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WORLD WATER DAY

MARCH – 2016

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President 74th Session

ADDRESS OF WELCOME
By
ENGR. CH. GHULAM HUSSAIN
PRESIDENT
PAKISTAN ENGINEERING CONGRESS
On
WORLD WATER DAY, 2016
on
Monday, 28th March, 2016
at
Pakistan Engineering Congress
Lahore

Venerable Chief Guest, Engr. Shamsul Mulk
Distinguished Delegates
Members of Pakistan Engineering Congress,
Fellow Engineers,

Ladies and Gentlemen!

Assalam-o-Alaikum
It gives me immense pride to apprise that Pakistan Engineering Congress has a unique distinction of commemorating World Water Day, along with the world since 2005 on the universally laid down themes. Not only this, the papers presented at these events from the Congress Forum have been published and distributed complimentary to all concerned in particular the Federal / Provincial Govt. Departments along with the recommendations formulated by the panel of experts.

Ladies and Gentlemen!

We are globally witnessing a technological revolution in all spheres of life like Super computers, Robotic manufacturing, Bullet trains shortening long distances, Air-travel network, connecting all corners of the world. Agricultural and Industrial advancement and standards of living where luxuries have become necessities. Emerging economies like China, India and others are challenging the elite economic powers through planned socio-economic development of their national resources, enhanced agricultural / industrial production, expansion of means of communication and transport and accelerated exports of goods and services.
In such a challenging scenario, Pakistan cannot allow itself the continued lethargy, ill-planning and criminal negligence in exploitation of its Water Potential

direly needed for bringing waste land under cultivation and generation of cheap hydel energy, to run its wheels of industry and accelerated industrial advancement to provide a decent living to its people and to ensure food security for its rising population.

Ladies and Gentlemen!

The present population of the world is about 7-billion and is visualized to touch 9-billion markwith only one planet for existence. Experts have visualized that amongst other amenities of life, it would require 70% increase in food production. Pakistan's population of 198 million is expected to touch a massive figure of 221 million by 2025. The increase in food production by 50% would be an uphill task. In this connection, the following remarks of a World Bank Report are pertinent;

"The Agriculture sector suffers from water shortage, frequent drought and poor farming practices, expose the rural communities to high vulnerability, especially women and children"

In order to ensure food security, poverty alleviation and opening up vast channels of employment, we have perforce to embark upon a massive efforts for preservation / conservation of Water Resources and above all optimum utilization of the Water Potential of the Country.

Ladies and Gentlemen!

The world is conscious of the immense significance of the precious water resources, both surface water and ground water resources. They have constructed numerous dams on each of their rivers, thereby using it for bringing additional lands under cultivation and for generation of cheap hydro power to boost industrial production for internal consumption and exporting goods for earning valuable foreign exchange. Let us see what is the scenario in Pakistan.

Ladies & Gentlemen!

- We were destined to put in place one mega reservoir after every 10 years but unluckily failed to construct even one such dam over the last 40 years due to which we are today facing massive energy deficit and are on the brink of a water starved Country.
- 30-35 MAF water every year flowed into the sea over the years without any productive use in agricultural, generation of cheap electricity and industrial development, etc.
- Pakistan has only 30-days storage facility in dams compared to 220-days storage in India & 1000 days in Egypt.
- According to International Standards 40% of the river flows are required to be stored. Pakistan have only 13.29 MAF storage against 58 MAF, a dismal position.

- We have not spared even the ground water resources 1-million tube wells are extracting water, without any regulatory frame-work, and without adequate re-charge system which is resulting in steep fall in water tables.
- Hill torrents produce 18 MAF water out of which 13 MAF can be used for bringing waste land under cultivation but no progress has been made resulting in flash floods and destructions during in last 6-7 decades.

Ladies & Gentleman!

RECOMMENDATIONS AND WAY FORWARD

The Framework

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

Surface Water Management

As a result of population growth, the surface water availability which was more than 5000 cubic meters per capita in 1950, has now (2016) reduced to about 1000 m^3 per person. Pakistan is at the threshold of being water scarce country.

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

Pakistan has the largest and the oldest contiguous irrigation system. After diversion of water at various barrages, 30 MAF of water, on the average, goes down the last barrage into the Arabian Sea every year.

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

Therefore, in order to have sustainable economic development, Pakistan must have more capacity to store water and make it optimal use.

Thank you for your participation and patient attention.

PAKISTAN PAINDABAD

APPLICATION OF COMPUTATIONAL FLOW DYNAMICS (CFD) ANALYSIS FOR SURGE INCEPTION AND PROPAGATION FOR LOW HEAD HYDROPOWER PROJECTS

***M. Mohsin Munir[1], Javed Munir[2]**

Abstract

Determination of maximum elevation of a flowing fluid due to sudden rejection of load in a hydropower facility is of great interest to hydraulic engineers to ensure safety of the hydraulic structures. Several mathematical models exist that employ one-dimensional modeling for the determination of surge but none of these perfectly simulate real-time circumstances. The paper envisages investigation of surge inception and propagation for a Low-Head Hydropower project using Computational Fluid Dynamics (CFD) analysis in FLOW-3D software. The fluid dynamic model utilizes its analysis for surge by employing Reynolds' Averaged Navier-Stokes Equations (RANSE). The CFD model is designed for a case study at Taunsa Hydropower Project in Pakistan. Various scenarios have run through the model keeping in view upstream boundary conditions. The prototype results were compared with the physical model testing results and proved quite accurate coherence with the physical model testing and offer insight into phenomenon which are not apