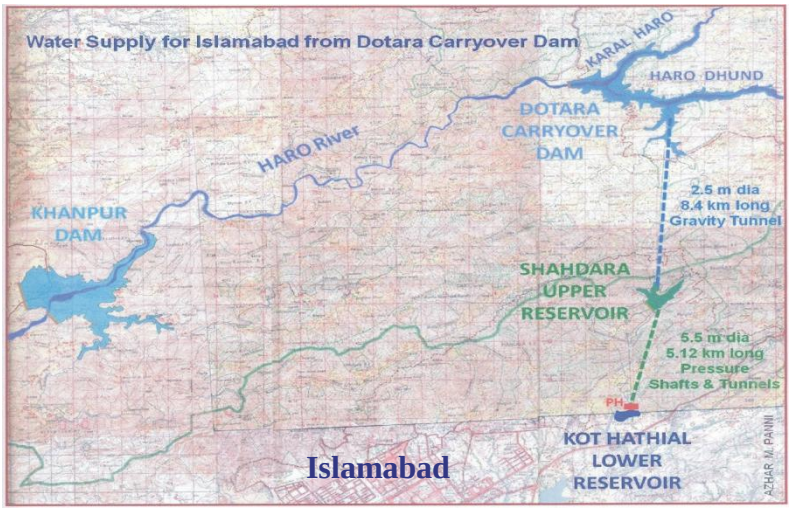


Figure-2: Layout Plan of Water Supply for Islamabad from Dotara Dam

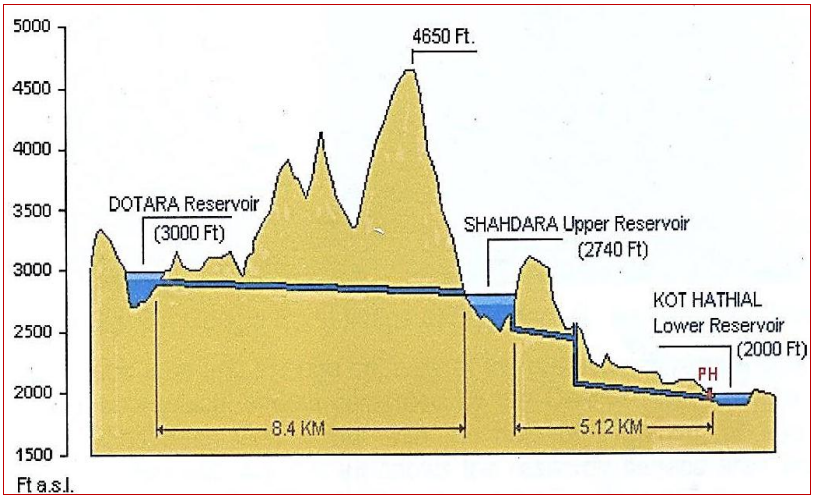


Figure-3: Longitudinal Profile of Water Supply from Dotara Dam to Islamabad

The water supply scheme from Dotara Dam is important because the Municipal and other uses of the Federal Capital Area are increasing day by day with population growth, increasing urbanization and industrialization. Diversion of water for Islamabad from Dotara Dam would meet immediate demand of Islamabad and relieve Khanpur dam to meet the anticipated increases in water demands of Industries, irrigation and domestic water supply, of the local areas. It is prudent that detailed design of Dotara Dam be taken up urgently.

Karachi

Karachi is the most populous city of Pakistan with a population of 15 millions as per 2017 census. Provision of adequate water is the top most requirement of the city.

Karachi is currently meeting just 50% of its total water requirement. The city needs 1100 million gallons of water daily but can only supply 550m gallons per day (MGD). Meanwhile, Karachi's population growth rate of 4.5% per annum means that nearly a million newcomers enter the city every year, further stressing the already-limited water supply.

In the later half of 19th century, the Karachi Municipality designed the first piped water supply system for the city which was commissioned in 1883. This scheme comprised of digging some, shallow wells on the banks of Malir River which is about 30 km from the main city. The well water was pumped into a 5 MGD capacity stone masonry gravity conduit which terminated at a Reservoir.

After establishment of a cantonment in Karachi during the 2nd World War, the city water demand increased. Under the Hilaya Scheme the city water supply was augmented by 20 MGD in two equal stages. This system originally drew water from Haleji Lake having a surface area of 28 sq. km and a storage capacity of 3000 acre feet. Water gravitates from the lake through a masonry conduit upto two pump houses in Gharo. Haleji lake is presently being used as a stand-by source.

After 1947, Karachi has become most important industrial and commercial center. The older system of water supply could not cope up with the growing demand. In order to meet shortages in supply and to cater the future demands of the expanding city, the Greater Karachi Bulk Water Supply Scheme was designed in 1953 for supply of 280 MGD potable water to the city. The scheme was divided into four equal phases, each of 70 MGD. It comprises open canals, covered conduits, a tunnel, several siphons and pumping stations. Water is drawn from the Kinjhar Lake.

In the 1st Phase (1961), a concrete lined canal and pipeline of 280 MGD capacity was built from Kinjhar Lake to Pipri and then a 140 MGD line to Karachi. In the 2nd Phase (1971) a 70 MGD capacity pump house was built at Dhabeji and reservoirs at Pipri and COD Hills alongwith additional distribution system.

Third phase was taken up during 1975 to 1978 period and added 70 MGD to the system. In the 4th phase (1987) major repairs and rehabilitation of existing system was taken up augmenting the Karachi water supply by 50 MGD. Earlier in 1981, a46 m, high dam was constructed by WAPDA on Hub River for supply of 89 MGD water to Karachi for domestic use. The quality of Hub Water is comparable to Indus water and therefore, similar parameters for pumping and treatment were adopted. The scheme is performing well and contributing its share. The growing population of the city, however, continues to remain under unbearable stress of water shortage.

Water Distribution inequalities are also present; there is no metering system to monitor real use or water waste. Under situation of extreme shortage in water supply, the responsible agencies resort to water tankers for making supplies to the residents. Eventually a tanker mafia takes over and sells water at exorbitant rates. The “water tanker mafia” also illegally punctures pipelines and siphons off water to sell at inflated rates. This has happened and continuing in Karachi and the people of low income groups are suffering beyond their capacities. The existing water supply system of Karachi is shown in Fig 4.

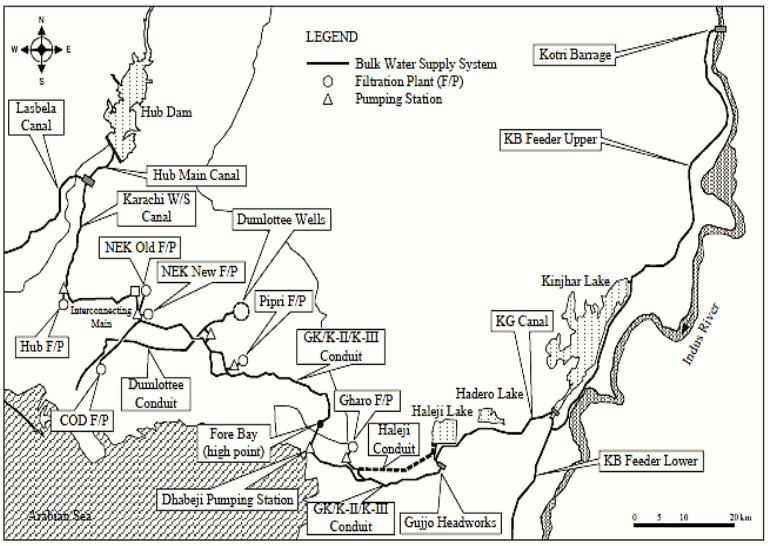


Figure-4: Existing Water Supply System of Karachi

To alleviate the crisis, Karachi's water board is working on the Rs.25 billion Karachi-4 (K-4) project, which will provide an additional 650 MGD to the city by drawing water from Kinjhar lake. There will be a gap in supply and demand by the time the initial phase is completed in two years. By then, the population will have climbed further, increasing the burden on the available water supply.

The water crisis in Pakistan's largest city is part of a broader trend of water insecurity affecting the entire country. The water shortage is Pakistan's biggest threat. A master study for identification of water supply requirements of the city during short, medium and long term plans (upto 2025) and for preparing feasibility studies has recently been assigned to a consortium of consultants. Karachites would need its urgent finalization and implementation.

Peshawar

The present urban population of Peshawar (1.97 million) is estimated to increase 3 times by 2050. Existing Water Supply System is based on ground water abstractions, with 477 deep tubewells and nearly 126 MGD water is being supplied. The demand is estimated to increase to 202 MGD by 2030.

The present number of reported water connections is 77,000 and the House Units are 354,000. It means that a large number of the inhabitants are without water connections.

Shortage of water availability has direct impact on the quality of life. There is need for province wide water and sanitation regulatory system. Reportedly, it is being developed and expected to start functioning soon.

There has been over reliance on tubewells and wells. Recently a Feasibility Study has been carried out titled "Greater Water Supply for Peshawar". Four possible locations in the vicinity of the city were considered as follows:-

Jabba Dam

The construction of Jabba dam has been planned by the provincial government for provision of clean drinking water facility to residents of Peshawar and Khyber Agency. Recently, the government has included the construction of Jabba dam in the Annual Development Program 2016-17 under its Peshawar Greater Water Supply Scheme (PGWS). Upon completion, this dam will help cultivation of an estimated 20,000 acres of land besides protecting Peshawar and Khyber Agency from floods. The dam is projected to provide about one million people with clean drinking water facility and store up to 38,000 gallons of water providing large scale agriculture benefits to local populations.

Bara Dam

In addition to Jabba dam, the feasibility study of Bara dam has also been prepared with an estimated capacity of irrigating 50,000 acres area in Khyber Agency's tehsil Bara and settled areas of Peshawar. The Bara dam will also serve as a source of drinking water for nearby areas and about two million cusecs potable water can be provided to the Bara Bazaar and about eight million cusecs to Hayatabad in Peshawar.

The life span of Bara Dam is estimated between 80 and 100 years besides its storage capacity of about 88,000 acre feet water.

Warsak Dam

A concept was presented few years ago that water from Warsak Dam should be brought to Peshawar as main source of water for Peshawarities. This scheme was presented as the first option for addressing water needs of Peshawar. Warsak Dam is located some 20 km North of Peshawar on River Kabul.

From engineering point of view the Warsak dam water supply scheme is the most viable as it is closely located with Peshawar and financially it will cost less than other projects.

Mohmand dam when built on upstream of Munda Headworks on River Swat some 37 km from Peshawar could be another future option.

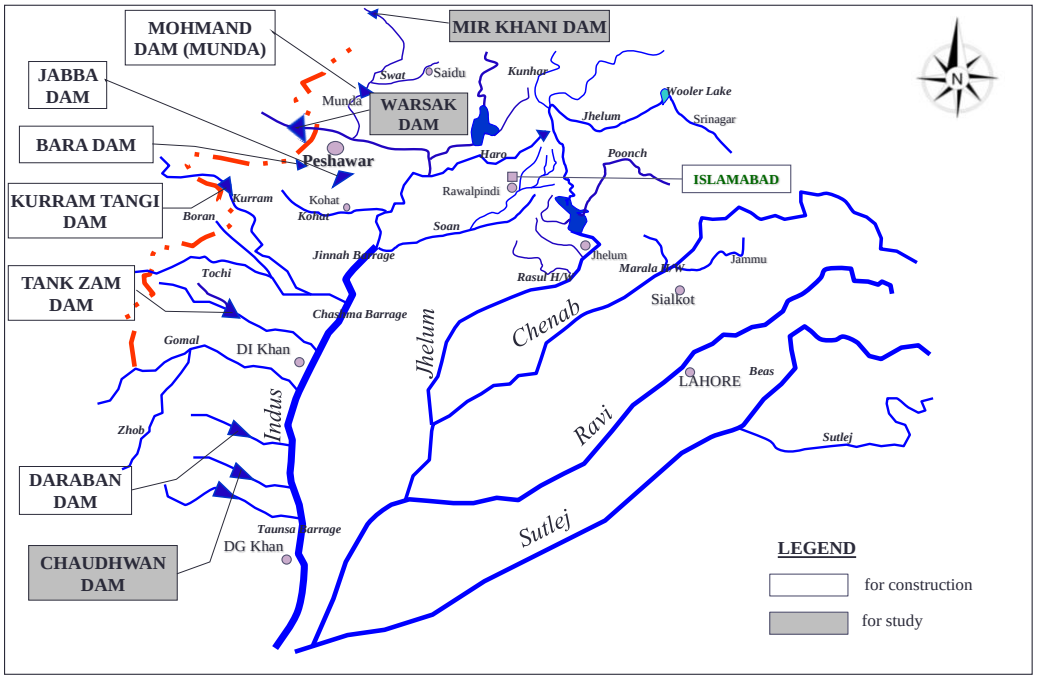


Figure-5: Small & Medium Project Dam Sites in KPK & FATA

Quality of Drinking Water

These projects would be sufficient to fulfil the fresh water needs of the growing population till 2060 besides increasing the overall agricultural production in KP and Fata. The completion of these projects would not only help raise water table in Peshawar that had been going down for last few years owing to rapid installations of tube-wells and excessive use of water but would also provide clean drinking water to Peshawaritis.

Most people consume water from tube wells. There is need for installation of more water filtration plants for purification of this water. Several of the existing plants are not delivering safe water due to lack of maintenance. Special funds are required for operationalization of all non- functional water filtration plants and repair/replacement of old water pipes.

The consumption of unsafe and contaminated water is leading to serious ailments like infant and child mortality, diarrhea, hepatitis, dysentery and malaria diseases.

The main projects being considered to include construction of gravity based water supply schemes in KP, solarization of 200 existing water supply schemes, provision for rehabilitation of disaster affected water supply schemes, construction and rehabilitation of water supply and sanitation schemes and restoration of non-functional damaged water supply schemes in the province.

About 800 tons of solid waste is being generated in the city of Peshawar. There is no Landfill site and a proper site has yet to be identified. There are three wastewater treatment plants in the City (constructed in 1990's). These plants were never put to operation and have since been abandoned.

Under Water and Sanitation Program (WSP) the World Bank provided technical assistance in 2009. Recently, NDC and Halcrow have prepared the "Peshawar Water and Sanitation Master Plan". The PC-I(Rs. 1140 million) has been approved and now there is need of urgent implementation.

Lahore

The Lahore water supply is totally dependent on groundwater abstractions. The aquifer under Lahore is broadly viewed as a single contiguous, unconfined aquifer. Groundwater for drinking purposes is extracted from a depth of 120-200 meters (400 to 650 feet). It is pumped for Lahore's domestic, industrial and commercial purposes. WASA supplies drinking water to more than 6.0 million people by means of 484 tube wells. Over time, water demand has increased from 180 litres per capita per day (lpcd) in 1967 to 274 lpcd in 2013. The total groundwater extraction from these 484 tubewells is about 2.2 million cubic meters per day (484 MGD). WASA tube wells run 14-18 hours per day and water is distributed from source to households through a network of 7,700 km long water supply lines and 600,000 connections.

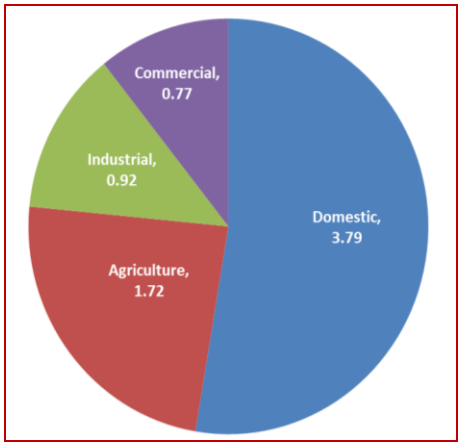


Figure-6: Water Uses in Lahore (MCM/Day)

The average annual rainfall of Lahore is 715 mm. However, its recharge to groundwater in urban areas is minimal due to urbanization. In general, groundwater discharge is

higher than recharge, which is the main reason for the rapid depletion of groundwater in the city.

The entire municipal waste from Lahore city is collected through a network of 14 main drains and discharge into the River Ravi without any treatment. The industrial waste is directly discharged in the canal system by 271 industrial units.

The second biggest source of pollution is the Hudiara Drain. Currently, there are around 100 industrial units located along the Hudiara Drain which discharge wastewater directly into the River Ravi. Most of these industries are low-polluting. In general, the groundwater quality is good near the River Ravi and gradually deteriorates in the south and south-western direction. Many studies have found higher arsenic level (50 parts per billion) in pumped groundwater in Lahore. The quality of shallow groundwater is generally considered poor as the tube wells are adversely effected by seepage from sewerage and drainage system. Since WASA extracts water from deep tubewells (200 m), the quality of pumped groundwater is relatively better.

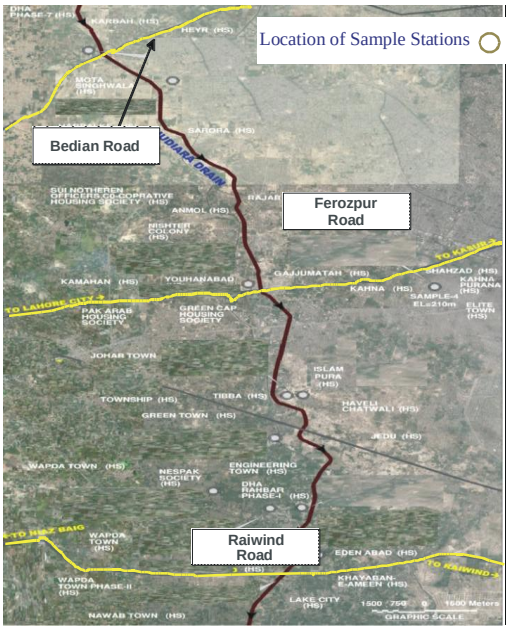


Figure-7: Layout Plan of Hudiara Drain

In the absence of any municipal water act or water-right law, groundwater is pumped indiscriminately by private housing schemes and industry. Total groundwater extracted by private housing schemes is approximately 0.71 MCM/day. Total domestic water use in Lahore is estimated at 3.79 MCM/day (834 MGC).

There are 2,700 registered industries in Lahore, out of which 75 per cent are categorized as large scale factories, which are the main users of groundwater. The textile industry makes up 20 per cent of the total and uses 69 per cent of the total industrial water consumption. The analysis of a recent study shows that groundwater extraction for industries is in the order of 0.92 MCM/day.

For commercial and institutional water uses (hospitals, educational institutes, mosques, shops and restaurants, public parks, offices, bus stands, railway stations and other similar places), WASA has provided 32,500 connections. Generally, water for commercial and institutional use is considered around 20 per cent of the domestic water use. Therefore, water usage for commercial purposes for Lahore city could be around 0.77 MCM/day.

The agriculture uses amount to about 1.72 MCM/day, thus making gross total uses by Lahore at 7.2 MCM/day (1584 MGD).

The wastewater generation in Lahore is estimated at 231 litres per capita per day (WASA Report, 2013). The total generation of wastewater is about 8.0 MCM/day and almost all is disposed off into the River Ravi without any treatment (JICA, 2010). Some industries discharge their wastewater on land or in soakage pits which results in groundwater pollution.

The difference between recharge and discharge is 250 MCM/day, which is equivalent to a 0.55m per year drop in aquifer levels. In urban parts of the city, the water table drop may be higher due to excessive pumping and insignificant recharge. The groundwater has reached close to the lowest acceptable level. Abstractions from present very low depths has extreme hazard to the health of the city dwellers. It is high time that new projects be taken up for surface water supplies and for the recharge of the dwindling aquifer. An appropriate option is to create fresh water pond in River Ravi in the vicinity of the city of Lahore and keep it fed from Marala-Ravi link canal. Groundwater recharge may be established in all available parks and open area which may be fed by rainwater harvesting.

QUETTA

Water supply for Quetta is dependent on groundwater abstractions supplemented by surface water conveyance from Hanna Lake and Spin Karez Dam.

The population of Quetta valley is exceeding three million and demand for water is increasing due to this surge in population numbers.

Quetta has been getting 28 million gallons of water per day (MGD) while the city has been facing shortfall of 17 MGD. In next 10 years, the demand for water in Quetta will reach about 75 MGD. Underground water level in Quetta has dropped down to 2000 feet deep and presently, the tube wells are extracting fossil water. The ground water table is depleting at an alarming rate and the problem is getting graver due to rapid increases in population. The situation calls for immediate attention.

After the completion of China-Pak Economic Corridor (CPEC), Balochistan would be closely connected with rest of the world and shall be required to meet the needs of international traffic. It is the need of hour to urgently solve major issues of Quetta including water shortage and solid waste management.

The nearest surface water source is Khost River, the site of Mangi Dam (built 1982) about 76 km from Quetta city. Mangi Dam Rehabilitation and Water Conveyance System project with an estimated cost Rs 10 billion is planned to meet water supply requirements of Quetta city and adjoining areas. The project envisages:

a. providing about 8.10 MGD for augmenting the existing under stress water requirements of Quetta Town,

b. shifting the existing trend of extracting underground water to more sustainable option of constructing the surface water storage reservoirs and

c. providing un-interrupted drinking water supplies to the inhabitants by means of Construction of Water Storage Tanks.

In order to achieve these objectives, a concrete gravity dam of 61 m height with a gross storage capacity of 29,530 AF is envisaged. Other parameters are Water Conveyance System, pumping main to high point, 60 Km of 600 mm and 450 mm dia pipeline and Water Storage Tanks.

The estimated cost of construction of Mangi Dam is Rs. 2.83 billion. Conveyance System may cost Rs. 5.15 billion alongwith other expenses at Rs. 1.4 billion. The annual recurring expenditure has been projected at Rs. 644 million for sustainability of the project.

Mangi Dam could supplement the existing supplies but it would not be able to fulfill total demand of water in Quetta. Studies need to be made to transfer water from Kachhi canal through a long pipe line.

Gwadar City

Gwadar is the key city and seaport for China Pakistan Economic Corridor (CPEC). As the road and marine traffic develops towards Gwadar, its commercial activities will increase manifold laying great demand on water supply for meeting the rapidly increasing municipal, commercial and industrial needs.

Present population of Gwadar is 50,000 persons which is projected to rise to 0.55 million persons by 2030 & 1.78 million by 2050. There is no groundwater and the surface water sources are very few. Water supply for meeting the emerging demands requires execution of challenging projects.

Water demands are estimated to be 30 MGD by 2030 and 108 MGD by the year 2050. Water demand estimated earlier in 2002 was based on a requirement of 59 liters per capita per day. At that time it was prepared to draw water from Mirani Dam at a rate of 104 lpcd which is equivalent to 23 MGD or 45 cusecs. On annual basis this would mean withdrawal of about 21% of water stored at Mirani. Considering the long conveyance line (120 km) and the future needs of farmers in Mirani command area, the proposal was not pursued further.

The groundwater under Gwadar is saline. Nearest surface water supply is from Akra Kaur Dam located 25 km north of the city. Akra Kaur reservoir capacity is only 10,125 AF (7.5 MGD) of which present supply to Gwadar areas is 1.35 MGD. The live storage at Akra Kaur is reducing due to sedimentation therefore, there is urgent need of finding and shifting to alternate sources. These sources include the following options.

	Dam	Distance from Gwadar	Storage
•	Swad Dam	71 km	33,000 AF
•	Belar Dam	74 km	2,000 AF
•	Talar Dam	90 km	52,000 AF

The above mentioned sources do not wholly meet the city's water demand and would also take a few years for implementation of projects, therefore a 0.20 MGD desalination plant has also been proposed to address the immediate needs. The desalination plant can be completed in much shorter times than the proposed dams and can meet the urgent demands.

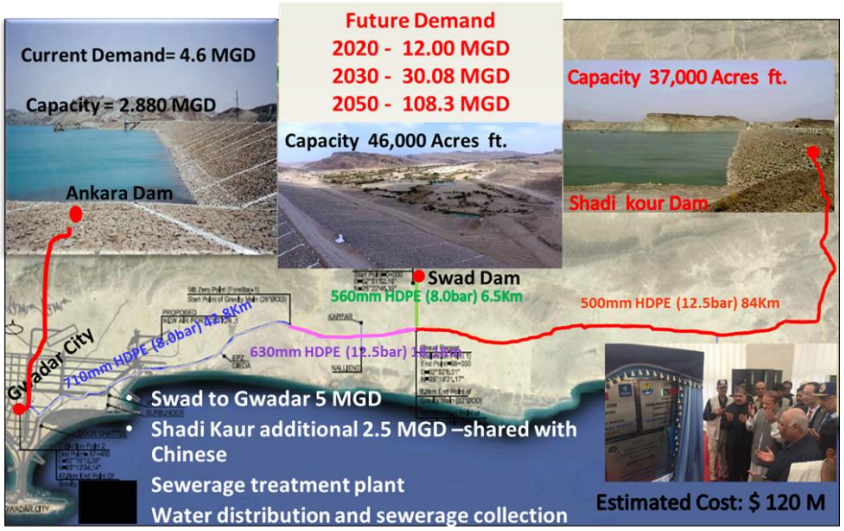


Figure-8: Fresh Water Supply & Waste Water Treatment System, Gwadar

Recommendations

1. The roles and responsibilities of different organizations need to be clearly defined to avoid overlapping and to ensure effective management of water resources at all levels. The capacity of institutions needs to be developed to undertake systematic sets of legislations and organizational changes to solve the water supplies, distribution, pricing and regulatory issues.

2. Keeping in view the growing problems of groundwater and its consequences on the future of water supply particularly for Lahore and Quetta, the regulatory organizations need to enhance the monitoring of groundwater abstraction and lay restrictions on the abstraction of groundwater in critical areas. In Lahore, for example, central parts of the city where a groundwater depression zone is being developed should be defined as a "groundwater protection zone" and pumping should be regulated. In Quetta the further expansion of tubewells should be stopped. Since groundwater plays an important role in economic development, the government needs to develop a strategy for long-term sustainability of this resource.

3. The importance of groundwater resources and the potential impacts of climate change on them should be discussed with all water users. Providing education and training to local communities about rainwater and runoff water harvesting for domestic use, agricultural use and for groundwater recharge will enhance the adaptation options to cope with current and anticipated future problems.

4. For long-term sustainability of drinking water supplies, the possibility of supplementing groundwater supplies with surface water supplies should be explored, wherever possible. For Lahore, provision of surface water supply from the River Chenab or BRBD canal system may be considered after addressing quality concerns. Similarly detailed designs and implementation of surface water supply schemes for Karachi, Islamabad, Peshawar, Quetta and Gwadar need to be expedited.

5. Further work should urgently be carried out on Dotara Dam, Jabba Dam, Bara Dam and the Water Supply Link from Tarbela Reservoir to Islamabad.

6. To increase recharge to groundwater, rainwater harvesting should be encouraged in all new and old housing schemes and in areas currently under WASA jurisdiction. For this purpose, special recharge zones may be developed to facilitate groundwater recharge.

7. In order to promote the culture of water conservation, a metering system should be introduced to charge water on a volumetric basis.

8. Water should be treated as an economic good and its exploitation rights be given through a proper permit system and compatible prices especially to the industrial sector. Industries can invest in treating wastewater at source and reuse it. To promote water conservation in the industrial sector, attention must be given to water intensive sectors such as textile processing, paper and pulp, leather and tanneries, sugar etc. because this is by far the most water consuming industries in the region.

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Paper No. 143

GROUNDWATER USE AND MANAGEMENT EXPERIENCE IN PUNJAB

Muhammad Nawaz Bhutta

GROUNDWATER USE AND MANAGEMENT EXPERIENCE IN PUNJAB

By

Muhammad Nawaz Bhutta[1]

ABSTRACT

The expansion of groundwater use for irrigation in Punjab during the past six decades has played a fundamental role in increasing agriculture production. Groundwater is also the source of drinking water for over 90% of the population and almost 100% industries use groundwater for their process requirements. Due to indiscriminate use of groundwater, there are threats of its declining, saline water intrusion, point pollution, deterioration of urban aquifers and concerns on sodification and arsenic contamination. There are several meaningful programs and policies that can be pursued to counter these threats. The expert level actions to be taken are: (i) to prepare/update hydro-geological maps and groundwater atlases for the benefit of decision makers and farmers. Investigate and reverse groundwater contamination. (ii) Preparation of groundwater recharge schemes for agriculture and urban areas. (iii) Promoting effective methods for groundwater recharge. (iv) Avoiding groundwater over exploitation. The policy level actions required are: (i) prioritize groundwater recharge projects. (ii) Stop financing overuse, as now occurs through reduced electricity tariffs for agricultural use, flat rates and non-collection of charges. (iii) Setting up of Groundwater Boards with clear tasks and capacities in monitoring, data dissemination, rule setting and enforcement. Rationalizing canal water allowances. (iv) Educating farmers about aquifer characteristics, water quality and sustainable uses. (v) Enforcing regulation against disposal of untreated toxic effluents into surface drains which are polluting groundwater and surface water, and (vi) Encouraging and enforcing rainwater harvesting.

1. INTRODUCTION

The total abstraction of groundwater in Punjab is estimated as more than 47 million acre foot (MAF). Most of this is used for agriculture. However, more than 90% of the population of Punjab depends on groundwater for drinking and domestic uses. With the restraints on large-scale surface water development since 1976, agricultural expansion in Punjab has been driven to a very large extent by the development of about one million private tube wells (PTWs) in the province. It is estimated that 75% of the increase in water supplies in the last four decades is attributed to public and private groundwater exploitation. The investment on these private tube wells is of the order of Rs. 60-80 billion whereas the annual benefits in the form of agricultural production are estimated at Rs. 400 billion, roughly equivalent to 5% of GDP. In addition, almost all industries rely for their water supply on groundwater.

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Groundwater use in several areas is more than recharge (WAPDA, 1988). Intrusion of saline groundwater from the central doabs into fresh groundwater zones is observed in a number of locations (MOWP, 2012).

In case of drinking water the major concern is groundwater quality. There are several problem spots, mainly in urban areas and around rural industries, where groundwater quality is contaminated with sewerage effluents, oil residues, chromium or other contaminants (Ashraf 2016). This holds true for major cities, where a large number of households still depend on individual wells for water supply.

1.1 The Changed Scenario

At the time of independence, groundwater use in Punjab was very limited - mainly through Persian wheels in the riverine areas. This changed dramatically from the mid-sixties onwards and accelerated in the mid-eighties. The government in several ways supported private groundwater exploitation. Foremost was the provision of power supply to tube well owners. The electricity charges, moreover were subsidized. Tubewell owners in Punjab were paying 40% less than the normal rate.

Locally manufactured low cost diesel pump sets entered the market in the second half of the eighties, resultantly the number of private tube wells started to rise dramatically (**Figure 1**). In 1960 groundwater accounted for only 8% of the farm gate water supplies in Punjab. As a result of the spectacular makeover of the water system 58 years later this had gone up to about 50%. The density of tube well points increased, which made it easier for non-tube well owners to have access to groundwater.As water tables fell rapidly in some areas, electrically operated submersible pumps are used which operate at depths of 25 meter and more.

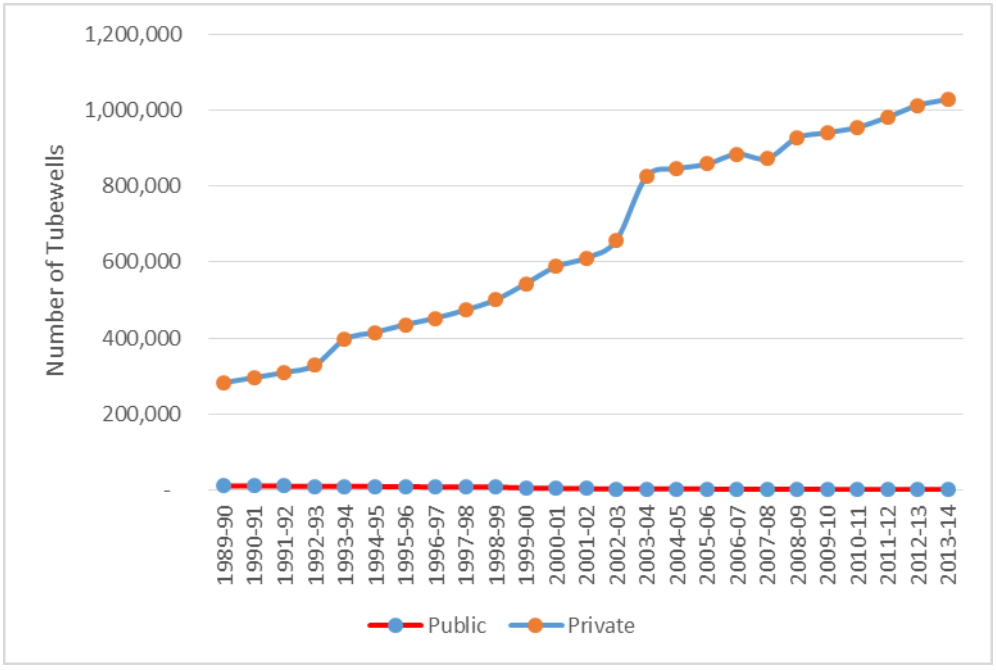


Figure 1: Growth of Tube Wells in Punjab

Number of tubewells by type of prime movers and annual Pumpage are given in the **Table 1**.

Table 1: Tubewell Number and Type of Prime Mover: Annual Pumpage

	Punjab	
Total Number of Tubewells/Lift Pumps	**Electric**	**Diesel**
	133,259	**895,165**
Days Per Year	183	124
Hours Per Day	6	5
Discharge (cfs)	1.5	0.7
Pumpage (AF)	18,106,900	32,051,383
Total Pumpage(AF)	**50,158,283**	

Source: Statistical Pocket Book of Punjab-2017

Rapid development of shallow tubewells in the Indus Plain resulted in the spectacular increase in productivity and made up for many of the deficiencies in water supplies. The intensive use of groundwater however, also requires more intense management – to address problems of a declining water table, saline water ingression and groundwater quality.

1.2 Legislation and Regulation

The first act that was promulgated in this field was the Punjab Soil Reclamation Act, 1952. This act created the basis for the Soil Reclamation Board to control waterlogging and salinity through the development and operation of drainage tubewells. For the designated land reclamation areas, the Board was in control of groundwater management and could also instigate a licensing procedure, permitting landowners to install private tubewells. Later on the Board was suspended and its executive powers were eventually transferred to the Provincial Irrigation and Power Department. At one stage in 1965 licensing rules were framed, yet they were never enacted. Another act, announced in 1958, covers the same ground. This act, the Pakistan Water and Power Development Authority Act, is the legal basis for the establishment of the Water and Power Development Authority (WAPDA). It also mentions that WAPDA would issue area-specific rules on groundwater use. Such rules were never announced.

Water quality issues for the first time got a legal cover with the Environmental Protection Agency Act that was promulgated in 1996. This Act provides the beginning of groundwater quality management. It establishes the Environmental Protection Councils at federal and provincial level that are charged among several other things with setting standards on groundwater quality. National environmental quality standards were established subsequently, dealing with industrial effluents but not with groundwater quality yet. The EPA Act resembles the other legislations in that it has a strong focus on giving permits and setting standards, but it has had difficulty in getting implemented.

Finally, the last laws with reference to groundwater management are the 1997 Provincial Irrigation and Drainage Authority Acts. They form the basis for the establishment of Provincial Irrigation and Drainage Authorities. Alongside responsibilities for irrigation and drainage operations and cost recovery, the new authorities are to ensure that groundwater monitoring is undertaken. Moreover, they have a mandate to initiate policies to address groundwater management problems.

1.3 Institutional Arrangements

At federal level, the Ministry of Water and Power serves as the umbrella institution. The Planning and Development Department oversees the review and approval of various projects. WAPDA carried out the planning and investigations for SCARP projects and implemented more than 35 SCARP projects involving vertical and horizontal drainage. The emphasis was on the preparation and construction of projects, and not much in water management as is important in the present scenario. The bias on drainage projects is also clear from the activities of the SCARP Monitoring Organization (SMO). SMO is a part of WAPDA and has been responsible for the groundwater monitoring. It concentrates on water levels observations and checks on tubewell water quality almost exclusively in the SCARP areas. At Federal Level, the International Waterlogging and Salinity Research Institute (IWASRI) and the Pakistan Council of Research in Water Resources (PCRWR) are involved in research on water resources. In short, at federal level there is no organization that exclusively deals with ground water management.

The groundwater management is a provincial responsibility. However, there is also no institutional focus for groundwater management at provincial level. Before independence, all the functions of groundwater development, management and monitoring were the responsibility of provincial irrigation departments, particularly in Punjab. In Punjab at one stage Ground Water Development Organization (GWDO) was established (1958) within the Provincial Irrigation Department. During 1960, the tasks of this GWDO were transferred to WAPDA.

As mentioned above, under the different Punjab Irrigation and Drainage Authorities Act of 1997 the development and management of both surface and groundwater has been vested in the newly created Provincial Irrigation and Drainage Authorities. These Authorities are still in the formative stage. The Authorities are also involved in the establishment of Farmers Organizations (FOs) for participatory irrigation management. This task may be stretched to include the local management of water resources. Water quality – including groundwater management – is part of the mandate of the Punjab Environmental Protection Department/Agency. Because of resource constraints, this task in practice is very narrowly interpreted for control of industrial wastes.

Several other provincial departments are involved in groundwater use, in particular the Public Health Engineering Department (water supply and O&M of the drinking water wells) and the Agriculture Departments (tube well census). After 18th Amendment in the Constitution of Pakistan, the Local Government Bodies have become involved in developing groundwater for domestic and industrial needs. While all these organizations have a partial mandate in groundwater development and monitoring, groundwater management and regulation is not undertaken by any one of these. Over the years, several efforts have been made to provide an institutional focus for groundwater

management in the different Provinces. Under the Punjab Private Sector Groundwater Development Project (PPSGDP), a Groundwater Unit was established in the Provincial Irrigation Department. Cognizant of the pressure on groundwater situation the Government of Punjab also commissioned the preparation of a Groundwater Regulatory Framework under the same project. It consisted of the development of groundwater data base, the preparation of mathematical models for simulation of groundwater conditions under present and future scenarios and support to the groundwater monitoring network of SMO. On the regulatory side, critical groundwater management areas were identified and a draft law was developed. Unfortunately, as with the other attempts, also this effort was short-lived and there was no follow-up when external funding under the above-mentioned project came to an end. Finally, during 2013, under the Groundwater Monitoring, Modelling and Management Project, Lower Bari Doab Canal, a groundwater management plan was prepared. Punjab Irrigation Department has created a groundwater cell in Irrigation Research Institute (IRI) and Directorate of Land Reclamation (DLR). DLR has also developed a database for groundwater in the province. This activity needs to be strengthened and adequately financed.

The lack of decisiveness in legal arrangements is mirrored by the absence of focus in institutional arrangements.

2. CURRENT USE IN Punjab

In Punjab, groundwater has played a central role in meeting increasing crop water requirements over the last decades. The total area of the Punjab is about 51 million acre (MA) of which 24.6 MA is under the irrigation system commanded by 24 major canals. Presently, about 38 MA of land is under cultivation. Both inside and outside the irrigation command groundwater has importantly contributed to the development of agriculture.

2.1 Irrigation Canal Command Areas

The first and foremost of these zones is the alluvial plain of Central Punjab, that consists of active and abandoned flood plains along the rivers and the bar uplands. The water-bearing stratum ranges in thickness to more than 500 m and is replenished by river flows, storm water and irrigation return flows.

The plains consist of six doabs, separated by the five rivers that define the landscape in the central Punjab. The native groundwater in the Indus Basin is saline because of its marine origin. Seepage from conveyance and irrigation network has developed freshwater layers of varying thickness that overlay deeper saline groundwater. The thickness of fresh groundwater is more near the recharging sources and decreases with an increase in the distance from recharging sources. Pumping groundwater from such an aquifer becomes complex. The amount of pumping in this case is mostly guided by water-quality considerations rather than water quantity because any excess pumping results in up-coming of saline water (Ashraf et al., 2012).

Along the rivers, the area is in many cases entirely groundwater dependent. These are the flood plains, where the inundation canals by and large ceased to function after the construction of the major reservoirs. The largest number of tubewells in the Central Punjab however,are located within canal commands itself. In most canal commands water use is conjunctive.

Areas under different water-table depth in irrigated areas of Punjab during the period from June 1999 to June 2014 are shown in **Figure 2**. It is evident that area with shallow watertable has been reduced and area with deep watertable has been increased.

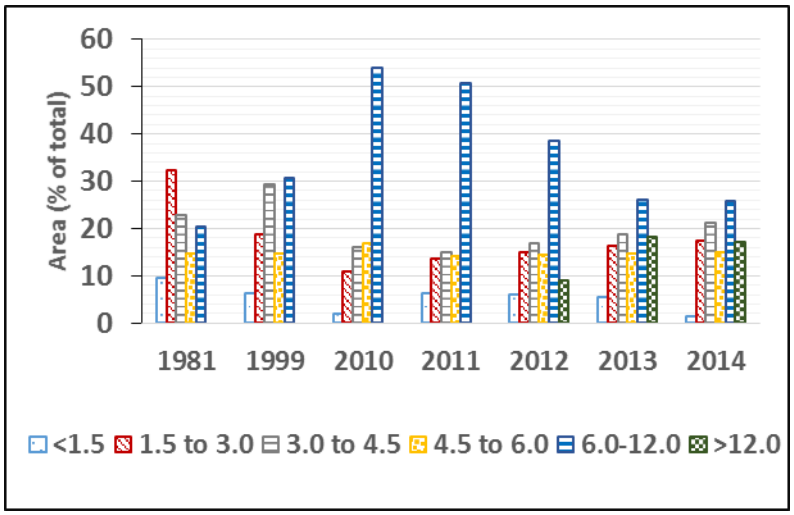


Figure 2: Groundwater table depth in irrigated areas of Punjab (June 1981-2014)

2.2 Pothohar and Cholistan

In other parts of Punjab, groundwater is equally important. Three more hydrogeological zones may be discerned, the Pothohar Plateau and Salt Range comprising a number of inter-mountain valleys and basins; the piedmont areas along Suleiman Range in the western part of the Province and the Cholistan Desert in the southeast. Agriculture in these (non-canal command) areas is heavily dependent on groundwater, supplemented by spate flows in the Suleiman Range area and relatively high rainfall in the Pothohar and Salt Range. Water tables are much deeper - up to 100 m. Water quality varies. In the Pothohar and Salt Range groundwater quality is good. In the piedmont zone, DG Khan and Rajanpur districts along the Suleiman Range, groundwater close to the foothills is saline but improves as one comes nearer to the Indus. In the Cholistan Desert groundwater is predominantly saline.

2.2.1 Groundwater Quality

Sediments underlying the Punjab Plain were deposited in a continuously subsiding basin. The sediments deposited during the process retained the brackish/saline water trapped in them. The rivers kept on adjusting their profiles of equilibrium to maintain their flow regime. During the Quaternary Era, the meandering rivers flushed these sediments in their flood plains and hence, the chemical quality of groundwater is generally:

- Fresh in the areas along the rivers;
- Brackish/saline in the central parts of the Doabs;
- Fresh in the Pothohar Plateau;

- At the foot of Suleiman Range (DG Khan and Rajanpur districts), it is fresh along the Indus and brackish on the piedmont slopes; and
- Predominantly brackish-saline in the Cholistan Desert.

During the last century, a weir controlled irrigation system was superimposed on these areas. Seepage from the canal system and irrigated fields has formed shallow fresh groundwater lenses/layers on top of the saline groundwater zones. However, there are still remnants of saline groundwater zones in the central parts of the Doabs. As per available data 23% of the canal command area has brackish to saline groundwater. **Figure 3** shows the general distribution of deep groundwater quality in Punjab.

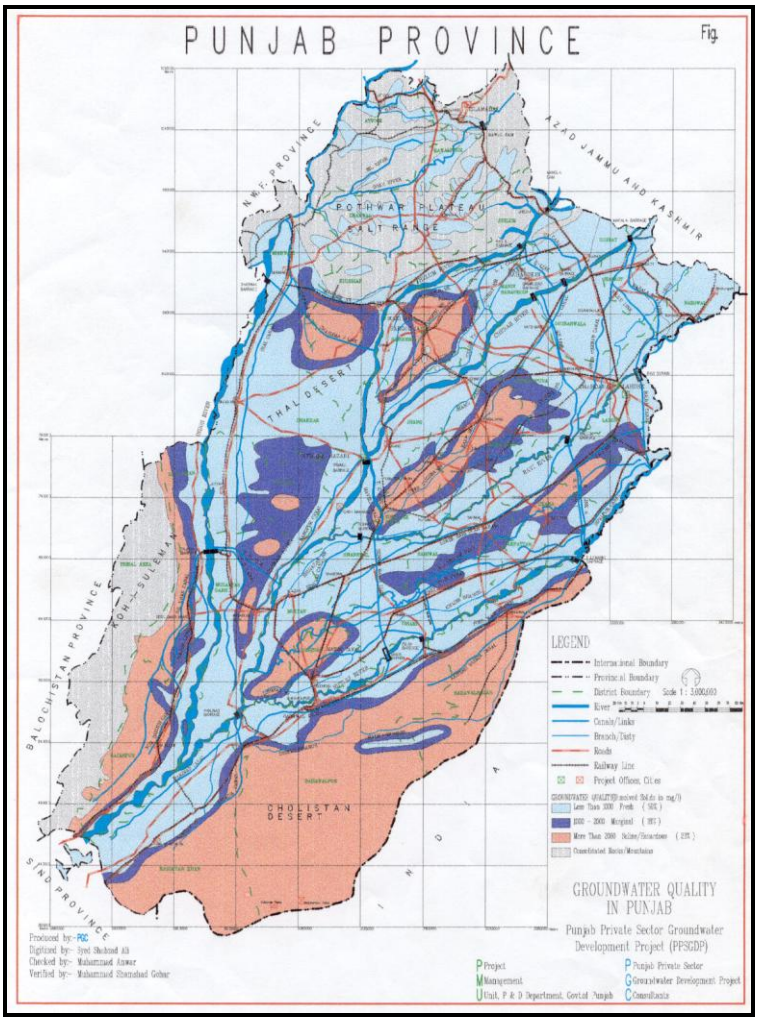


Figure 3: Punjab Groundwater Quality

2.2.2 Groundwater Budget

Table 2 presents a generalized groundwater budget for Punjab for three studies i.e. PPSGDP 1998, ACE 2002 and MOWP 2012. Aquifer recharge in Punjab comes from

rainfall recharge, especially in the northern Punjab where rainfall is higher, seepage from the irrigation system – estimated at 38% and return flow from groundwater use, estimated at 15-20% of pumped water. The budget shows that during the year recharge and discharge are balanced in certain areas having insufficient inflow. The latest studies have estimated an increase in recharge from rainfall, irrigation system and return flows. A decrease in recharge from rivers in certain areas has also been shown. A new element of recharge from Indian Indus Basin has been indicated in the MOWP 2012 study.

Groundwater abstraction has been increased, whereas reduction in base flow to river has been decreased. This can be justified due to lowering of watertable in the vicinity of rivers.

Table 2: Groundwater Budget of Punjab (MAF)

i) Recharge Components	**PPSGDP 1998**	**ACE 2002**	**MOWP 2012**
Recharge from Rainfall	6.50	6.34	7.91
Recharge from Irrigation System	20.70	27.17	32.68
Return flow from GW Abstraction	4.63	7.16	9.76
Recharge from Rivers	3.25	1.8	2.41
Recharge from India Indus Basin			3.89
Total (i)	**35.08**	**43.21**	**56.64**
ii) Discharge Components			
Groundwater Abstraction (Public + Private)	30.89	35.8	48.78
Groundwater abstraction by domestic, industrial			3.01
Non-beneficial ET losses	1.63	4.2	2.83
Base flow to rivers/groundwater outflow	2.56	3.21	1.51
Change in storage			
Total (ii)	**35.08**	**43.21**	**56.13**
Net recharge	**0**	**0**	**0.51**

2.3 Urban Areas

Most of Punjab's major cities rely on piped supply from the Water and Sanitation Agencies and private pumping for domestic water supply. Almost 100% industrial water comes from groundwater. The large scale exploitation of the aquifer in the cities and in

urban periphery has however, led to falling water tables (Figure 4) and to contamination of water supplies by leaking sewerage systems and septic tanks.

Water tables in Lahore have fallen at a rate of 0.55-1.0 m annually over the last forty years. With successive increase in groundwater pumping, the groundwater balance of the Lahore city started showing negative trends since 1970's. Groundwater elevation contours for 2009 show a big depression (about 36m deep, within a radius of about 25 km) in Lahore city (Figure 3). The decline in water table in Lahore is attributed to reduced recharge capacity due to development of built-up area and loss of flow in the Ravi River as well as the increased abstraction, tripling over the last twenty years. In 2010, there were about 467 tubewells operated by WASA. Including all other consumers i.e. cantonment board area, private housing societies, industries and individual groundwater users, total groundwater withdrawal was about 1300 cusecs (Basharat and Rizvi, 2011). With this groundwater withdrawal, annually pumped groundwater volume is 1161 MCM (0.94 MAF).

The depth to watertable near the Bhopattian chowk on Raiwind road increased from 9.2m in 1993, to 10.4m in 2003. But near to River Ravi adjacent to Thokar Niazbeg, the depth to watertable increased by 10.8 m during 1999 to 2009.It is mainly due to desiccation of Ravi River, particularly after the construction of Thein Dam in India. Similarly, in Mughalpura (city center), the drop in watertable was 3.5m, over a period of six years. On the other hand, in the surrounding agricultural areas, no long-term aquifer depletion trend has been found. The minimum annual depletion rate is along the Ravi River i.e. in Shahdra, Krishan Nagar, Farrukhabad (0.43m), the areas of Data Nagar and Ravi road (0.45m), Sabzazar and Shadbagh 0.57m), Baghbanpura, Samanabad, Johar Town 0.83m), Ichra, Township, Green Town, Garden Town (1.0m) and Gulberg, Mozang, Mughalpura, Mustafabada (1.08m). Overall average annual groundwater depletion is 0.78m in WASA water supply area, whereas maximum depletion of 1.5 m/annum was found in the tubewells installed at Doungi Ground, Fazlia Colony of Mozang Sub-Division. In addition, over-exploitation of deeper groundwater is causing groundwater pollution due to leakage from shallow unconfined aquifers.

On an average, groundwater depletion varies from 0.40 to 1.5 m/year. Upper layer of groundwater is being rapidly polluted with disposal of untreated industrial effluents as well as leakage from sewerage system. Therefore, the deep aquifer being heavily exploited is under the threat of pollution from the top shallow groundwater. Comparison of TDS in groundwater samples with the previous studies shows that the quality of groundwater is deteriorating with time. However, TDS and Arsenic contents are less in deep wells. Therefore, WASA and private groundwater users have increased bore depths from 150 to 230 m, in the past few years.

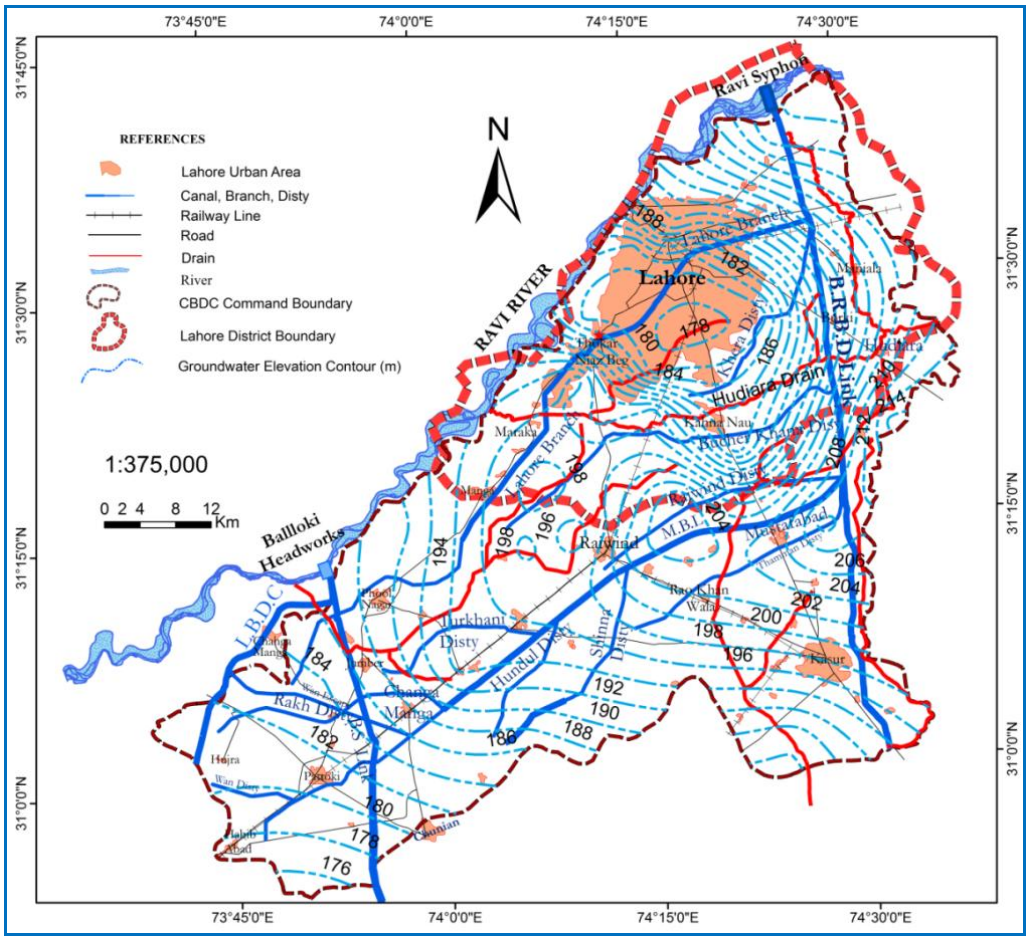


Figure 4: Groundwater Elevation Contours (2009), in the CBDC

Hudiara drain, Ravi River and sewerage disposal via soaking pits and open ponds in surrounding villages are major source of pollution for Lahore aquifer. Also of concern is the municipal waste disposal - mostly without treatment - which is likely to be a major threat to the underlying fresh groundwater and downstream surface water users. Surface water allocation would also be required for the Lahore city (of the order of 0.5 MAF) from Indus Basin Irrigation System, for water supply and additional recharge to the aquifer.

The population ratio for 2030 to 2010, 2040 to 2030 and 2050 to 2040 was calculated for Lahore city, and the population in selected 16 other cities was projected for the corresponding years with these ratios. Corresponding domestic water requirements were calculated for 2010, 2030, 2040 and 2050 for all the 17 cities (Table 4). The total domestic water requirement for these 17 major cities in Punjab for the year 2050 is estimated to be 4.474 BCM (3.637 MAF) per year (IWASRI Publication 303).

Table 3: Population Growth andDomestic Water Requirements for Major Cities

CITY	Census population (000)		Estimated urban population (000) and domestic water demand (MCM/year							
			2010		2030		2040		2050	
	1981	1998	Population	Water Demand	Population	Water Demand	Population	Water Demand	Population	Water Demand
Lahore	2953	5143	6699	734	10928	1197	12909	1413	14933	1635
Faisalabad	1104	2009	2552	279	4163	456	4918	538	5689	623
Rawalpindi	795	1410	1804	198	2943	322	3476	381	4021	440
Multan	732	1197	1547	169	2524	276	2981	326	3448	378
Gujranwala	601	1133	1614	177	2633	288	3110	341	3598	394
Sargodha	291	458	595	65	971	106	1147	126	1326	145
Sialkot	302	422	526	58	858	94	1014	111	1173	128
Bahawalpur	180	408	534	58	871	95	1029	113	1190	130
Jhang	196	293	374	41	610	67	721	79	834	91
Sheikhupura	141	280	350	38	571	63	674	74	780	85
Gujrat	155	252	326	36	532	58	628	69	727	80
Kasur	156	245	305	33	498	54	588	64	680	74
RY Khan	119	234	288	32	470	51	555	61	642	70
Sahiwal	151	209	257	28	419	46	495	54	573	63
Okara	127	202	251	28	410	45	484	53	560	61
Jhelum	147	107	180	20	294	32	347	38	401	44
DG Khan	191	102	137	15	223	24	264	29	305	33
Total	**10322**	**16102**	**18339**	**2009**	**29918**	**3274**	**35340**	**3870**	**40880**	**4474**

3. GROUNDWATER MANAGEMENT ISSUES

Punjab province issues include: (i) Progressive depletion of groundwater particularly near urban centers and in canal commands with lower water allowance which has increased pumping costs. (ii) Strong evidence of deterioration of groundwater quality including pollution. (iii) Salt accumulation in root zone due to more dependence on groundwater.(iv) Small farmers in certain canal commands have been deprived of groundwater use. (v) Importance of monitoring and research of groundwater not realized and hence not adequately financed and staffed.

In spite of substantial financial resources dedicated to the water sector, overall, not many initiatives have been taken to address the opportunities and threats in groundwater management.

4. ADDRESSING GROUNDWATER QUALITY DETERIORATION

In groundwater quality concerns are increased salinity, sodicity, arsenic and fluoride levels. In addition there is point pollution near municipal and industrial areas.

4.1 Salinity and Sodicity

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

The heavy reliance on groundwater can cause increased groundwater salinization, in particular at the tail-end areas of canal commands. Groundwater after being pumped recharges back in the shallow aquifer from where it is reused again. This recycling has caused increase salinity levels (Murray-Rust and vanderVelde 1992). More threatening than secondary salinization is secondary sodicization. Data from the Drainage Atlas (IWASRI_WAPDA, 2005) suggest that in several parts of Punjab,soil sodicity is increasing. The issue has not been investigated in detail, therefore, requires more attention.

4.2 Arsenic and fluoride contamination

Pakistan Council of Research in Water Resources (PCRWR) implemented a series of national projects to monitor drinking water quality in Pakistan. The survey from 24 major cities of Pakistan (2002-2006) shows that more than 80% samples were found unsafe for human consumption. The major contaminants identified were; bacteria, arsenic, nitrate and fluoride (Ashraf, 2016).The extent of arsenic contamination of groundwater has also recently been documented. There are several reports (among others PCRWR, 2004) of areas with high fluoride content, such as Salt Range, Bahawalpur, Manga Mandi – Kalalanwala (Punjab).

4.3 Protecting the Groundwater from Pollution

A second important challenge concerning groundwater quality is to protect groundwater from pollution. The uncontrolled discharge of industrial effluent and municipal sewerage poses a threat to the availability of potable water, especially in major urban centres. During study, conducted by the Environmental Protection Department in Punjab (EPD, 2003) took 280 samples, distributed evenly over all districts in the Province. It found the concentration of the different heavy toxic metals (cyanide, cadmium, chromium, mercury, lead, boron, nickel, selenium, zinc) to be in excess of WHO guidelines for 1 to 25% of the samples. Bacterial contamination was the largest concern, affecting 64% of the samples.

Similarly, under the Punjab Private Sector Groundwater Development Project (PPSGDP), groundwater quality checks were undertaken. Samples - mainly from the hand pumps and private tubewells - were collected from Sheikhupura, Sargodha, Jhang, Muzaffargarh and Toba Tek Singh districts. These studies indicate that pesticides residues have been found in the shallow groundwater aquifer especially in the cotton belt zones. In the areas downstream of the various industrial units, the concentration of heavy/toxic metals was generally beyond permissible WHO limits. Near the industrial

clusters along Gujranwala and Sheikhupura roads arsenic, lead and selenium were prevalent.

5. REVERSE THE LOWERING OF WATER TABLE

The indiscriminate pumping results in groundwater depletion, particularly towards the tails of the doabs and the canal commands. It also affects the equity in the distribution of water*i.e.* irrationally high water withdrawals at the canal head at the cost of water allocation for the tail-enders. The tail enders face three prone problems due to inequity of water distribution: (i) they do not get canal water (for which they pay and have the right to get it); (ii) due to less recharge available, there is more stress on groundwater resulting in increased water-table depth and reduced profitability (more tubewell installation and operational costs). In certain cases, the most commonly used centrifugal pumps become uneconomical to install due to increased water-table depth; (iii) the groundwater quality is also deteriorating due to saline water intrusion from the deeper depths and from the adjoining saline water areas. Therefore, higher groundwater use is also causing soil salinization. Once soils are salinized, these take long time to reclaim (Ashraf, 2016).

The lowering of the watertable in *Barani* areas has also caused considerable hardship. It has undermined livelihoods and affected the availability of drinking water and generally increased vulnerability to droughts. It has also changed access to groundwater.

The drought of 1997-2002 had the effects of groundwater overuse over the following decade. Worst hit areas were the parts of Pothohar Plateau and Cholistan Desert in Punjab where large number of wells went dry or became saline. It may be argued that the sheer presence of tube wells relieved the effects of the drought, but the issue is double-edged, because overall the falling water table reduced resilience and made it more difficult to find alternative sources of water.

The cost of these deep tube wells is high and can only be afforded by a privileged few with access to financial resources of their own or of banks. This increase in pumping cost with the decline in water tables is a general trend. In the unconfined shallow aquifer of the Indus valley for instance centrifugal pumps are most common. These pumps have a maximum suction depth of 20 feet. Beyond this depth farmers have to construct a sump. With gradual increase in water table depth, the farmers have to deepen their sumps and this is not only uneconomical but also hazardous at depths more than 50-60 feet. Below that depth, deep well turbine pump may have to be used as prime mover. This more than doubles the cost , taking groundwater use out of the reach of small farmer.

6. ADDRESSING WATERLOGGING

Paradoxically a few areas in Punjab are still suffering from waterlogging. These areas are located in the topographic depressions and/or along main canals – feeders. They are found especially in areas with high irrigation duties and/or saline groundwater. SMO-IWASRI, WAPDA data indicate that 2.5 to 9% of the irrigated land is still waterlogged **(Figure 5**). Improved irrigation efficiency and better drainage facilities are proposed to mitigate this.

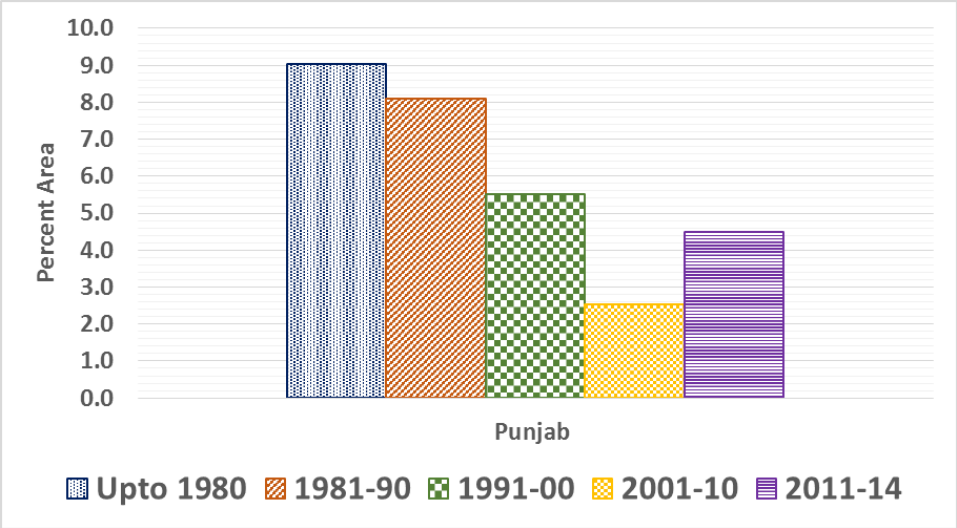


Figure 5: Waterlogged Area during June1980-2014

7. SETTING THE FINANCES RIGHT

A final challenge is to address the continued financial support to the overuse of groundwater through subsidies on pumping, both in the private and the public sectors. Tariffs for agricultural tubewells are approximately 35% below rates for the domestic or industrial uses. In the current scenario, such financial incentives are an anomaly, yet they continue to be used with considerable political opportunism. In response to the drought in Punjab politicians for instance called for free electricity for agricultural wells, not for tightening up groundwater regulation.

As a corollary, there has been substantial discussion on energy pricing for agricultural usage. An argument, that is made frequently, is that the electricity subsidies for agricultural use should be phased out, in order to encourage farmers to use groundwater more judiciously. This demand management argument, however, has only limited validity. Reduced subsidies would probably only marginally promote efficient water use. The expenditures on diesel or power are less than those on fertilizer or pesticide. Water is a crucial but relatively cheap input and this will not be changed considerably.

8. PRIORITY AREAS FOR ACTION

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

The priority areas for action of first and foremost concern are: (i) Re-examine irrigation duties in canal command; (ii) Promote and support local groundwater management and recharge and rainwater harvesting; (iii) Initiate institutional coordination; (iv) Stop financing overuse; (v) Tackle groundwater pollution in selected places.

8.1 Surface Water Storage

To minimize the use of groundwater for irrigation, there is a need to construct dams with substantial storage capacity to enhance groundwater recharge.

8.2 Re-examine Irrigation Duties

In canal commands the most important strategy in balancing supplies and demand in groundwater is to re-examine surface water supplies. With close to 1000,000 tube wells in Punjab, conjunctive water use in fact presents itself as the most powerful mechanism for water management. At present water allowances in the perennial canals range from 2.8 cusecs/1000 acres (LCC, LJC in the Punjab)to 7 cusecs/1000 acres(MuzafarGarh Canal). There is no reasonable justification for these differences, particularly because they trigger wasteful water use in the top-end commands.

A re-examination would need to be done within the Province separately for the canals. Undertaking the re-examination in this manner should avoid the stalemates usually associated with inter-provincial water distribution. There is a case to reduce the wide variance that now exists between canal commands within the Province. Water budgets could be developed, looking at the prevailing agricultural production systems as they have developed over the years, the expected production systems in the future, groundwater quality and current groundwater use, and the scope to improve water management, i.e. reduce water logging, control ingression from saline groundwater zones into fresh water zones or create flood water buffers for later conjunctive use. So far the issue of re-examining canal supplies has been a political no-go area. However, there has never been a systematic discussion on the merits, including the considerable possible impact of releasing water for other areas and the considerable benefits of reduced water logging for health and property. A strategy for re-examining canal supplies would need to incorporate a systematic information campaign to avoid dysfunctional polarization.

8.3 Avoid Groundwater Disasters at Critical Areas

The awareness and micro-planning programs should be complemented by the active promotion of alternatives to current intense and often wasteful groundwater use – such as alternative crops, soil water retention measures, affordable micro irrigation and local water harvesting techniques. The important point however, is to engage a social mobilization campaign that will set the local regulation going. In this regard, there is also a need to activate the role of local government in this field. Much needs to be done is to build capacities in this field and in water resource management in general.

8.4 Legislation and Institutional Measures

A number of agencies have been involved in groundwater development and monitoring. However, there is no coordination, proper staff availability and adequate logistics. None of these agencies has complete knowledge of the issues and none has operational

responsibilities in groundwater management. What is required is to develop a focal point within each provincial administration that will promote and enforce regulation, coordinate the activities by various agencies and gradually develop a database. According to current legislation, the Punjab Irrigation and Drainage Authority (PIDA) has this task. The PIDA is to ensure that groundwater monitoring is undertaken regularly and have a mandate to initiate policies to address groundwater management problems.

In other comparable countries in the region, special full-fledged units have been created in the main irrigation or water resource departments (for instance Egypt) or special departments, closely attached to water use departments have come into force (West Bengal, Andhra Pradesh). This is very much the need of the day. It is proposed that Groundwater Cells are set up in the PIDA. It is important to consider these Groundwater Cells as 'principal agencies' and not as sole bodies. The Groundwater Cells should coordinate the data collection by the most competent parties, not necessarily undertake it itself. The Cells should also be the mechanism to assess the requirements by different users (agricultural, industrial, domestic and environmental) – that may be diagonally opposite - and should facilitate finding pragmatic solutions. The establishment of the Groundwater Cells needs to be supported by a package of measures – legislative, in institutional development and in data collection. Without such programs, initiatives will not go very far, as experience with earlier efforts shows.

Some rules and laws exist for pollution control. These must be implemented as per principle of "polluters pays". If necessary further regulations shall be introduced. Presently, data on aquifer characteristics, groundwater levels and groundwater quality, in as far as they exist are with SMO and DLR.For areas exclusively dependent on groundwater, time series data are missing. Moreover, the data have generally been non-available to the public at large and to groundwater users in particular. Data are hard to get and often presented in formats that make them complicated to understand even for the experts. This has made it difficult for anyone to transform it into meaningful results. . There is need to hot spots of groundwater mining and develop strategies to revert the situation. Information sharing should be part of such programs, communicating results to local media, decision makers and key stakeholders.

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

There is a need, however, to revive the effort. A broad-based awareness campaign on the limits to groundwater utilization and on effective actions to reverse overuse should be part of this. Such a campaign should break the grounds for local regulation and familiarize a large number of people with the legal provisions, as they exist. The net should be cast wide, hoping to find local champions to promote groundwater regulation.

Participatory hydrological monitoring and local micro planning should follow up from the campaign. In participatory hydrological monitoring groundwater users are being facilitated to measure groundwater fluctuations and prepare local groundwater budgets.

Efforts in the past to put in place appropriate legal measures concern the development of a 'Groundwater Regulatory Framework' for the Punjab Province under PPSGDP. The main features pf the legal framework included: (i) Ownership of water, common ownership, private ownership; (ii) Constitutional and Islamic aspects; (iii) Water rights-International and Pakistan law; (iv) Constitutional perspective and human rights; (v) Existing legal framework; and (vi) Proposed Legal Framework.

NDC & Lahmeyer (2013) concluded that water resources in LBDC are under intense pressure. Quality and quantity of groundwater are deteriorating rapidly. Present rate of groundwater abstraction is not sustainable. The recommended Framework for Groundwater Management is based on: (i) Sustainable management of land and water resources by stakeholders and include regulatory framework and water rights, economic instruments, awareness raising and stakeholders participation; (ii) Sustainable use of the aquifer wherein the groundwater quality and quantity are stabilized by resource monitoring and evaluation, contaminant and pollution control and managed recharge abstraction.

These legal framework need to be complemented by program of implementation, allocating resources for enforcement, legal awareness building and training.

8.5 Realign Financing Mechanisms

In spite of the overuse of groundwater in several areas, exploitation of groundwater continues to be subsidized and still draws partially on public budgets. Agricultural electricity tariffs are below cost, and recovery is low. These funds should be diverted to recharge of groundwater projects.

9. ACTIONS REQUIRED

9.1 Irrigation System

Re-examining water allocation for different canal commands, keeping in mind official irrigation duties, actual deliveries, cropping patterns, groundwater quality, current groundwater use and over- or under-exploitation.This needs to be complemented by an extensive information campaign to opinion makers to avoid the discussion becoming captive to politicization.

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

9.2 Institutional Measures

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

Initiate a social mobilization programme to develop local groundwater regulation, focused on participatory hydrological monitoring and micro-planning. Engage tehsil administration in these efforts.Strengthen capacity of Farmer Organizations to manage

water resources through training programmes and local water budgeting.Punitive and physical measures be taken to stop contamination of groundwater.

9.3 Technical Measures

There are several meaningful programs and policies that can be pursued to counter the perceived threats. The actions are to be taken at expert level are: (i) Prepare/update hydro-geological maps & groundwater atlases for the benefit of decision makers and farmers. (ii) Investigate and reverse groundwater contamination. (iii) Sample design of tubewells for different depths of water tables and different aquifer characteristics. (iv) Prepare a groundwater recharge manual for different conditions in Pakistan. (v) Preparation of groundwater recharge schemes for agriculture and urban areas. Perfect methods for groundwater recharge shall be propagated. (vi) Prepare guidelines for local use of saline water for different regions and crops. (vii) Avoid groundwater disasters at hot spots – using regulatory and investment measures. (v) Extract undisturbed and skim fresh groundwater layers overlying saline water and ensure/ initiate development of improved technologies.

9.4 Policy Measures

The actions required at policy level are: (i) Planning and Development Division to prioritize groundwater recharge projects. In case of groundwater recharge a broad range of recharge options – from water harvesting to spate irrigation – should be developed and used. (ii) To minimize the use of groundwater for irrigation, there is a need to construct dams with substantial storage capacity. In addition small dam, mini dams and delay action dams shall be constructed. (iii) Stop financing overuse, as now occurs through reduced electricity tariffs for agricultural use, flat rates and non-essential operation of public sector wells in fresh groundwater zones. (iv) Punjab Government to setup Groundwater Boards with clear tasks and capacities in monitoring, data dissemination, rule setting and enforcement. Also rationalize canal water allowances, design & approve groundwater recharge schemes/projects. (v) Provincial Agriculture Departments to educate farmers about aquifer characteristics and water quality issues. (vi) EPA to enforce regulation against disposal of untreated toxic effluents into surface drains. Waste water must be treated by individual industrial unit. (vii) Encourage and enforce rainwater harvesting and prepare and implement groundwater recharge schemes.

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Paper No. 144

GROUNDWATER PROSPECTS, CHALLENGES AND MANAGEMENT STRATEGIES IN INDUS BASIN

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GROUNDWATER PROSPECTS, CHALLENGES AND MANAGEMENT STRATEGIES IN INDUS BASIN

By:

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Abstract

In Pakistan, on-demand availability of groundwater has transformed the concept of low and uncertain crop yields into more assured crop production. Increased crop yields has resulted in food security and improved rural livelihoods. However, this growth has also led to problems of overdraft, falling water tables and degradation of groundwater quality, and yields generally remain well below potential levels. Over the last three decades, Pakistan has tried several direct and indirect management strategies for groundwater management. However the success has been limited.

There is a need to develop frameworks and management tools that are best suited to Pakistani needs. Pakistan should follow both supply and demand management approaches. For demand management, adoption of water conservation technologies, revision of existing cropping patterns and exploration of alternate water resources should be encouraged.

Keywords: Groundwater, Water Quality, Regulation, Aquifer, Irrigation demand

Introduction

Groundwater has emerged as an exceedingly important water resource and its increasing demand in agriculture, domestic and industrial uses ranks it as a resource of strategic importance. Global estimates show that approximately 4,430 km^3 of fresh water resources are abstracted annually, of which 70% are used in agriculture, 25% in industry and 5% in household (Kinzelbach et al. 2003). On the whole, annual groundwater abstracted for the world can be placed at 750–800 km3, which is about one-sixth of the total freshwater abstraction (Shah 2000). The amount of groundwater contribution to agriculture is less as compared to surface water on the global scale, yet its unique advantages like reliability, accessibility, on-demand availability, less capital investment and high productivity outweighs the volumetric access of surface water.

Indus Basin Irrigation System (IBIS) of Pakistan was designed about a century along with an objective to expand settlement opportunities, prevent crop failure and avoid famine (Jurriens and Mollinga 1996). IBIS is a gravity run system with minimum management and operational requirements, which is an advantage with an inherited disadvantage of inflexibility. The operation of IBIS is based on a continuous water supply

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and is not related to actual crop water requirements. Irrigation canals are usually not allocated more than their design capacity, of which a typical value is about 2mm/day. Despite significant increases in storage capacities, it is essentially a supply-based system. This cannot accommodate changing water demands during the crop season. The total surface water availability in the Indus Basin is 137 × 109 m^3 with a total served area of 16.7 million ha (Bhutta and Smedema 2007)

Large amounts of ground water are present under unconfined conditions in the Indus Plain and other parts of Pakistan. The aquifer in the Indus Plains mainly consists of sandy alluvium to a considerable depth and form a highly transmissive aquifer system. The thickness of the sandy deposits vary from more than 300 m (1000 ft) in Punjab and upper Sindh to around 60 m (200 ft) in lower Sindh. The aquifer hydraulic conductivity varies from 50 to 200 m/d in Punjab and KPK and from 25 to 50 m/d in Sindh as finer alluvial deposits were carried by river water to lower parts of Indus Plains.

The ground water reserve is constantly being replenished by recharge from different sources as seepage from irrigation canals, watercourses and fields, seepage from link canals, seepage from rivers, and recharge from precipitation. All of the recharge to the ground water body cannot be usefully recovered e.g. recharge in the areas having saline ground water, areas which are shallow or have low transmissivity. The extent of recharge estimate differs widely. In 1988 WAPDA estimated total recharge as 56 BCM and useable recharge as 36 BCM. The annual recharge was estimated by Chandio and Aftab (1997) as 62 BCM. ACE- Halcrow (2001) estimated the total ground water balance as 82 BCM. FPC (1990) estimated useable recharge as 45 BCM. Thus the sustenance of ground water reserve depends upon the recharge from the surface water system in the region. The total useable recharge per annum which can be recovered is estimated as 28.9 BCM with salt content less than 1500 mg/l and additional 6.7 BCM with salt content varying from 1500 to 3000 mg/l.

Although the ground water is available in large quantities, yet its exploitation is quite costly. The surface water supplies cost only Rs. 30 to 50 per acre-feet (AF) to farmers. On the contrary the ground water costs Rs. 1200 to 1500 per AF in shallow water table areas (DWT < 10 m) and Rs. 2600 to 4500 per AF in deep water table areas (DWT > 20 m). Nevertheless the ground water serves useful purpose of supplying water extremely needed for domestic use, industrial use and irrigation use especially in the event of droughts.

Groundwater Fluctuations

Pakistan has been endowed with vast quantities of ground water. The ground water resources of the country exist in the form of vast unconsolidated aquifers in the Indus Plain which have been recharged in the geologic times from natural precipitation and river flows, and more recently, by the seepage from canal system and agricultural fields (PANCID,2005). A total of 35 million hectares mostly located in the Indus Plains (in Punjab and Sindh) are underlain with groundwater of various qualities. Smaller quantities of ground water are also available in arid zones, intermountain valleys and areas with recharge sites. The piedmont plains for various rivers in Baluchistan also contain small amounts of groundwater.

The ground water reservoir is constantly being recharged by irrigation systems, rivers and precipitation and, thus, represents renewable resources. The groundwater reservoir underlying the Indus Plains is an inherent offshoot of the canal system in the area. The total groundwater recharge is estimated as 82 billion cubic meters - BCM (66 MAF) out of which useable recharge is as 45 BCM (36 MAF) per annum. The groundwater is being exploited by installing public and private tubewells, mostly for irrigation, municipal and industrial purposes. The groundwater now supplies about 45% of the crop water requirements in the country (Bhatti, 2005). It is considered that further ground water development potential of the irrigated Indus Plains is of the order of 10 BCM (8.1 MAF) per annum.

Data on groundwater use are scarce; however, Figure 1 presents a back-cast of the probable trajectories of growth in groundwater use in selected countries (Shah, 2009). In the USA, Spain, Mexico, and North African countries, like Morocco and Tunisia, total groundwater use peaked during the 1980s. In South Asia and the north China plains, the upward trend began during the 1970s and is just plateauing now in 2014. A third wave of growth in groundwater irrigation is now taking place in many parts of sub-Saharan Africa and in some south and south-east Asian countries, such as Cambodia, Indonesia, Viet Nam, Laos, Myanmar, and Sri Lanka (Barker and Molle, 2002; Giordano, 2006; Shah, 2009).

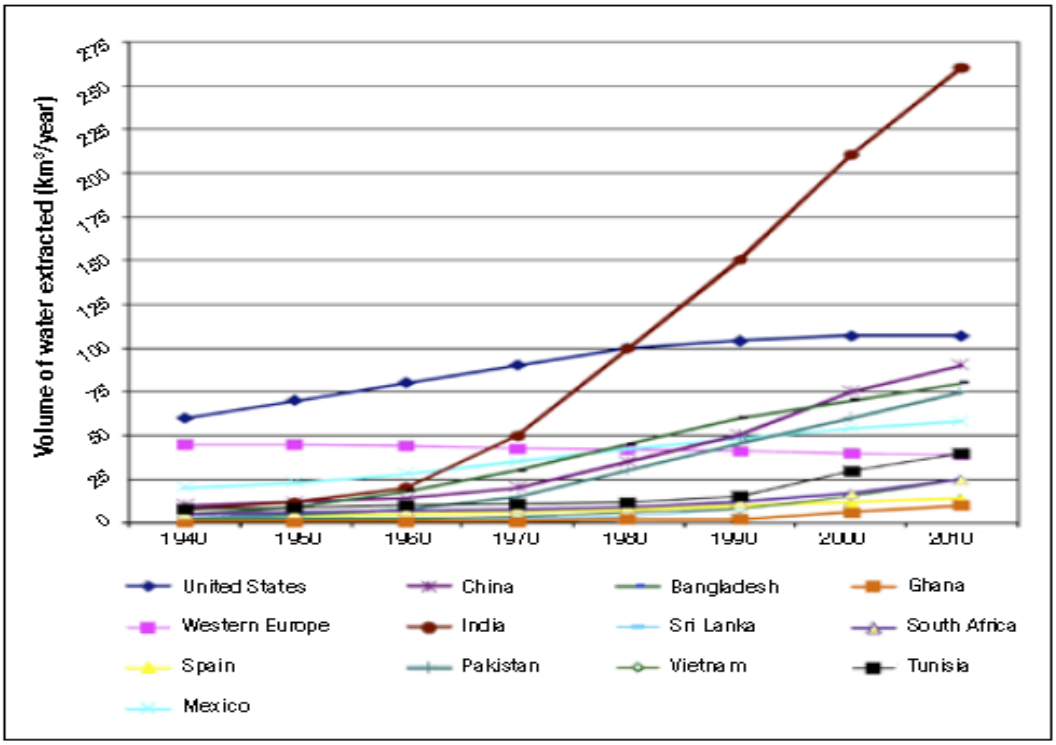


Figure 1: Growth trends in global groundwater use

Groundwater Use for Irrigation at International Level

There are three distinct groups. First are the many low-income developing countries (such as India) where the marginal value product of groundwater is modest, but it is the basis of livelihoods for large sections of the population. Second, includes regions (like California, Morocco, and Spain), where groundwater-value productivity is high and groundwater irrigation continues because it has a large impact on commercial farming incomes and on agricultural exports. The third includes regions (like Jordan) where groundwater is often the only source of irrigation. This economic dynamic is critical to success in eliciting farmer participation in the sustainable management of aquifers. Technical interventions that fail to factor in this dynamic will have little chance of success. Figure 2 provides a broad 'picture' of prominent groundwater-irrigation economies based on estimates of the proportion of the population dependent on groundwater irrigation for their livelihoods, the annual volume of groundwater used, and the value of groundwater-irrigated agricultural output (in US$) produced per cubic meter of water.

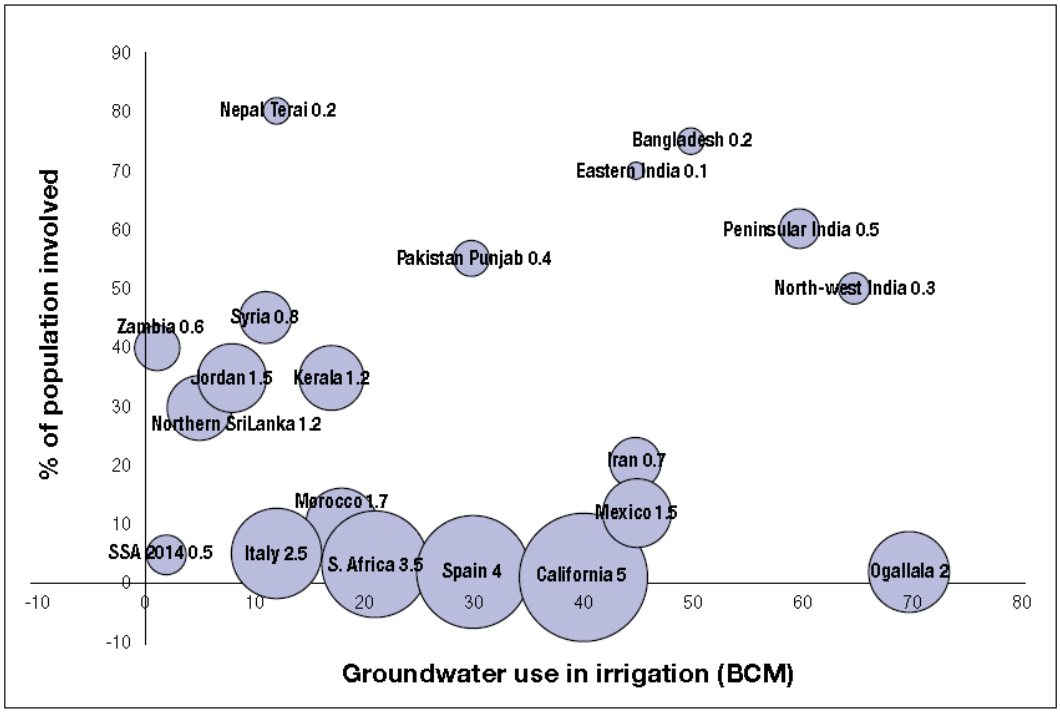


Figure 2: Prominent groundwater-irrigation economies: Volume of groundwater use (billion m3/ year), proportion of the population dependent on groundwater-irrigation (%); and value of groundwater-irrigated farm output (US$/m3)

Groundwater Quality

The groundwater reservoir in Pakistan is much greater than all present and potential surface water storage reservoirs in the country. However, the quality of the ground water varies from completely fresh to extremely saline. In total some 8.13 million ha is underlain by fresh water (salt content less than 1500 mg/l), 1.94 million ha by marginal

water (salt content 1500 to 3000 mg/l) and 6.4 million ha by saline water (salt content more than 3000 mg/l). The major areas of fresh water lie adjacent to the rivers whereas the interior parts of Doabs and areas farther away from rivers generally have saline ground water. The sustenance of ground water reserve depends upon the recharge from the surface water system in the region. The total useable recharge per annum which can be recovered is estimated as 28.9 BCM with salt content less than 1500 mg/l and additional 6.7 BCM with salt content varying from 1500 to 3000 mg/l.

Fresh ground water also occurs in areas outside the Indus Plains in small isolated basins close to presently active areas of water recharge such as torrent beds, old river beds such as Hakra River and intermountain valleys such as Bannu, Mardan, Peshawar areas in NWFP and Quetta, Mastung, Lorali valleys and Makran coast in Baluchistan. Some of these aquifers are sufficiently deep and transmissive whereas other areas may be shallow or have low transmissivity. Such water is usually in small amounts and is generally exploited for human consumption and small-scale orchards production. The recharge to various aquifers outside the Indus Plains is 1.2 BCM. Areas outside the canal commands have generally deep saline ground water. The saline areas may have a thin layer of fresh water overlying the lower saline water. Such fresh water can also be skimmed to some extent for beneficial uses.

Groundwater Use

Indus Basin Irrigation System was designed for an annual cropping intensity of about 75 percent with the intention to spread the irrigation water over as large an area as possible to expand the settlement opportunities (Jurriens and Mollinga, 1996). Now, the increasing demand for food to cope with the ever-increasing population has caused the annual cropping intensities to rise to 150 to 180 percent in different canal commands. This has been possible only with increasing contribution of groundwater for meeting additional water requirement but has resulted in both mining and quality deterioration of the aquifers. Large-scale groundwater irrigation demonstrated under Salinity Control and Reclamation Projects (SCARPs) in 1960s led to a proliferation of private tubewells with a capacity of about one cusecs (cfs) and less by farmers in the 1970s, 1980s and onward. The cropping intensity was 102.8, 110.5 and 121.7% during 1960, 1972 and 1980 respectively (Ahmad, 1995), and now operating at about 150% and even higher in different areas. As a result, groundwater mining due to higher abstraction rates as compared to the corresponding recharge is well reported in the literature (Shakir et al. 2011; NESPAK/SGI. 1991; Steenbergen and Olienmans, 1997; Halcrow 2006; Basharat and Tariq 2012).

Ground water is generally exploited for human consumption and irrigation and agricultural production by installing tubewells in public or private sector. In areas with shallow water tables, the ground water is pumped out under SCARP program to provide drainage of the areas. Water is pumped by installing either public or private tubewells in the country. Under different SCARPs more than 16,500 tubewells of different capacities were installed in both fresh and saline ground water areas during the period 1960 to 1995. These wells have average annual pumpage of 5.93 and 5.23 BCM in Kharif and Rabi periods, respectively. The number of public/SCARP tubewells is now decreasing due to reasons as mechanical life of the wells and SCARP Transition Program where

public tubewells are being disinvested and sold/transferred to private sector in various parts of the country.

The challenges associated with tubewell development are overdraft, high energy cost, pollution, soil salinity. In the Punjab 12, 67 and 21% are driven by electricity, diesel engines (high speed peter engine as well slow speed) and tractors, respectively. The percentage of electric tubewells has decreased from more than 30% in 1991 to around 11% in 2002 due to an upward change in electricity tariff. The tubewell utilization is 17.75% for electric tubewells, 6.54% for peter diesel engines and 7.79% for tractor driven tubewells with overall average as 8.76% (11.36% in Kharif and 6.15% in Rabi). The annual pumping is determined as 13.2, 20.9 and 9.32 BCM for electric, diesel and tractor driven tubewells respectively and total pumping as 43.4 BCM.

Skimming well technology with multiple strainers is used in areas having a thin layer of fresh water atop lower saline aquifer. Some 2 to 26 strainers spaced 1.5 to 4/5 m with depth ranging from 9 to 27 m have been used as most used. Such wells with 3-6 strainers spaced uniformly on periphery of 1.5 m diameter circle with strainer depth not exceeding 60% of the fresh layer thickness can produce 3-8 l/s discharge with 4-6 hrs. pumping per day; longer screens and/or longer pumping duration will result in irreversible upcoming beneath the well and consequent deterioration of water quality.

Ground Water Development Potential

The ground water resources in the country are not fully exploited by now. Analysis for 1985-86 (Wapda 1988) indicate that further ground water development potential of the irrigated Indus Plains (Table 1.11) is of the order of 10.25 BCM (8.3 MAF) per annum (Punjab = 6.79 BCM, Sind = 2.1 BCM, and NWFP = 1.36 BCM). The ground water development potential outside the Indus Plain is small and estimated as 2.0 BCM (1.62 MAF) per annum. PANCID (2005) estimated the future potential as 7.4 BCM (useable potential = 66.6 BCM, present pumpage = 59.2 BCM). Bhatti (2005) noted that the sustainable groundwater potential in Pakistan is 48 MAF/annum (Punjab = 36, Sindh = 8, KPK = 2, Baluchistan = 2 MAF) with additional development potential of 6 MAF only. The ground water development potential is not uniformly distributed and in some areas the present abstraction exceed the annual recharge in the area. Part of the water recharge in the marginal and saline areas may also be exploited by tapping and skimming the overlying lenses of fresh ground water by suitable technology including skimming and scavenger wells. Ground water exploitation in Pakistan had already resulted in various problems in some regions. These problems include excessive water table lowering due to ground water mining, saline water upcoming, and lateral saline water intrusion. Presently ground water development in Pakistan is unrestricted, unregulated and without any proper plans. It is necessary that future ground water development in the country must be well guided and regulated with the intention to not accentuate the above mentioned problems at minimum or better to reverse and overcome the problems being faced due to earlier ground water developments.

Masood (2001) and Masood and Gohar (2000) estimated that Punjab province has annual pumping as 36 MAF and the recharge is estimated as 30.8 MAF resulting in decline of ground water table levels. For total command area of 24.62 MA, the area with depth to water table of less than 3m decreased from 39.2% in 1960 to 25.2% in 1999. The area

with depth to water table greater than 3m increased from 60.8% in 1960 to 74.8% in 1999. This indicates ground water table falling trend in the region.

Water Conservation Strategy

To work out a sound and cogent water conservation strategy is the need of the time, as demand for water continues to rise because of increasing use of water in agriculture and industry for the purpose of economic development and due to rapid growth of population, whereas there is limited supply of water. Water management is the biggest challenge of 21st century confronted by the country, as irrigated agriculture is 24 percent of GDP, the livelihood for the majority of country and input of agro-based industry/exports. It has been made known that a considerable amount of water is lost during its conveyance for the seepage in the lengthy canals. Proper lining of the canal system could reduce these losses. According to a WAPDA Report more than 5 MAF of irrigation could be saved by lining of minor canals and addition 3.6 MAF could be saved by improvement of water courses. It is heartening to note that Government of the Punjab has introduced modern telemetery system to check and control water theft by the farmers. In order to overcome the menacing of water shortage and its losses, it has become imperative to work on the lines of "Blue Revolution" which is threshold of the strategy meant for making use of more effective techniques and obtaining optimum results for reduction in water losses. The definition of "Blue Revolution" has been coined as a system of drip irrigation that delivers water directly to the roots of crops by cutting use of water by 30 to 70 percent and raising crop yield on the average by 20 to 90 percent.

The Medium Term Development Framework (MTDF)

> (i) adoption of integrated approach, rational resource use, and the introduction of water efficient techniques; (ii) containment of environment degradation; (iii) institutional strengthening, capacity building and human resource development (HRD); (iv) improving performance and utilization of local systems through better planning, management and community participation; (v) improving quality of life and easy access to water supply, especially for women, (vi) improving sanitation through sewerage and drainage schemes; (vii) promoting increased take up of household sanitation; and (viii) improving the understanding of the linkages between hygiene and health through community education campaigns, especially among the women and children.

Apart from MTDF strategy following recommendations are proposed in the contest of water conservation and management; Crash program for cleaning of water channels including canals/water courses and distributaries. Participatory water management at secondary tertiary level in collaboration with provincial irrigation departments.

The groundwater should be considered as Government property, there should be regulation and restrictions on groundwater pumping. Regulating ground water pumping by issuance of licenses to check overdraft of aquifer. Better water management for increasing cropping intensity with riverine area. Technical land levelling, surge irrigation, high irrigation efficiency technology including drip and sprinkler.

The high delta crops should be replaced with low delta crops. Strengthening of institutional capacity building by improving financial sustainability. Better and more

efficient use of funds. To harness the uncultivated lands for irrigation purpose, storage of flood water during Monsoon season by construction of a series of small dams/reservoirs on the barren lands and Barani areas of Northern Punjab, KPK and Balochistan. Attracting more foreign investment by making an environment lucrative to it. Launching of incentive based public campaign emphasising conservation of water at all levels.

Recommendations

There should be integrated effort of research and implementing institutions to find the solutions to groundwater issues by comprehensive studies as per the followings.

i. Trends in groundwater pollution; trends in loss of groundwater quality and related aquifers services.

ii. Conjunctive use and management of groundwater and surface water.

iii. Urban-rural tensions; opportunities for co-management.

iv. Management of recharge / discharge processes and aquifer equilibrium states

v. Groundwater policy and governance.

vi. Legal framework for sustainable groundwater governance.

vii. Trends in local groundwater management institutions / user partnerships.

viii. Social adoption of groundwater pumping technology and the development of groundwater cultures: governance at the point of abstraction.

ix. Macro-economic trends that influence demand for groundwater and related aquifer services.

x. Governance of the subsurface and groundwater frontier.

xi. Political economy of groundwater governance.

xii. Groundwater and climate change adaptation.

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Paper No. 145

HYDRAULIC PERFORMANCE EVALUATION OF LONG INVERTED SIPHONS FOR IRRIGATION CONVEYANCE SYSTEM - A CASE STUDY

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HYDRAULIC PERFORMANCE EVALUATION OF LONG INVERTED SIPHONS FOR IRRIGATION CONVEYANCE SYSTEM - A CASE STUDY

By:

Engr. M.Mohsin Munir[1], Engr. Irfan Mahmood[2], Engr. Kamran Ahmed[3], Engr. Javed Munir[4]

ABSTRACT:

Inverted syphons are closed pressure conduits that take flow from one point to another through syphon action. They are used widely in irrigations projects as conveyance systems especially where natural topography comprised of alternate ridges and valleys. The paper envisages hydraulic performance evaluation of these syphons and study of common problems associated with these types of conveyance systems for irrigation. Further, a case study project is presented where more common issues were identified. Finally several methods to rectify highlighted short comings are recommended.

Keywords: siphon, head loss, conveyance, hydraulic, evaluation

1. Introduction

A siphon is a closed conduit designed to run full and under pressure. These siphons are most commonly used when it is necessary to take flow in gravity pipes, pumping main or open channel beneath a natural or man-made obstacle such as river, estuary, highway and railway line.

Siphons are usually made of circular concrete or PVC pipes connecting two canals or reaches in a series. Some siphons have rectangular cross-sections. Siphons have straight alignment or may have changes in the direction of flow. A typical diagram of inverted siphon is shown in Figure-1 as under:

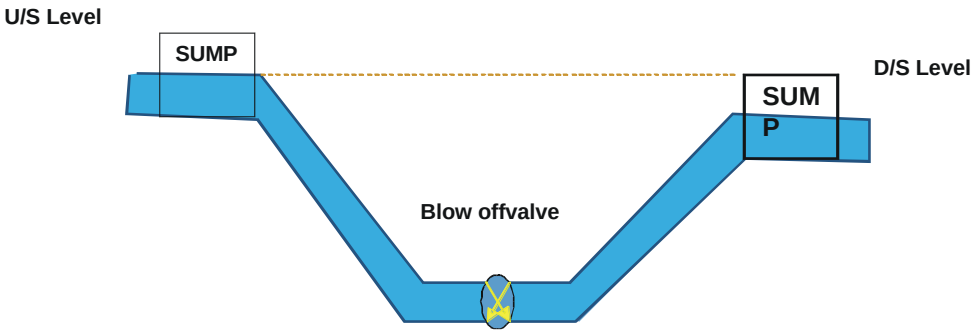


Figure-1: Inverted Siphon

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[2] Senior Engineer, NESPAK

[3] Chief Engineer, NESPAK

[4] General Manager, NESPAK

2. Objective of Study

The main objective of the study was to investigate/ identify the problems in the existing inoperative irrigation conveyance system of Uthwal-Lakhwal dam and then carried out detailed design of after rectifying the identified problems.

Uthwal/Lakhwal Dam is located on SaujKas(a tributary of Soan River) that outfalls in Indus River. Dam site is located in Pothohar plateau (in northern Punjab), near village Uthwal/Lakhwal, at a distance of about 16 Kmsouth-west of Chakwal city in District Chakwalas shown in Figure-2.

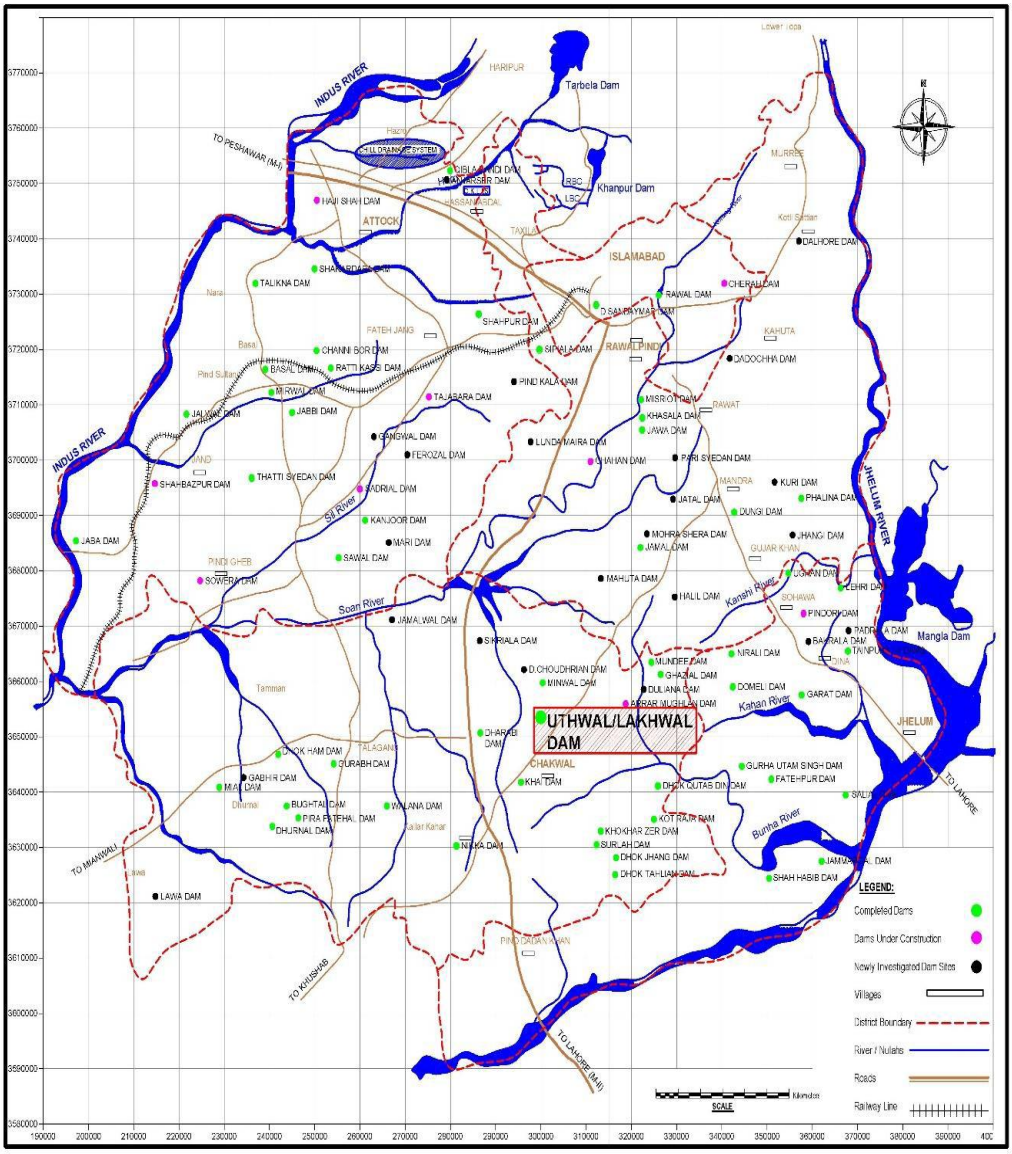


Figure-2: Project Location Plan

2.1 Review of Existing System

Hydraulic design review of the existing inoperative irrigation conveyance system, off-taking from dam body upto last sump, carried out using data provided by the Client. While carrying out this task a site visit had been conducted by a team of NESPAK experts for reconnaissance survey along with two SDOs of the Irrigation Department Chakwal. During the site visit, different components of water conveyance system were observed. It was noted that the elevation differences between u/s and d/s ends of inverted siphons are in the range of 20 ft to 205 feet. This indicated that the failure of the system was due to the extraordinary topography and unusual site conditions, in addition to the inappropriate material of the siphons.

2.2 Data Extraction and Digitization

Data from L-sections of as-built-drawings has been used for review and analysis of the existing conveyance system. Relevant data was selected and digitized as shown in Tabel-1.

Main irrigation conveyance system from dam body upto last sump, consists of 15 water conveyance structures. The structures have been analyzed using internationally accepted standard procedures / criteria recommended by 'USBR' to estimate the hydraulic parameters.

Table-1: Inventory of Main Irrigation Conveyance System

Sr. No.	RD		Length	Structure Type	Channel Material	Dia / Bed Width	Disch-arge	Manning's Roughness 'n'	Bed Level		Available Head	Longitu-dinal Slope
	From	To							U/S	D/S		
	ft	ft	ft			ft	ft^3/s		ft	ft	ft	ft/ft
1	0+000	1+000	1000	Gravity Pipe	R.C	3	12	0.016	1455.00	1454.12	0.88	0.00088
2	1+000	3+895	2895	Gravity Pipe	R.C	3	12	0.016	1453.86	1450.31	3.55	0.00123
3	3+895	4+958	1063	Open Channel	R.C	2.5	12	0.016	1450.31	1449.38	0.93	0.00087
4	4+958	6+317	1359	Siphon-1	H.D.P.E	2.3	12	0.01	1448.82	1447.94	1.23	-
5	6+317	6+665	348	Gravity Pipe	R.C	3	12	0.016	1447.94	1446.90	1.04	0.00299
6	6+665	6+947	282	Open Channel	R.C	2.5	12	0.016	1446.90	1446.40	0.50	0.00177
7	6+947	8+852	1905	Gravity Pipe	R.C	3	12	0.016	1446.33	1443.46	2.87	0.00151
8	8+852	11+794	2942	Siphon-2	H.D.P.E	2.3	12	0.01	1441.96	1439.87	2.47	-
9	11+794	12+431	637	Gravity Pipe	R.C	3	12	0.016	1440.39	1439.69	0.70	0.00110
10	12+431	15+410	2979	Siphon-3	H.D.P.E	2.3	12	0.01	1438.63	1436.51	2.89	-
11	15+410	15+656	246	Gravity Pipe	R.C	3	12	0.016	1436.51	1436.26	0.25	0.00102
12	15+656	16+339	683	Open Channel	R.C	2.5	12	0.016	1436.26	1435.07	1.19	0.00174
13	16+339	22+638	6299	Siphon-4	H.D.P.E	2.3	12	0.01	1433.48	1428.80	5.03	-
14	22+638	24+994	2356	Gravity Pipe	R.C	3	12	0.016	1428.76	1426.15	2.61	0.00111

Table-2: Summary of Hydraulic Design Review of Irrigation Conveyance System of Uthwal-Lakhwal Dam

Sr.	RD		Length	Structure Type	Channel Material	Dia/ Bed Width	Disch-arge	Manning's 'n'	Bed Level		Availab le	Slope	Flow Type	Computed Water Level		Overt Level		Availab le Water Seal	Computed Water Seal	Minimum Required Water Seal	Total	Velocit y	Entrapment Check for Q50	Remarks
	From	To							U/S	D/S				U/S	D/S	U/S	D/S							
	ft	ft	ft			ft	ft³/в		ft	ft	ft	ft/ft		ft	ft	ft	ft	ft	ft	ft	ft	ft/s		
1	0+000	1+400	1400	Gravity Pipe	R.C	3	12	0.016	1455.00	1453.87	1.13	0.00081	Sub-Cri	1456.99	1455.86						1.13	2.41		Computed flow velocity of 2.41 ft/sin gravity pipe seems to be less. It must be at least 2.5 ft/s for self-cleansing. Flow of water through this pipe is under gravity. Provided dia of pipe is on the higher sice, t sherd *bo*
2	1+400	4+000	2600	Gravity Pipe	R.C	3	12	0.016	1453.87	1451.27	2.6	0.00100	Sub-Cri	1455.7	1453.1							2.63		Computed f ow velocity of 2.63 ft/s in gravity pipe is sufficient for self-cleansing. Flow of water through this pipe is under gravity.
3	4+000	5+063	1063	Channel	P.C.C	3	12	0.016	1451.27	1449.23	2.04	0.00192	Sub-Cri	1453	1451.56							1.72-229		Computed flow velocity ranges from 1.72 to 2.29 lft/s in open channel due to backwater effect from d/s to u/s end. Low flow velocity will cause silt deposition in the channel. It must be at least 2.5 tl/s 'or so" clear; rw. -lere type of flow is sub-critical.
4	5+063	6+412	1349	Syphon-1	P.R.C.C	3	12	0.016	1449.23	«™	*u*	0.00104		1451.56	1450.83	1452.23	1450.83	1451.56	1452.30	1452.48	0.73	1.7	Satisfactory	Computed fowvelocity of 1.7 ft/s in syphon s very less due to bigger diameter than 'csU'ixl. Vcocitymust be at least 3.5 ft/s for sell cloais ig. Invert level of syphon at inlet '■ ■■.1.
5	6+412	6+764	352	Gravity Pipe	R.C	3	12	0.016	1447.83	1446.59	1.24	0.00352	Sub-CD	1449.10	1448.20						0.90	3.11 - 4.23		Computed fowvelocity ranges from 3.11 to 4.23 ft/s in gravity pipe due to backwater effect from d/s end to u/s end. Flow of water through this pipe is sub-critical.
6	6+764	7+000	236	Channel	P.C.C	3	12	0.016	1446.59	1446.33	0.26	0.00110	Sub-Cri	1448.20	1447.98						0.22	2.42 - 2.48		Computed fowvelocity ranges fro-ii 2>2 to 2.43 ft/s in open channel due to backwater effect Velocity seems to be satisfactory for self clears Tyce ol r <:,\- is sua cnxcl in this segment.
7	7+000	8+986	1986	Gravity	R.C	3	12	0.016	1446.33	1443.51	2.82	0.00142	Sub-Cri	1447.98	l44b.1t.						2.82	3.01		Computed fowvelocity of 3.01 ft/s in gravity pipe seems to be sufficient for self cleansing. Flow type through this pipe is sub
8	8+986	11+944	2958	Syfficn 2	P.R.C.C	3	12	0.016	1443.51	1440.39	3.12	0.00"jb		1445.16	1443.39	1446.51	1443.39	1445.16	1446.58	1446.76	1.52	1.7	Satisfactory	Computed fowvelocity of 1.7 ft/s in syphon s very less due to bigger diameter than espied. VeecityiM.s:boatleas.:3.bts "or ic-lf dealing. Invert level of syphon at inlet needs to be lowered.
g	11+944	12+553		Gravity Pipe	R.C	3	12	0.016	1440.39	1439.22	1.17	0.00192	Sub-Cri	1442.25	™,м						0.36	1.81-261		Computed fowvelocity ranges from 1.81 to 2.61 ft/s in gravity pipe due to backwater effect from d/s to u/s end. Low velocity will cause silt deposition at d/s end. Flow of water through this pipe is sub-critical.
10	12+553	16+553	4000	Syphon-3	P.R.C.C	3	12	0.016	1439.22	1436.86	2.36		Sub-Cri	*mm*	1439.86	1442.22	1439.86	«™	1442.29	144247	2.03	1.7	Satisfactory	Computed fowvelocity of 1.7 ft/s in syphon s very less due to bigger diameter than required. Velocity must be at least 3.5 ft/s for self clears ig. Invert level of syphon at inlet needs to be lowered.
11	16+553		247	Gravity Pipe	R.C	3	12	0.016	1436.860	1436.040	0.320	0.00332	Sub-Cri	1438.45	1438.29						0.16	2.11-3.15		Computed fowvelocity ranges from 2.11 to 3.15 ft/s in gravity pipe due to backwater :ffect from d/s to u/s end. Low velocity will .v.fir .■.■■ .'>■ dly_ c i..r:. aniy.
12	16+800	17+426	626	Channel	P.C.C	3		0.016	1436.04	1435.07	0.97	0.00155	Sub-Cri	1438.29	1438.09						0.20	1.33-1.78		Computed (low velocity ranges from 1.33 to 1.78 ft/s in open channel due to Backwater effectfrom d/s to u/s end. Velocity seems :c ie very e=.s to' selfcleanBlng and wil ıı.sн =.ilt depirt'nin n the channel 1'*m~i.m vfiiir. *y ~.i-=t 31 eisi? sitf. to-w *Cleansing
13	17+426	26+956	9530	Syphon-4	P.R.C	3	-	0.016	1435.07	1430.35	«	0.00050		1438.09	1433.35	1438.07	1433.35	1438.09	1438.14	1438.32	4.74	„	Satisfactory	Co-pi.ted Dnw vAjnT. *y ol ' f h,\ in cyptv.n s »6fv en di.e to .icq"' diamate' if an -sci. i«1 Vskv -y -lust neat e«t ^ tfs lo-self-cleansing. Invert level of syphon at Inlet
14	26+956	29+904	2948		».c	3	.2	0.016	1430.35	1426.13	,,,	0.00141	Sub-Cri	1432.00	1427.83						4.17	3.01		Computed fowvelocity of3.01 ft/s ■■ ciaviiy jipe is sufficient for self-cleansing. Flow ot
15	29+904	40+000	10096	Syphon-5	P.R.C.C	3		0.016	1426.18	1415.25	10.93	0.00108		1427.83	1418.25	1429.16	1418.25	1427.83	1429.25	1429.43	5.02		Satisfactory	Computed fow velocity of 1.7 ft/s in syphon s very less due to bigger diameter than required. Velocity must be at least 3.5 ft/s for self-cleansing. Invert level of syshon at inlc:

3. RECTIFICATION OF IRRIGATION CONVEYANCE SYSTEM

3.1 Material Selection of Inverted Siphons

In case of inverted siphons, pipes that could be used at proposed sites at Uthwal-Lakhwal irrigation conveyance system include:

- DI (Ductile Iron) Pipes
- MS (Mild Steel) Pipes
- PRCC (Pre-stressed Reinforced Concrete) Pipes (for head less than 50 ft)
- HDPE (High Density Polyethylene) Pipes

High Density Polyethylene (HDPE) is preferable for inverted siphons over other material due to the following aspects:

- Low Cost of Installation
- Low Maintenance
- Chemical Inertness
- Leak free Joints
- Long Service Life
- Temperature Resistance
- UV Resistance
- Flexibility
- Visco-Elasticity

Since, DI pipes are not locally available and being very costly cannot be proposed for inverted siphons. The life of HDPE pipes ranges from 50 to 100 years, whereas life of MS pipe has been experienced as about10-15 years in buried condition and about 15-20 years in open conditions. It is concluded that HDPE pipe has life 3 to 5 times more than MS pipe and more suitable for the economics of the project.

3.2 Design Criteria

After identification of the problems causing failure of irrigation conveyance system of the Uthwal-Lakhwal dam, for a design discharge of 12 ft^3/s,design review had been started using following design criteria:

3.2.1 Gravity Pipe

Reinforced Concrete (RC) pipes are proposed as gravity pipes ensuring following parameters;

a. Permissible flow velocity shall range from 2.0 ft/s to 10 ft/s

b. Manning’s Roughness coefficient will be used as 0.016

c. Longitudinal slope will be adjusted in such a manner to eliminate the backwater effect

3.2.2 Open Channel

Reinforced Concrete (RC) rectangular channels are proposed as open channels ensuring following parameters;

a. Permissible limit of velocity will be used from 2.0 ft/s to 10 ft/s

b. Manning's Roughness coefficient will be used as .016

c. Longitudinal slope will be adjusted in such a manner to eliminate the backwater effect

3.2.3 Inverted Siphon

High Density Poly Ethylene (HDPE) circular pipes have been proposed for inverted siphons ensuring following parameters;

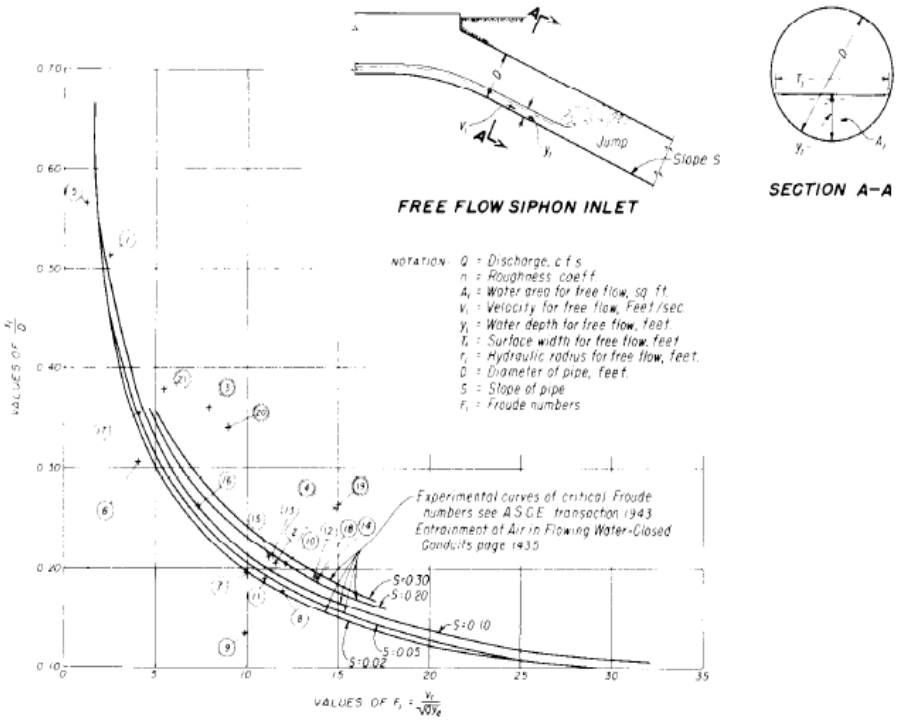
a. Permissible limit of velocity will be used from 2.5 ft/s to 10 ft/s. The velocity of a long siphon is of particular importance, economically, because a slight change in pipe size can make a great change in the structure cost.

b. Manning's Roughness coefficient will be used as 0.01 for pipes.

c. Size / diameter of siphon will be adjusted to obtain total head loss equal to total head available across each siphon to pass design discharge. To minimize the possibility of backwater effect, the total head loss computed will be increased by 10% as a safety factor.

d. Minimum required seal will be ensured at u/s end to obtained proper syphoning action to pass design discharge within the required limit of velocity.

e. The condition for air entrainment for siphon flowing partially full is determined using the given criteria (Figure-3) mention in "Design of Small Canal Structures, USBR (1978). In this figure, experimental curves of critical Froude numbers are given. Froude number and y/d ratio are calculated and checked in the figure corresponding point of both the parameters. If the corresponding point lies below the curves of critical Froude numbers it indicates the safe from air entrainment and if above the line it means air entrain will occur.



NOTES

Siphon inlets marked thus (5), have given trouble in operation and air outlets were installed in some cases to relieve the blowing back of air and water.
All other siphons have not given trouble in operation.
Study made indicates that free flow siphon inlets designed so that Froude number will not fall above the critical curves established by experiments will give satisfactory performance

Procedure to determine Froude number

For a given Q, diameter D, slope S, and coeff. n, calculate the following:

a. y_1 Using Manning's Formula
b. A_1
c. V_1
d. $T_1 = 2\sqrt{(D-Y_1)Y_1}$
e. $Y_e = \frac{A_1}{T_1}$
f. $F_1 = \frac{V_1}{\sqrt{gY_e}}$

Figure-3: Air Entrainment in Inverted Siphon
(Ref: USBR Design of Small Canal Structures)

f. Syphons are checked for bubbles and air pockets movement inside/outside the syphons when flowing full, using Figure-4 mentioned in "USDI, Water and Power Resources". Here dimensionless flow rate and slope inside the syphon are calculated and checked in figure corresponding point for both the parameters. The position of

corresponding point indicates movement of bubbles and air pockets inside the syphon along flowing water or outside the syphon against flowing water.

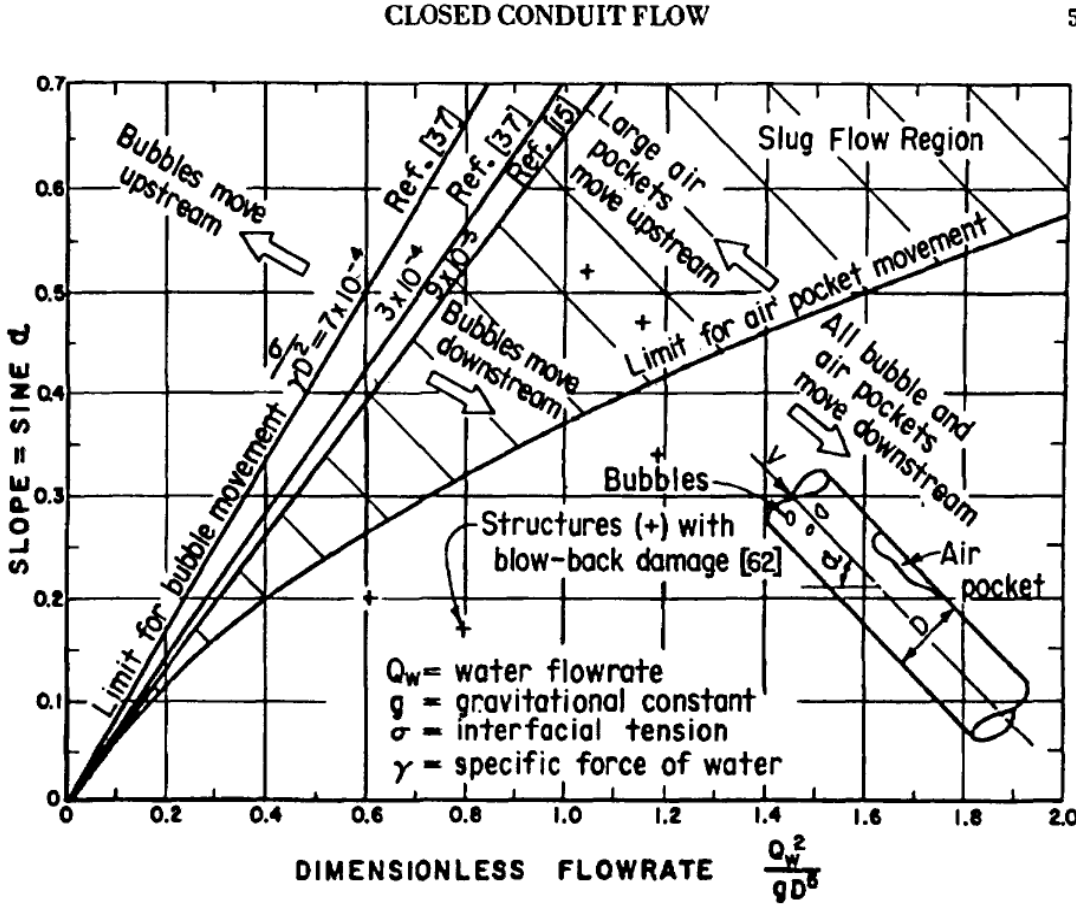


Figure-4: Bubble Motion in Closed Conduits Flowing Full

Data obtained from L-sections of as-built-drawings and new survey have been used for detail design of the main irrigation conveyance system. Relevant data was selected and digitized as shown in Tabel-1.

All five siphons are newly proposed using HDPE material considering safety, extraordinary topography, unusual site conditions and high heads. Whereas, physical conditions and hydraulic designed parameters must be verified at site for all segments of the conveyance systems.

Summary of estimated hydraulic design parameters of these structures is given in Table-3.

Table 3: Summary of Hydraulic Design Parameters of Irrigation Conveyance System of Uthwal-Lakhwal Dam

Sr. No.	RD		Length	Structure Type	Channel Material	Dia / Bed Width	Discharge	Manning's 'n'	Bed Level		Available Head	Slope	Flow Type	Computed Water Level		Overt Level		Available Water Seal	Total Head Loss	Flow Velocity	Air Entrainment Check for Q50	Remarks
	From	To							U/S	D/S				U/S	D/S	U/S	D/S					
	ft	ft	ft			ft	ft^3/s		ft	ft	ft	ft/ft		ft	ft	ft	ft	ft	ft	ft/s		
1	0	1000	1000	Gravity Pipe	R.C	3	12	0.016	1455.00	1454.12	0.88	0.00088	Sub-Cri.	1456.93	1456.05	-	-	-	0.88	2.50	-	Computed flow velocity is 2.5 ft/s that is sufficient for self-cleansing. Type of flow in this segment is sub-critical with depth of flow of 1.93 ft.
2	1000	3895	2895	Gravity Pipe	R.C	3	12	0.016	1453.86	1450.31	3.55	0.00123	Sub-Cri.	1455.59	***1452.37***	-	-	-	3.21	2.32 - 2.81	-	Estimated flow velocity is 2.32 to 2.81 ft/s from d/s end to u/s end sufficient for self-cleansing. Flow through this pipe is under sub-critical condition with depth of flow of 1.73 ft.
3	3895	4958	1063	Open Channel	R.C	2.5	12	0.016	1450.31	1449.38	0.93	0.00087	Sub-Cri.	1452.37	1451.44	-	-	-	0.93	2.32	-	Computed flow velocity is 2.32 ft/s. Here type of flow is sub-critical with depth of flow of 2.1 ft.
4	4958	6317	1359	Syphon-1	HDPE	2.3	12	0.010	1448.82	1447.94	1.23	-	-	1451.48	1450.25	1451.13	1450.25	1451.48	1.23	2.86	Satisfactory	Estimated flow velocity of 2.86 ft/s in the siphon is sufficient for self-cleansing. Invert level of siphon at inlet is so adjusted for better hydraulic performance/ siphoning action. Here total head loss calculated is 1.23 ft.
5	6317	6665	348	Gravity Pipe	R.C	3	12	0.016	1447.94	1446.90	1.04	0.00299	Sub-Cri.	1449.27	***1448.46***	-	-	-	0.81	3.53 - 3.98	-	Computed flow velocity ranges from 3.53 to 3.98 ft/s with 1.56 ft to 1.33 ft depth of flow in gravity pipe due to backwater effect from d/s end to u/s end. Flow of water through this pipe is sub-critical.
6	6665	6947	282	Open Channel	R.C	2.5	12	0.016	1446.90	1446.40	0.5	0.00177	Sub-Cri.	1448.46	1447.96	-	-	-	0.50	3.07	-	Computed flow velocity is 3.07 with depth of flow of 1.56 ft in the channel. Type of flow is sub-critical in this segment.
7	6947	8852	1905	Gravity Pipe	R.C	3	12	0.016	1446.33	1443.46	2.87	0.00151	Sub-Cri.	1447.95	1445.08	-	-	-	2.87	3.08	-	Computed flow velocity of 3.08 ft/s in gravity pipe is sufficient for self-cleansing. Type of flow is sub-critical with depth of flow of 1.62 ft.
8	8852	11794	2942	Syphon-2	HDPE	2.3	12	0.010	1441.96	1439.87	2.44	-	-	1444.62	1442.18	1444.27	1442.18	1444.62	2.44	2.86	Satisfactory	Estimated flow velocity of 2.86 ft/s in the siphon is sufficient for self-cleansing. Invert level of siphon at inlet is so adjusted for better hydraulic performance/ siphoning action. Here total head loss calculated is 2.44 ft.
9	11794	12431	637	Gravity Pipe	R.C	3	12	0.016	1440.39	1439.69	0.7	0.00110	Sub-Cri.	1442.18	1441.48	-	-	-	0.70	2.73	-	Computed flow velocity is 2.73 ft/s in this segment. Type of flow is sub-critical with depth of flow of 1.79 ft.
10	12431	15410	2979	Syphon-3	HDPE	2.3	12	0.010	1438.63	1436.51	2.47	-	-	1441.30	1438.82	1440.94	1438.82	1441.30	2.47	2.86	Satisfactory	Estimated flow velocity of 2.86 ft/s in the siphon is sufficient for self-cleansing. Invert level of siphon at inlet is so adjusted for better hydraulic performance/ siphoning action. Here total head loss calculated is 2.47 ft.

Sr. No.	RD		Length	Structure Type	Channel Material	Dia / Bed Width	Discharge	Manning's 'n'	Bed Level		Available Head	Slope	Flow Type	Computed Water Level		Overt Level		Available Water Seal	Total Head Loss	Flow Velocity	Air Entrainment Check for Q50	Remarks
	From	To							U/S	D/S				U/S	D/S	U/S	D/S					
	ft	ft	ft			ft	ft^3/s		ft	ft	ft	ft/ft		ft	ft	ft	ft	ft	ft	ft/s		
11	15410	15656	246	Gravity Pipe	R.C	3	12	0.016	1436.51	1436.26	0.250	0.00102	Sub-Cri.	1438.35	1438.10	-	-	-	0.25	2.65	-	Computed flow velocity is 2.65 ft/s with depth of flow 1.84 ft. Type of flow through this segment is sub-critical.
12	15656	16339	683	Open Channel	R.C.C	2.5	12	0.016	1436.26	1435.07	1.19	0.00174	Sub-Cri.	1437.84	1436.65	-	-	-	1.19	3.05	-	Computed flow velocity is 3.05 ft/s with depth of 1.58 ft in this 2.5 ft wide rectangular channel. Type of flow through this segment is sub-critical.
13	16339	22638	6299	Syphon-4	HDPE	2.3	12	0.010	1433.48	1428.80	5.03	-	-	1436.14	1431.11	1435.79	1431.11	1436.14	5.03	2.86	Satisfactory	Estimated flow velocity of 2.86 ft/s in the siphon is sufficient for self-cleansing. Invert level of siphon at inlet is so adjusted for better hydraulic performance/ siphoning action. Here total head loss calculated is 5.03 ft.
14	22638	24994	2356	Gravity Pipe	R.C	3	12	0.016	1428.76	1426.15	2.61	0.00111	Sub-Cri.	1430.55	1427.94	-	-	-	2.61	2.74	-	Computed flow velocity is 2.74 ft/s with depth of flow 1.79 ft. Type of flow through this segment is sub-critical.
15	24994	33185	8191	Syphon-5	HDPE	2.3	12	0.010	1423.15	1417.00	6.50	-	-	1425.82	1419.31	1425.46	1419.31	1425.82	6.50	2.86	Satisfactory	Estimated flow velocity of 2.86 ft/s in the siphon is sufficient for self-cleansing. Invert level of siphon at inlet is so adjusted for better hydraulic performance/ siphoning action. Here total head loss calculated is 6.50 ft.

4. CONCLUSIONS & RECOMMENDATIONS

In the light of hydraulic design carried out for the irrigation conveyance system, following conclusions and recommendations are suggested:

1. Total head loss calculated in the main irrigation conveyance system is 31.62 ft which is less than total head available i.e. 50.69 ft. It indicates that the system can carry design discharge of 12 ft^3/s from dam body to last sump at RD 33+185 under NPL of 1470 ft amsl.
2. Pipe material at siphon locations has been changed from PRCC to HDPE pipe which can sustain the pressure for head more than 50 ft.
3. Computed flow velocity of 2.86 ft/s in all HDPE siphons is sufficient for self-cleansing. This is due to adopted size of siphons and improved roughness coefficient.
4. Invert levels of siphon at inlets have been lowered for better hydraulic performance and siphoning action.
5. Total head loss is calculated with comparison to available head at each siphon to estimate required water seal. This indicates appropriate size of siphons have been selected.
6. Maximum efforts have been made to retain existing gravity pipes and open channels subject to their physical conditions and verification of designed hydraulic parameters at site otherwise will be reconstructed.
7. To ensure the safety and suitable functioning of open channels, proper arrangements of water crossings at different locations must be provided.

Paper No. 146

WATER A NATURAL RESOURCE OF SUSTAINABLE DEVELOPMENT FOR PAKISTAN'S ECONOMY

M. Munir Ch., M. S. Qureshi, Dr. A. B Sufi, S. Laraib Zaidi

WATER A NATURAL RESOURCE OF SUSTAINABLE DEVELOPMENT FOR PAKISTAN'S ECONOMY

By

M. Munir Ch[1]., M. S. Qureshi[2], Dr. A. B. Sufi[3] and S. Laraib Zaidi[4]

SUMMARY

The nature plays a vital role in water resources extent and quantity especially for agricultural economies and development as a whole in every walk of life. The 4th Assessment Report (AR4) by the three working groups of the Intergovernmental Panel on Climate Change (IPCC) has projected that average global surface temperature will increase by approximately over 4°C by the 21st century. The recent annual average temperatures for Northern and Southern Pakistan are about 19°C and 24°C respectively. The glaciers constitute about 2,700 km^3 of stored volume of ice (Roohi, 2005), equivalent to about 14 years of average Indus River System inflows. The thermal regime of Hindu Kush Himalayan (HKH) glaciating region has in general warmed up and the frequency of occurrence of moderate as well as severe heat waves have also increased significantly.

The climatic change in Pakistan has slowed down melting of glaciers and snow from mountains due to low temperatures in recent years in northern area, thus reducing flow of rivers resulting in severe water shortages during winter. However, temperature in the northern glaciating area is again rising since 2014-2015. Based on the studies available, it looks likely that the HKH glaciers are receding under the influence of global warming and their melting will increase with increase in summer temperatures. Recent simulation modeling conducted by Global Change Impact Studies Center (GCISC), Geneva, Switzerland, on Indus flows for a scenario where temperature will rise by 4°C and glaciers would shrink to half of their present size, indicates that overall annual river flows would reduce by about 15% and the monthly flow pattern would also change considerably, with more water coming in spring and early summer and less water in the later part of summer.

The extremes of nature are never feasible for water resource. Only a favorable climate is a source of balanced development. It is pertinent to explore that how we can use nature to overcome the water challenges of the 21st century. Environmental degradation along with climate change, are driving the water-related crises we observe around the world. Floods, drought and water pollution are all made worse by degraded vegetation, soil, rivers and lakes. When we neglect our ecosystems, we make it harder to provide everyone with the water we need to survive. Solutions based on conservation of nature

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have the potential to solve many of our water challenges. We need to do so much more with 'green' infrastructure and harmonize it with 'grey' infrastructure wherever possible. Planting new forests, reconnecting rivers to floodplains, and restoring wetlands will rebalance the water cycle and improve human health and livelihoods. Due to anticipated major climate change related concerns, it is anticipated that it will increase variability of monsoon rains enhancing the frequency and severity of high floods, as happened during 2010 and recent past droughts. Incorporating realistic scenarios, water resources availability is a fundamental element of sustainable development. Water resources and climate change not only affects agriculture, but these also affect urban centers, industry and human health. Management of water resources requires a balanced and careful review of current knowledge under a comprehensive framework for the national development purposes of all sectors of life including environmental requirements.

1. INTRODUCTION

Water availability is the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. It is vital for reducing the global burden of disease and improving the health and welfare of society. It is central to the production and preservation of a host of benefits and services for the people. Water is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society and the environment. Water is a finite and irreplaceable resource that is fundamental to human well-being. It is only renewable if well managed. Today, more than 1.7 billion people live in river basins where depletion through use exceeds natural recharge, a trend that will see two-thirds of the world's population living in water-stressed countries by 2025. Water can pose a serious challenge to sustainable development if managed efficiently and equitably, water can play a key enabling role in strengthening the resilience of social, economic and environmental systems in the light of rapid and unpredictable changes. The extreme weathers are never feasible for water resource. Only a favorable climate is a source of balanced development. It is pertinent to explore that how we can get benefit from nature to overcome the water challenges of the 21st. century.

Environmental damage, together with climate change, is driving the water-related crises we see around the world. Floods, drought and water pollution are all made worse by degraded vegetation, soil, rivers and lakes. When we neglect our ecosystems, we make it harder to provide everyone with the water we need to survive and nourish. Nature-based solutions have the potential to solve many of our water challenges. We need to do so much more with 'green' infrastructure and harmonize it with 'grey' infrastructure wherever possible. Planting new forests, reconnecting rivers to floodplains, and restoring wetlands will rebalance the water cycle and improve human health and livelihoods. Agriculture plays a key role in providing (i) food availability (ii) an important source of income to purchase food; and (iii) foods with high nutritional status. Food security in Pakistan is dependent on agriculture and agriculture depends on availability of land and water. There has neither been any substantial horizontal expansion (new lands coming under cultivation) nor any significant vertical (per acre yield) growth despite having massive potential on each of the two areas. At the same

time land and water resources are becoming scarcer every day. The vertical growth has been more difficult and arduous part. Over the last 6 decades, our institutions and relevant agencies have not been able to educate farmers on crop management issues. The farming practices are still not at par with international standards and about 30% of horticulture crops are lost at postharvest level. Yields of all major cash and food crops are well below the world average. However, due to non-development of resource base, per capita water availability is falling and country is heading fast towards a water deficient country.

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

Over 1.7 billion people are currently living in river basins where water use exceeds recharge, leading to the desiccation of rivers, depletion of groundwater and the degradation of ecosystems and the services they provide. As countries develop and populations grow global water demand (in terms of withdrawals) is projected to increase by 55% by 2050. . Already by 2025, two thirds of the world's population could be living in water-stressed countries if current consumption patterns continue. The economic loss from the inadequate delivery of water and sanitation was estimated to amount to 1.5 % of gross domestic product of the countries included in a WHO study on meeting the MDGs. According to some estimates, over 80% of wastewater is discharged without treatment. Water-related disasters are the most economically and socially destructive of all natural disasters. Since the original Rio Earth Summit in 1992 floods, droughts and storms have affected 4.2 billion people and caused USD 1.3 trillion of damage.

As Pakistan is water scarce country the shortfall of about 30 MAF of water by the year 2030 is to be met through creating storage facilities and diverting 21.5 MAF to canals which at present is flowing to sea after allowing 8.6 MAF for environmental flows. This additional diversion of 21.5 MAF at canal head would add about 15.6 MAF at farm gate. Exploiting, a potential of 6.4 MAF from groundwater and 3 MAF from rain water harvesting will add to this, making additional water availability at farm gate about 20 MAF. The program of water course improvement by 2030 will cover all the water courses of country enhancing water course efficiency significantly and will save wastage of water in the irrigation system and thus the total water availability at farm gate would be

about 143 MAF. The water requirements of 143 MAF by 2030 for all water using sectors would be safely met. Campaign on efficient use of water in domestic, industrial and agricultural sectors have been launched to disseminate knowledge and information to the water users especially farmers.

Rain water harvesting and use of treated water are also being adopted. Water is key factor for agro-socio-economic uplift through green revolution in the country. The additional water availability for irrigation and other relevant developments of efficient water use coupled with crop management as anticipated above, the country would not only be able to sustain food security but also export more agricultural products. It can easily be seen that water plays a pivotal role in development of all sectors of life.

2. MILLENNIUM DEVELOPMENT GOALS (MDGS)

The Millennium Development Goals (MDGs), agreed in 2000, aim to have the proportion of people without sustainable access to safe drinking water and basic sanitation between 1990 and 2015. A total of 748 million people still do not have access to an improved drinking water source and existing indicators do not address the safety and reliability of water supplies. To reach the requirements of the right to access to safe drinking water requires real improvements for several billions of people. In July 2010, the General Assembly adopted a resolution, which “recognized the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights”. The MDG target for sanitation is an even more pressing challenge, with 2.5 billion people currently lacking access to improved sanitation and over one billion still practicing open defecation. At current rates of progress, the sanitation target will be missed by over half a billion people. These global aggregates also mask large disparities between nations and regions, rich and poor, between rural and urban populations, as well as between disadvantaged groups and the general population. There is currently no global target to improve hygiene, despite this being one of the single most cost-effective public health interventions. As the time limit for the MDGs draws to a close in 2015, the global community is taking stock of how it can move towards a sustainable future. The MDG framework did not address the full water and development agenda, nor fully recognize its synergies with other areas and concerns.

3. SUSTAINABLE DEVELOPMENT GOALS (SDGS) ON WATER

The Rio+20 Conference (2012), was an opportunity to reflect on progress towards sustainable development over the previous 20 years. One of its main outcome was an agreement to launch a process to develop a set of Sustainable Development Goals, which were built on the Millennium Development Goals and converge with the post-2015 development agenda. The Zaragoza Conference focused on the tools for implementation stated in the outcome document of the United Nations Conference on Sustainable Development, held in Rio de Janeiro from 20 to 22 June 2012, entitled "The future we want", which included finance, technology and capacity building, adding the institutional and policy dimensions. Emphasis on ‘Sustainability’ was not included and human rights and inequalities

were also largely ignored in the MDG framework. Subsequently, member states have agreed that human rights, equality and sustainability should form the core of the development agenda and be recognized as critical for true development. UN-Water's overarching goal is that "Securing Sustainable Water for all". The water goal and targets directly address the development aims of societies, promote human dignity and ensure achievements are sustainable over the long term leading development outcomes for the water utilizing sectors.

Sustainable development was explicitly popularized and contextualized by the Brundtland Commission in the document "Our Common Future" where it was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987). The Brundtland Commission focused on three pillars of human well beings; economic, socio-political and ecological/environmental conditions. The basic concept endorses putting in place strong measures to spur economic and social development, particularly for people in developing countries, while ensuring that environmental integrity is sustained for future generations.

4. EFFECT OF GLOBAL WARMING 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 proportionately 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. Temperatures induced shifts in the relative amounts of rain and snow and in the timing of snowmelt in mountainous areas are considered likely. Climate induced changes in hydrology will affect the magnitude, frequency, and costs of extreme events. Flooding could become more frequent and extreme. Recent reports of the Inter-governmental Panel of 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.

The water resources in our region (Near East) are also affected by climate changes in the world at large. There is a significant change in climate of Asia, in general, and Near East, in particular, to warrant global climate change concerns, such as follows (IPCC, WG-II):

a) **Lhasa, Tibet:** Warmest June1998 on record. Temperatures above 25°C (77°F) for 23 days.

b) **Himalayas, India:** Glacial retreat at record pace. The Dokriani Barnak Glacier receded over 20 m in 1998, despite a severe winter. The Gangorti

Glacier is retreating about 30 m per year. These predictions indicate a significant loss of Himalayan Glaciers which look quite over ambitious estimation.

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

d) **Middle East:** Severe drought has affected many parts, including Iran, Iraq and Jordan. Rainfall in parts of Iran decreased by 25% as compared to 1999. Eighteen out of the country's twenty-eight provinces are suffering in Iran.

e) **In Iraq the flow of Tigris and Euphrates** rivers have reduced by around 20% of their average flow, with serious consequences for irrigated farming. Jordan's agricultural production has been severely affected in recent past due to drought. Most countries in Middle East are suffering the consequences of prolonged water-shortages.

The evidences listed above show that in the recent past dry years in Pakistan were not isolate events; as the whole Near East region suffered as well. A macro-scale hydrological model for river-flow suggests that the runoff of the Indus will decrease by 27% by the year 2050. This implies that the availability of fresh water in Pakistan is highly vulnerable to climate change. 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 for the agricultural, industrial and hydropower sectors will put additional stress on water resources.

The 4th Assessment Report (AR4) by the three working groups of the Intergovernmental Panel on Climate Change (IPCC) has projected that average global surface temperature will increase by approximately over 4°C during the 21st century. The recent annual average temperatures for Northern and Southern Pakistan are about 19°C and 24°C respectively. The glaciers constitute about 2,700 km3 of stored volume of ice (Roohi, 2005), equivalent to about 14 years of average Indus River System inflows. The thermal regime of Hindu Kush Himalayan (HKH) glaciating region has in general warmed up and the frequency of occurrence of moderate as well as severe heat waves have also increased significantly.

The climatic change in Pakistan has slowed down melting of glaciers and snow from mountains due to low temperatures in recent years in northern area, thus reducing flow of rivers resulting in severe water shortages during winter. However, temperature in the northern glaciating area is again rising since 2014-2015. Based on the studies available, it looks likely that the HKH glaciers are receding under the influence of global warming and their melting will increase

with increase in summer temperatures. Recent simulation modeling conducted by Global Change Impact Studies Center (GCISC), Geneva, Switzerland, on Indus flows for a scenario where temperature will rise by 4°C and glaciers would shrink to half of their present size, indicates that overall annual river flows would reduce by about 15% and the monthly flow pattern would also change considerably, with more water coming in spring and early summer and less water in the later part of summer.

Due to anticipated major climate change related concerns, it is projected that it will increase variability of monsoon rains to enhance the frequency and severity of high floods as happened during 2010 and recent past droughts. Incorporating realistic scenarios of water resources availability is a fundamental element of sustainable development. Water resources and climate change not only affects agriculture, but these also affect urban centers, industry and human health. Management of water resources requires a balanced and careful review of current knowledge under a comprehensive framework for the national development purposes of all sectors of life including environmental requirements.

5. WATER REQUIREMENTS V/S AVAILABILITY

Population rise, urbanization and better socio-economic conditions have brought increasing pressure on water resources. Water availability in Pakistan is 900 m^3 per capita/year in 2017; this is already well below the 1,700 m^3 per capita/year threshold for water stressed conditions. Thus Pakistan is already fast moving into a condition of 'water scarcity'. This situation is likely to deteriorate in future as the gap between supply and demand widens. However, the gross additional water demand in 2017 for all sectors is about 21.0 MAF (15 MAF for agriculture and 6.0 MAF for municipal water supply, rural potable and sanitation, industry and the environment). The corresponding requirement at the canal head is nearly 30 MAF. Water available for future development is about 38 BCM (31 MAF) including 21.5 MAF of river flow, 6.4 MAF from groundwater and 3 MAF from rainfall harvesting. Future water requirements for all sectors are given in Table-1 and discussed in the proceeding paragraphs:

Table-1: Future Water Needs at Farm Gate (MAF)

Sector	**Year**					
	2000*	**2010****	**2017****	**2020****	**2025***	**2030****
Agriculture	99.0	104.0	109.0	114.0	119.0	124.0
Water Supply & Sanitation	4.5	6.0	7.5	9.0	10.5	12.0
Industry	3.5	3.8	4.1	4.5	4.8	5.1
Environmental Protection	1.3	1.4	1.5	1.6	1.7	1.8
Total	**108.3**	**115.2**	**122.1**	**129.1**	**1.36.0**	**142.9**

Source: *National Water Policy Vol.-II, January 2003-(2000 & 2025)

**Computed (2010, 2017, 2020 & 2030)

a) **Agriculture:** The total area of the country is 79.61 Mha of which 29.4 Mha is designated as cultivated area. About 15.4 Mha cultivated land is served by canal water, while the remaining 5.2 Mha is rain fed while the remaining 8.8 Mha area is barren, needing additional water for irrigation. Almost 90 percent of water resources are being used to meet crop water demand. Increases in agricultural production to meet the needs of a rising population, will require additional water. Based on population growth projections, by 2030 an estimated additional 15 MAF will be needed for agriculture at the farm gate. The agriculture is by far the thirstiest consumer of water globally, accounting for 70% of water withdrawals worldwide, although this value varies considerably across countries. Rain fed agriculture provides production in the world, and its current productivity is, on average, little more than half the potential obtainable under optimal agricultural management. Pakistan economy depends on agriculture which requires water as a prime input facto for raising crops. This sector provides subsistence and livelihood to over 70 % of population.

b) **Municipal Use***:* The current total water uses for domestic and municipal purposes in both urban and rural areas are estimated at 7.5 MAF. By 2030 requirements for water supply, rural potable water and sanitation are estimated to be 12.0 MAF with an increase of 4.5 MAF as compared to 2017. Worldwide, an estimated 748 million people remain without access to an improved source of water and 2.5 billion remain without access to improved sanitation. More than half the world already lives in urban areas and by 2050, it is expected that more than two-thirds of the global population of 9 billion will be living in cities. Furthermore, most of this growth will happen in developing countries, which have limited capacity to deal with this rapid change, and the growth will also lead to increase in the number of people living in slums, which often have very poor living conditions, including inadequate water and sanitation facilities. Therefore, the development of water resources for economic growth, social equity and environmental sustainability will be closely linked with the sustainable development of cities.

c) **Industry** - There are over half a million large and small industrial units in the country, of which nearly 120,000 are engaged in textile, chemical, fertilizer, tanneries and other manufacturing and processing activities. The water use by all industries and mines in year 2017 is estimated to be 4.1 MAF. This is expected to rise to 5.1 MAF by 2030, i.e. an additional requirement of 1.0 MAF. The Industry and energy together account for 20% of water demand. More-developed countries have a much larger proportion of freshwater withdrawals for industry than less-developed

countries, where agriculture dominates. One of the biggest is globalization and how to spread the benefits of industrialization worldwide and without unsustainable impacts on water and other natural resources.

d) **Environment** - The environmental water requirement for 2017 is about 1.5 MAF. In order to ensure adequate water throughout Pakistan for wetlands, environmental protection and increased irrigated forestry, about 1.8 MAF water will be required by the year 2030.

e) **Ecosystems**: These are perhaps the most important challenge to sustainable development to have arisen in the last decades is the unfolding global ecological crisis that is becoming a barrier to further human development. From an ecological perspective, the sustainable development efforts have not been successful. Global environmental degradation has reached a critical level with major ecosystems approaching thresholds that could trigger massive collapse. The growing understanding of global planetary boundaries, which must be respected to protect Earth's life support systems, needs to be the basis of the future sustainable development framework.

6. WATER RESOURCES

Pakistan's water resources comprise of surface and ground water which are briefly described as follows:

6.1 Surface Water

The Indus River System is the major source of surface water which derives mostly from snow and glacial melting. Schematic Diagram of Rivers and Irrigation System and Land use of Pakistan are shown in **Figures 1 and 2**. Pakistan receives snowfall on the mountains during winter. Rainfall is in monsoon during July to September and it varies in magnitude, time of occurrence and aerial distribution. The mean annual precipitation ranges from less than 100 mm in parts of the Lower Indus Plain to over 750 mm near the foothills in the Upper Indus Plain. Pakistan is dependent on the four western rivers including Kabul, Indus, Jhelum and Chenab. Post-Tarbela (1976-2017) flows in Indus at Kalabagh, Jhelum at Mangla and Chenab at Marala and with eastern rivers small contribution on an average are 140 MAF. The three eastern tributaries of the Indus – Ravi, Sutlej and Beas – were allocated to India for its exclusive use. The Kabul River contributes 17 MAF on an average to the surface supplies of the country.

Consequent to Indus Water Treaty, Pakistan built Mangla and Tarbela Dams and link canals to transfer inter rivers (Indus Jhelum and Chenab) waters for irrigated agriculture in the commands of Ravi, Beas and Sutlej rivers whose waters were allocated to India. This opportunity of assured supplies through building additional storages and network of irrigation canals brought green revolution in 1970's. Further productivity was enhanced by adopting better varieties of crops

like Maxi Pak wheat, Irri.8 rice and Baharia Maize along with genetic techniques and cultural practices. With high population growth and reduction in storage capacity due to sedimentation of the reservoirs, Pakistan which was affluent in water in seventies, became water scarce by end of 2000. No mega storage dam was built after completion of Tarbela Dam in 1976. Although Kalabagh Dam design was ready by 1987 but it could not be built due to non-consensus between the stake holders. Pakistan faces recurrent floods and droughts. During the last two decades three flood diversion canals, i.e. Greater Thal, Rainee and Kachhi Canals were completed to irrigate 0.21 Mha. A few small dams were built; i.e. Mirani, Sabakzai, Gomal Zam and Satpara which irrigate 0.11 Mha area. Diamer Basha Dam with live storage of 6.4 MAF is being started which would not only meet water shortages in the Indus Basin but would also supply water to some additional land to boost economy of Pakistan.

Pakistan is using mostly flood irrigation system. Water is diverted from rivers, by constructing dams/barrages, into canals, distributaries and water courses leading to the farm. Indus Basin Irrigation system one of the World's oldest and the largest contiguous irrigation system comprises of 19 barrages, 54 main canals having length over 60,000 kilometers and water courses length 1.6 million kilometers. Most of the canals built are unlined and about 40% of the diverted water at canal head is lost during conveyance to the farm gate. There has been significant improvement due to On Farm Water Management; lining of canals distributaries and watercourses, laser land leveling, low delta crops, salt tolerant varieties, furrow and bed, high efficiency drip and sprinkler irrigation techniques.

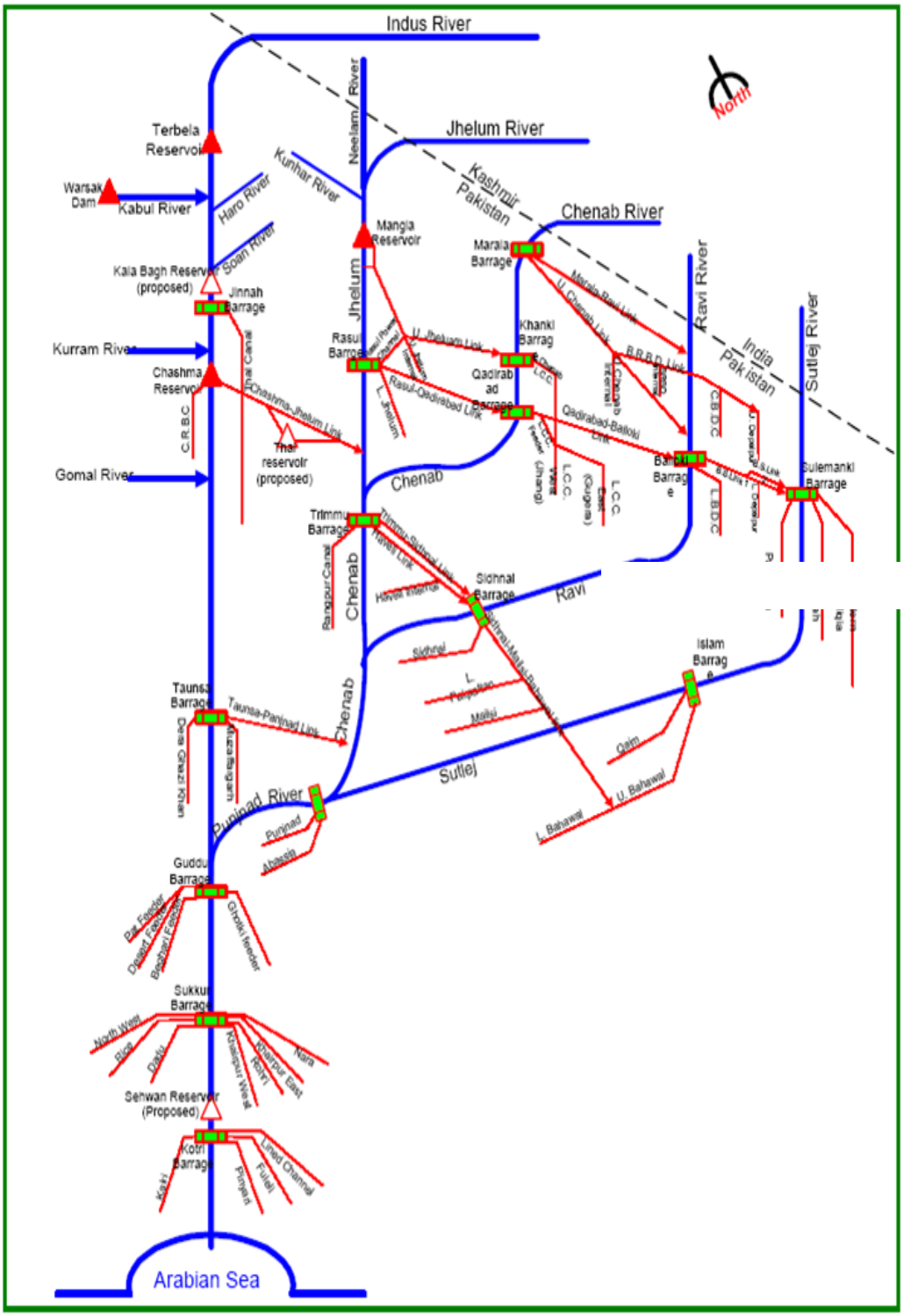


FIGURE 1: Schematic Diagram of Rivers and Irrigation System of Pakistan

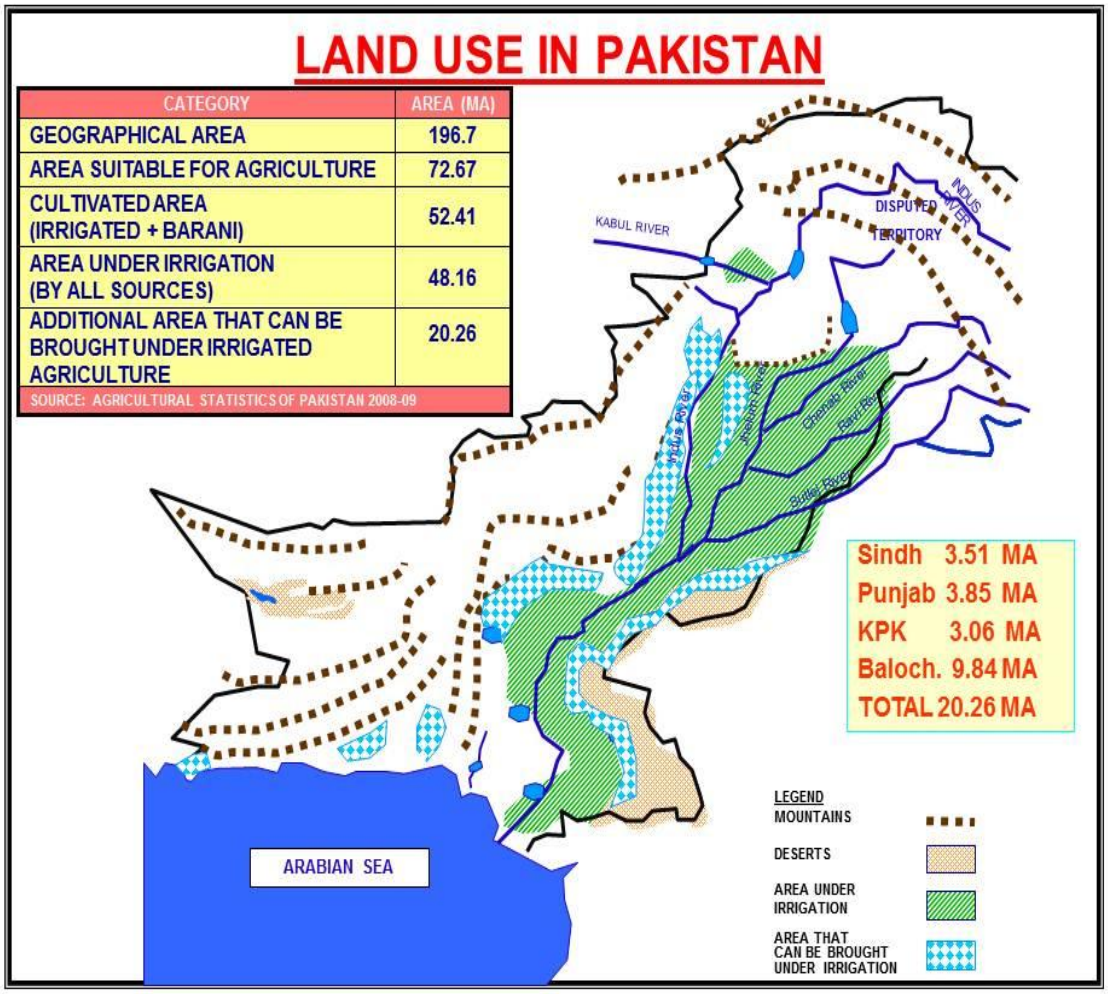


FIGURE 2: Land Use Map of Pakistan

6.2 Ground Water

Pakistan is extracting about 50 MAF from the aquifers and in fresh areas it has crossed the sustainable limit of safe yield. This over-mining and pollution of aquifers has resulted in secondary salinity and the presence of fluorides and arsenic in water, which in turn is degrading the quality of agricultural lands and creating health issues. The northern part of the Indus Basin has fresh water and most of the southern part has saline.

The Indus Waters Treaty led to the construction of multiple hydraulic structures. These enabled Pakistan to enhance water availability at canal head works to about 104 MAF. However, this has now decreased to 100 MAF because of the

lack of further surface water development since construction of Tarbela dam and the significant loss of on-line storage capacity due to sedimentation. Out of the 100 MAF of annual canal diversion, only 58.3 MAF reaches the farm-gate and remaining 41.7 MAF is lost due to seepage and evaporation.

Pakistan is faced with increasing water scarcity and depending on assumptions of various future demand scenarios. Annual water requirements at canal head could be in the range of 135-170 MAF in the coming years. Existing irrigation system is working on 40-45 percent efficiency. The National Water Strategy envisages raising irrigation efficiency to 50 percent from the current level of 40 percent. In order to improve the existing system, various steps such as On-Farm Water Management Program (OFWM) projects have been started in all provinces, including Gilgit-Baltistan, Azad Jammu & Kashmir and Islamabad Capital Territory areas. The projects undertaken are: - National Program for Improvement of Watercourses in Pakistan, Chaghai Water Management and Agriculture Development Project (IDB Assisted), National Project to stimulate the Adaptation of Permanent Raised Beds in Maize-Wheat and Cotton-Wheat Farming System in Pakistan. Efficient irrigation system is a pre-requisite for higher agricultural production as it helps in increasing the crop intensity. Despite the existence of a good irrigation canal network in Pakistan, it suffers from wastage of a large amount of water in the irrigation process. Water is the key input for agriculture, industry & urban development, as well as achieving Millennium Development Goals and targets and reducing poverty. The water sector gained major focus throughout the last decade in the development programs. Since water availability is persistently decreasing, the challenge is to formulate an effective and comprehensively efficient system of water resource management. The focus areas of investments in water sector are:

Augmentation of surface water resources by construction of small/medium and large dams is the need of the time. Conservation measures (lining of irrigation channels, modernization/ rehabilitation of irrigation system, lining of watercourses and efficiency enhancement etc.). Protection of infrastructure from onslaught of floods and water logging & salinity needed. Adoption of resource conservation technologies is fundamentally required. The Major Water Sector Projects under Implementation are given in Table-2. Although proposed Kalabagh Dam's design in ready since 1987 it could not be constructed due to lack of consensus between provinces, however, technically it is quite a viable project. In addition to the storage and irrigated projects, to upgrade irrigation for 291,000 Acres, a program has been started under "National Program for Water Conservation through High Efficiency Irrigation System (Drip & Sprinkler)" in Pakistan.

Table-2: WAPDA Major Water Sector on-going and recently Completed Projects

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

7. WATER SECTOR ISSUES

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

7.1 Water Shortage

Pakistan is one of the world's arid countries, with an average rainfall of under 240 mm per year. According to the benchmark water scarcity indicators (Faulken Mark), Pakistan`s per capita water availability is about 900 m^3 in 2017 and it places the country in the “high water stress” category (**Table**-**3**). The water shortage scenario in Pakistan is further aggravated with high variability of rainfall. The climate change and global warming is likely to severely affect the availability of water. After the loss of 3 major rivers, Ravi, Sutlej and Beas, to India under the Indus Waters Treaty 1960, India’s construction of water storage infrastructure at Baghlihar and Kishanganga, is threatening the uninterrupted flow of water downstream into Pakistan. The per capita water availability v/s population is shown in **Figure**-**3**.

Table-3: Water Scarcity Indicators, FAO – 1992 (Faulken Mark)

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

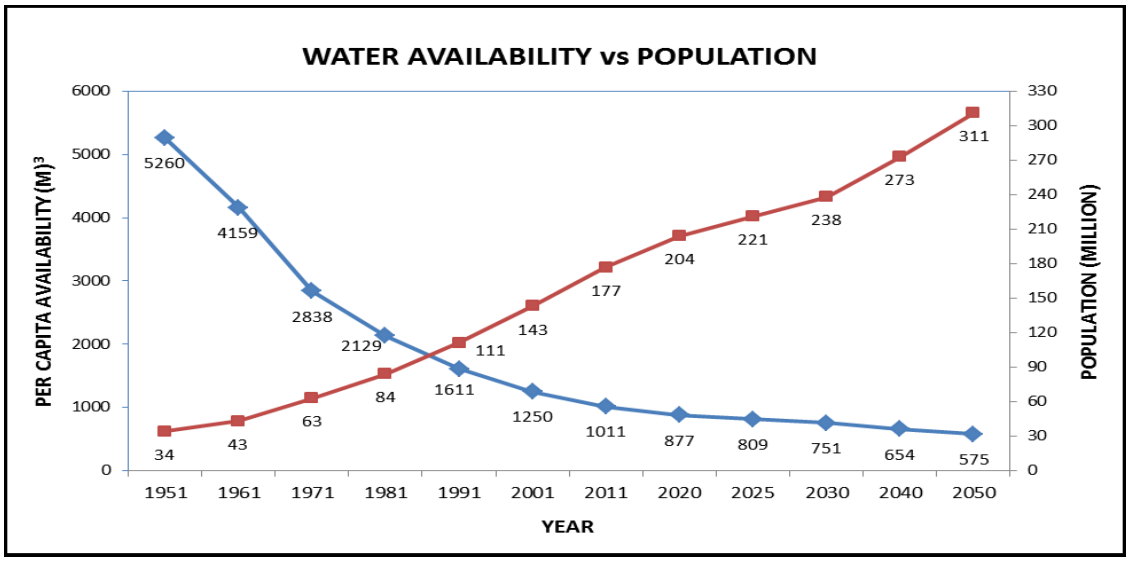


Figure 3: Water Availability v/s Population Growth

7.2 Low Water Productivity

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

Zone	Proportional Basis	
	Land	Water
Pakistan Punjab	3	5
Indian Punjab	6	8
California- USA	10	10

7.3 Aging and Outdated Infrastructure

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

7.4 Low Water Charges

The water charges are very low and covers only 19% of O&M cost of irrigation network. The system maintenance requires a lot more attention due to deferred maintenance over the Past 100 years. The adequate water costing could offset O&M cost and could generate finances for new water sector projects. However price control for crop production needs attention as farmers are mostly deprived from appropriate prices of production.

7.5 Innovative Knowledge Based Management

Challenges of the 21st century require the frontiers of knowledge and innovative approaches rather than historic practices. The institutions need redefining of their roles and to develop their capacities according to new responsibilities for efficient water use.

7.6 Ownership, Reforms and Management

The irrigation infrastructures operation and on-farm practices need ownership of the stakeholders; such as farmers, professionals and revenue collectors. A joint management mode needs to be devised as Area Water Boards and Farmer's Organizations. Equity: Water provides prosperity and jobs, and acts as a "force multiplier" in the national economy. However, serious concerns exist with respect to spending common pool money to the benefit of selected groups in the absence of policy on equity. The disadvantaged groups are: a) Users at tail end of canal commands, b) Farmers outside Indus Basin.

7.7 Reservoir Sedimentation

Pakistan has three major reservoirs, which had as built storage capacity of 18.64 MAF. The storage capacity of Tarbela, Mangla and Chashma reservoirs has depleted by 4.99 MAF or 27% by the year 2017 due to sedimentation. It is estimated that the gross storage capacity would be reduced by 6.00 MAF or 32% by the year 2025 as shown in **Table-4**. Due to loss of storage, agriculture of Pakistan is facing water shortage during low flow seasons.

7.8 Un-captured Water

Despite acute water shortage in the system, data shows that a substantial amount of water escapes below Kotri to the Arabian Sea. Post-construction of Tarbela (1976-2010) average annual escapages below Kotri were 31.48 MAF, with a maximum of 91.83 MAF in 1994-95 and minimum of 0.79 MAF in 2000-01 (**Figure 4**). Most of the flow to the sea occurs during Kharif season and very little during Rabi season. For better water management, storage capacity should be equivalent to at least 40 percent of total water availability but Pakistan's live storage capacity is about 13 percent of its overall river flows.

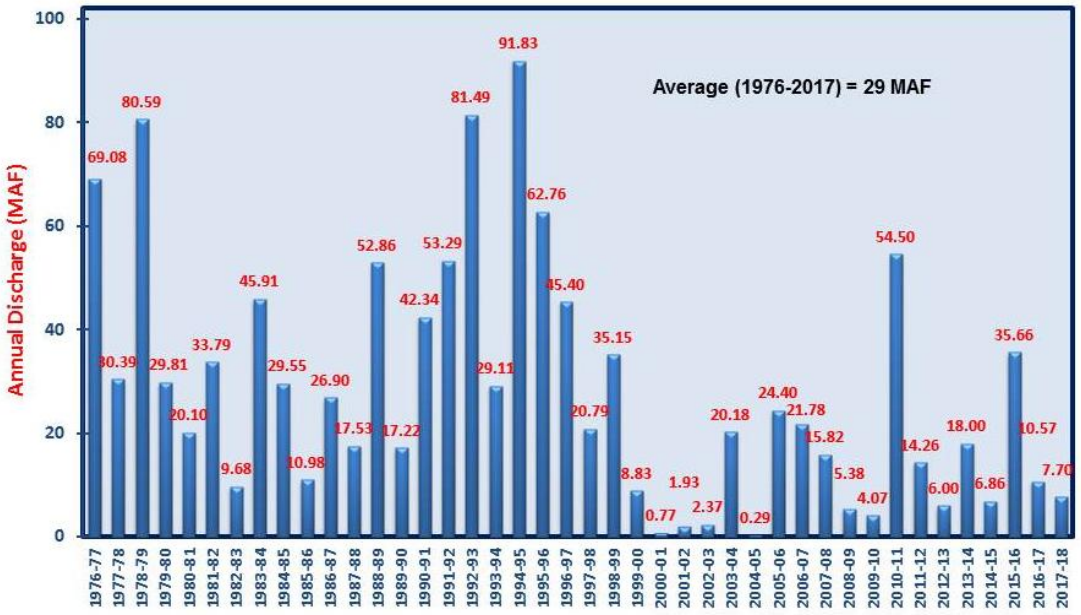
Table 4: Storage Loss Due To Sedimentation

Reservoir (Commissioning Year)	Storage capacity			Storage loss	
	Original	Year 2017	Year 2025	Year 2017	Year 2025
	MAF	MAF (%)	MAF (%)	MAF (%)	MAF (%)
Tarbela (1976)	9.68	6.06 (63%)	5.37 (56%)	3.62 (37%)	4.3 (44%)
Mangla (1967)	5.34	4.35 (82%)	4.19 (79%)	0.99 (18%)	1.15 (21%)
Chashma (1971)	0.72	0.38 (53%)	0.27 (38%)	0.34 (47%)	0.45 (62%)
Sub-Total	15.74	10.79 (69%)	9.83 (63%)	4.95 (31%)	5.91 (37%)
Addition of Raising Mangla (2012)	2.90	2.86 (99%)	2.81 (97%)	0.04 (1%)	0.09 (3%)
Total	18.64	13.65 (73%)	12.64 (68%)	4.99 (27%)	6.00 (32%)

Source: WRM Directorate, WAPDA

7.9 Groundwater

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



Source: WRMD WAPDA based on data supplied by Govt. of Sindh

Figure 4: Water Escapages below Kotri (MAF)

7.10 Rainwater Harvesting

Rainwater harvesting in Pothohar areas is a reasonable source of water for raising crops. With this technique about 5 to 6 % GDP earnings are generated. It is a good source of income and livelihood of uphill areas in the country and it is about 5.2 Mha contributing towards uplift of the peoples of such areas. The rainwater harvesting provides about 3 MAF water.

8. FUTURE STRATEGIC AREAS FOR WATER MANAGEMENT

The core areas require immediate attention while formulating contingency action plan and management/policy plans to keep the country ever green are described in the proceeding paragraphs.

8.1 Water Demand Management

Water availability is diminishing with a growing population and increasing urbanization. The need for better water demand management is well established.

The following strategy represents some areas of immediate attention:

- Promoting efficient water use
- Rationalizing water price
- Optimizing cropping pattern to save water
- Integrated use and recycling of water
- Ground water regulation to avoid over mining
- Climate Change Impact on Water and Agriculture

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 have 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 spring runoff. Because the temperature projections of climate models calculate less 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 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 human beings. Flooding could become more frequent 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.

A macro-scale hydrological model for river-flow suggests that the runoff of the Indus will decrease significantly by the year 2050 (IPCC, A4-WG-II). This implies that the availability of fresh water in Pakistan is highly vulnerable 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 for the agricultural, industrial and hydropower sectors will put additional stress on water resources.

8.2 Increasing the Productivity of Land and Water

Gaining more yield and value from less water can reduce future demand for water, limiting environmental degradation and easing competition for water. Adoption of best agriculture practices and resource conservation technologies can help to gain more yield per limit area.

9. CONCLUSIONS

The shortfall of about 30 MAF of water by the year 2030 is to be met through creating storage facilities and diverting 21.5 MAF to canals which at present is flowing to sea after allowing 8.6 MAF for environmental flows. This additional diversion of 21.5 MAF at canal head would add about 15.6 MAF at farm gate. The program of water course improvement by 2030 will cover all the water courses of country enhancing water course efficiency significantly and will save wastage of water in the irrigation system. It may be emphasized that water plays a pivotal role in development of all sectors of life.

10. RECOMMENDATIONS

Campaign on efficient use of water in domestic, industrial and agricultural sectors have been launched to disseminate knowledge and information to the water users especially farmers. Rain water harvesting and use of treated water are also being adopted. Water is key factor for agro-socio-economic uplift in the country. Additional storages and other relevant developments of efficient water use in the country would not only be able to sustain food security but also would export more agricultural products to sustain the economy.

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Paper No. 147

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES OF PAKISTAN

Qazi Talat Mahmood

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES OF PAKISTAN

By:

Qazi Talat Mahmood

1. Introduction

The economies of South Asian nations are highly dependent on summer of monsoon and water supplies from glaciers and snowmelt. However, excessive and inadequate rainfall causes floods and droughts respectively, which have damaging effects threatening food security in many cases. Global climate change is an emerging concern, which may cause serious impacts on the monsoons, frequency, intensity and distribution of rain spells on temporal and spatial scales, accelerated melting of glaciers and increased number of floods and droughts. Potential direct impact of climate change include reduction in inflows to water reservoirs, water shortage for agriculture, insufficient recharge of groundwater and sharp decline in per capita water availability.

Current vulnerabilities to climate are strongly correlated with climate variability, in particular precipitation variability. These vulnerabilities are largest in semi-arid and arid low-income countries like Pakistan. According to IPCC Fourth Assessment Report 2007, with the increase in temperature, the increase in frequency and intensity of extreme events is "very likely" i.e. 90% sure. Under warming conditions, the summer season will expand while winter will shrink. Ultimately, the snowfall will occur for a shorter duration and melting will continue for longer period bringing drastic changes in water balance. Snowmelt and supply of water will be available much earlier than the present (prior to Kharif sowing) and may be inadequate when required in early autumn for Rabi sowing. Soil degradation will be the major challenge for sustainable crop production. Both summer and winter weather patterns are expected to yield the same amount of precipitation in a highly erratic behavior over time and space. The economies where water management practices would not be able to face the challenges posed by climate change will be highly vulnerable to the vagaries of global warming.

2. Adaptation to Climate Change

On adaptation side the Climate Change pose tremendous challenges in Water Sector. It is necessary to consider its potential impacts on different dimensions of water resources and its management: Most visible potential impacts include:

1. Rain fall will increase in some areas and decrease in some others;
2. Floods and droughts will be more intense; storms and floods will be longer in duration, more intense while droughts will also be more frequent apart from longer in duration;
3. Aridity will increase in many areas due to increased evaporation; and
4. With the drier ground, less water will percolate into the deeper aquifers. Floods and droughts will be caused by temperature increase and shrinking of glaciers of

low fields. So first increased and then reduced water flows will cause floods and then droughts.

5. Due to shrinkage of glaciers, there will be increase in river flows for few years, thereafter there will be permanent loss in river flow. Increase in flow can cause floods whereas low flow in river will result in drought conditions.

The aforementioned potential impacts will have some very obvious rather deleterious and direct consequential impacts on how the people use and manage water:

1. Where water availability is reduced, the communities will either have to adapt to use less water or bring water from farther afield at greater cost;
2. Agriculture will be affected badly resulting in low productivity;
3. Lower river flows will cause reduction in hydel power generation and resultantly power failures/shortages will affect the economic and social life of the communities unless new investments are made to augment-electric power shortages/failures;
4. More frequent and intense floods will increase the cost of investment in flood protection works as well as that of associated infrastructure such as roads and storm water drains;
5. The less direct impact will be less pollution discharges with reducing flows of rivers and streams causing environmental degradation;
6. The increased flood risks will reduce the land available for settlement;
7. Rising sea level will infiltrate unusable saline water into coastal aquifers reducing the water supply of coastal communities in small island estates; and
8. The precipitation may increase in one season and decrease in another. Such climatic change may lead to change in all components of the global freshwater system.

According to IPCC fourth assessment report 2007, the South Asian Region's economies with greater dependency on agriculture and water resources will be greatly affected by Global Climate Change, causing serious impacts on monsoon patterns, frequencies and intensities of rain spells on temporal and special scale, causing melting of glaciers thus increasing the frequency of floods and droughts.

3. Pakistan's Climate and Water Scenario

The per capita availability of water in Pakistan in 1951 was approximately 5260m^3 against the population of approximately 34million. In early 1980s, in a population of 9 million, each Pakistani was receiving 2200 m^3 of water to meet his annual demand. Afterwards the water availability is continuously on the decrease. In 2010, 1066m^3 per-capita water was available to population of above 167.72 millions and in 2025, this gap will increase too much as is evident from Figure -1. Pakistan has crossed the limit of water scarcity i.e. 1000m^3 per-capita water availability in 2013.Gross per capita water availability in Pakistan will decline to as low as ~ 858 m^3/yr in 2025.

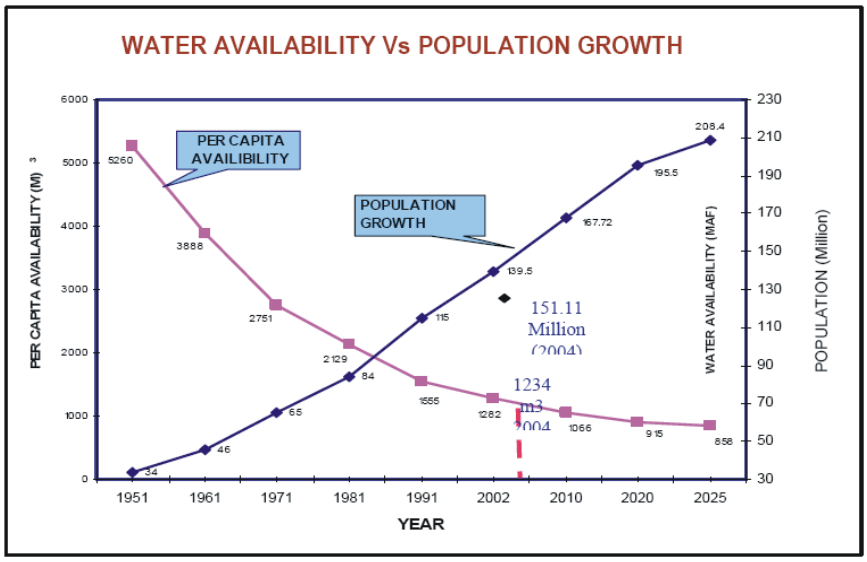


Figure 1: Gross per capita water availability in Pakistan

Recent Trends of Climate Change in Pakistan based on climatic data of last 75 years (1940 – 2015) are summarized below:

- Rise in mean daily temperature of 0.6-1.0°C in arid coastal areas, arid western/northwestern mountains and hyper arid plains;
- Decrease of 10-15% in both winter and summer rainfall in coastal belt and hyper arid plains;
- Increase in rainfall of 18-32% in monsoon zone especially the sub-humid and humid areas;
- Decrease of 5% in relative humidity over arid plains of Balochistan;
- Solar radiation intensity increased by 0.5 to 0.7% over the southern half of country;
- 3 - 5% decrease in cloud cover over central and southern Pakistan resulting in increase of sunshine;
- 3 - 5% increase in Evapotranspirative rate due to 0.9°C temperature increase. Expanding aridity in northern parts outside monsoon range and arid regions;
- 5% increase in net irrigation water requirement with almost no change in rainfall;
- Frequency of extreme events such as heavy rain, flash floods, dust/thunderstorms, hailstorm, heat waves, density and persistence of fog has increased significantly;
- The intensity of weather systems also increased during the last quarter of the 20th century; and
- There is a visible shift in summer and winter weather pattern from the normal;

The water resources sector is both the lifeline and gear of development in Pakistan. The main source of water is Indus River System. The key vulnerability of Pakistan Water Resources to Climate Change will be increased variability in river flows due to change in frequency and intensity of extreme Climate events, the glacier retreat, increased Glacier Lake Outburst Floods (GLOFs), river floods and droughts, depletion of water storage capacity, due to siltation/sedimentation, flash flooding, water-logging and salinity, degradation of environment causing impacts on water quality, shrinking wetlands and increasing demands for water in all the sectors.

While the mitigation options are not much important for the reason that mitigation is global and reversal may take decades, the adaptation will be essentially a handy tool in addressing the short-term impacts. The best preparation for managing the unpredictable future climatic changes is to put in place a water resources infrastructure and management system which is driven to a much greater degree by knowledge (including but not limited to hydrological knowledge) and which is designed and operated to be much more flexible and adaptive. Increased water storage capacity will be required to store water during the high flood seasons so that the same could be utilized not only in the low flow period of the same year but in subsequent drought years too. Besides large dams, small dams will be needed to store water for local irrigation, domestic use and the off-grid hydropower generation.

For GLOFs, the development of an effective monitoring and early warning system has to be put in place to forewarn the downstream dwellers of any imminent danger. Safe draining of potentially dangerous glacial lakes can be taken up to mitigate GLOF events. Also important for a country like Pakistan is to reduce water losses in fields, the canal system and water channels. Besides preventing the losses, the available water needs to be optimally utilized to increase the yield per unit of land and water. That will require the latest agronomic practices & the precision land leveling to economize water in flood irrigation system, developing seed varieties which can survive in water stressed conditions and the state-of-the-art efficient irrigation systems such as sprinkler and drip irrigation. To sustain the mangrove forests and save the coastal ecology from saline sea water intrusion, continued round-the-year release of recommended river water below Kotri Barrage would require to be ensured besides effective coastal management of entire coastal belt of Pakistan.

In order to collect the rain and snow water, water harvesting on a broader scale will be a useful adaptation mechanism both for agriculture and for domestic water consumption. The water harvesting mechanisms include methods like terrain land alteration, terracing, contour farming, micro catchment farming, inter-dunal water harvesting, hill torrent water harvesting, and the rooftop water harvesting.

All the measures as highlighted above would need a National Action Plan to be implemented in the Water Sector to face up to the Climate Change Scenario. These plans envisage heavy investment for development of a series of water storages, implementation as of a comprehensive flood protection program, program for improving the canal delivery efficiencies, improving the recharge of fresh aquifers, regulating ground water use, sediment management of water storages and canals, improved inter agency coordination for greater linkages, an effective water development and

management-research program and dissemination of research and mass awareness etc.

These measures will need financial resources beyond the capacity of Government budgetary financing. Therefore, besides allocating annually sizable resources under the public sector development program, all available international windows of financing will have to be tapped for project financing, direct investment and various other modes combining all these methods under different mechanisms.

4. Climate Change Vulnerability Analysis of Water Resources of Pakistan

The water resources sector is both the lifeline and the gear of development in Pakistan. The main source of water in Pakistan is the Indus River system. The system resembles a funnel, with a number of water sources at the top converging into a single river that flows into the Arabian Sea (Figure: 2). Under the 1960 Indus Basin Treaty with India, Pakistan was entitled to the flow of three western rivers (Indus, Jhelum and Chenab), with occasional spills from the eastern rivers Sutlej and Ravi diverted upstream by India. The rivers under Pakistan control are mainly fed by snowmelt and glacier melt however Chenab and Jhelum Rivers also receive rainwater under monsoon depressions during summer. The average annual inflows of the western and eastern rivers and their tributaries at the rim stations is 142 MAF whereas the main Indus River dominates the flows by contributing more than 45% of these average annual flows.

Indus River System Pakistan

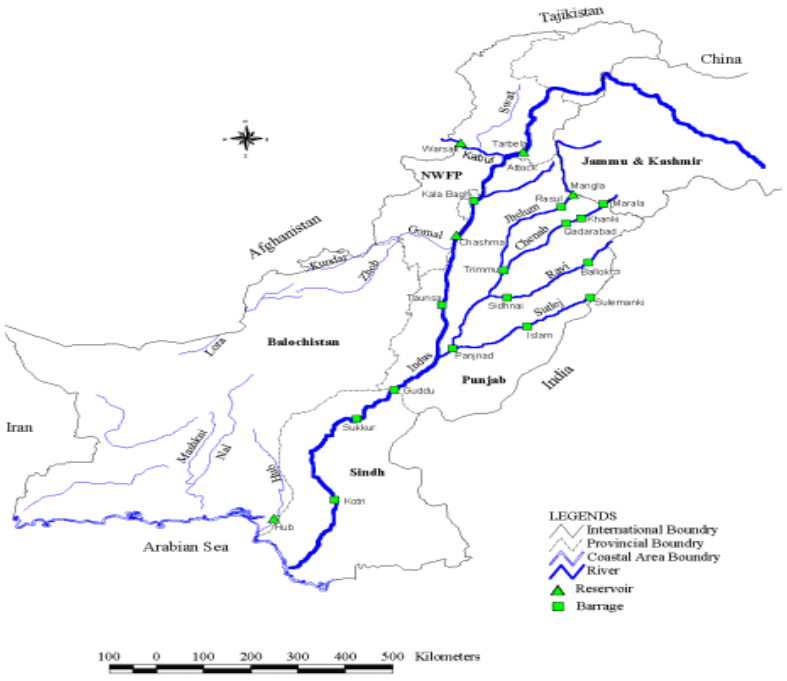


Figure 2: The Indus River System, Pakistan

The rainfall in Pakistan is low and erratic. Most of the rainfall occurs during the monsoon season. Both the intensity and volume in monsoons season are high and cannot be utilized by crops. Generally, half of the country receives less than 200 mm of annual rainfall.

The groundwater aquifers of the Indus Plains are the second major source of freshwater and are mainly recharged by the precipitation, the river flows, and the seepage from the canal systems, distributaries, watercourses and application losses in the irrigated fields. These vast aquifers of freshwater are being exploited to an extent of about 50 MAF through pumping for agriculture, industrial and domestic usage.

The hydrological system of the Indus Basin is complex. It combines runoff from glaciers, snowmelt and rainfall. It is further complicated by variable snow cover in space and time and by upward migration of melting temperatures with altitude. Glacier melt is the largest component of water supply in Indus River whereas combined water from glacier melt and snowmelt dominate flow for Chenab and Kabul rivers. The Jhelum River is mainly fed by snowmelt and rainwater under summer monsoon system.

Like many other developing countries in the region, Pakistan's long-term water availability and power generation rest on continued flow from the rivers of the Indus Basin originating from the Hidukush-Karakoram-Himalayas (HKH). It is indeed very difficult to predict future changes in weather patterns on regional level or to assess the real impact of climate change on water resources. However, geographical location of Pakistan places the country in heat surplus zone on the earth making it very high on vulnerability scale on weather changes.

Projected Global temperatures will likely to alter the hydrologic cycle in ways that may cause substantial impacts on water resource availability and changes in water quality. For example, the amount, intensity, and temporal distribution of precipitation are likely to change. Warmer temperatures will affect the proportion of winter precipitation falling as rain rather snow, how much is stored as snow and ice, and when it melts. Long-term climatic trends could also bring changes in vegetation cover that would alter a region's water balance. In addition, changes in the quantity of water percolating to the groundwater storage will result in significant changes in aquifer levels, in base flows entering surface streams, and in seepage losses from surface water bodies to the groundwater system.

4.1 Precipitation (Intensity & Frequency)

A simple-minded explanation for the resulting intensification of the hydrologic cycle is that "what goes up must come down." Of course, it is not that simple but the overall scientific consensus is that globally the Earth will be getting higher averaged precipitation. Exactly how much global average precipitation will increase is less certain. An increase in global average precipitation does not mean that it will get wetter everywhere and in all the seasons. In fact, all climate model simulations show complex patterns of precipitation change, with some regions receiving less and others more precipitation than they do now. The local balance between changes in precipitation and changes in actual evaporation will determine the net change in river flows and groundwater recharge.

In Pakistan, where year-to-year variations in precipitation are very high, it will be further increased due to increase in frequency and intensity of rain events. According to IPCC Fourth Assessment Report 2007, with the increase in temperature, the increase in frequency and intensity of extreme events is"very likely" i.e. 90% confidence. Also extremes of daily precipitation are likely to increase in many regions of South Asia, East Asia, Australia and New Zealand. Figure.3 shows 25% increase in precipitation over whole Pakistan for last 100 years.

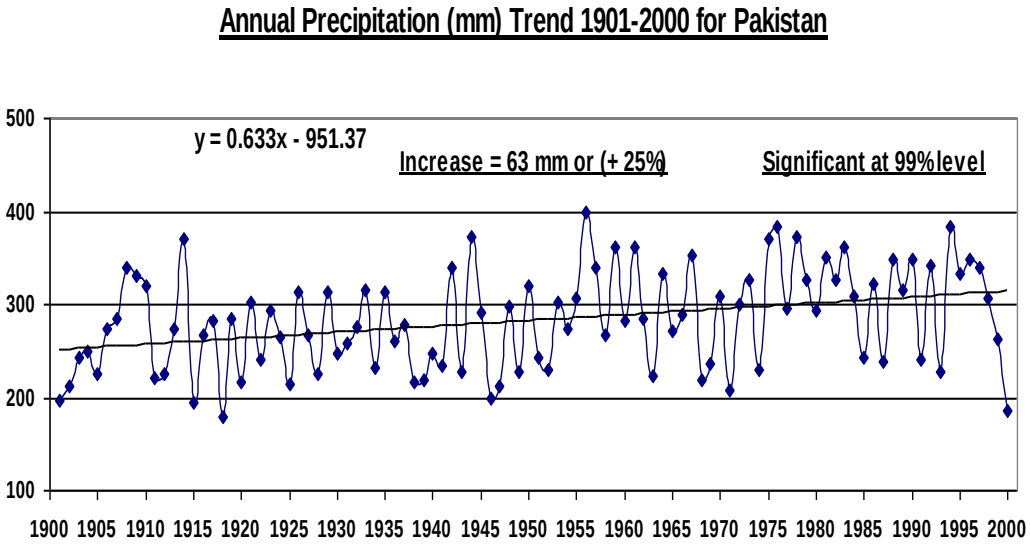


Figure 3: Precipitation Trend over Whole Pakistan using CRU Data (20th Century)

In addition to changes in global average precipitation, there could be more pronounced changes in the characteristics of regional and local precipitation due to global warming. In South Asian region these variabilities are mainly driven by global phenomena such as Indian Ocean Dipole, El Nino and La Nina. However, how these global phenomena relate to the variability in regional precipitation under monsoon system is complex and not yet fully understood.

4.2 Impacts due to Glacier's Retreat in HKH

The phenomenon of glacier retreat is of particular concern to Pakistan since its economy is heavily dependent upon Agriculture, which in turn depends upon the melt water from the glaciers and snowmelt in HKH region. It is particularly worrisome in the light of some recent reports forecasting the effect of glacier melt in the Himalayas particularly on the flows of Indus River System.

According to the World Bank Report, 2005, "Pakistan's Water Economy: Running Dry", Western Himalayan glaciers will retreat for next 50 years causing increase in Indus River flows. Then the glacier reservoirs will be empty, resulting in terrifying decrease of 30% to 40% in flow of Indus Basin over the century.

4.3 Floods

The existing flood management strategy includes flood flows regulation by three major reservoirs (Tarbela, Chashma on Indus & Mangla on Jhelum), protection of important private & public infrastructure, urban/rural abadies and adjoining agricultural lands located along the rivers banks by flood embankments and spurs & other interventions, besides, Flood Forecasting & Early Warning System, Rescue & Relief measures in case of flooding situation. The Provincial Irrigation Departments (PIDs) maintain about 6,807 km of flood protection embankments and around 1410 spurs along main and other rivers. Province-wise break up of existing flood protection facilities is given in **Table-1**.

TABLE-1: EXISTING FLOOD PROTECTION INFRASTRUCTURE

Sr. No.	Provinces / Federal Line Agencies	No. of Protection Works
1	Punjab	1,185
2	Sindh	261
3	Khyber Pakhtunkhwa	784
4	Balochistan	260
5	Gilgit-Baltistan	30
6	FATA	209
7	AJ&K	13
	Grand Total	2,742

Since its creation, Pakistan has faced 22 severe flood events i.e. 1950, 1955, 1956, 1957, 1959, 1973, 1975, 1976, 1977, 1978, 19981, 1983, 1984, 1988, 1992, 1994, 1995, 2010, 2011, 2012, 2013 & 2014, the 2010 floods were worst ever in the country. The floods of various magnitudes since 1950 to 2013 affected vast areas in the four provinces including Gilgit-Baltistan, FATA & Azad Jammu & Kashmir.

Flood damages are caused mainly due to riverine flooding in main rivers and flash floods in Secondary & Tertiary Rivers/Hill Torrents, Coastal flooding due to Cyclone & urban flooding due to torrential rains and inadequate storm drainage facilities, besides, GLOFs. The unprecedented floods of 2010 were the worst floods in history of the country in which about 1985 people lost their lives, 1,608,184 houses were damaged/ destroyed, 17,553 villages were affected and total area of 160,000 Km^2 was affected.

Owing to adverse impacts of climate change, in the recent years, vulnerabilities of communities to coastal & urban flooding have also increased. The Sindh province, particularly southeastern parts of the province was severely affected due to unprecedented rains and inadequate drainage facilities during Monsoon Season-2011. The torrential rains during 2012 rains/floods affected Southern Punjab, Sindh & Balochistan provinces; about 571 people lost their lives, 636,438 houses were damaged/ destroyed, 14,159 villages were affected and a total area of 4,746 Sq.km was affected.

The recent floods of 2014, affected cropped area of about 2.415 million acres (9,779 square kilometers) affecting 4,065 villages, claiming about 367 lives, fully damaging 107,102 houses and a population of about 2.600 million has been affected. The historical flood events experienced in the past and their damages are given in the **Table-2**.

TABLE-2: HISTORICAL FLOOD EVENTS IN PAKISTAN

Sr. No.	Year	Direct losses (US$ million)	Lost lives (No)	Affected villages (No)	Flooded area (Sq-km)
1	1950	488	2,190	10,000	17,920
2	1955	378	679	6,945	20,480
3	1956	318	160	11,609	74,406
4	1957	301	83	4,498	16,003
5	1959	234	88	3,902	10,424
6	1973	5134	474	9,719	41,472
7	1975	684	126	8,628	34,931
8	1976	3485	425	18,390	81,920
9	1977	338	848	2,185	4,657
10	1978	2227	393	9,199	30,597
11	1981	299	82	2,071	4,191
12	1983	135	39	643	1,882
13	1984	75	42	251	1,093
14	1988	858	508	100	6,144
15	1992	3010	1,008	13,208	38,758
16	1994	843	431	1,622	5,568
17	1995	376	591	6,852	16,686
18	2010	10,000	1,985	17,553	160,000
19	2011	3730	516	38,700	27,581
20	2012	2640	571	14,159	4,746
21	2013	2,000	333	8,297	4,483
22	2014	440	367	4,065	9,779
23	2015	170	238	4,634	2,877
24	**2016**	**6**	**153**	**43**	-
25	**2017**	**-**	**172**	**-**	-
Total		**38,171**	**12,502**	**197,273**	**616,598**

4.4 Glaciers Lakes Outburst Floods (GLOFs)

Glaciers movement is the major cause of abrading bedrock and valley sites. Advancing glaciers take lot of debris with them and spread near the snouts. They leave all their debris on retreat forming lakes surrounded by the moraines banks. Such lakes start filling with the melting ice as long as the moraine walls can hold the water pressure. With rapid melting of glaciers, glacier lakes level can rise over the banks formed of moraines can give way, leading to the catastrophic events known as Glacier Lakes Outburst Floods (GLOF), thus making these high altitude lakes potentially very hazardous. Most of such dangerous glacial lakes are concentrated near the headwaters of rivers basin just downstream of glaciers. Sometimes high floods are caused by the formation of temporary natural lakes by landslides or glacier movement and their subsequent collapse. In Pakistan, 2420 glacial lakes are identified in the HKH region covering a total area of almost 126 Sq. Km. Among these identified glacial lakes, 52 are declared as potentially dangerous glacial lakes (Roohi et al,. 2005). These potentially dangerous lakes can burst anytime and cause flash floods and are continuous risk to the downstream livelihood. There does not appear any specific coping mechanism against GLOF except the development of an effective monitoring and early warning system to forewarn the downstream dwellers of any imminent dangers of GLOFs.

As the glaciers are reported to be retreating worldwide and in particular glaciers in Himalayas region are retreating on faster rate, GLOF phenomena could be triggered and require urgent attention to develop an effective monitoring and warning system to save the life and property of most vulnerable people inhabiting the mountain slopes.

4.5 Droughts

Droughts are considered to be the most devastating phenomena which cause widespread damage to the biological potential of land, extinction of livestock and devastation of human life and economy. According to the IPCC “Technical Paper on Climate Change and Water draft for Government and Expert Review” increasing frequency and intensity of droughts in many parts of Asia are attributed largely to rise in temperature particularly during summer and normally drier months, and during ENSO events.

Pakistan experienced the worst drought of the history from 1998 to 2002. It was triggered by the history’s strongest El Nino event which not only distributed the weather pattern of Pakistan but all over the globe. Balochistan, Sindh and southern Punjab were the worst hit area where thousands of animal died, thousands acre orchards dried and a large proportion of population migrated to neighboring regions in search of survival. Large-scale migration put a huge pressure on natural resources of less affected areas creating shortage of commodities. Lesson should be learnt from this event and a contingency plan to cope such situation is the call of the moment.

4.6 Sedimentation and Loss of Reservoir Capacity

Pakistan, situated in arid and semi-arid zone, is suffering seriously with the soil erosion problems. This erosion, caused by glacier/ice melt and decrease in natural vegetation due to deforestation and improper land usage, deposits heavy sediments in the dams and reservoirs downstream.

The Indus River and its tributaries transport considerable amount (≅ 200 M ton/year) of sediment from their upper mountain catchments, causing silting in the major reservoirs located at Tarbela, Mangla and Chashma. Figure. 5 shows the original total design capacity of these reservoirs was 15.6 MAF. However, it is now estimated that, by 2025, the deposition of silt will further reduce their storage capacity by 33.12% (10.5 MAF).

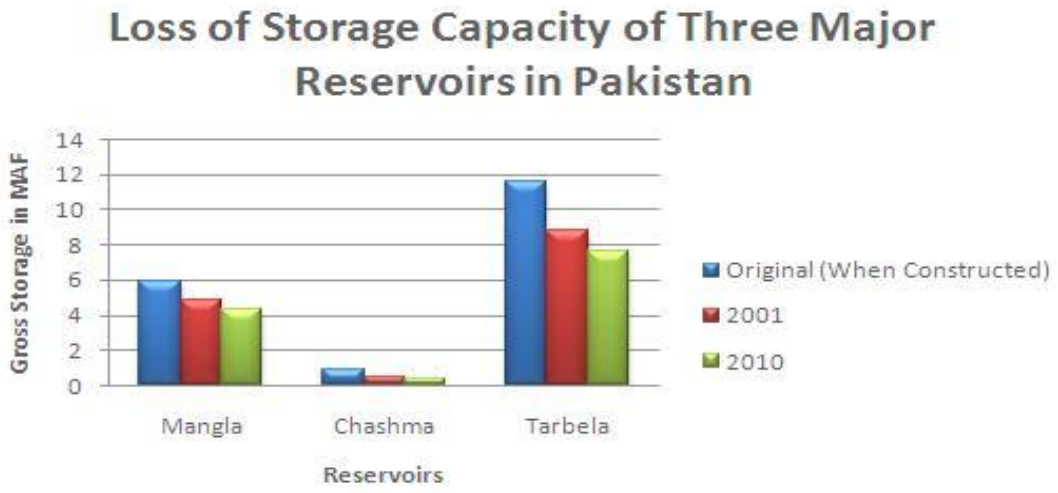


Figure 5: Loss of Storage Capacity of Three Major Reservoirs and Total

4.7 Groundwater Depletion

Groundwater in the Indus Basin aquifer, which can be withdrawn to put to beneficial use is neither unlimited nor permanent and has to be recharged. A larger yield can be obtained temporarily by pumping in excess of the prevailing recharge but can result further in a decline of water table and serious problems like quality and quantity of groundwater. This aquifer with a potential of about 50 MAF is being exploited to an extent of about 40 MAF by over 562,000 private and about 16,000 public tube wells (Kahlown & Majeed, 2004). According to IPCC Technical Paper on Climate Change and Water "Groundwater levels of many aquifers around the world show a decreasing trend during the last few decades, but this is due to excessive groundwater pumping and not to climate-related decrease in groundwater recharge". Although it seems direct climate effect but animal, plants and human beings living in warmer climate would extract more ground water to meet their requirements.

4.8 Sea Level Rise and Degradation of Coastal Areas

According to IPCC Fourth Assessment Report, 2007, the greatest increase in vulnerability is expected to lie on the coastal strips of South and South East Asia. In Pakistan there is 1050 km long coastline spread along the provinces of Sindh and Balochistan. In Sindh province mangroves are found in the Indus Delta and have an area of about 600,000 ha. In Balochistan province, the mangroves' total area is estimated to be 7,340 ha. These mangroves provide food and shelter during larval stage of the life cycle for some 80% of the commercial species caught from water. Indus delta Mangroves are the largest arid climate mangroves in the world an area of 345,000 ha.

Currently, the Indus Delta faces major threats due to inadequate fresh water flows in deltaic region. The increased variability in the river flows due to extreme climatic events expected under climate change will further aggravate the situation. Another major threat is the sea level rise, which could significantly contribute to losses of coastal wetlands and mangroves.

The IPCC Third Assessment Report (2001) identified sea level rise as one of the most important coastal impacts of global warming, and identified several key impacts. This seawater intrusion is also caused by sea level rise, a worldwide Climate Change related phenomenon. According to National Institute of Oceanography (NIO), Pakistan, the sea level at Pakistan's coastline shows an increasing trend of 1.1 mm/year, i.e. within global average range of 1.7±0.5 mm/year for the 20th Century (IPCC, Technical Paper on Climate Change on Water 2007).

5. Conclusions and Recommendations

Global warming is now an established phenomenon and effects are very clear in most parts of the world in the form of variability and intensity taking place in the climate system. Climate change has visible impacts on water, agriculture, forestry, biodiversity and ultimately the socio-economic sectors. It is predicted that there will be more droughts and floods in future due to climate change. In the wake of such changes, it is imperative to formulate a response strategy for short, medium and long terms. National Policy on Climate Change is an endeavor to face the adverse impacts of Climate Change.

The main objective of Climate Change policy relating to water sector is to assess the likely impact on water resources and to formulate a well-thought-out adaptative strategy for various sub-sectors of water to face the future challenges of Global Climate Changes. Also, draft National Water Policy submitted to CCI for final approval addresses the climate change impacts in a holistic manner. Following are the salient actions to be taken:

- Development of infrastructure to store more water for utilization in lean flow periods. To that end there is a greater need than even before to develop and forge national consenses on a cascading system of dams on river Indus utilizing all the available sites to discharge our liability to coming generations.
- Expedite work on construction of Mega dams, Small dams, and water harvesting projects. The financing factor retarding construction of mega dams may be addressed on war footings, exploring all the available avenues of funding.
- Stop wastage of water and resort to efficient water use
- Develop appropriate rainwater harvesting system commensurate with local needs.
- Construct series of water storages for retention of floodwaters for their effective utility.
- Protect life, property and infrastructure from floods, through a comprehensive and long-term flood protection plan. Develop a flood response plan and make

sure that general public is aware of this plan and if necessary public awareness level be raised through electronic and print media.

- Develop and implement regulatory framework for ground water use. Encourage to employ latest techniques for the extraction and skimming of fresh groundwater without disturbing the underlying saline water.
- Establish an institution to carry out research into the future availability of water especially in Climate Change conditions. As the climate change phenomenon is slow and long term, it requires a long-term commitment.
- Establish linkages between different water sector organizations for data and knowledge sharing.
- Ensure the water rights of the provinces in accordance with the 1991 Water Accord.
- Establish a database system on water sector information.
- Develop public awareness about importance of water

The array of potential adaptive responses available to human societies is very large. With too much uncertainties about the future water availability the best preparation for managing unpredictable future changes is to put in place a water resource infrastructure and management system which is driven to a much greater degree by knowledge (including but not limited to hydrologic knowledge), and which is designed and operated to be much more flexible and adaptive.

Paper No. 148

A REVIEW ON: WATER SAVING TECHNIQUES FOR DOMESTIC, AGRICULTURAL AND INDUSTRIAL WATER USAGE

Engr. Dr. Muhammad Saeed, Engr. Rahmat Ullah Sheikh, Engr. Muhammad Shoaib

A REVIEW ON: WATER SAVING TECHNIQUES FOR DOMESTIC, AGRICULTURAL AND INDUSTRIAL WATER USAGE

by

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Abstract

It is not only the agriculture sector where the aquifers are under increasing stress, but many of the major cities other than Lahore (within and outside the irrigation system) are facing water supply sustainability issues due to increasing population and industrialization, especially the urbanization phenomenon. It is a fact that the country is continuously approaching the low level limits of water availability, which is presently 915m^3/person/year.

Due to almost pause regarding development of large dams and sedimentation of existing reservoirs, the additional water consumption is being met from the aquifers; as a consequence unprecedented depletion and quality deterioration of the resource is an emerging issue. Similarly, increasing water stress has already alarmed to look into the reasons of emerging situation of excessive groundwater depletion in certain irrigated and urban areas like Lahore, with depletion rates of 16-55 cm/year and 40-150 cm/year, respectively.

It has been projected that urban water requirement for 25 major cities of Pakistan would be 6.34 and 8.67 BCM, for year 2030 and 2050, respectively, against the current supply of about 4.0 BCM. Therefore, the current situation of increasing water demands, calls for integration of water demand and supply within and across all the water use sectors, in addition to the construction of large dams by the Federal Government. In this regard, to save the freshwater, the responsibility lies to every individual for optimal usage.

The outcome of this paper is to promote water efficient techniques at individual and organizational level. The High Efficiency Irrigation System and other water saving techniques should be adopted in the agricultural sector in order to improve water productivity. Also, building additional mega dams and adopting integrated water resources management (IWRM) principles for overall water management at Indus Basin Irrigation System (IBIS) scale is the only option for sustainable water management. Also, public awareness raising both at political and masses level is recommended.

Keywords: Groundwater, water scarcity, water quality, depletion, aquifer, mega dams, water saving.

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1 Introduction

Water is the elixir for life. The quality of water is of vital concern for mankind because it sustains life. It is a matter of history that pollution of drinking water caused water born disease, epidemics and is still looming large of the horizon of developing countries like Pakistan. Adequate supply of potable safe water is absolutely essential and is the basic need for all human being on the earth. Due to rapid industrialization and subsequent contamination of surface and ground water sources, water conservation and water quality management has now-a-days assumed a very complex shape? Attention on contamination and its management has become a need of the hour, because of it's for reaching impact on human health. In order to ensure the right quality of water for this purpose it is extremely important to monitor underground water with all aspects into consideration.

Water is one of the most useful, most abundantly available substances in nature. It is an essential constituent of all animal and plant life. Water covers nearly 3/4th of the earth surface by liquid as well as solid ice. Water is distributed in nature in different forms, such as rain water, river water, lake water, sea water, ground water etc. Rain water is the purest form of naturally occurring water. It evaporates from sea as a result of extensive heat. Since rain water is produced by a process of distillation, it is considered to be the purest form of water. The rain water, however, is associated with dissolved gases such as CO_2, SO_2, and NH3 etc. from the atmosphere. Water is used for Domestic purposes such as drinking, cooking, washing, bathing. It is also used in Agricultural and Industrial purposes.

1.1 The Sources of Fresh Water:

1.1.1 Surface Water:

Surface water sub-classified into following types.

a) **Rain water**: Rain water is most pure form of water. It is naturally occurring as it is obtained by process of natural distillation. (Evaporation and condensation).

b) **River Water:** River water is another form of surface water. River water mainly contains dissolved inorganic salts comprising chlorides, sulphates, bicarbonates of Ca, Mg and Fe.

c) **Lake Water:** The chemical composition of lake water is almost fixed. It, usually, contains much less amounts of dissolved minerals than even well water, but quantity of organic matter present in it is quite high.

d) **Sea Water:** It is the most impure form of natural water. All impurities from river water are carried into the sea. Hence, sea water

1.1.2 Underground Water:

The rain water when reaches to ground, gets percolated in soil and becomes underground water. Generally, underground water is clear and colorless, but when water seeps down the ground, it dissolved inorganic salts.

2. Over view of current status of Pakistan against water availability, storage and usage.

2.1 Water Availability in Pakistan

Surface Water 154.88 MAF

Ground Water:

- Total irrigated area of Pakistan 39.5 Million Acres
- Saline groundwater area 24.7 Million Acres
- Fresh groundwater area 14.8 Million Acres
- Total quantity available 59 MAF
- Present extraction 50 MAF
- Balance 9 MAF (economic limit)

Pakistan is extracting 50MAF of groundwater against total resource of 59 MAF. The remaining 9 MAF has already reached its economic limits. The over-mining of aquifer has resulted in secondary salinization along with presence of fluorides and arsenic. This is degrading the quality of agricultural land and resulting in multiple diseases (Meredith A. G. & Peter G. M, March-2017).

Table 1: Surface Water Supply at Canal Level

Year	2004	2025
Water Availability	104 MAF	104 MAF
Requirement (including drinking water)	115 MAF	135 MAF
Overall Shortfall	11 MAF (10.5%)	31 MAF (29.8%)

* WAPDA Vision 2025.

2.2 Lake Storages

Pakistan has already reached water stress situation, a situation which is going to degrade into out-right water scarcity as a result of high population growth. On the other hand, up to April 2008, 1,017 MAF of water has gone to the sea unutilized over the last 30 years which is equivalent to 10 years of canal withdrawals. In monitory terms, the value of unutilized water is US$ 149 billion after deducting 300 MAF required for environmental purposes.

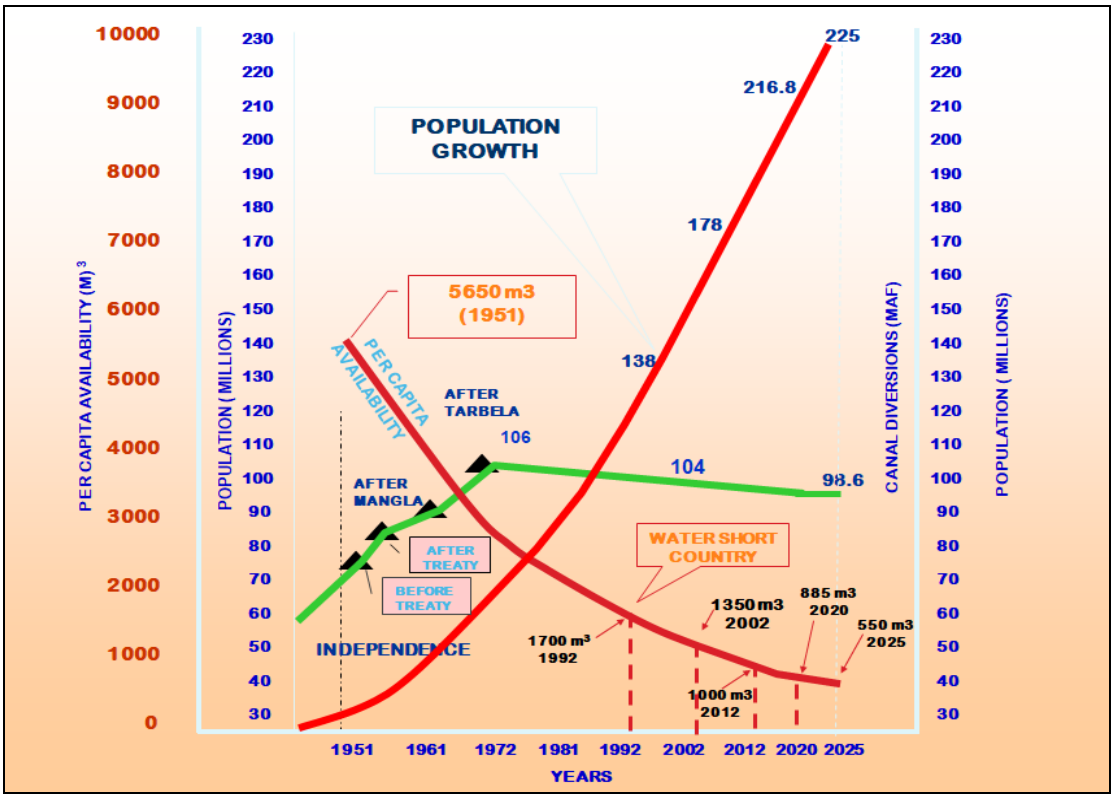


Figure 1: Per Capita Storage (*WAPDA Vision 2025).

2.2.1 Per Capita Storage

Pakistan's storage capacity is only 132m^3/person as against Australia's 5000m^3/person and is reducing due to sedimentation.

America	6,150 m^3/person
Australia	5,000 m^3/person
Pakistan	132 m^3/person

2.2.2 Carry over Capacity

Egypt (Aswan)	1,000 days (Niles)	Australia	600 days
America	900 days (Colorado)	India	120 to 220 days
South Africa	500 days (Orange River)	Pakistan	30 days

For better water management, 40% of total water availability is required for storage, but Pakistan's storage capacity is only about 7% of total available water.

Table 2: Water Storages Capacity in Pakistan

RESERVOIR	LIVE STORAGE CAPACITY		STORAGE LOSS	
	ORIGINAL	YEAR 2013	YEAR 2013	YEAR 2025
TARBELA	9.69 (1974)	6.58 (68%)	3.11 (32%)	4.16 (43%)
MANGLA (POST RAISING)	8.24 (2012)	7.39 (90%)	0.85 (10%)	1.16 (20%)
CHASHMA	0.72 (1971)	0.26 (36%)	0.46 (64%)	0.64 (89%)
TOTAL	18.65	14.23 (76%)	4.42 (24%)	5.96 (37%)

* WAPDA Vision 2025.

3. Current water usage in Pakistan

3.1 Productivity per Unit of Water

Pakistan's productivity per unit of water is one of the lowest in the world. It is only one third of that of India. (Parameshwar Hegde, 2016)

Canada	8.72 kg/ m^3	USA	1.56 kg/ m^3
China	0.82 kg/ m^3	India	0.39 kg/ m^3
Pakistan	0.13 kg/ m^3		

3.2 Productivity per Unit of Land

Pakistan's productivity per unit of land is also one of the lowest in the world and is even less than arid countries like Saudi Arabia and Egypt. (Col Harjeet Singh, 2010)

France	7.60 T/ha	Egypt	5.99 T/ha
Saudi Arabia	5.36 T/ha	Punjab (India)	4.80 T/ha
Pakistan (Average)	2.24 T/ha	Punjab (Pak)	2.30 T/ha

3.3 Pakistan's contribution to GDP per unit of water

World average contribution of per cubic meter of water to the GDP is US$ 8.6 whereas Pakistan's contribution per cubic meter of water is less than half of that. On the other hand, in developed economies the contribution of one cubic meter of water ranges from US$ 30 to 40 (Ahmed and Gautam, 2013).

World (Average)	8.60 US$	Developed Countries	30-40 US$
Malaysia	10 US$	Pakistan	0.34 US$

4. Water Management Technologies:

4.1 Investigate the feasibility of the following general options in your operations.

- Reducing the flow of water.

- Modifying the equipment or installing water saving devices.
- Replacing existing equipment with more water-efficient equipment.
- Water treatment, recycling, and reuse.
- Changing to less water using process. (Watersmart Guidebook)

4.2 Buildings

4.2.1 Install water efficient fixtures in restrooms and showering areas.

- Industrial facilities often have domestic water uses such as toilet flushing, sinks for hand washing, and showering facilities. These represent great opportunities for water savings (Watersmart Guidebook for Restrooms Plumbing).
- Examples of fixtures that can be retrofitted include:
- High-Efficiency Toilets
- High-Efficiency Urinals
- Faucet aerators in sinks used for hand washing
- Efficient showerheads

4.2.2 Manage on-site laundry facilities efficiently.

Many industrial and commercial facilities consume a considerable amount of water for laundering.

- For residential style washing machines be sure and select a low water factor. As of January 1, 2011 top and front loading Energy Star clothes washers will be required to have a water factor of 6.0 or less. Whereas the standard water factor is 9.5.
- Multi-load machines should be set to run efficiently with separate settings for each cycle.
- If large volumes of laundry are being processed assess the feasibility of installing a tunnel washer.
- Evaluate costs and benefits for using laundry systems that recycled water or use ozone technology.

4.2.3 Utilize efficient technology in kitchen areas.

Kitchen facilities are a likely candidate for reducing water use in any facility. The following are items that can be retrofitted:

- Rinse dishes with an efficient pre-rinse spray valve
- Use a dishwasher that meets Energy Star standards
- Install in-line flow restrictors for dipper wells. Also look for new water efficient dipper well technology

- Replace boiler based food steamers with boiler-less technology
- Strainers can reduce water used by garbage disposals

4.3 Employees

Creating a workplace culture that focuses and takes pride in efficiency can be a very beneficial component of a water conservation plan. Increased awareness will ensure more staff members are monitoring water use (AWE Business Guide, 2013).

Things that can be done:

- Give recognition to those who initiate water-efficiency procedures and processes.
- Make resource conservation part of performance reviews, especially for line managers.

4.4 Equipment

4.4.1 Improve cooling tower efficiency.

Cooling towers often represent the largest percentage of water consumption in industrial operations. Some ways to improve the efficiency of cooling towers and reduce water use include:

- Eliminate once-through cooling.
- Install a conductivity controller on each cooling tower.
- Equip cooling towers with overflow alarms.
- Use high-efficiency drift eliminators.
- Install sub-meters to monitor make-up and bleed on each cooling tower.
- Properly train and educate cooling tower operators. (AWE Introduction to Cooling Towers)

4.4.2 Replace water-cooled equipment with air-cooled equipment when feasible.

Water use is often a hidden component of industrial and commercial equipment as it is used for cooling purposes. Often this equipment is available with technology that uses air for cooling. The pros and cons of each should be determined before switching. A couple factors to consider are energy efficiency and performance.

Equipment that falls into this category includes:

- Air compressors
- Vacuum pumps
- Ice machines
- Refrigeration condensers
- Hydraulic equipment

- X-ray processing equipment

4.4.3 Retrofit steam sterilizers.

Steam sterilizers are utilized by hospitals, research institutions, and pharmaceutical manufacturing. Steps can be taken to reduce the water used by these devices:

- Jacket and Chamber Condensate Cooling Modification
- Ejector Water Modification

4.5 Landscaping/Irrigation

If an irrigation system is used, make sure it is properly set up and maintained.

- Irrigate hydrozones based upon the plants' water needs.
- Install weather-based SMART irrigation controllers.
- Regularly inspect the sprinkler heads to make sure they are not damaged or malfunctioning in any way.
- Adjust sprinklers so they are not spraying water on paved surfaces.
- Install and maintain rain sensors, either wireless or wired, on the irrigation controller if it does not have a built-in one.
- Have an irrigation professional design, install and maintain the irrigation system.
- Specify in professional services contracts and check regularly that landscaping maintenance employees/contractors follow landscape industry best management practices.

4.5.1 Landscape with water-wise landscaping principles

Many commercial and industrial facilities have landscapes that require irrigation. Taking action to make this efficient can save a lot of water:

- Use native plants or other plants that require little water to thrive in your region.
- Plant turf grass only in areas where people will use it actively for recreation.
- Organize your landscape into hydrozones. Hydrozones are areas of landscape with plants and vegetation that have similar water requirements. This prevents over watering of some plants and avoids under-watering of others.
- Keep soil healthy and add mulch to prevent water loss through evaporation.
- If watering with a hose, make sure it has a shut-off nozzle.
- Water landscapes in the morning to prevent water loss due to evaporation. Avoid watering when it is windy.

- Use a rain barrel to collect water for use in the landscape.

4.5.2 Water conservation technologies in Irrigation

Following are some technologies to preserve water in irrigation

1. Precision Land Leveling
2. Bed Planting Technology
3. Drip Irrigation System
4. Bucket-drip Irrigation System
5. Watercourse Improvement
6. Pit sowing for Sugarcane
7. Tunnel Farming
8. Rainwater harvesting
9. ASR Technology
10. Skimming Well Technology
11. Solar operated Tube well
12. Perforated Pipe Irrigation System
13. ICT in Agriculture
14. Reuse of Wastewater for Irrigation

Table 3: High Efficiency Irrigation Systems

S.r. #	Crop	Water Saving (%)	Yield Increase (%)
1	Cotton	62	60
2	Sugarcane	47	167
3	Maize	35	75
4	Citrus	22	44
5	Mango	36	100
6	Potato	62	75
7	Onion	56	69
8	Tomato	50	150

4.6 Other Water Saving Techniques

4.6.1 Dry sweep or use a water broom when possible, instead of using a hose to clean floors, sidewalks, and other hard surfaces.

Water brooms should be used only when traditional brooms are not able to clean the surface in a satisfactory manner. Additionally, water brooms are superior to hose and spray nozzles in both water efficiency and cleaning effectiveness.

4.6.2 Make sure all hoses are equipped with an automatic shut-off nozzle.

Hoses that don't have an automatic shut-off nozzle and are left running can waste 8-12 gallons (30.3-45.4 liters) per minute.

4.6.3 Use non-potable water for industrial process use.

Potable water is often not required for many industrial uses and can be substituted with non-potable or reused water. Sources include but are not limited to air conditioner condensate, cooling tower blow down, and rainwater.

Following are some technologies to preserve water in irrigation.

6. Conclusion and Recommendations

6.1 Conclusions

Pakistan's storage capacity is only 132m^3/person as against Australia's 5000m^3/person and is reducing due to sedimentation.

Pakistan's productivity per unit of water is one of the lowest in the world i.e. 0.13 kg/ m^3, it is only one third of that of India.

For better water management, 40% of total water availability is required for storage, but Pakistan's storage capacity is only about 7% of total available water.

World average contribution of per cubic meter of water to the GDP is US$ 8.6 whereas Pakistan's contribution per cubic meter of water is less than half of the world average.

Pakistan's productivity per unit of land is also one of the lowest in the world i.e. 2.24 tons/ha and it is less than arid countries like Saudi Arabia and Egypt.

6.2 Recommendations

Landscape with water-wise landscaping principles may be adopted.

Install water efficient fixtures in restrooms and showering areas.

Replace water-cooled equipment with air-cooled equipment when feasible.

Make sure all hoses are equipped with an automatic shut-off nozzle.

Dry sweep or use a water broom when possible, instead of using a hose to clean floors, sidewalks, and other hard surfaces.

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Paper No. 149

FLOOD WATER STORAGE IN AQUIFER THROUGH NATURAL RECHARGE- A CASE STUDY OF RECHNA DOAB, PUNJAB, PAKISTAN

Ghulam Zakir Hassan, Ghulam Shabir, Faiz Raza Hassan, Saleem Akhtar

FLOOD WATER STORAGE IN AQUIFER THROUGH NATURAL RECHARGE- A CASE STUDY OF RECHNA DOAB, PUNJAB, PAKISTAN

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Abstract

Pakistan is the 4th largest user of groundwater where groundwater is being used to meet the needs of agriculture, industrial and domestic sectors. Groundwater exploitation meets approximately one fifth of current world water needs for all uses combined. Water resources in Pakistan are limited to groundwater and rainfall that falls on the mountainous area which might cause flash floods. In Indus Basin, aquifer is considered the main water supply that fulfills the water demands of different users in the Country. During the past 50 years, the aquifer exhibits a continuous decline in the water level and gradual increase in the water salinity. The Indus Basin aquifer is recharged mainly from the limited rainfall and the flash floods in the Indus irrigation System. Rechana Doab is identified as a flood prone area where several flash floods were recorded and resulted in significant infrastructural damages, population displacement and sometimes loss of lives. The aim of this research is to identify the natural recharge of shallow aquifer through flood water storage.

In January 2014, a major flood event was occurred and caused significant changes in the hydrogeologic conditions of the shallow aquifer where groundwater levels and water salinity are periodically measured through extensive monitoring wells installed by Punjab Irrigation Department. The data of monitoring wells shows that after the flood 2014 in Rechana Doab, an average increased in the groundwater levels was 2.57 ft. The estimated volume of flood water stored in aquifer of Rechana Doab through natural recharge after flood 2014 was 1.90 MAF. While the potential of diversion and storage of flood water is 14 MAF. It has been further concluded that besides huge damages from floods, if flood water is stored in aquifer through natural recharge by adopting safety measures, it will have many benefits including recharge of aquifer, conservation of water resources and reduce the pollution concentration. Furthermore, this water could be used at later stage through shallow groundwater wells.

Key words: Flood Storage, Indus Basin, Rechana Doab, Punjab, Pakistan

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Background

Groundwater, as a natural resource and an element of the environment, used in human activities, is of a dual character **(Borevsky et al., 1989).** On one hand, it is a moving resource in the earth depths and abstracted out of it. On the other, it is a part of total water resource of the earth in many countries i.e95%in Tunisia, in Belgium it is 83%, in the Netherlands, Germany and Morocco it is 75%. It is used for Agriculture, Industrial and Domestic sectors. In most of European countries (Austria, Belgium, Denmark, Hungary, Romania and Switzerland) groundwater use exceeds 70% of the total water consumption. In countries with arid and semiarid climate, groundwater is used for irrigation (Southern and Western areas of the United States of America, Spain, Greece, Iran, India, the Yemen and some other areas of Africa and Asia). Groundwater exploitation meets approximately one fifth of current world water needs for all uses combined. That proportion varies by country and by sector (UNESCO, 2004). Most of the 750-800 billion m3/year of global groundwater withdrawals are used for agriculture (Shah et al., 2000). At the same time, global water scarcity forms a major constraint on sustaining and enhancing agricultural productivity. Between 1900 and 1995, the demand for freshwater increased six fold, which was twice the rate of population growth (Gleick, 1993).

Pakistan is blessed with a plenty of water resources including a large groundwater reservoir underlying the Indus Basin but this natural resource is under serious threats and need immediate measures for its sustainable utilization. Due to increased population, industrial evolution, development of infra structures and reduction in recharge, groundwater is in under tremendous pressure in urban areas. For example in Lahore city (provincial capital) groundwater has fallen even more than 100 ft below the natural surface and average annual rate of groundwater depletion is 2.54 ft. Pakistan is 4^{th} largest user of groundwater after India, USA and China. In Pakistan, current per capita water availability (1200 m^3/person) is low, which puts us in the category of a high water stress countries on the globe. UNESCO predicted that by 2020 water shortage will be a serious worldwide problem (WWAP, 2012).

Agriculture is the single largest sector of Pakistan's economy contributing about 21.8% of the Gross Domestic Product (GDP), and is the source of earning of 44.7% of the total employed manpower of the country. However, the potential of agricultural production and to bring more area under cultivation depends on availability of water. Surface alongwith availability of groundwater has helped in increasing cropping intensity from 67% in 1947 to 150% or even more in 2015.The annual groundwater pumpage has increased from 4 billion m^3 in 1959 to around 60 billion m^3 in 1999-2000. About 79 % area in Punjab and 28% area in Sindh provinces had fresh groundwater suitable for agriculture Afzal (1999) and Bhutta (1999). In Punjab province about 40-50% crop water requirements are being met from groundwater through about 1.2 million tubewells installed by the farmers. Whereas surface water is not evenly distributed over the year and seasonal variation, droughts and floods can create extreme situations. During the past 50 years, the aquifer exhibits a continuous decline in the water level and gradual increase in the water salinity (Hassan et al, 2014) which indicates that the abstraction exceeding natural recharge.

Flood water should be recharged to store water which is mostly wasted during flood. In some country of the world i.e. in Paleozoic aquifers systems, 50,000 km^3 volume of water was stored and the natural recharges based on the river base flow data was estimated at 234 km3/yr (Rebouças, 1976). The main objective of the present work is to identify flash floods and the contribution extent of floods to recharge the shallow groundwater aquifer of Rechana Doab.

2. Study Area

2.1 Location Study Area

The current study was carried out to identify the flash floods in Ravi and Chenab Rivers and natural recharge of flood in Rechana Doab (area between Ravi and Rechana Rivers). Study area is located in the Punjab Province and falls in north-eastern part of Pakistan. Rachana Doab is bounded by two rivers, on the South and East by the Ravi River while on the North and West by the Chenab River respectively. It lies between longitude 71°48′ E to 75°20′ E and latitude 30°31′N to 32°51′ N. The gross area of this Doab is approximately 2.97 million ha, with a maximum length of 403 km and width of 113 km, including 2.3 million hectares of cultivated land. It is one of the oldest and most intensively developed irrigated areas of the Punjab, Pakistan.

2.2 Topography and Geomorphology

The topography of Rechana Doab area is flat in general with a little slope from North to South ranging from about 0.25 m/km in the north and northeast to less than 0.2 m/km to the south and southwest. The hydraulic gradient in the upper half of Rechana Doab is steeper than the land surface gradient, but flattens out markedly in lower reaches of the Doab. The aquifer depth varies from 300 to 500 m **(WAPDA 1976).**

2.3 Soil and Aquifer parameters

The alluvial sediments mainly consist of grey and greyish-brown fine to medium sand, silty sand, silt and clay. Gravel and very coarse sand are uncommon; Kankar, a calcium carbonate material of secondary origin, is found associated with fine grained strata. Some areas with similar soil composition contain high percentage of silt and very fine to fine sand with low percentage of clay. Pure clay is generally found in lenses but is not common in the area. Porosity was estimated at 0.35 from drill cuttings by Greenman et al (1967). Estimates of specific yield are from 0.07 to 0.25, with a few values as low as 0.01 and as high as 0.40. The average value for all tests was 0.14. The horizontal permeability is greater than vertical (Bennett et al., 1967).

2.4 Climate

Rechana Doab is mostly comprises of Semi-Arid on the basis of climatic conditions. The annual precipitation here is 250-500 mm. Climate depending on geographical locations, is typically characterized by four seasons: a cool and dry winter period (December to February), hot and dry spring (March to May), rainy summer or monsoon period (June to September) and a retreating monsoon period (October and November). There is a great variation in the patterns of rainfall in different climatic regions of Pakistan. The monsoon rain occurs from mid-July to mid-September caused by winds arising from the Bay of Bengal whereas the winter rains normally originate from the Arabian Sea. The monsoon accounts for about 75% of annual rainfall.

2.5 Irrigation System

Nature has blessed our country with plenty of surface water which originates from Himalayans in the north and flows toward Arabian Sea through river Indus and its tributaries. Rivers are natural channels which carry a huge quantity of surface water. The discharge in a river increase as it flows from the mountains to the sea because the catchment area increases and large number of streams and tributaries join it.

Irrigation System of Pakistan is the largest irrigation network in the world. It is mainly comprises of Indus River and its tributaries, three reservoirs, 19 barrages, 12 inter-river link canals, 45 main canals. A number of barrages and head works were constructed on different rivers. The main tributaries of Indus are eastern rivers includes Sutlej, Beas, Ravi and western rivers Chenab, Jehlum. Under the Indus Basin Treaty 1960, water of eastern rivers was allocated to India and water of western rivers was allocated to Pakistan. Irrigation of Rechana Doab is plotted in figure.1).

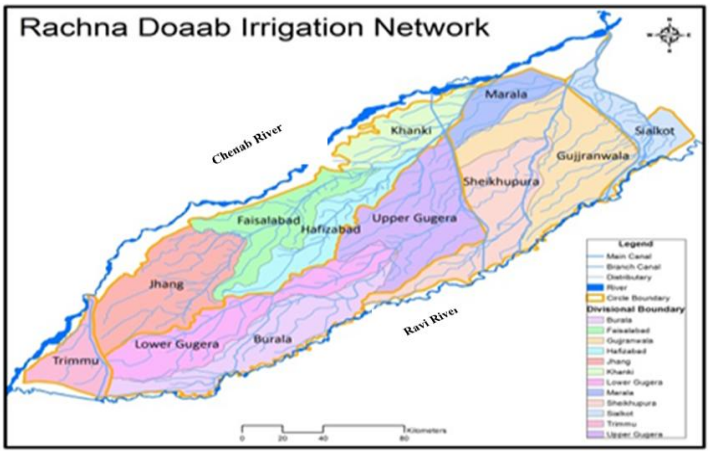


Figure 1: Irrigation network in Rechna Doab

Chenab River

Chenab River, the western river, enters in Pakistan a little over Head Marala with very sharp changes in slope (130 ft/mile above Tandi reduced to 2 ft/mile close to Trimmu). Its length in Pakistan is 880 km with 11,399 square mile catchment area. Chenab River comprises four barrages (Marala, Khanki, Qadirabad and Trrimmu) and head works which were constructed for water control and water diversion into canals. Its average annual flow rate is 26 MAF. Chenab River has twelve major tributaries (6 each in occupied Jammu & Kashmir and Pakistan). Palkhu is the largest tributary of Chenab River. Its length is 75 miles with 793 Sq.miles catchment areas. Floods in Chenab River and Jhelum River are mostly due the result of excessive rainfalls in its hilly catchment in lower Himalayas. Snowmelt makes no significant contribution in flood peaks in Chenab River. Since, there is no storage reservoir across Chenab River due to which peak flood flow cannot be minimized.

Ravi River

Ravi River is the smallest of five eastern rivers of the Indus River System (IRS). It enters in Pakistan at Jassar, about 120 km upstream of Lahore and joins the Chenab River

near Kabirwala after flows down about 520 km. Its length in Pakistan is 731 km with 11,399 square mile catchment area. Its average annual flow rate is 7 MAF. Ravi River comprises two barrages (Balloki and Sidhai) and head works which were constructed for water control and water diversion into canals. The average annual flow of the Ravi River in Pakistan territory was 7 million acre feet (MAF) during the period 1922 to 1961 but due to Indus Water Treaty of 1960 between India and Pakistan, right to use the water of this river were allocated to India. The average annual flow from 1985 to 1995 was recorded as 5-MAF which was further decreased to 1.1 MAF in years 2000-2009 due to construction of hydropower projects/dams on Ravi River by India. Ravi River seems to be the main source of recharge in the North-West of Lahore. For the last two decades, Ravi River remained almost dry except in monsoon, so the recharging through River has seriously decreased.

3. Floods and Its Causes

Floods are generally caused by different natural processes and human activities. Floods have been recognized as a major natural calamity in Pakistan and the country has a long history of flooding from the Indus River and its tributaries (Chenab River, Jhelum River, Ravi river, Sutluj River and Beas River).

Floods in the Chenab River and Ravi are related to high intensity rainfall and/or releases of water from reservoirs in the upper reaches. Flooding is caused by the inadequate capacity within the banks of rivers to contain the high flows brought down from the upper catchments. The problem is exacerbated because of obstructions to flow, silting up of river beds, etc.

The previous highest floods discharge recorded in the rivers after the creation of Pakistan are indicated in the Fig.2.

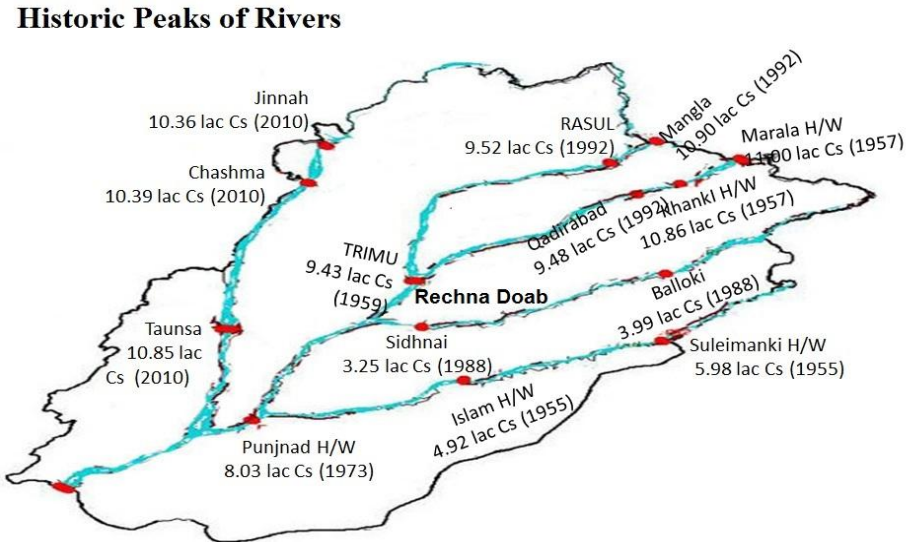


Figure 2: Historic peaks discharges in Indus River and its tributaries during Floods.

Source: Irrigation Department

3.1 Positive Aspects of Flood 2014

Water a component of the natural environment play role of backbone for the existence of life on the planet earth. It is a renewable but finite resource and is unevenly distributed with time and space. Province Punjab has experienced flood events during the past several decades. Flood during 2014 resulted in significant infrastructural damages, population displacement and sometimes loss of lives. In the province of Punjab but also have some positive aspect on the aquifer.

3.2 Flood Water Storage in Aquifer through Natural Recharge

Natural groundwater resources are understood to be the total amount of recharge (replenishment) of groundwater under natural conditions as a result of infiltration of precipitation, seepage from rivers and lakes, leakage from overlying and underlying aquifers, and inflow from adjacent areas. This definition has been generally accepted. However, some researchers (Vsevolozhskii et al., 1984) hold that natural groundwater resources have to include infiltrating irrigation water, seepage losses from channels and reservoirs in addition to natural recharge, i.e. natural groundwater resources represent total replenishment under conditions not disturbed by development.

According to research studies, storing of flood water as groundwater has a number of essential advantages when compared with surface water: as a rule it is of higher quality, better protected from possible pollution including infection, less subject to seasonal and perennial fluctuations, and much more uniformly spread over large regions than surface water. Very often groundwater is available in places where there is no surface water. Putting groundwater well fields into operation can be gradual in response to growing water demand while hydro technical facilities for surface water use often require considerable one time investments.

4 Results and Discussion

4.1 Impact of Flood on Groundwater Recharge

Ranges of depth to watertable (DWT) and groundwater recharge potential in Rechana Doab during post monsoon of year, 2010 are elaborated in Table 1&2.

Table 1: Area with different Ranges of Watertable depth in Rechana Doab during Oct. 2010

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

Table 2: Area for Groundwater Recharge Potential in Rechana Doab during Oct. 2010

Depth to be Recharged (m)	Area		Specific Yield	Volume of Water (ha.m)
	(ha)	(acre)		
1.50	1174321	2900574	0.20	352296.30
4.50	839591	2073790	0.20	755631.90
8.00	303222	748958	0.20	485155.20
12.50	134568	332382	0.20	336420.00
17.50	6006	14835	0.20	21021.00
Total Volume of Water Hectare Meter (ha.m)				**1950524.40**
Million hectare meter (Mha.m)				**1.95**
Million Acre Feet (MAF)				**15.80**

Different watertable depth ranges (percent area) in Rechana Doab during October, 2010 and June -2012 are represented in Bar chart as shown below in Figures. 3 & 4.

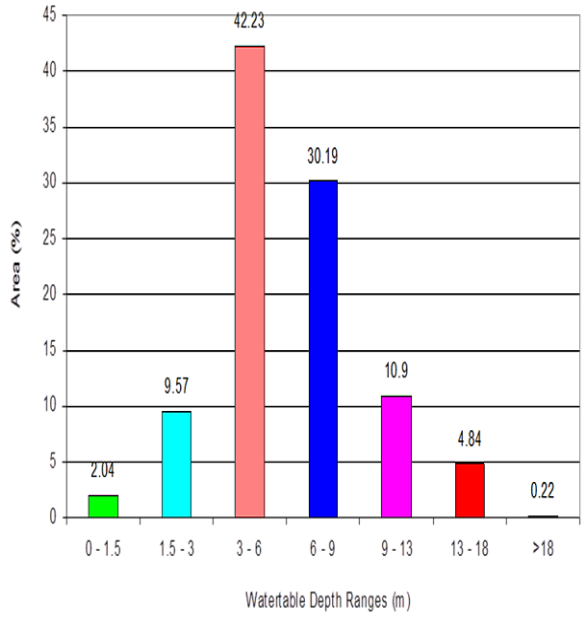


Figure 3: Area (%) in Rechana Doab with watertable depth ranges during October, 2010

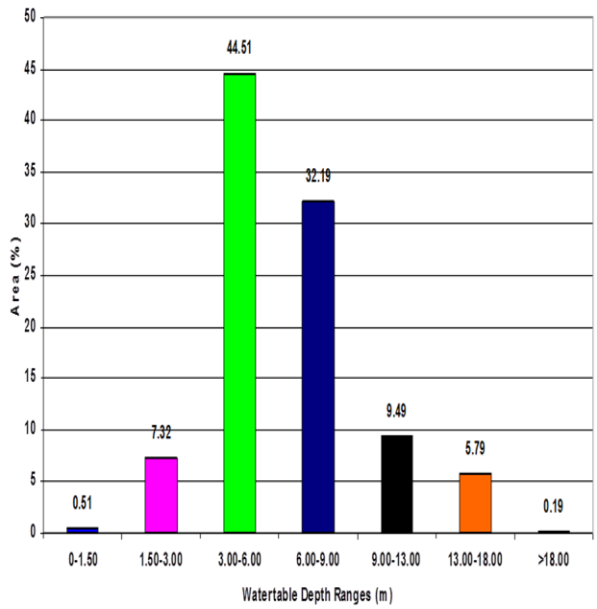


Figure 4: Area **(%)** in Rechana Doab with watertable depth during Jun-2012

Table 3: Recharge Potential in irrigated areas of Rechana Doab during Jun-2012

Depth to be Recharged (m)	Area (ha)	Area (acre)	Specific Yield	Volume of Water (ha.m)
1.5	1239234.01	3060908	0.2	371770.2
4.5	896170.85	2213542	0.2	806553.8
8	264283	652779	0.2	422852.8
12.5	161063.16	397826	0.2	402657.9
17.5	5173.68	12779	0.2	18107.89
Total Volume of Water Hectare Meter (ha.m)				**2021943**
Million hectare meter (Mha.m)				**2.022**
Million Acre Feet (MAF)				**16.381**

Fig. a

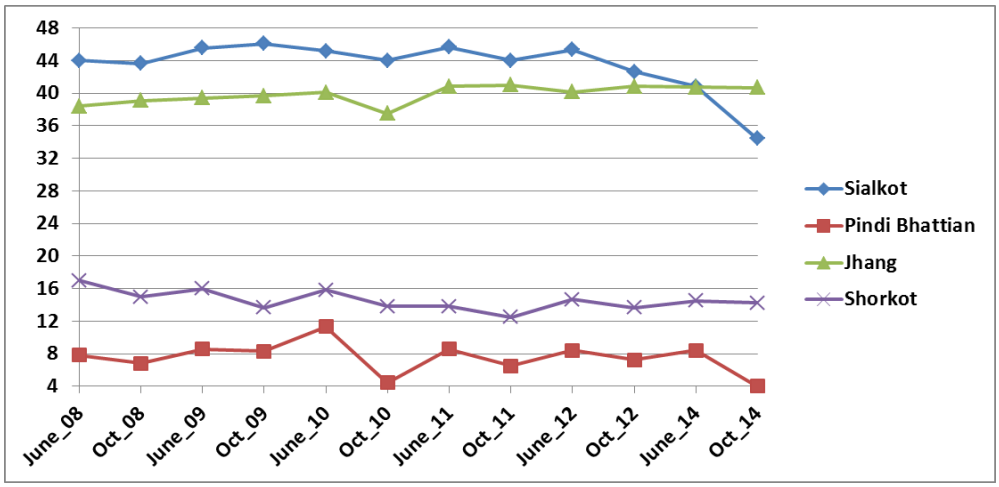
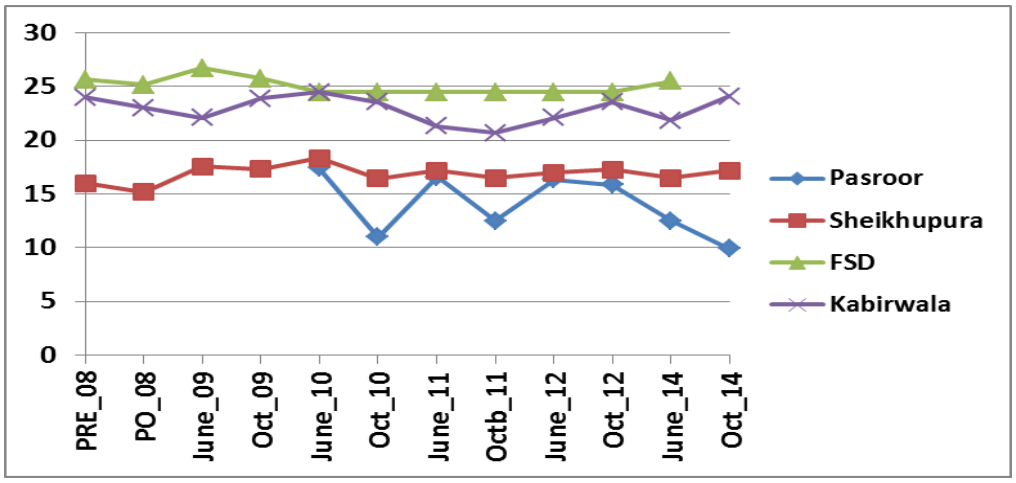


Fig. b 2



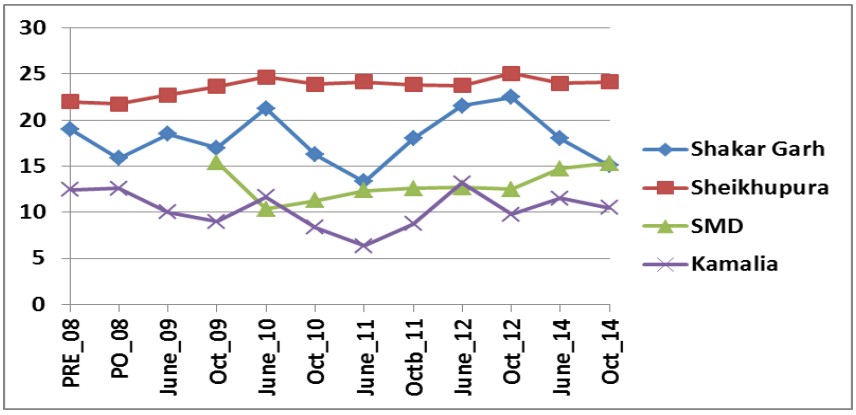


Figure 5: (a, b & c): Temporal fluctuations in depth to watertable (ft below NSL) at selected points in Rechana Doab (2008 to 2014)

Groundwater is brackish for which one of the causes is heavy industrial pollution in the West areaof Faisalabad especially where is no irrigation system. Groundwater investigation was conducted byapplying Groundwater Model (MODFLOW). It was further observed that along the rivers and canals, groundwater level is higher and quality is good (IRI, 2012).

Groundwater monitoring at different sites of the provinces conducted during year 2010, 2011 and 2012 indicated that Groundwater levels fell at an average rate of 1-2 ft/year in some areas of Rechana Doab as shown in figure 5 (a, b &c). Recharge potential in Rechana doab during October 2010 and June 2012 were found out as 15.80 and 16.381MAF respectively. Groundwater monitoring at different sites of the provinces was conducted after monson. Data analyse indicates that groundwater level in Rechana Doab increased at average 2.57 ft/season due to flood 2014 (Figure. 6). Total recharge of groundwater during flood season 2014 Doab was 1.90 MAF (IRI, 2015)in other words 1.90 MAF of flood water was stored in aquifer through natural recharge.

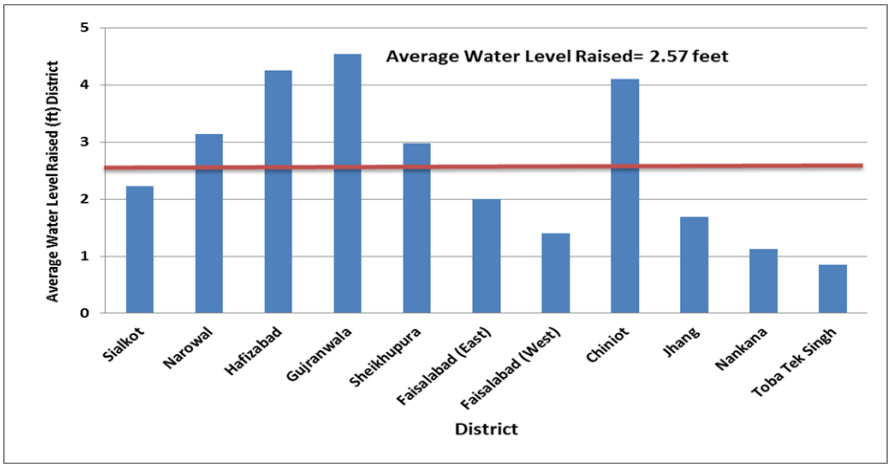


Figure 6: Average water level raise (ft) in various areas in Rechana Doab after flood 2014

Table 4: Groundwater Recharge potential- Rechana Doab

DTWT (ft)	Km^2	%age	Depth to be recharged (ft)	Potential for Recharge (MAF)
<10	2184	9	0	0.00
10-20	10596	43	5	2.62
20-30	7102	29	15	5.26
30-40	3129	13	25	3.86
>40	1762	7	30	2.61
Total				**14**

Recharge potential in Rechana Doab during flood 2014was found up to 14.0 MAF (Table-4).

Comparison of Groundwater levels in Rechana Doab were elaborated in the figure 7, when there is no flood and after flash floods in the rivers. Thiessen Polygons using GIS were dawn to calculate total natural recharge from flood 2014 in different areas of Rechana Doab. (Figure 8). After floods, percent of area of water table less than 10 feet was increased from 9 % to 17 percent (%) whereas area of water table ranges from 10-20, 20-30, 30-40 and less than 40 feet decreased respectively (Figure. 9)

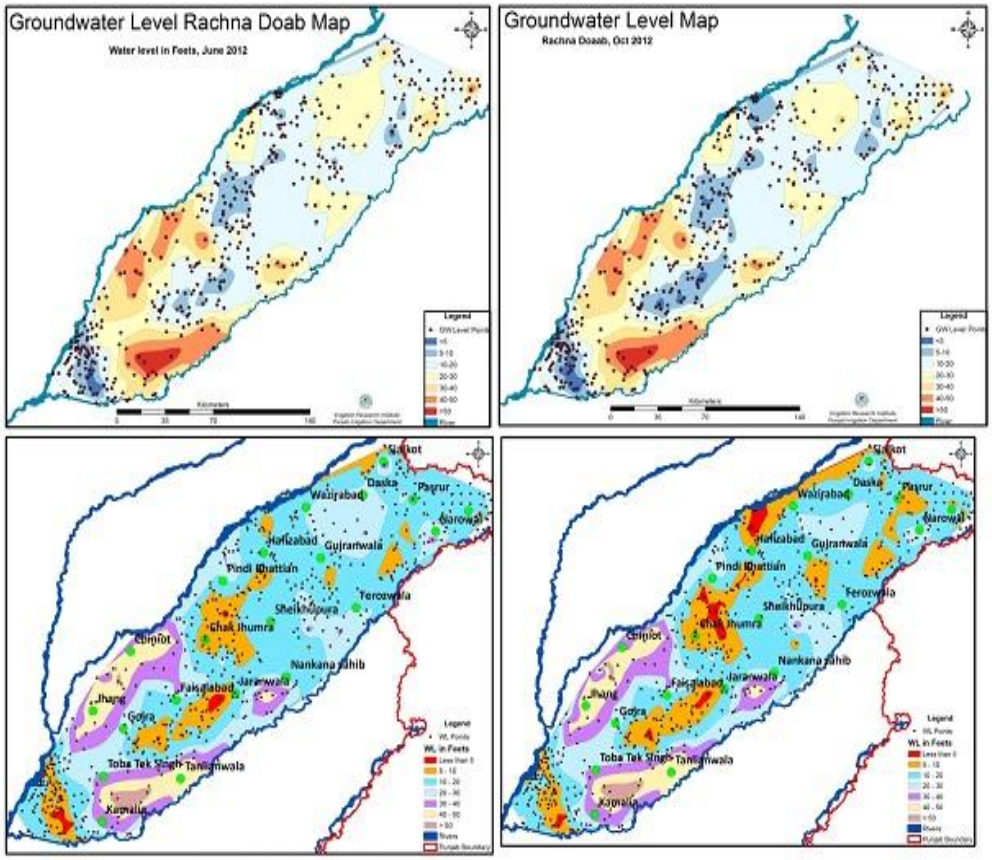


Figure7: DTWT situation in Rechana Doab during pre-monsoon and post-monsoon (2012 and 2014)

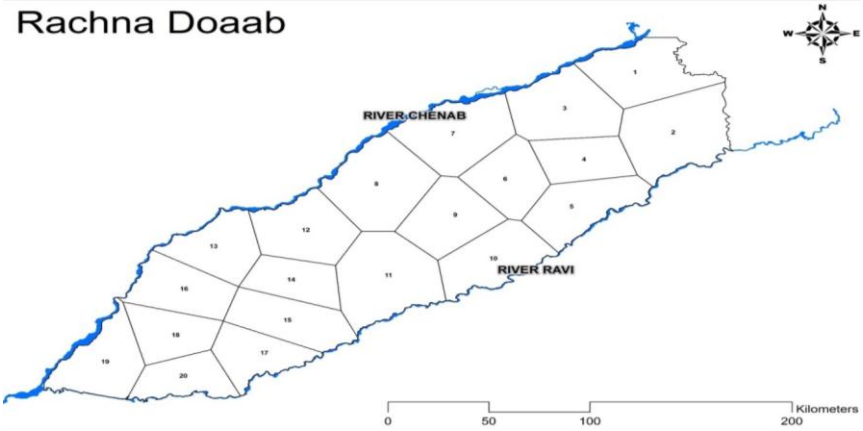


Figure 8: Thiessen Polygons using GIS of Rechana doab

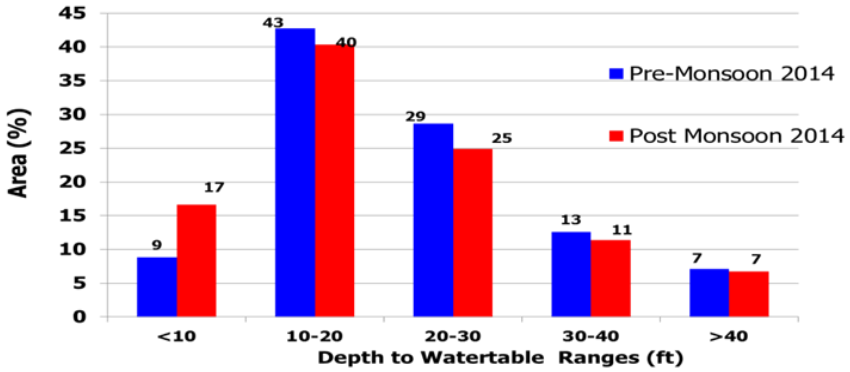


Figure 9: Area under different Depth to Watertable Ranges in Rechana Doab (Pre & Post Flood, 2014)

5. Conclusions

From the analysis of data from groundwater monitoring and natural recharge of flood following conclusions have been made.

- Natural recharge of flood increased the availability of groundwater.
- After natural flood recharge, depth of water table decreased which can stable this pumpage cost.
- As where water table has gone below from 15-20 to 50-60 ft in certain areas, the cost of pumpage has increased more than 100 times.
- After floods, percentage of area of water table less than 10 feet was increased from 9 % to 17 percent ((%)) whereas area of water table ranges from 10-20, 20-30, 30-40 and less than 40 feet decreased respectively.

- Groundwater levels fell at an average rate of 1-2 ft/year in some areas of Rechana Doab during year Oct. 2010 and June 2012 and estimated recharge potential was 15.80 and 16.381MAF respectively.
- Groundwater level in Rechana Doab increased at average 2.57 ft/season due to flood 2014. Total recharge of groundwater during flood season 2014 Doab was 1.90 MAF, in other words 1.90 MAF of flood water was stored in aquifer through natural recharge.

6. Recommendations

i. Development of Structures like dams, reservoir, and pond to store flood water.

ii. Construction of flood channels to divert flood water in desert areas like Cholistan, Thaletc.

iii. Allow flood waters to spread overland through pre-planned breaches

iv. Artificial recharge of aquifer from flood water

v. Detailed program of groundwater monitoring to prepare groundwater potential maps for further hydro-geological investigations is direly needed.

vi An Integrated Flood Management approach embedded within IWRM is to be adopted.

vii. Design, maintenance standards and operation rules for barrages should be reviewed and updated

viii. Flood Plain Maps and Flood Protection Plans should be updated regularly

ix. Coordination be enhanced with WAPDA for reservoir operation of Mangla Dam.

x. Adaptive measures be worked out to mitigate impacts of floods and Climate Change

xi. Strengthen the capacity of research Institutes to study storage of flood, Climate Change and collaborate actively with national and international organizations

xii. Urban groundwater pumpage in major cities e.g. Lahore, Gujranwala etc. should be managed and supplemented by surface water.

xiii. Encourage rainfall harvesting in Urban and Rural areas.

xiv. Formulation of long-term policy and special legal framework for comprehensive master planning to guard against fast depleting groundwater resources to ensure sustainable use of groundwater in rural and urban areas.

xv. Awareness raising and capacity building of the stakeholders must be ensured

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Paper No. 150

MONITORING MICROBIAL REGROWTH AND INACTIVATION POTENTIAL OF CHLORINE IN A LAB-SCALE WATER DISTRIBUTION NETWORK

Amrah Qureshi, Imran Hashmi & Romana Khan

MONITORING MICROBIAL REGROWTH AND INACTIVATION POTENTIAL OF CHLORINE IN A LAB-SCALE WATER DISTRIBUTION NETWORK

By:

Amrah Qureshi[1], Imran Hashmi[21], Romana Khan[1]

Wastewater intrusion in drinking water distribution networks increase the risk of microbial contamination, exhibiting varying degrees of resistance and pathogenicity in a complex bacterial consortium. In Pakistan, bacterial regrowth and contamination of water supply networks is a leading cause of drinking water degradation and waterborne diseases. The present study examines the efficacy of chlorine to inactivate gram-negative *Escherichia coli* and *Pseudomonas aeruginosa,* and gram-positive *Staphylococcus aureus* in drinking water. Scaled up distribution network was built to simulate real water supply channels. It was observed that at exposure of 3.0 mg/L chlorine dose, complete inactivation of *S. aureus* and *P. aeruginosa* occurred at 35 minutes and 120 minutes respectively. However, *E. coli* resisted inactivation and superseded in survival with a maximum reduction to 6-log. Furthermore, a negative correlation was observed between residual chlorine and microbial regrowth. Drinking water distribution systems need to be monitored periodically for microbial contamination to ensure safe water supply at consumer's end.

Keywords: bacterial inactivation, chlorine,distribution network, drinking water

Introduction

In early 1900's, disinfection of water for its safe consumption emerged as a prime concern and resulted in a substantial decrease in water-borne diseases worldwide such as cholera and typhoid fever (McGuire, 2006). To control microbial contamination in drinking water transmission systems, water is disinfected via treatments such as chlorination, ozonation, chloramination, UV treatment etc., prior to distribution. Wastewater intrusion in drinking water supply networks increase the risk of microbial contamination, exhibiting varying resistance and pathogenicity in a complex bacterial consortium.

Leakages from pipes, joints, valves, storage tanks provide entrance pathways to microbes. Disinfectant performance can be evaluated by heterotrophic plate count (HPC) bacteria and total coliforms presence in drinking water. Drinking Water Guidelines issued by WHO regulates the count of coliforms and fecal coliforms at 0 CFU/100 ml of water sample, coliform and fecal coliforms should be 0 CFU/ 100 mL of water sample (WHO, 1993). Same limits have been issued by the European Union directive. USEPA dictates that HPC must remain below 500 CFU/mL. China states that HPC in tap water

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should be < 100 CFU/mL with no total coliforms be detected in 100 mL of water (Liu *et al.,* 2015)

Chlorination is applied as the only disinfection method in Pakistan. But there is a considerable lack of knowledge about responses of microbial populations to chlorination process. In addition, the distribution network is a gigantic reactor in which numerous physicochemical and biological reactions occur. The system gets even more complex because of spatio-temporal variations in some parameters such as residence time, temperature and flow regime. On the way to consumer's end, many qualitative parameters may vary in pipes, such as turbidity, total dissolved solids (TDS), Electrical conductivity (EC), pH, temperature, residual chlorine, contact time and circulating bacterial counts. Holistically they result in water quality deterioration also because of decreasing residual chlorine concentration, especially for long residence times ultimately leading to bacterial regrowth further away in the distribution network(Robescu*et al.,* 2008).

Sometimes disinfection just injures rather than kill bacteria, which would be able to repair their damaged structures and grow further away in the (DWDS) Drinking Water Distribution System (a Mixture Substance). A number of authors have reported regrowth in disinfected DWDS (Jjemba*et al.,* 2010; Li *et al.,* 2013). Microbial regrowth becomes possible even when small quantities of biodegradable organic matter enter the distribution system. A few bacteria such as Pseudomonas have the ability to grow in distilled water lines (Escobar *et al.,* 2001).Mahto and Goell (2008) drew insignificant correlations between HPC, coliforms and free and total chlorine residuals, concluding that coliform survival and growth are not repressed by low levels of residual chlorine ranging from 0.01 to 0.41 mgCl_2/L and total chlorine ranging from 0.02 to 1.23 mgCl_2/L.

Materials and Methods

Specie identification and preparation of bacterial inoculum

Klebsiellapneumoniae (KY859812.1) and *Pseudomonas aeruginosa* (KY859813.1) were wastewater isolated and grown on selective media i.e. EMB agar and Cetrimide agar respectivelyto isolate species for inactivation experiments. Gram-staining and Analytical Profile Index tests were performed to confirm specie. *S. aureus* ATCC6538 was obtained and cultured on Mannitol Salt agar (Ayeni*et al.,* 2017).Colonies were grown on nutrient agar and incubated at 37°C incubation for 24 hours. Later they were inoculated in nutrient broth for further incubation. Media with bacterial growth was centrifuged at 4000 rotations per minute. Pellet formed was re-suspended in phosphate buffer twice. Inoculum was set to 10^8 CFU/mL to be used in inactivation experiments.

Chlorine solutions

Stock solution of 5% sodium hypochlorite was prepared and diluted in de-ionized water to get chlorine solutions. Further dilutions were made to achieve final free chlorine dose of 1, 2 and 3 mg/L as verified by the DPD colorimetric method (Helbling and Van Briesen, 2007).

Sampling and analysis

After the addition of humic acid, iodine solution, bacterial inoculum and chlorine dose, samples were periodically collected at 1, 35 and 120 minutes in designated sterile glassware with appropriate preservation for further analysis. Microbial samples (5 ml) were obtained at selected time intervals in sterile test tubes. 0.1 mL sodium thiosulfate was added to quench any residual disinfectant. Samples (50 mL) were collected pre-chlorination, and at selected time intervals for physicochemical measurements and analyzed immediately for chlorine residual, pH and temperature. All experiments and sampling was done in replicates.

Lab-scale setup

A prototype distribution network was setup at lab using HDPE pipes of length 220 meters in two loops and a reservoir with capacity of 588 litres. Peristaltic pump flowed water from the reservoir and into the pipelines. For this study, working volume of 100 litres was used. The schematic diagram of prototype drinking water distribution network is shown in figure 1.

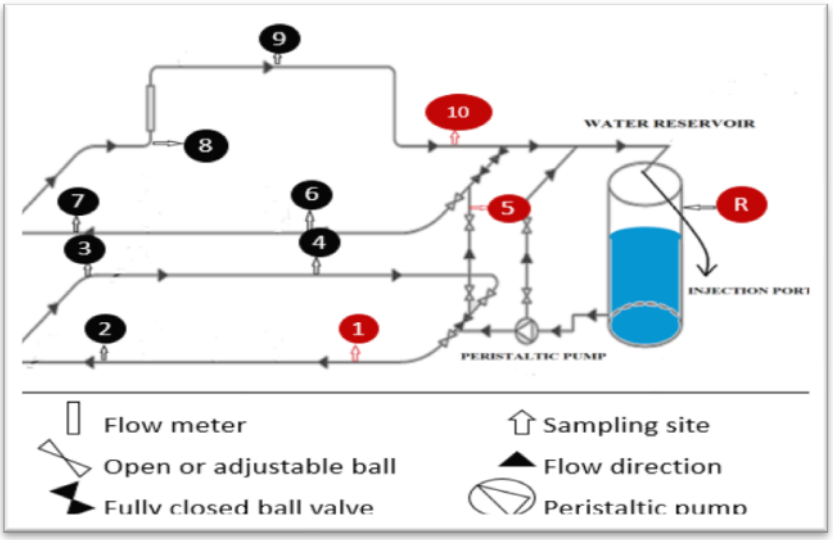


Figure 1: Schematic diagram of Prototype Distribution Network

Results and Discussion

Figure 2 below shows mix culture inactivation results as observed at 1, 35 and 120 minutes at chlorine dose as low as 1 mg/L. At 1 mg/L dose, a sudden 2-log reduction (99.99 % removal) of bacteria was noted i.e. 5-log reduction with highest inactivation of *P. aeruginosa* among the other two bacteria as shown in Figure 2. *K. pneumoniae* was notably more resistant to chlorine than *P. aeruginosa* (Goel and Bouwer, 2004). Bacterial regrowth was observed at 120 minutes in case of all three bacteria.

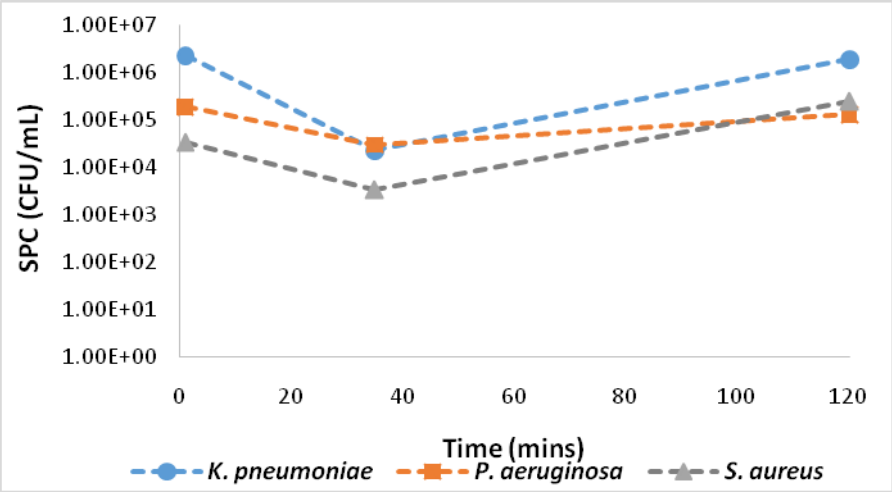


Figure 2: Bacterial inactivation at 1 mg/L chlorine and 1, 35 and 120 minutes

Figure 3 shows inactivation at 1, 35 and 120 minutes of contact with 2 mg/L chlorine dose. Bacterial regrowth was observed after 35 minutes. The loss of residual disinfectant in the system was accompanied by an increase in the level of bacteria. Virto*et al.* (2005) supported this by stating under suitable conditions, injured cells might repair cellular damage and recover in the distribution system resulting in bacterial regrowth.

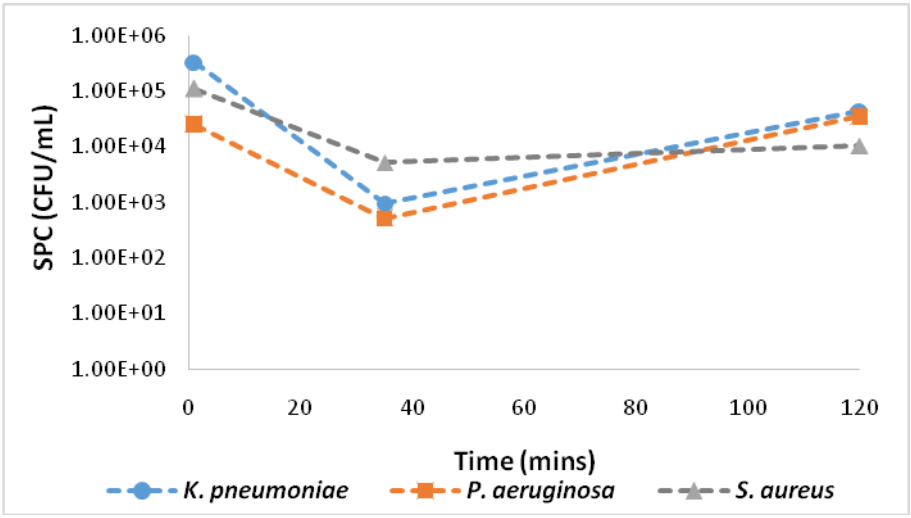


Figure 3: Bacterial inactivation at 2 mg/L chlorine and 1, 35 and 120 minutes

Similar bacterial regrowth was observed at increased dosages at prolonged contact times. Chlorine residual diminished with time with no disinfectant residual left at prolonged contact times indicating unstable property of free residual chlorine in the system (Zhang and DiGiano, 2002).

In Figure 4, survival rate of *K. pneumoniae*can be seen to be highest among other bacteria which regrew even before complete inactivation. While highest

inactivation was found in case of *S. aureus* as gram-positive cells are damaged more by chlorine than gram negative cells (Virto et*al.,* 2005). *S. aureus* and *P. aeruginosa* cells injured at 35 and 120 minutes respectively and regrowth occurred in *K. pneumoniae*at prolonged contact times.

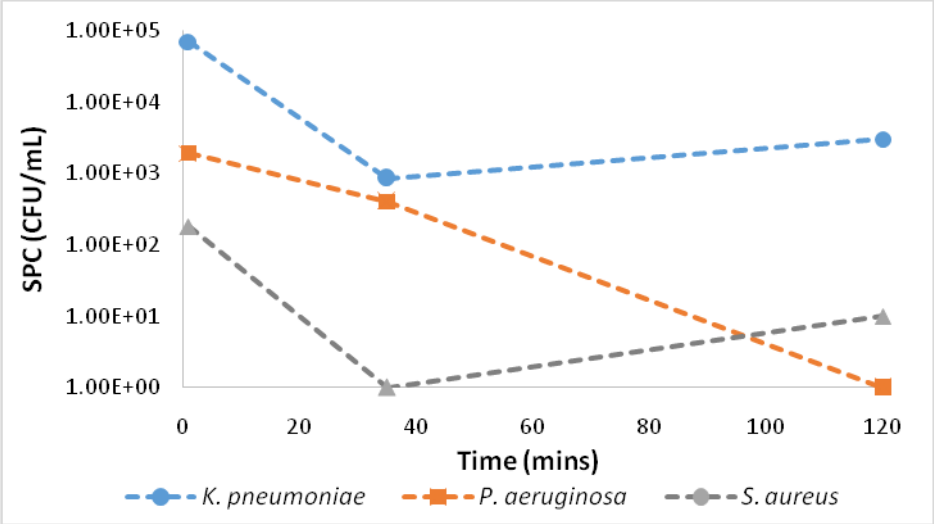


Figure 4: Bacterial inactivation at 3 mg/L chlorine and 1, 35 and 120 minutes

Jjembae*t al.* (2010) reported that rapid loss of chlorine in the system results in bacterial regrowth as also has been shown in figure 5. The repairement of injured microbial cells was accompanied by loss of residual free chlorine from the distribution network.

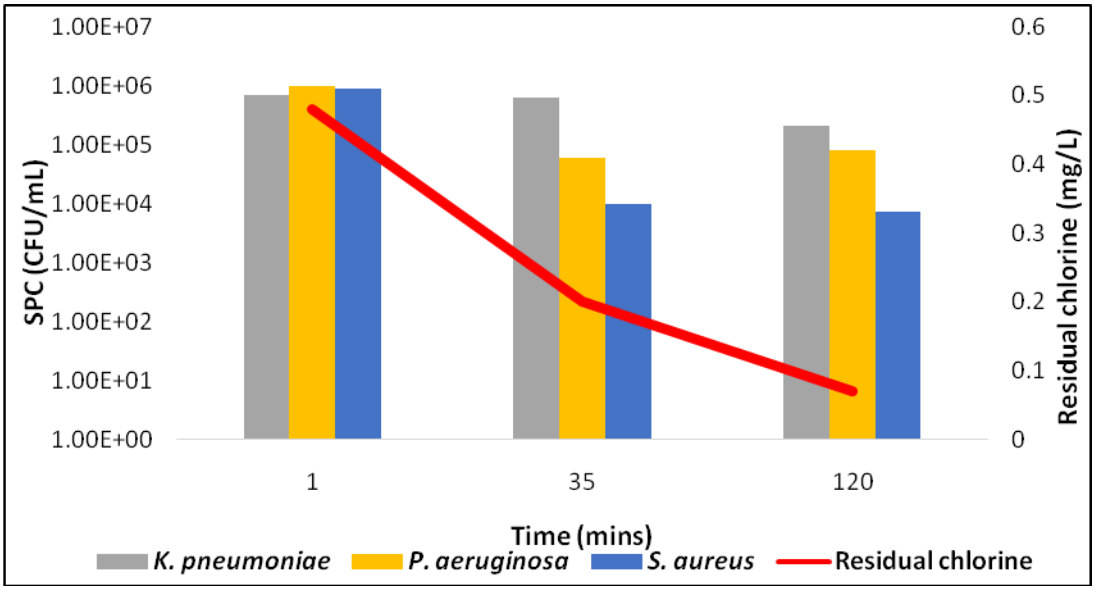


Figure 5: Bacterial reduction versus residual chlorine

Conclusions

P. aeruginosa becomes less susceptible to conditions when they act in a consortium. *K. pneumoniae*was fittest to survive in consortium of bacteria therefore it is a commonly detected pathogen in drinking water networks. *S. aureus* being gram-positive does not survive among gram-negative bacteria. The results further showed a negative correlation between bacterial regrowth and disinfectant residual. At longer contact times, free chlorine diminishes from the system thus suggesting a key factor in regrowth of bacteria.

Acknowledgements

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Paper No. 151

ARE WE DRINKING QUALITY AND SAFE WATER IN PAKISTAN

Dr. Muhammad Anwar Baig, Adnan Anwar Baig

ARE WE DRINKING QUALITY AND SAFE WATER IN PAKISTAN

By

Dr. Muhammad Anwar Baig & Adnan Anwar Baig[1]

Abstract

Human beings depend heavily on water for survival. They, for example, do not eat food for several days, but cannot survive without drinking water. Adequate supply of fresh and clean drinking water is a basic need for all human beings on the earth. During life time, an average person consumes 80,000 liters (~ one and a half big tankers) of water for its growth and maintenance. With the development of industry and modern agriculture has created a number of environmental problems including water pollution with their serious effects on human health. Most common water-borne diseases are typhoid, cholera, paratyphoid fever, dysentery and jaundice etc., in addition to chemicals and heavy metal related health problems. Worldwide, water-borne diseases only, account for the deaths of 3.5 million people a year! That's equivalent to a jumbo jet crashing every hour, and the majority of these are children. Drinking water at your home comes from a variety of sources including public water systems (surface or underground), private wells, or bottled water. Today, the most common steps in water treatment used for community water systems include: sedimentation, filtration, disinfection and fluoridation. Household water treatment systems mostly includes boiling, filtration, softening, distillation and disinfection. Thus, it is important to know where drinking water comes from, how it has been treated, and if it's safe to drink. The market is literally flooded with water treatment options. This lecture will introduce the reader to understand various sources of water, techniques used and which one to choose from the available options.

Key Words: Water quality, water pollution, water treatment methods

Introduction:

Water is extremely important for human beings. Holy Quran tells us "We gave life to everything from water". While looking at the modern biomedical information, we find that human body contains almost 60 % water and among various organs, the brain is composed of 70 %, the lungs are nearly 90 % and blood is contains about 83 percent water. Based on these facts UN has also declared in its decisions "Water is fundamental for life and health. The human right to water is indispensable for leading a healthy life in human dignity. It is a pre-requisite to the realization of all other human rights." (UN Committee on Economic, Cultural and Social Rights 26. November 2002). On an average, each day humans must replace 2.4 liters of water, some through drinking and the rest taken by the body from the foods eaten. During life time, an average person

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consumes 80,000 liters (~ one and a half big tankers) of water for its growth and maintenance.

As of today more than a billion people around the world lack access to safe drinking water supplies. If the trends continue, almost 3.0 billion people out of a global population of 8.5 billion could be facing water shortages by 2025. Over 80% of these people would most likely be found in the rural areas of developing countries (Naegele, 2004). This looming threat becomes more disturbing considering that there is enough potable water across the various world regions to guarantee water for all human beings. The only major reason for the growing water scarcity is that a small fraction of global freshwater is actually used by people; whereas, its major share is diverted to industrial and agricultural purposes, and is used for many other things besides producing food (Clarke, 2013). Provision of pure water to all the people by the government is not only a basic need and precondition for a healthy life but it is also a vital human right of all the people which mustn't be ignored at any cost. Various improved water supply technologies have been developed by the modern world nations which included household connections, public standpipes, boreholes, protected dug-wells, protected springs and rainwater collections (Moriarty *et al.,* 2010).

Sources of Water Pollution

The water gets polluted from various sources. These can be natural or man-made as naturally (Yadav *et al.,* 2011). By plants, animals, sediments, chemicals from rock and anthropogenic activities like sewage, industrial effluents, agriculture (fertilizers, pesticides), air pollution, and solid waste (Fig, 1).

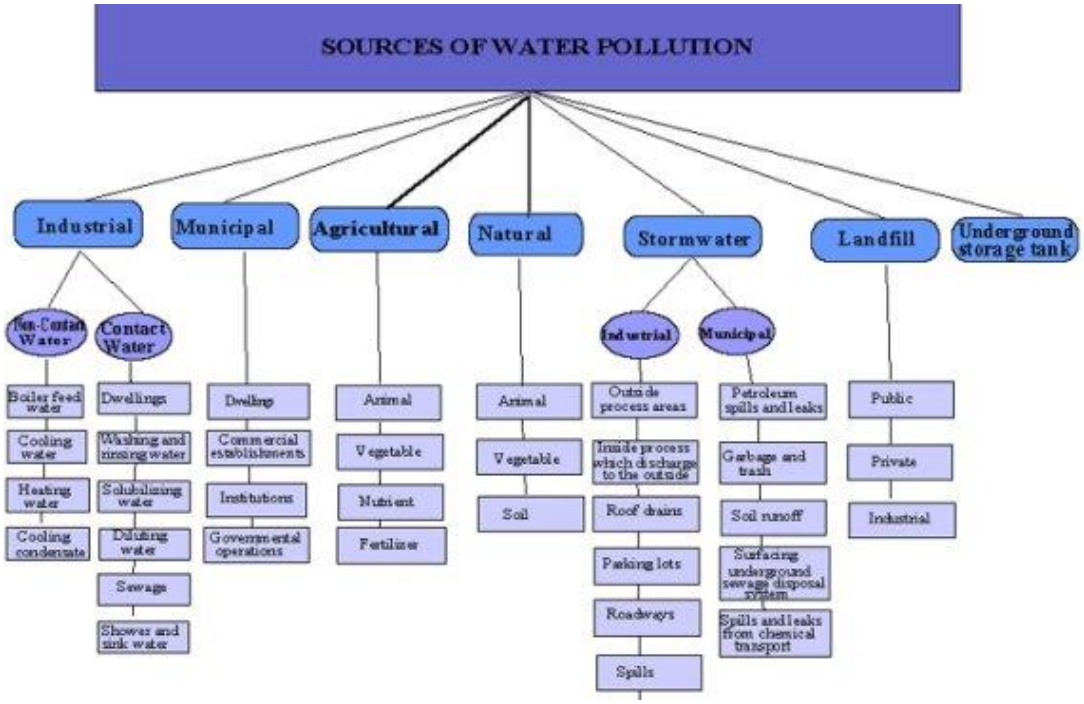


Figure 1: Classification of the sources of water pollution

The causes of water pollution in developing countries are mainly human activities which are grouped and shown in figure 2.

The water which usable and safe for drinking is called safe water in scientific terms. This must possess the 6 characteristics: free from pathogenic organisms, clear, not saline, free from offensive taste or smell, free from compounds that may have adverse effect on human health and free from chemicals that cause corrosion of water supply systems.

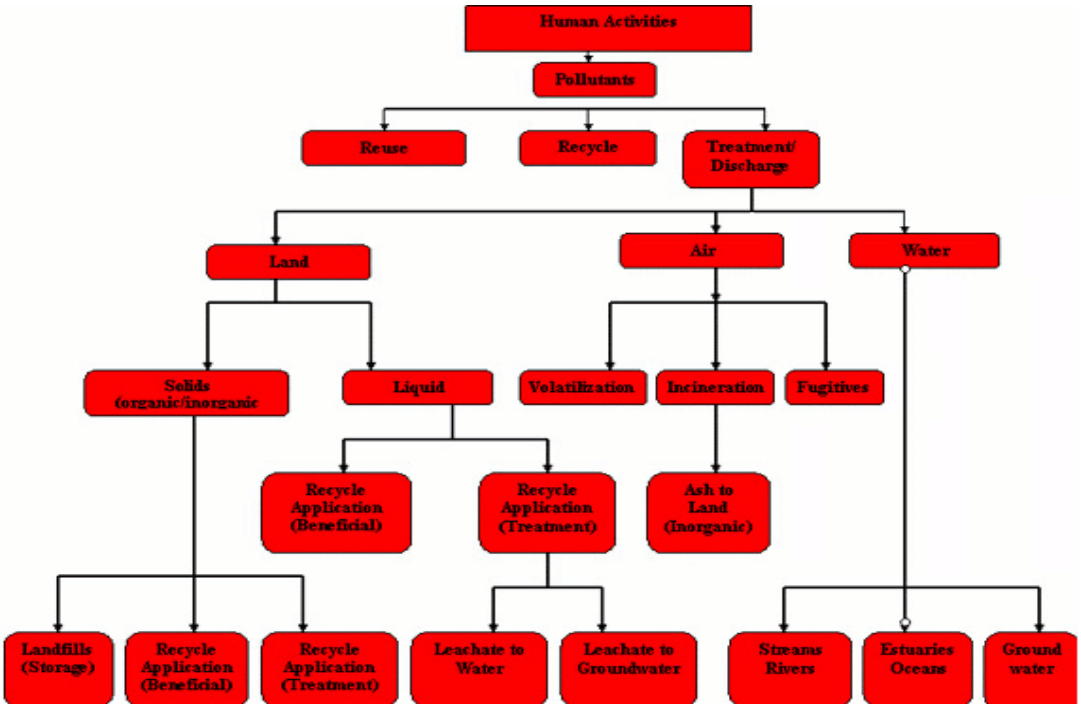


Figure 2: Flow of pollutants from human activities

In natural conditions meeting these criteria is usually difficult and to provide such water for public, treatment is required one way or the other as natural water may not meet all the above stated characteristics. Polluted water is cause of many health issues (Table, 1) specially children and old age people.

Table 1: Nature of pollutants and their health impacts in the form of diseases

Sr. No	Contaminant	Disease / Impact
1	Bacteriological Contamination	Cholera, Diarrhea, Dysentery, Hepatitis, Typhoid Infectious diseases can be spread through contaminated water
2	Arsenic	Cancer (lungs, bladder, skin, prostrate, kidney, nose and liver), diabetes, kidney diseases, hypertension, heart diseases, birth defects, black foot diseases.
3	Lead	Can accumulate in the body, damage the central nervous system
4	Sodium	Hypertension

Sr. No	Contaminant	Disease / Impact
5	Potassium	Hyperkalemia
6	Pesticides	Can damage the nervous system and cause cancer because of the carbonates and organophosphates that they contain.
7	Chlorides	Can cause reproductive and endocrinal damage
8	Nitrates	Especially dangerous to babies that drink formula milk. It restricts the amount of oxygen in the brain and cause the “blue baby” syndrome
9	Fluorides	In excessive amounts can make your teeth yellow and cause damage to the spinal cord
10	Petrochemicals	Even with very low exposure, can cause cancer

Drinking Water Supply Situation in Pakistan:

As per standards given by WHO, human needs at least 50 liters of water per day to meet the needs including drinking, bathing, cooking and maintaining hygiene. These may vary from regions and climatic zones. In Pakistan, only 3-4 % of the nation’s sweet water resources are used by households, for various purposes including bathing, cooking and drinking. It is very unfortunate that unchecked urban growth has heightened the need to ensure uninterrupted access to improved drinking-water supply, especially in mega cities like Karachi, Lahore, Faisalabad, Multan, Rawalpindi, Gujranwala, Peshawar and Quetta etc., where traces of multiple deadly rudiments including the human feces are reported by laboratory reports. Moreover, Pakistan is among several Asian countries that have problems in providing a reliable supply of safe drinking water (Table 2).

Table 2: Technical Assessment Survey of Existing Water Supply Schemes in Pakistan

Province	Districts Surveyed	Water supply scheme reported by provinces	Surveyed water supply schemes			No of Schemes found Functional
			Total	Urban	Rural	
Punjab	33	4100	3883	746	3137	2725
Sindh	22	1300	1247	123	1124	529
KP	16	3000	2203	474	1729	1710
Baluchistan	14	1600	1034	480	554	968
GB/AJK	11	2000	1794	18	1776	1379
Total	96	12000	10161	1841	8320	7310

Heavy industrialization and dense living conditions causes increased levels of contamination in existing water supplies. Inadequate water supplies and poor sanitation standards are the main causes of fatal water borne disease in the country. As one warning of the high-scale of the drinking problem prevalent in our society, it is

anticipated that more than 2.5 lac infant children die of diarrheal diseases every year (WHO/UNICEF, 2006). This shows height of criminal neglect exhibited by the civic bodies towards public right of safe drinking water. Major source of water supply in Pakistan is groundwater which is found to be contaminated with salts and minerals due to intense irrigation and waste water addition as given in the figure -3 below.

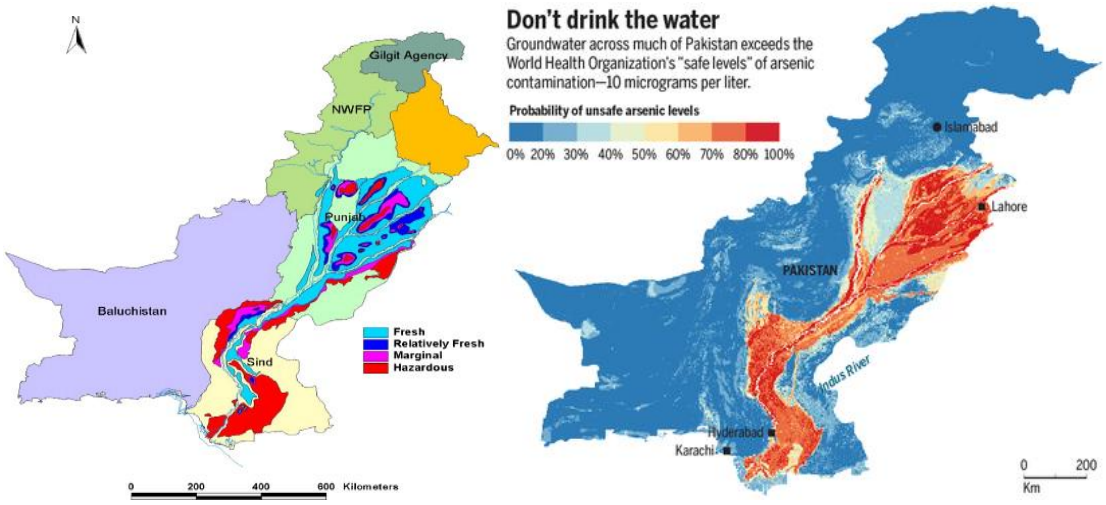


Figure 3: Groundwater quality of Indus basin as monitored WAPDA and PCRWR

Methods of Water Treatment

Drinking water at our door step comes from a variety of sources (Table, 2) including public water systems (surface or underground), private wells, or bottled water. Today, the most common steps in water treatment used for community water systems include: sedimentation, filtration, disinfection and fluoridation. Household water treatment systems mostly includes boiling, filtration, softening, distillation and disinfection. Thus, it is important to know where drinking water comes from, how it has been treated, and if it's safe to drink.

Surface water is mostly available in Pakistan and is generally polluted due to its exposure with open environment and may be needing pre-treatment before its actual treatment for desired use. Pre-treatment includes roughing filtration, pre-sedimentation and pre-chlorination. Treatment includes, slow-sand filtration – for small communities, full scale treatment – large cities, diatomaceous earth – field scale treatment, advanced treatment – used as required

The contaminants present in the water can be grouped roughly into five types i.e. particulates, bacteria, minerals, chemicals, and pharmaceuticals. The methods to remove these elements range from simple and inexpensive to elaborate and costly. Listed below are general brief descriptions of the twenty-five methods available in the market to purify water. These are grouped under five different categories as follows:

1. Using techniques of separation, heat, light and gravity

Sedimentation, gravitationally settles heavy suspended material while boiling water for 15 to 20 minutes kills 99.9% of all living things and vaporizes most chemicals. Distillation boils and recondenses the water. Ultraviolet light is a good bactericide, but has no residual kill, and works only in clearly filtered water.

2. Filtration

It could be slow sand or rapid sand depending on nature of suspended material, backwashing and pressure available. Paper or cloth filters are disposable and filter to one micron, but do not have much capacity. Compressed charcoal/carbon block is the best type of charcoal filter that can remove chemicals and lead, but is easily clogged, so should be used with a sediment pre-filter. Granular charcoal is cheaper, but water can flow around the granules without being treated. Powdered charcoal is a very fine dust useful for spot cleaning larger bodies of water, but is messy and can pass through some filters and be consumed. Reverse osmosis uses a membrane with microscopic holes that require 4 to 8 times the volume of water processed to wash it in order to remove minerals and salt, but not necessarily chemicals and bacteria.

3. Use of chemicals

Chlorine is common, cheap, but extremely toxic. It does not decrease physical or chemical contamination, is a carcinogen, and causes heart disease. Iodine is not practical, and is mostly used by campers. Hydrogen peroxide kills bacteria with oxygen, is chemically made and is very toxic. It is used in emergencies. Silver is an effective bactericide but a cumulative poison which concentrates and doesn't evaporate. Lime and mild alkaline agents should also be used with caution only by large water plants. Neutralizing chemicals react with the unwanted chemicals and produce outgases and a sediment, but levels of need vary. Coagulation-flocculation adds chemicals which lump together suspended particles for filtration or separation. Ion exchange, exchanges sodium from salt for calcium or magnesium, using either glauconite (greensand), precipitated synthetic organic resins, or gel zeolite, thus softening the water.

4. Oxidation

Aeration sprays water into the air to raise the oxygen content, to break down odors, and to balance the dissolved gases. However, it takes space, is expensive, and picks up contaminants from the air. Ozone is a very good bactericide, using highly charged oxygen molecules to kill microorganisms on contact, and to oxidize and flocculate iron, manganese and other dissolved minerals for post-filtration and backwashing. Electronic purification and dissolved oxygen generation creates super oxygenated water in a dissolved state that lowers the surface tension of the water and effectively treats all three types of contamination: physical, chemical and biological.

What options are available in Pakistan:

1. **Municipal supply** Most of the cities have the system of water supply through laid pipe networks. The situation is pathetic and lots of complaints are recorded for cross contamination as is visible in the following figure 4 and table 3.

Table 3: Water samples found contaminated in different cities

City	Percent (%) samples contaminated			
	Year 1	Year 2	Year 3	Year 4
Islamabad	74	40	65	48
PUNJAB (11 cities)				
Faisalabad	**79**	**38**	**38**	**46**
Bahawalpur	**76**	**68**	**52**	**72**
Gujranwala	**57**	**71**	**43**	**64**
Gujrat	**100**	**78**	**78**	**67**
Kasur	**70**	**40**	**50**	**40**
Lahore	**43**	**38**	**44**	**50**
Multan	**87**	**56**	**31**	**56**
Rawalpindi	**87**	**64**	**73**	**67**
Sheikhupura	**64**	**28**	**36**	**45**
Sialkot	**40**	**40**	**70**	**60**
Sargodha	**-**	**-**	**75**	**92**

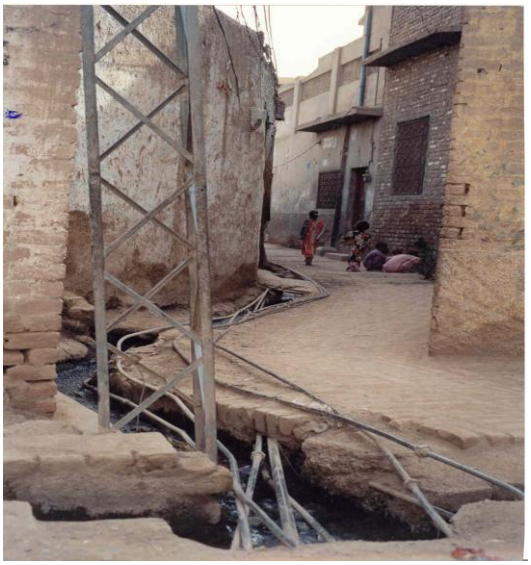


Figure 4: Domestic water supply lines laid down in different cities and towns

2. Community water filtration plants

As a remedial measure and meeting pressing demands, government installed community water filtration plants in various cities starting from Islamabad and Rawalpindi. Such plants are being operated with the assistance of WASAs and CDA/TMAs. (figure 5)

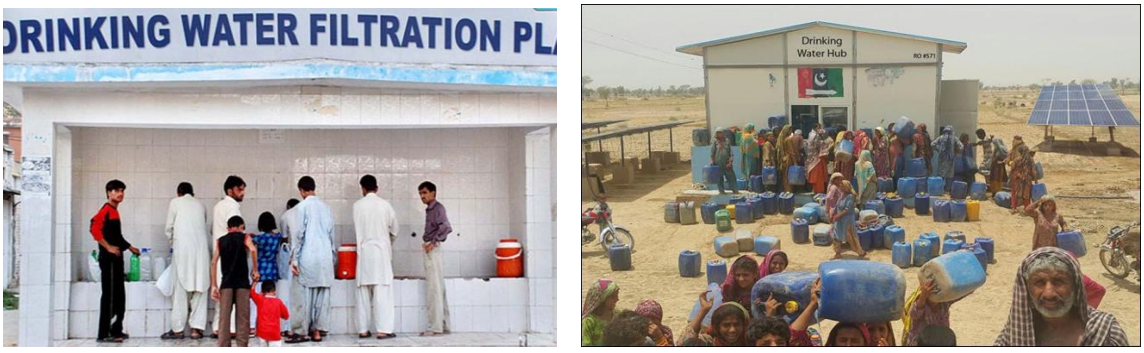


Figure 5: Community drinking water filtration plant in Rawalpindi Sindh

3. **Domestic water filters:** In order to avoid waiting in lines for the collection of water for drinking, people with resources have opted to install domestic water plants but their operational& maintenance component is not being handled properly. Figure below (6) shows one of the significant quality issue rather more polluted water than coming from supply.



Figure 6: Domestic water filters two stage (right) and three stage (left)

4. Bottled Water

The poor quality of drinking water has forced a large cross-section of citizens to buy bottled water. However, many of the mineral water companies were found selling contaminated water. In developed countries such as the United States and Canada, bottled water has become an especially dynamic major commercial beverage category by registering as an attractive option for health conscious consumers. At the same time, bottled water serves at least a partial solution to the problem of often-unsafe water found in many economically developing countries. Much of the world's bottled water market is still highly fragmented and controlled by local brands, but consolidation is definitely taking place, as four companies have come to dominate much of the market. Today, bottled water has become one of China's fastest growing Fast Moving Consumer Goods (FMCG). In 2013, China consumed 15% of bottled water globally surpassing the US to become the No.1 consumer of bottled water (Fig. 7).

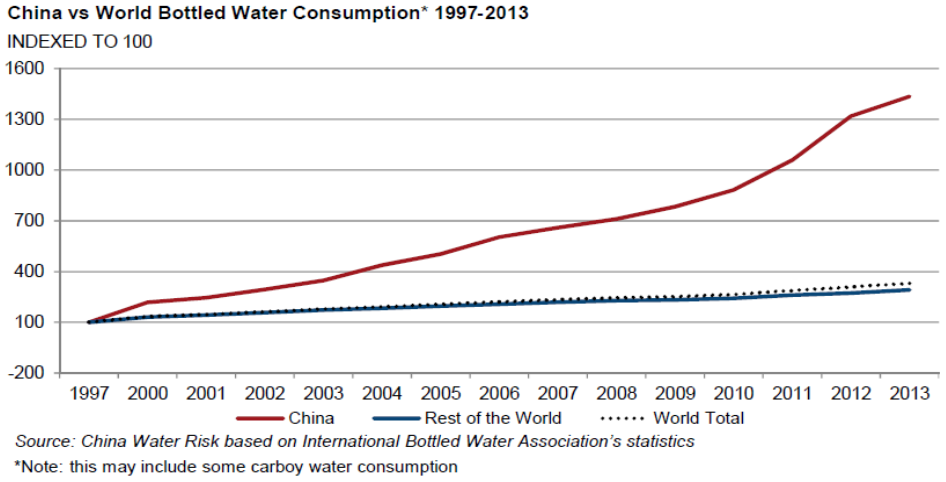


Figure 7: Bottled water consumption in China Vs World 1997-2013

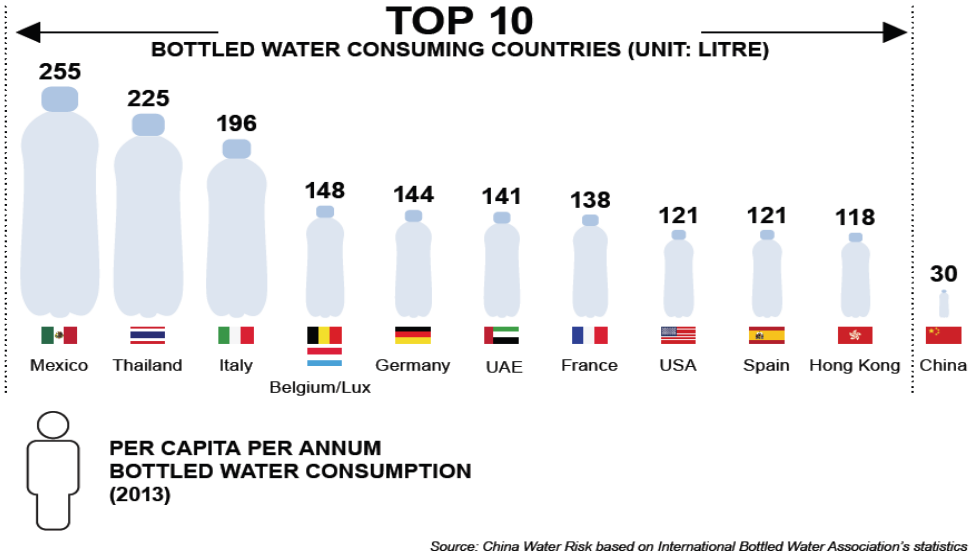


Figure 8: Per capita per annum bottled water consumption (2013)

To monitor and improve the quality of bottled water, the government of Pakistan through Ministry of Science and Technology has designated the task for quarterly monitoring of bottled/mineral water brands to PCRWR. According to the monitoring report for the quarter October-December, 2015. Bottled water tapped into some different consumer trends around the globe (Table, 4).

Table:4: Status of Bottled/mineral water quality reported in Quarterly Monitoring (July-Sept 2017)

Sr. No.	Item	Nos.	% age
1.	Total Brands collected	131	100
2.	Overall Safe	119	91 (80 in 2016)
3.	Overall Unsafe	12	09 (20 in 2016)
4.	Chemically Safe	126	96 (83 in 2016)
5.	Microbiologically Safe	124	95 (97 in 2016)

During the past thirty years, use of bottled water is increasingly moved up the world over, as it has become a global phenomenon. Bottled water sector, despite its excessively high price compared to tap water, is measured as one of the powerful sectors of all the food and beverage trade as its consumption increases by an average of 12% every year. Like other countries, in Pakistan too water security is one of the most

critical challenges faced today. Drinking water problems in the country are quite different from those in developed countries.

Conclusion:

As given by the Results of five years National Water Quality Monitoring Programme which covered 23 major cities, 8 Rivers, 9 lakes and many reservoirs showed widespread bacteriological contaminants in the drinking water. Chemical contaminants in drinking water such as arsenic, fluoride and nitrate are discovered at various locations. Arsenic contamination was found in southern Punjab and central Sindh.

Similarly bottled water companies have used marketing tacts to convince the public but unfortunately, bottled water is not only hazardous to our health, but it is also equally disastrous to the environment. As described by Pakistan Council of Research in Water Resources (PCRWR) which has found 27 brands of bottled water being sold in Pakistan to be unsafe for drinking due to contamination against water quality standards set by the Pakistan Standard Quality Control Authority (PSQCA).

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Paper No. 152

NATURE-WATER NEXUS: MANAGING CURRENT WATER CHALLENGES

Engineer Mumtaz Hussain

NATURE-WATER NEXUS: MANAGING CURRENT WATER CHALLENGES

By:

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ABSTRACT

In 2.1 billion people are deprived of potable water and sanitation services. Many countries are facing water stress conditions. Aquifers are being depleted and polluted at alarming rate. Unabated urban sprawl all over the world has created scores of environmental, socio-economic, moral, political, psychological & health issues. Fatal water borne diseases are haunting the humanity all the time. Present situation is attributed to policy failures, ill-conceived plans, rudimentary master planning and poorly managed watersheds. Contributory causes are poorly managed watersheds, mixing of waste water & potable water, ill established storm drainage system and inflow of wastes & effluents into water bodies.

For meeting sustained water requirement of the ever increasing global population there is tremendous need of implementing an integrated multi-tier Nature based approach. Nature provides simple and workable solutions for mitigating adverse impacts of water security, water scarcity and water pollution. Relevant stakeholders at local, regional, national and international rungs (like World Health Organisation, Food & Agriculture Organistion and International Panel on Climate Change of the United Nations) need to be actively involved in formulation of policies, plans and strategies in the backdrop of natural solutions. Representatives of management, administration, media and communities should be consulted during entire life cycle of a water project. Joint expert team of disciplines like water resources, water quality, environment, healthcare, geology, public health engineering, economics and constructors should plan & execute the natural solutions. It needs to be highlighted that Nature provides the solution to settlement of all illicit activities.

Key Words: Water stress conditions, aquifers, extreme events, water borne diseases, integrated multi-tier approach, nature based solutions, Urbanisation.

1. INTRODUCTION

1.1 Global Water Base

The Planet Earth comprises of one fourth land and three fourth water. The Nature has provided water resources in forms of oceans, seas, glaciers, icebergs, rains, springs, rivers and underground, of course, sufficient in quantity & quality for sustenance of life. 97.5% of the total water is found in oceans and

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seas. Only 2.5% component is fresh water. Fresh water is composed of snow & ice (68.77%), underground water (31.1%), rivers, streams, lakes & reservoirs (0.26%). Of the total quantity of water existing on the fresh water portion is merely 0.007%.

1.2 Available Water

Availability of fresh water at global and Asia level is about 6,000 and 2500 m^3/capita/year respectively. World average figure is projected to decrease to 4,800 m^3/capita/year by the year 2025 for a population of over 7 billion. Sustainable Development Goal assures to provide safe water to everyone by the year 2030. At present availability of water is about 1,000 m^3/capita/year in Pakistan.

2. NATURE-WATER NEXUS

2.1 Vital Component of Living Organisms

Water is vitally required for organisms to live. Human body has 60% water. Water fauna are composed of 90% water. Trees have 40%, milk has 80% and citrus fruits have above 80% water. It is found in solid, semi-solid, liquid, vapour and gas forms.

2.2 Natural Cycles

2.2.1 Natural Hydrologic Cycle

Natural hydrologic cycle keeps balance between demand and supply of water. Solar energy and gravity maintain this cycle. Resultantly one-third each of total precipitation falling on earth is evaporated & transpired back into atmosphere, forms surface run-off and percolate into ground respectively. Rising temperature enhances rate of evaporation, evapo-transpiration and hydrologic cycle. Type of terrain has significant impact on hydrologic cycle. Disturbance in hydrologic cycle leads to water related disasters like floods, droughts, landslides and hailstorms.

2.2.2 Nutrient Cycles

Nutrient cycles are water based, of course with the solar energy as prime mover. These include carbon, nitrogen and phosphorous cycles.

2.3 Ecosystem Services

Ecosystem implies a specific biological community and its physical environments interacting in an exchange of matter and energy is known as ecosystem. It provides services like soil, land, water and air for sustenance of life on Planet Earth. In nutshell water is an integral component of all ecosystem.

3. CURRENT WATER CHALLENGES AND THEIR NATURAL MANAGEMENT

The ensuing water crisis has created endless environmental, socio-economic-cultural, political, aquatic disasters, transboundary and intra-state adverse impacts. The most daunting challenges are appended below:

3.1 Damage to Physical Environments

- Deterioration of natural habitats/landscapes
- Water pollution, sedimentation and erosion
- Water Losses

  In developing countries about 75% water is allocated for irrigation but half of this quantity does not reach the agricultural fields due to evaporation and seepage losses.
- Inadequate drainage resulting in waterlogging, salinity and ruined soil environment

3.2 Destruction of Biological Environments

- Loss of natural capital
- Extinction of flora and fauna species
- Disappearance of wildlife

3.3 Socio-economic-Cultural Impacts

3.3.1 Degradation of socio-economic-cultural values

3.3.2 Health concerns on account of water borne diseases (WHO)

- Unsafe water, inadequate sanitation and insufficient hygiene account for 9.1% of global burden of diseases & 6.3% all deaths.
- 20% children with age of lesser than 14 years in developing countries face death.
- Half population of developing countries contract water borne diseases.

3.3.3 Difficulty in observance of cultural taboos and religious rituals

3.3.4 Poverty and poor quality of life

3.3.5 Water insecurity

In turn it harms socio-economic-cultural security and human security.

3.3.6 Water Scarcity

One-third population is undergoing moderate/severe water stress. 2.1 billion people have no access to potable water supply and adequate sanitation.

3.3.7 Aquatic Disasters

Water is both creative and destructive. Water relevant disasters are generated by anthropogenic as well as natural phenomena. A few natural disasters caused by water are mentioned below:

- **Water Erosion**

  It is the movement of the soil caused by the falling raindrops and running water. The process consists of detachment of the soil grains (particles and small aggregates), transportation of the detached grains over the land surface, falling out of the grains from the suspension and finally depositing as sediment on a new site. The process is aided by the **Gravitational Force**. Types of water erosion are sheets, rill, gully and steam bank erosion.

  - **Damages caused**
    - ✓ Loss of fertile soil cover
    - ✓ Textural changes
    - ✓ Loss of nutrients
    - ✓ Abrasion losses by flying soil particles
    - ✓ Air pollution
    - ✓ sedimentation
  - **Management of Water Erosion**

    A few parameters for management of water erosion are: Agricultural Practices, Afforestation and Overgrazing.

3.2.2 Landslides / Mudflows

Heavy rains and hill torrents cause the landslides/mudflows in mountainous areas. Suggested steps for overcoming such trends are mentioned in the following:

- Suitable drains with effective outfall should be provided on the hill side.
- Tree plantation should be done along the road on hill side

3.2.3 Hill Torrents

In Pakistan these provide water potential of 19 MAF. With this quantity of water 6 million acres of culturable wasteland can be irrigated. These cause huge damages to life and property because of flash floods. Impacts of hill torrents may be reduced by allowing their uninterrupted flow into nearby water bodies.

3.2.5 Avalanches and Snowmelts

- Afforestation should be done along the avalanche paths especially on the elevation below 3,000 meters.
- Necessary warning system be evolved to inform the people about the avalanche season (December to June) so that they may either shift to safe places or take preventive steps.
- Run-off generated from avalanches or snow melts need to be managed promptly.

3.2.6 Sea Water Intrusion

It may be controlled by following means.

- Tree plantation in coastal areas
- Prohibiting excavation of sand along beach line

3.2.7 Droughts

Drought is defined as a period in which lack of water reduces growth and final yield of staple crops of an area.

- **Causes of Droughts**

  Droughts are caused by scores of upheavals that are mentioned below:

  - **Meteorological Phenomena**

    La Nina and El Nino phenomena are one of the main factors which affect the climatology. Their impacts may vary in terms of space and timings.

  - **Natural Causation**

    Natural events contribute towards droughts to a small extent. The natural factors are destined to keep a desirable balance whereas the anthropogenic activities have completely distorted the worldwide climatology.

  - **Soil Characteristics**

    Physical, biological and chemical properties of soil determine the extent of droughts. Cohesive soils with higher contents of organic matter & moisture resist drought conditions.

  - **Erosion and Sedimentation**

    The erosion and sedimentation are the ominous threats for land. With severity of aridity and climate, the rate of erosion in Pakistan is increasing.

- **High Temperatures**

  In the plain areas of Pakistan summer temperature rises upto 48^{o}C. In Sibi and Jacobad areas of Sindh temperature of 53^{o}C has been experienced.

- **Annual Rainfall**

  It ranges from 40-600 mm per year in Pakistan.

- **Anthropogenic Factor**

  In the present Anthropocene Era the human activities are multiplying. Generation of greenhouse gases, global warming increased tropospheric temperature) and damage to ozone layer are mainly generated by human beings on account of mismanagement of natural and manmade resources.

- **Impacts of Droughts**

  Although the droughts are a normally happening phenomenon in Pakistan yet during the last two decades reduced rainfalls and increasing temperatures have intensified the severity of droughts. Ultimately the existing physical, biological and socio-economic environments have been damaged to a great extent leading to heavy losses of life and property. Impacts of droughts depend on frequency of their occurrence, relative longevity, severity and exposure extent of the affectees. The worst ever droughts had occurred from 1998 to 2004. A few significant impacts are given below:

- **Drought Management**

  The impacts of droughts may be prevented/minimized/controlled by implementation of the following mitigation measures:

  - **Environmental Aspects**

    - ✓ **Adaptation**

      Development of adaptation skills in all sectors to cope with the obtaining drought scenario. This is true for all living organisms.

    - ✓ **Drought Resistant Crops**

      Cultivation of drought resistant crops.

    - ✓ **Disease Control**

      In existing natural low lying areas efforts should be put in for extensive storage of water to be used by the human beings, livestock and the crops.

- **Administrative Steps**
  - ✓ **Early Warning**

    An effective system of early warning should be introduced at national, provincial district and city, town & village levels. The farmers should be kept well informed.
  - ✓ **Modern Irrigation Technologies**

    Drip and sprinkler methods of irrigation should be popularized.
  - ✓ **Shifting** of livestock should be done in advance to nearby safe places where feed and fodder are available.
- **Medical Assistance**

  Arrangements for medical assistance to the marooned communities.

3.2.8 Hydro Salinity and Waterlogging

Hydro Salinity is developed due to surface irrigation and rise of capillary water to root zone. At global level half of irrigated land is facing hydro salinity. On account of twin menace of hydro salinity and waterlogging, 40,000 hectares of land is rendered unproductive in Pakistan per annum.

3.2.9 Tsunami

Tsunami is the water hazard caused by earthquakes and sometimes by underwater volcanic activity or a landslide. It is misinterpreted as a tidal wave. In fact tsunami is not generated by a sea tide. According to UNESCO Report, 1991 their wavelength may be several hundred kms and speeds of over 600 kph. Their speed and length decreases when these approach the coast but the crest height increases. The height of the crest may be as high as 30 meters.

3.2.10 Watershed Management

Some of the significant management strategies are given below:

- Overgrazing should not be permitted as it will denude and pulverize the area.
- Afforestation should be carried out extensively to obstruct the outflow of soil, boulders etc.
- Minimum quantities of agricultural chemicals be used so that these do not enter the water bodies subsequently.

- Soil erosion should be minimized by increasing vegetative cover, embankments and damming.
- The aim of the best watershed management is to retain moisture, delay the water flow and decrease run off.

3.3 Water Conservation

Human beings are not permitted to waste water. Its extravagant use is forbidden. Humans may use the Divine gift for their sustenance in moderation, provided that they do not resort to wastage.

3.4 Water Pollution

3.4.1 Almighty Allah (ﷻ) provides pure water in form of rainfall. It is potable, clean and pure. To keep good health, it is imperative to utilize potable water. People need to keep water protected from the injurious germs, insects, chemicals and other contaminants.

3.4.2 Like other natural resources pollution of water is strictly prohibited. The Holy Prophet (ﷺ Peace and blessing of Allah be upon him) has advised not to pollute water with impurities. Also flowing water is considered as clean. The Holy Prophet (ﷺ Peace and blessing of Allah be upon him) said that: **none of you shall pass his urine into standing water and then take a bath in the same (water).** He also emphasized that: **never should any one of you urinate into standing water and save yourselves from three cursed matters, namely, defecating at watering points, centre of the path & shadow place**.

3.4.3 The lakes, wetlands and reservoirs should be protected against pollution. Inflow of water should not contain any pollutants. Wastes and effluents should not be permitted to enter these water bodies.

3.5 Size of cities and towns

The size of urban centers should not be permitted to than the management capability. The cities and towns should preserve Nature rather than exhibit artificial setting.

3.6 Climate change

Pakistan is 10th worst affected country in the world on account of climate change. Impacts of climate change should be minimized through best environmental practices.

3.7 Cardinal Points for Water Management

Integrated management system offers effective solutions for optimum utilization of natural resources including water. Consumption of water is much more in urban areas than that of rural localities because of higher standing of living and multiple uses. If due to the size of cities it is not

possible to provide the required quantity. Thus undue expansion should not be permitted instead new urban centres may be established.

3.7.1 Seek community participation, through mutual consultation.

3.7.2 Observation of equity, fairness and transparency during entire lifecycle commencing development of water resources, demand and consumption. According to Sustainable Development Goal 6, everyone must have access to safe water by 2030.

3.7.3 Environmental preservation, conservation and self health should be observed during management of water resources.

3.7.4 While Designing Water Solutions Natural factors should be kept in view. No activity should cause adverse impact on Nature and natural resources. Efforts should be made to enhance natural capital.

3.7.5 All developmental activities including urban localities should be developed in unison with Nature. The natural balance should be least disturbed

5.6 Status of Water

For solving the water crisis situation special status of water be kept in view:

It is imperative to understand the special status of water. This is a unique natural resource which is public & private, inland & cross boundary, economic & social good, individual & community, intra-state & interstate, human & other biodiversity, commonality and cooperation & tension. It is the common bounty which is endowed for benefit & welfare to the entire life irrespective of time and space limitations.

5.6 Waste Water Management

5.6.1 Generation of Domestic Sewage and Industrial Effluents

Domestic sewage is generated at the rate of 80% of water quantity consumed. The industrial effluents and storm water form 20% portion of the total municipal sewage. It is worth mentioning that only 8% municipal wastewater is treated.

5.6.2 Natural Applications of Waste Water

The waste water may be used in a variety of natural ways as under:

- **Hydroponics**

  The wastewater after the desired treatment is used for horticulture purpose (growing of vegetables, flower plants and fruit trees) in the stony and gravely soils.

- **Recharging of Aquifer**

  The treated effluents are successfully used for artificial recharging of the groundwater.

- **Use in Aquaculture**

  Certain plants and fishes are cultured in an aquatic environment.

- **Landscape Watering**

  The treated effluents can be safely used for landscaping areas with restricted and open access.

6. RECOMMENDATIONS

Basing on the above discourse following recommendations are made:

6.1 Natural principles of water development, exploitation and consumption should be applied at all levels for ensuring its equitable and just provision to human beings and other biodiversity occupying the Planet Earth.

6.2 Nexus between Nature and water should never be weakened.

6.3 Centers should be established at global, regional and national levels for carrying out research and development studies for optimum utilization of water in light of natural injunctions.

6.4 Global bodies such as United Nations, Organisation of Islamic Cooperation, SAARC & ECO and National Institutions need to revisit the water related protocols, conventions & respective national legislation for improving their efficiency & effectiveness in the backdrop of natural solutions for addressing current water crisis in the world.

6.5 All divine religions advocate equality & respect for utilization of natural resources including water. In this connection Inter-Faith Dialogue may be initiated for improving performance of water sector to incorporate morals and ethics.

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Paper No. 153

MICROBIAL FUEL CELL FOR THE TREATMENT OF INDUSTRIAL WASTE WATER

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By:

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Abstract

Waste water is a global challenging issue which has taken attention of different sectors to treat it. From the last decade, microbial fuel cell (MFC) has grabbed the attention of researchers due to its multifunctional processing. In this review, the microbial fuel cell has provided a mechanism in which cathodic and anodic chambers are utilized. These MFC's not only treated the waste water but also involved in electricity production by using the inhabited microbes. Different MFC's technologies are used by the municipal, agricultural and industrial sector to treat waste water like single (26-506mWm^{-2}), dual (45mMwm^{-2}), air cathode (339.4 mMwm^{-2}), flat plate (72 mMwm^{-2}), and baffle (161 mMwm^{-2}), up flow (0.40volts) and catalyst and mediator less (230 mMwm^{-2}). Gradually by the enhancement of the technologies, MFC has shown a promising removal efficiency of COD from 80% to 98%. This can be utilized at large scale to cope up the energy crises as well as water purification.

Key Words: Microbial fuel cells, waste water treatment, COD, electricity generation.

INTRODUCTION

Wastewater and Diseases

The organic matter contamination is one of the alarming environmental issues in the world. Measures and regulations of environment have increased the development of technologies of the wastewater treatment that can achieve the goal of pollution treatment along with recovery of valuable products (Logan et al., 2006).

Prevention of water pollution and protection of public health by preserving water supplies to avoid the extent of diseases, are the two important reasons for treating wastewater (Lau et al., 2016; Chen et al., 2016). In a study some researchers found the disease burden (GII) among people living along the wastewater system in **Hanoi River**. It was found that disease burden was found among those people who were living along the river and were in direct or indirect contact with wastewater, including farmers who use waste water in aquaculture and agriculture. Another similar study was carried out in **Kampala, Uganda**. The findings concluded the same results that public health problems were associated with exposure to wastewater. Specifically children and adults living and working along the waste water and reuse system in the area (Fuhrimann et al., 2016).

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However, Wastewater is an important source of energy. The energy stored in wastewater is available in three forms:

- Nutritional elements such as nitrogen, phosphorous etc.
- Organic matter
- Thermal energy (McCarty et al., 2011).

The energy stored in the domestic wastewater is in two forms which are thermal and chemical energy. The available chemical energy (26%) is available in the form of carbon which is measured as **Chemical Oxygen Demand (COD),** and other nutrient compounds (like Phosphorous and Nitrogen). On the other hand, Chemical energy holds the major portion of energy (74%). The extraction of chemical energy can be very effective but the harvesting of thermal energy can only be done by using heat pump. The treatment of wastewater processes can be changed to energy yielding processes rather than energy consuming by the extraction of this energy. This will minimize the environmental pollution (Gude et al., 2013).

Microbial fuel cell (MFC) are the reactors in which microorganisms, present in waste water or added as an inoculum, covert the chemical energy in matter to electrical energy. Its importance has been increased due to its simultaneous application in treating wastewater with lesser sludge production i.e. pollution control (Logan et al., 2006). MFCs provide several environmental (water reclamation, lower sludge volumes for disposal, low footprints of carbon); energy (direct generation of electricity, centralized and decentralized applications, energy savings by anaerobic treatment due to elimination of aeration, and low sludge yield); economic (eliminate downstream processes, revenue through energy and value-added products-chemicals, low operational costs) and operational benefits (good resistance to environmental stress, self-generation of microorganisms, and amenable to real-time monitoring and control) (Li et al., 2014)

Municipal or domestic wastewater

Microbial fuel cell can be used in energy production while treating waste water biologically because of its high organic contents. **Single Chamber Microbial Fuel Cell (SCMFC)** was used in a test. The effluent from the primary clarifier from a local plant was used whereas continuous flow conditions were observed. The reactor generated the maximum electrical power of **26 mW m^{-2}** while reducing the value of **COD** up to **80%** from the wastewater. Power generated was related to the **hydraulic retention time (HRT)** and to the strength of influent wastewater over the range of **50-220 mg/L and 3-33 h of COD**, respectively. The production of current mainly relies on the efficiency of cathode while the favorable cathode efficiency was obtained providing flow of air passively rather than forced **(4.5-5.5 L/min).** Power generation in Microbial fuel cells may act as a new way to the wastewater treatment (Liu et al., 2004). A Schematic diagram of single chambered microbial fuel cell (SCMFC) is shown below in the **figure1.**

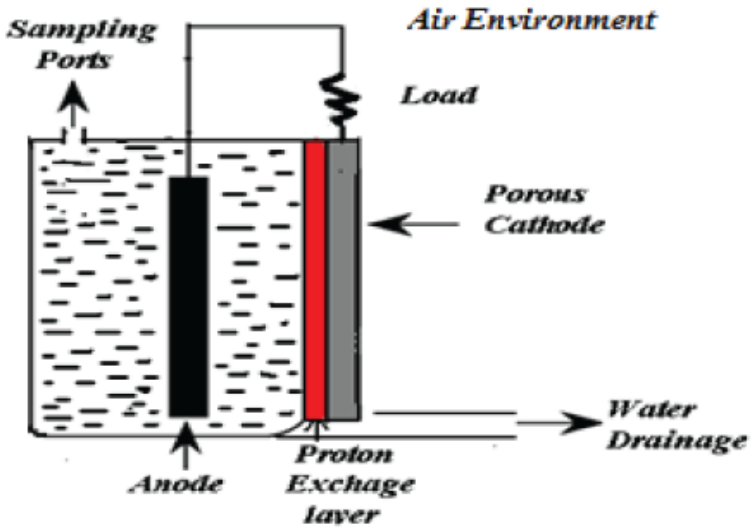


Figure1: Schematic diagram of single chambered microbial fuel cell (Pant et al. 2010)

In another study, a **Flat Plate MFC (FPMFC)** was designed and operated as a plug flow reactor by using **electrode/proton exchange membrane (PEM) system**. The reactor used consists of a channel which was formed between two plates separated by the PEM assembly. Electricity generation was noted by pumping wastewater solution wastewater into the anodic chamber, continuously. The system was initially habituated with domestic wastewater for 1 month. Average power density and COD (chemical oxygen demand) removal were noted **72 mW/m^2** at liquid flow rate of 0.39 mL/min and **42%**, respectively for 1.1 hour HRT (hydraulic retention time). At a longer HRT i.e. 4.0 h, there was **79%** COD removal with average power density of **43 mW/m^2**(Min et al., 2004). Flat Plate MFC (FPMFC) electrode/proton exchange membrane (PEM) system is shown below in the **figure 2**.

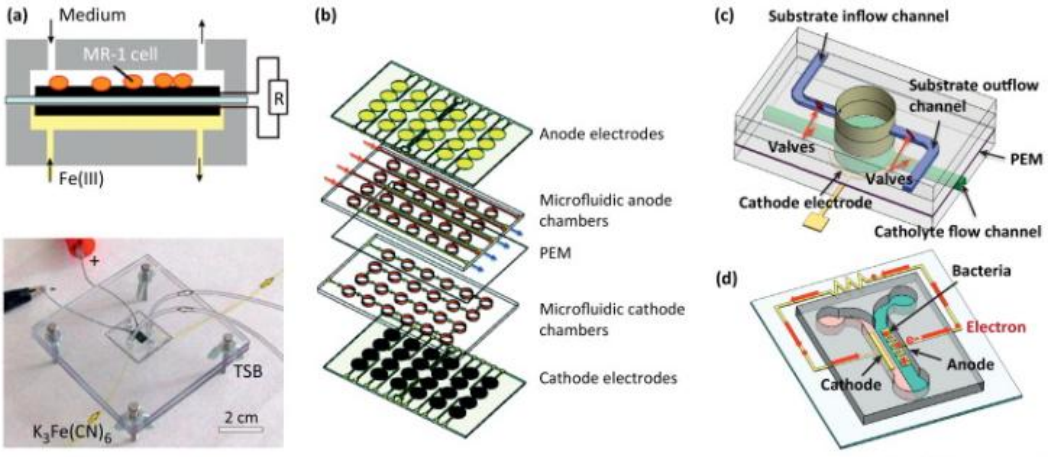


Figure 2: Flat plate microbial fuel cell along with electrode/proton exchange membrane (PEM) system (Han et al, 2013)

Agricultural Wastewater

The use of wastewater for irrigation purposes can be proved a solution to the water shortage in an area, but it can be a serious threat to the environment. Organic matter overloading in wastewater limits the availability of oxygen in the soil as microbes present in soil consume the oxygen for aerobic decomposition of organic matter, making the treatment of wastewater necessary prior to irrigation. Technologies or methods like constructed wetlands, lagoon ponds, conventional methods for wastewater treatment, membrane filtration, membrane bioreactor and others, can be used for this purpose. But need of large land areas for operation properly and high investment costs are limits for such treatment technologies/methods. MFC is a technology that is not only feasible economically but can also improve water quality along with reduction of energy shortages. Abourached and other researchers compared the Microbial Fuel Cell and conventional wastewater treatment plant. Aeration system replacement by MFC at a conventional treatment plant was analyzed and findings have given a promising idea of MFCs construction and use at larger scale and have made these real world applications. It was concluded that Microbial Fuel Cells can be more efficient in treating wastewater than other conventional methods, before using it for irrigation. This technology is important as it has potential to empower the farmers along with enhancement of water, energy and food security (Abourached et al., 2016).

In a study, the energy extraction with a 200-L MFC system while treating the municipal wastewater was investigated. A commercial energy harvesting device was successfully used to convert produce **0.8-2.4 V to 5 V** for running a DC motor and charging capacitors. Four different types of connections, with different numbers of MFC modules were used to examine the extraction of energy and conversion efficiency. The best performance with the highest conversion efficiency of **~80%** and power output of **~114mW** was exhibited by the connection containing three rows of the MFCs. These results indicated that an MFC system can be used for energy production at large scale in near future (Ge et al., 2015).

Industrial wastewater

The MFC substrate is important because it serves as the energy source and nutrient. The concentration of substrate and composition defines the efficiency of chemical energy conversion into bio-energy. In a study, it was demonstrated that swine wastewater can be treated using microbial fuel cell while producing current at the same time. Produced electricity may depend upon the type of microbial fuel cell. Maximum power density of **45mW/m^2** was found by using **two-chambered MFC** whereas single-chambered system produced 6 times more power **(261mW/m^2).** Electricity generation was accompanied by **86.6%** removal of COD and **87.4%** removal of NH_4-N (Min et al., 2005). A dual chamber microbial fuel cell is illustrated below in the **figure 3**.

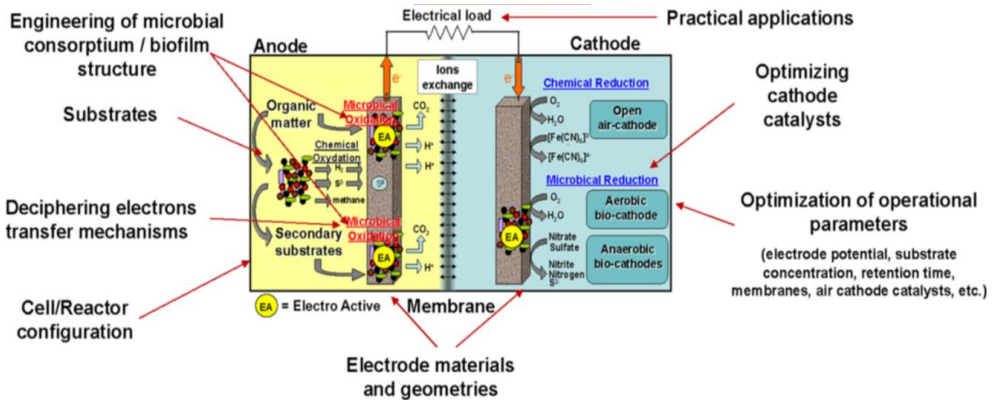


Figure 3: Dual chamber microbial fuel cell (Santoro et al, 2017)

Starch processing wastewater consists of high concentration of protein and starch, which makes it potential energy resource for the MFCs' applications. Some researchers operated an air-cathode MFC with membrane electrode assembly and indicated starch processing wastewater as a good substrate **(4852 mg/l of COD)** for production of electricity in this Microbial Fuel Cell. Maximum power density of 239.4mW/m^2 (a current density of 893.3mA/m2) and voltage output of 490.8 mV were noted in the third cycle, with 8.0% (maximum) columbic efficiency and least internal resistance of 12Ω. COD removal efficiency increased up to **98.0%** while NH_4-N removal efficiency was **90.6%** with respect to time (Lu et al., 2009). The rate of substrate loading affects the functioning of the Microbial Fuel Cell for electricity production and substrate removal.

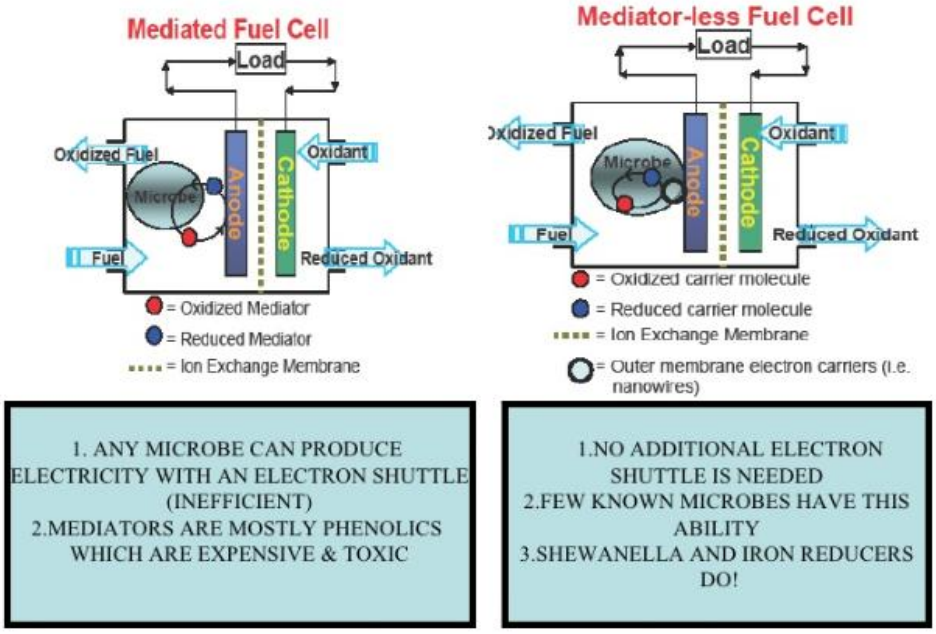


Figure 4: Comparative analysis of mediated fuel cell and mediator –less fuel cell (Santoro et al, 2017)

A clear analysis of mediated fuel cell and mediator –less fuel cell is shown above in the **figure 4**. This effect was studied by using a catalyst and **mediator-less microbial fuel cells (CAML-MFC) technology** with protein food industry wastewater. The highest power, current density, voltage and current intensity produced were 230 mW/m^2 on the anode surface, 527 mA/m^2 on the anode surface, and 0.422 V at ORL 0.18 g COD/ld and 2.53 mA at Organic Loading Rate 0.4 g COD/ld, respectively. 21% coulombic efficiency was the highest that was achieved at ORL 0.18 g COD/ld. The maximum removal efficiency of **NH_3, BOD_5, COD, TSS, P and SO_4** from the real wastewater used as MFC fuel were **73, 79, 86, 68, 18 and 30** respectively. Showing that different Organic Loading Rate not only result in variation in current and voltage output but also affect the efficiency of treatment process (Mansoorian et al., 2013). Air-cathode single chamber microbial fuel cell (SC-MFC) was utilized to simultaneously reduce nitrogen and organic pollutants along with electricity generation from tannery wastewater under pH 7 conditions at 37ºC. Soluble Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN) and Ammonia Nitrogen NH_4N were reduced by 88, 50 and 35%, respectively, with 4 day semi-batch mode with initial concentrations of these pollution 1100, 431, and 206.08 mg L^{-1} respectively. However, electricity generated was negligible **(7 mWm^2)**. In general nitrogen treatment systems cannot be completed in single chamber or reactor which is its limitation. But Single Chambered Microbial Fuel Cells can remove nitrogen pollution and electricity generation simultaneously, in a same reactor. Simultaneous electricity generation and wastewater treatment along with minimal energy consumption for operation makes this technology more beneficial for use (Sawasdee et al., 2016). Effectiveness for electricity generation was demonstrated by two-chambered MFC with activated sludge. The study showed that the wastewater of chocolate industry can be used as both catholyte and anolyte for the electricity generation. Microbial community at anode was analyzed phylogenetically revealing the presence of *Firmicutes*, *a-, b- and c-Proteobacteria, Firmicutes, Planctomycetes, Bacteroides, Nitrospora, Spirochaetes*, and major population of unclassified bacteria. Various new bacterial groups were also identified in the anodic microbial community. Overall, the findings suggested that the chocolate wastewater is a readily biodegradable waste source for electricity generation in MFCs (Patil et al., 2009). Seafood processing wastewater is involved in packaging and processing of varieties of squids, fishes, shrimps and crabs. It has high organic contents due to fish heads, intestinal remains, blood, flesh pieces and scales. By using up-flow Microbial Fuel Cell technology, Total Chemical Oxidation Demand and Soluble Chemical Oxidation Demand of seafood processing wastewater can be treated up to **83% and 95%,** respectively, at **Organic Load Rate of (OLR)** of 0.6 g d^{-1}. While an open circuit voltage of 0.40 V at an organic loading rate of 2.57 g d^{-1} can be achieved at the same time. Therefore, up-flow MFC technology is able to treat seafood processing wastewater successfully (Jayashree et al., 2016). A comparative analysis of all industrial sectors utilizing different microbial fuel cell technologies along with their power density and COD removal efficiencies is shown below in the **table 1.**

Table 1: Power density and COD removal efficiency by different industrial sectors.

Waste water sector	Type of MCF	Power densitymWm-2	COD removal efficiency%	references
Municipal wastewater	Single chamber MCF	26	80	(Liu et al., 2004)
Municipal wastewater	Flat plate chamber MCF	72	42	(Min et al., 2004)
Agricultural Wastewater	MCF	Apprx.114	Apprx.80	(Ge et al., 2015)
Industrial wastewater	Dual chamber MCF	45	86.6	(Min et al., 2005)
Industrial wastewater	Single chamber MCF	261	-	(Min et al., 2005)
Industrial wastewater	Air cathode MFC	239.4	98	(Lu et al., 2009)
Protein food industry	Catalyst and Mediator less MFC	230	86	(Mansoorian et al., 2013)
Sea food industry	Up flow microbial fuel cell industry	0.40volts	83	(Jayashree et al., 2016)
Synthetic waste water	Single chamber MFC	506	-	(Chae et al., 2009)
Synthetic waste water	Baffle chamber MCF	161	-	(Lee et al., 2008)

Synthetic Wastewater

Microbial fuel cells are proved efficient in carbon removal from wastewaters. Synthetic wastewater that can be used in MFCs includes sucrose, glucose, xylose, acetate and other different substrates which are organic in nature in the anodic chamber for oxidation by microbes (Pant et al., 2010). For microbial community, acetate is used as a substrate which is used commonly as a carbon source. Acetate is degraded by the exo-electrogenic bacteria as it is easily bio-degradable and it is also the end product of various metabolic pathways and as a source of complex carbon (Biffinger et al., 2008), as in the anaerobic digestion of wastewater sludge, the matter which contains carbon is converted into short chain organic acids like acetic acid etc. MFC with substrates such as acetate are compared with domestic wastewater and glucose as substrate, produced higher power densities. Using a single-chamber MFC, Liu and some researchers reported that the power produced with acetate as substrate (506 mW/m^2 , 800 mg/L) was higher than that generated with butyrate (305 mW/m^2 , 1000 mg/L). Some researchers compared the performance of four substrates in terms of power output and **coulombic efficiency (CE).** The highest coulombic efficiency of acetate fed MFC was **72.3%,** whereas butyrate, propionate and glucose resulted 43.0%, 36.0% and 15.0%, respectively (Chae et al., 2009). When protein-rich wastewater was compared with acetate as substrate in MFC, the latter one achieved more than double maximum

electric power and half of the optimal external load resistance as compared that which used protein-rich wastewater (Liu et al., 2009). Another substrate which is used in microbial fuel cells research is glucose. A power density of 216 W/m^3 was achieved when the batch was fed from glucose (Rabaey et al., 2003). Hu studied the feasibility of generation of electricity from the anaerobic sludge which is used as a substrate in MFC and compared its results with that of glucose. In a **baffle-chamber** which is a **membrane-less MFC**, anaerobic sludge was added and a limited power of **(0.3 mW/m^2)** was generated. On the other hand, by using glucose a maximum power **161 mW/m^2** was generated, in the same system. The **energy conversion efficiency (ECE)** of substrate i.e. glucose and acetate in MFC was compared, in the study (Lee et al., 2008). The ECE was 42% for acetate, but for glucose the efficiency was only 3% which results in a low power density as well as current. Some researchers discover that the lowest conversion efficiency was obtained in glucose-fed MFC due to the loss of electron by competing bacteria, but the diverse structure of bacteria enabled the substrate and maximum power density to be more utilized (Chae et al., 2009).

Variety of Substrates

Several researchers have examined landfill leachate as a substrate for MFCs. The maximum Output Circuit Voltage achieved varied from report to report, which depends upon the type of landfill leachate, and the age of landfill leachate. Sonawane and some researchers demonstrated that landfill leachate can be utilized as substrate in a Microbial Fuel Cell. Three MFCs with different cathode effective areas were used. All the reactors showed very high Output Circuit Voltages of around 1.3 V (Sonavane et al., 2016). In another study, two designs, circle of volume 934 mL and large-scale MFCs with a volume of 18.3 L, were tested in batch cycles in which landfill leachate was used as a substrate. 635 mV was generated, which is the maximum voltage, using the larger-scale MFC whereas by the usage of Circle MFC maximum power densities of 24 to 31 mW/m^2 (653 to 824 mW/m^3) were achieved (Damiano et al., 2014). Some researchers treat urban landfill leachate which was run for a period of 155 days by using an air-cathode MFC. On the 153rd day maximum values for open cell voltage (OCV) and power density were reached which were 398 mV and 278.2 mW/m^3 respectively, as they both increased with time (Puig et al., 2011).

Proteins can also serve as substrate in microbial fuel cell. The wastewaters containing meat, blood and fatty tissue, paunch contents and meat extracts from animals was examined and it was found that the production of electricity with higher power densities relatively, can be persistent by the utilization of proteins and solutions which are rich in proteins. For effective wastewater treatment MFCs can be used to treat the wastewater of meat packing plant and other wastewaters which contain high protein content. The removal efficiency of COD and BOD for proteins and wastewater obtained from the meat packing plant were actually higher than that of domestic wastewater, on mass basis (Heilmann et al., 2006). The MFC performance could be manipulated easily by simply changing the conditions of initial culture and/or substrates. It was demonstrated by using various carbon sources as initial conditions for culture in microbial fuel cells (containing Micrococcus luteus) and the changes which occurred in current pattern were monitored. It was deducted from these experiments that when the same carbon sources are used as initial culture media, the carbon sources were completely utilized. This was

considered to the fact that the metabolic pathway of microorganisms was already adapted by the same carbon sources. Glucose was found to be the most widely used monosaccharide, irrespective of the initial conditions. It was also observed in some extremophiles such as ***Bacillus thermoglucosidasius*** **and** ***Bacillus licheniformis*****,** which are thermophilic microorganisms. On the other hand, there was no current production noted when fructose was used either as a substrate or for initial carbon source. It signifies that the fact that disaccharides like fructose and pentose sugars is not readily utilized as compared to that of hexoses. It was concluded that the general substrate and the initial carbon sources could be glucose regardless of initial carbon sources and starch, which can be one of the most promising carbon sources. This effort showed that the environmental microorganisms can be used as a catalyst in MFCs (Choi et al., 2007).

Microbial community analysis

Dairy manure was tested by using it as anodic substrate for an improved design of biocathode microbial fuel cell. At 6% of total suspended dairy manure the maximum power density which was achieved was 15.1Wm^{-3}. In order to build detailed microbial communities the 454-pyrosequencing technology was adopted. The members of family Alcaligenaceae with relative abundance, 38.3% which were present in abundance in the bio-cathode showed a distinguished feature of density of the cathode. In addition, the families of *Nitrosomonadaceae* (3.1%), *Pseudomonadaceae* (3.3%), *Enterobacteriaceae* (4.0%), *Bradyrhizobiaceae* (4.2%), *Brucellaceae* (5.1%) and *Xanthomonadaceae* (6.0%) were important components of the cathode community (Zhang et al., 2012). Bacteria on the bio-cathode can facilitate cathodic reduction reaction for a MFCs. Zhang and other researchers outlined the community of cathodic bacteria with high reduction activity using the Illumina pyrosequencing method. Highly diversified and novel population structure was found by this. Cathodic biofilm community structure was dominated by ***Aquificae*** **(7.1%),** ***Actinobacteria*** **(7.7%),** ***Bacteroidetes*** **(9.7%),** ***Firmicutes*** **(25.0%), and** ***Proteobacteria*** **(42.7%). And the population of** ***Acidovorax*****,** ***Soehngenia*****,** ***Clostridium*****,** ***Sulfurihydrogenibium*****,** ***Flexibacter*****, and** ***Mycobacterium*** was predominant. This clearly shows that different varieties of the microbial communities can be used in microbial fuel cells which make this technology more cost effective and feasible (Zhang et al., 2017).

The performance of bio-cathode microbial fuel cells depends upon electrode material and microbial action. In an experiment, the composition of microbial community was analyzed by Sun and some researchers which were attached on four bio-cathode materials and the investigation of the relationship between microorganisms and power generation was also studied in bio-cathode MFCs. Four types of materials were used in the study, which are: **granular semi-coke (GS), granular activated carbon (GAC), carbon felt cube (CFC) and granular graphite (GG)** and were used as biocathodic materials on the MFC. The results had shown that different bio-cathode materials had an important influence on the microbial species type in bio-cathode MFCs. The dominant phyla were *Bacteroidetes* and *Proteobacteria* whereas in electron transfer process of CFC, GAC and GS packed bio-cathode MFCs, *Betaproteobacteria* and *Comamonas* might play important roles. For power generation, *Acidovorax* may be correlated, in a GG packed MFC (Sun. et al., 2012).

Effect of process parameters

The rate of conversion of substrate was relied on the mixing, establishment, mass transfer trends in a reactor, growth and biomass OLR was reported in terms of the efficiency of microbial fuel cells (Rabaey et al., 2003), efficiency for transporting electrons, the proton exchange membrane (PEM) (Liu and Logan 2004; Jang et al., 2004) and the potential on the MFC. The produced over potential at cathode and anode is an important factor and measured as an open circuit potential. The usual range in which this potential is reported is 750 mV and 798 mV. The parameters which affect the generation of over potentials are electrochemical characteristics of the electrode, its potential, its surface and its kinetics along with the electron transfer and the current production mechanism of the MFC. Resistance of membrane and internal resistance of electrolyte between electrodes for proton migration are main parameters that influence the working of MFC. The electrodes should be placed very close to each other as possible as they could be with the mixing of contents of the reactor, in order to minimize this resistance (Rabaey and Verstraete 2005). The concentration of the substrate had affected the performance of anode but did not affect the working of cathode, while the conductivity of the solution has affected the performance on cathode but not on the anode. Power generation by using domestic wastewater was increased up to 62% as a result of applying double size of cathode while the generation of power was only 12% when the size of anode is doubled. This information is very important in the manufacturing of MFCs at higher scales. Another factor which has an effect on the generation of electricity and lost in potential is organic loading rates (OLRs). An estimation of **organic loading rates (kg COD/m3) 7.98, 5.93, 3.96, 1.98** was recorded in various pharmaceutical wastewater (Velvizhi and Mohan 2011).

Nutrient Removal in MFCs

The wastewater which leaves the chamber of anode is rich in nitrogen and potassium compounds. The compounds of nitrogen and potassium can be removed or regenerated in the form of compounds like ammonia or struvite ($MgNH_4PO_4.6H_2O$). It is a crystal of magnesium ammonium phosphate (MAP) along with ammonium (NH_4), magnesium Mg, and phosphorous P in equal molar concentrations which is combined with six water molecules (Le Corre et al., 2009; Etter et al., 2011).

Nitrogen removal in MFCs

The conventional method for removal of nitrogen through nitrification and denitrification reactions has intensive effects on carbon, energy and cost as well. This orthodox method of nitrification includes the aerobic oxidation of ammonia into simpler compounds like nitrate (NO^{3-}) and nitrite (NO^{2-}), and the process of denitrification, which is the reduction of nitrate into nitrogen gas (Ahn et al., 2010). The latter process requires an electron donor which is typically organic compounds, in order to give energy to the bacteria from the reduction reaction of nitrite/nitrate. The electrons from the organic compounds can be accepted by nitrates, which will be reduced into nitrogen gas (as in a conventional process of denitrification). In MFC, the energy required for the reduction of nitrogen compounds in the process of denitrification can be reduced drastically if we use the electrode of cathode directly as the electron donor (Gregory et al., 2004). The first reported species which has the ability to use graphite as the electron donor was

'Geobacter' which reduces the compound directly from nitrate into nitrite. In a new study, the denitrification process in the cathode was combined with oxidation of organic carbon at anode, by using microbial fuel cells (Clauwaert et al., 2007; Virdis et al., 2008).

Phosphorous removal in MFCs

The removal of phosphorus from the wastewater is in the form of struvite. Controlled reclamation of struvite can be achieved by several approaches from the wastewater. Most of the studies regarding the reclamation of struvite have focused on the increase of pH of solution or the separation of carbon dioxide, by the addition of chemical base such as Mg $(OH)_2$, NaOH and $Ca(OH)_2$ or through aeration, respectively (Cusick and Logan 2012). In another study, digested sewage sludge was used in order to obtain the orthophosphate which will be released from iron phosphate. This reaction was by the addition of ammonium and magnesium along with adjustments in pH which is resulted in the formation of struvite (Fischer et al., 2011). 94.6% of phosphate was reclaimed, in a study conducted by Zang and some other (Zang et al., 2012).In order to enhance the efficiency and benefit of process in the MFC unit, the Cusick and Logan produced struvite with the production of hydrogen simultaneously. In a single chamber unit struvite was successfully precipitated out which is in the form of phosphorus i.e. **(0.3–0.9 g/m^2 -h)** with the removal of 40% of soluble phosphate at an energy efficiency of **73 ± 4%** which is high. The efficiencies of energy produced and **hydrogen production rates** are **(0.7–2.3 m^3 H_2/m^3 -d)** obtained in this study which have suggested that the energy which is required for the production of struvite by using an MESC can be compensated by energy which is recovered by the production of hydrogen (Cusick and Logan 2012).

Integration with other beneficial processes

The simple and ambient operations in MFCs make them a suitable process for different environmental remediation applications. In order to generate clean and sustainable electricity Microbial Fuel Cells can be incorporated with other active or passive wastewater treatment systems (Xu et al., 2016). Either after the primary treatment of MFC or after the anaerobic digestion process for the improvement of water quality Microbial Fuel Cells can be used as processing units. To make MFCs wastewater treatment system and management at centralized and decentralized level i.e. at community and domestic level it can be integrated within the existing wastewater management and treatment systems present in the industrial sectors in order to increase the efficiency of energy and resource utilization. The treatment of wastewater can be improved by combining the MFC process with conventional treatment processes which are less cost effective. For the production of high electricity and for the removal of COD and nitrogen some researchers have constructed single-chamber air-cathode MFCs. A low-cost flocculation process was combined to discharge higher quality of wastewater. It was found that overall CO_2 efficiency was improved from **82.5 ± 0.5% to 96.6 ± 0.2%** with the combination of the flocculation. Cost analysis of the combined technology showed a net economic benefit of **$ 0.026 m^{-3}**. So such combinations of MFC and other low cost technologies can be effective in treating different wastewater to low pollutant levels in a low cost (Ding et al., 2017).

The MFC technology may provide a new technique to minimize operating cost of the treatment plant of wastewater, by making the possibility of advanced and new

treatments in economical ranges for the developing and developed countries (Liu et al., 2004). In another study, MFC was linked with Fluidized Bed Membrane Bio-electrochemical Reactor (MBER) for treating cheese factory waste water. The above combination achieved the following reductions in: **COD** reduction of **90%** and a reduction of **> 80%** of suspended solids along with the presentation of energy-neutral potential due to the generation of electricity generation from MFC (Liu et al., 2014). For the purposes of bio-indication, MFCs have been designated as a suitable technology. The generation of the current has been successfully linked with the amount of organic matter present in system which is studied in some areas. The applications of MFCs which are used for continuous clogging assessment was determined in **Horizontal Subsurface Flow Constructed Wetlands (HSSF CW).** In order to achieve this purpose, two membranes-less microbial fuel cells (MFC) were built up and operated for five weeks in vivo conditions. The anode used in this MFC was gravel-based and it was loaded with sludge that had been accumulated in a pilot HSSFCW used for treating domestic wastewater. Results had shown that the correlation of the electric charge to the amount of sludge accumulation (degree of clogging) is negative. When the sludge was accumulated in the MFC the electron transfer almost stopped which was equivalent to 5 years of clogging (Ca. 10 kg TS m^{-3}CW). Under the stance of this result it was obvious that MFC has a great potential for clogging assessment (Corbella et al., 2016). MFCs are more efficient and cost effective technology as compared to other technologies which are used for treatment processes. Another researcher used Microbial electrolysis cells (MECs) and Microbial fuel Cells (MFCs) for direct energy recovery in the form of electricity or hydrogen obtained from the organic matter. The efficiency of removal of organic matter and different energy products values were compared for MFCs and MECs which were fed with the wastewater of domestic or winery. Total recoveries of energy (kWh/kg-COD) and the percentage of TCOD removal were lower for MECs than MFCs with both types of wastewaters. The estimated merchant value is less which is produced by the MECs for hydrogen was \$6/kg-H_2, and the cost of hydrogen for domestic wastewater and winery wastewater is \$3.01/kg-H_2 and \$4.51/kg-H_2 respectively (Cusick et al., 2010).

Conclusion:

Different modifications have been used with the microbial fuel cell technique. The modifications are Single Chambered Microbial Fuel cell, flat plate microbial fuel cell, dual chambered microbial fuel cell, mediator less microbial fuel cell etc. they have shown different efficiencies with different parameters. This technique has shown best results when it is combined in series or integrate it with other treatment techniques. The advantage of using microbial fuel cell is that we can treat waste water along with the generation of few volts of electricity. It shows efficiency of COD removal, nutrients removal like phosphorous and nitrogen and carbon compounds as well. This energy generated in this process can be stored in capacitors or in batteries for further use

Microbes present in the anodic chamber break down the organic matter present in the wastewater and treat the water with simultaneous production of electric potential, and this study confirms it. The highest voltage produced in one of the municipal waste treatment MFC was from 2.4V to 5V.

As we know that Pakistan is energy scarce country so we can apply microbial fuel cell technology to overcome the shortage of energy along with the treatment of waste water. This is a very recent technology which is very helpful in the current scenario in Pakistan, where there is shortage of energy and excess of wastewater. The microbial fuel cell can be made on a very basic level that is at domestic level so it should be introduced in the country. These cells can be used in areas where there is problem of wastewater treatment. The areas which are less privileged by energy and water can use this method for treatment of wastewater for energy production and conservation of water at the same time. The microbial fuel cell is a source of green energy. It should be introduced in the Northern as well as in the remote areas of Pakistan because shortage of electricity in these areas is common. The energy which is produced by the cells can be stored in the capacitors and batteries, or different technologies can be used to increase the electric potential so it can be used for daily use. This can generate revenue for energy generation as well as for wastewater treatment plant. Studies should be carried out at advance level to make this technology closer to real world.

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Listing of Papers Presented at Various World Water Day(s), Commemorated by

Pakistan Engineering Congress

Sr. No.	Title of Paper	Name of Author
	2005 – Water for Life:	
1.	Constructing New Dams for Pakistan's Survival	Engr. Dr. Izhar-ul-Haq,
2.	Implementation of Indus Waters Treaty 1960	Engr. Syed Jamaat Ali Shah
3.	Pakistan's Water Resources Development and Global Perspective	Engr. M. Mushtaq Ch., General Manger (P&D) Water, WAPDA, Dr. Allah Bakhsh Sufi
4.	Reducing the Impact of Unplanned Urbanization of a Riparian Eco-System: A case study on designing a Plan for Sustainable Utilization of Flood Plains on River Ravi	Dr. Amin U. Khan
5.	Ground Water use in Pakistan : Opportunities and Limitations	Dr. Muhammad Nawaz Bhutta
6.	Development of Sub-Surface Drainage Data Base System for Use in Waterlogging and salinity Management Issues	Dr. Aftab H. Azhar, M. M.Alam, M. Rafiq
	2006 – Water Scarcity:	
7	World Water Day, March 22, 2006 – Water Scarcity	Engr. Muhammad Mushtaq Chaudhry
8	Water as Instrument of Peace the Vision of Indus Waters Treaty 1960	Engr. Syed Jamaat Ali Shah
9	Water Resources Development in Pakistan	Engr. Dr. Izhar-ul-Haq, S. Tanveer Abbas
10	Risk Perception towards flooding and environment in low income urban communities	Dr. S. M. Saeed Shah, M. Kaleem Sarwar
11	Bringing drainage towards integrated water resource management in the Indus Basin	Dr. Muhammad Nawaz Bhutta
12	Introducing Modern Environment Friendly Technology for Water Management in Customary environment of Pakistan	Abdul Hakeem Khan, Sarfraz Munir, Dr. Hugh Turral
13	Assessing the Behaviour of Groundwater Recharge using Water table Fluctuation Method	Jehanzeb Masud, Asaf Sarwar
14	Hydro Energy and Water Vision in Pakistan	Abdul Qayyum

2007 – Coping with Water Scarcity:

15	Water Scarcity & Wapda Vision 2025	M. Mushtaq Chaudhry, Dr. Allah Bakhsh Sufi
16	Combating Water Scarcity	Dr. Izhar-ul-Haq, S. Tanveer Abbas
17	Role of Groundwater in Coping with Scarcity of Water	Dr. Muhammad Nawaz Bhutta
18	Coping with Water Scarcity & Indus Waters Treaty Vision	Engr. Usman-e-Ghani
19	Growing Scarcity of the Water Resource	Shafqat Masood
20	Waste Water Re-use for Crop Production: An Option for Sustainable Agriculture Under Water Scarce Environments	Sarfraz Munir, Abdul Hakeem Khan, Waqas Ahmad, Aamir Nazeer
21	Efficient Irrigation Techniques to Cope with Water Scarcity	Engr. Muhammad Yasin
22	Groundwater Sustainability to Cope with Water Scarcity	Jehanzeb Masud, M. Arshad

2008 – Sanitation:

23	Key Note Address on Access to Basic Sanitation –A Challenge for All	Jawed Ali Khan
24	Generation & disposal of Solid Waste at Model Town Central Park Lahore	Attia Dastgir, Zahid-ul-Haq, Dr. Allah Bakhsh Sufi
25	Drinking Water Quality: Removal of Heavy Metals from Contaminated Water	Muhammad Iqbal, Asma Saeed, Muhammad Saleem
26	Hospital Hazardous Waste Management	Ali Sher A. Baloch, Asma Iftikhar
27	Appropriate Technologies of Sewage Treatment For Urban Centers & Large Villages of Punjab	Engr. Shabbir Ahmad Qureshi
28	Adverse Effects of Poor Waste Water Management Practices On Ground Water Quality in Rawalpindi And Mitigation Strategies	Lt. Col Islam-ul-Haq TI (M) (Retd), W. A. Cheema
29	To Study the Performance of an Innovative, On Site Waste Water Treatment System	Dr. Zahiruddin Khan
30	How to Improve Medical Waste Management	Dr. Fayyaz Ahmad Ranjha
31	Monitoring of Microbial Quality of Drinking Water in Tench Area, District Rawalpindi, Pakistan	Shaukat Farooq, Dr. Imran Hashmi, Sara Qaiser, Sajida Rasheed, Asma Saeed

32	Solid Waste Management Practices in Lahore	Dr. Muhammad Tufail Siddiqui

2009 – Transboundary Waters:

33	Transboundary Waters – Perspective of Indus Water Treaty-1960	Engr. Usman-e-Ghani
34	Transboundary Waters and Sustainability of Irrigated Agriculture in Pakistan	Riaz Nazir Tarar
35	Indus Water Treaty-1960 – A Challenge for our Sustainability	Engr. Shafqat Masood
36	Transboundary Water Issues of Pakistan and some other Countries	Dr. Allah Bakhsh Sufi, Zahid Hussain Khan, Asghar Ali Hale Pota
37	Effect of Transboundary Water Agreements on Water and Food Security of Downstream Riparian Communities – A Case Study of Indus Waters Treaty	Sarfraz Munir, Waqas Ahmad, Asghar Hussain
38	Protection of Water Quality and its Sustainable Use in Pakistan	Dr. Muhammad Nawaz Bhutta

2010 – Communicating Water Quality Challenges and Opportunities

39	Prevalence of ESCHERICHIA COLI within Public Drinking Water supply in 1-8 Sector Islamabad	Sajida Rasheed, Dr. Imran Hashmi, Sara Qaiser
40	Safe Drinking Water and Sanitation in Punjab	Salman Yusuf
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43	Managing Water Scarcity and Quality Deterioration in Pakistan Challenges and Options	Dr. Allah Bakhsh Sufi, Talib Hussan, Khalid Javed
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48	Role of Brackish Water in the Reclamation of salt Affected Soils	Munawar Ali, Muhammad Rafiq

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50	Assessing Microbiological Safety of Drinking Water: A Case Study of Islamabad, Pakistan	Dr. Imran Hashmi, Sara Qaisar, Syeda Asma, M. Talal Ali Khan, Sidra Abbas
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2012 – Water and Food Security:

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61	Managing Demand Side of Water Scarcity Equation – Prospects and Potential of Drip Irrigation.	Chaudhry Mohammad Ashraff, Malik Muhammad Akram, Dr. Maqsood Ahmed, Hafiz Qaisar Yasin

62	Managing Water Resources For Food Security in Pakistan	Irshad Ahmad, Dr. Allah Bakhsh Sufi, Talib Hussain
63	Discovering Linkages between Water and Food Security Dimensions	Ali Hasnain Sayed, Ms. Dure Shahwar
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66	Quality of Drainage Water and its Irrigation Prospects in Sindh Province of Pakistan	Khalid Mahmood Subhani, Zafar Iqbal Raza, Dr. Muhammad Mehboob Alam
67	International Experiences in Groundwater Management and their Viability in Pakistan for Resource Sustainability	Muhammad Basharat, Syed Javed Sultan
68	Ground Water Table fluctuations in Irrigated Areas of Rechna Doab – Punjab	Muhammad Saeed, Syed Javed Sultan, Dr. M. Mehboob Alam

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70	Environmental Degradation around River Ravi - Caused by the division of Indus Basin Rivers	Engr. Dr. Izhar-ul-Haq, Abdul Khaliq Khan
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72	Water Cooperation – Resilience to Climate Change	Engr. Ahmad Kamal
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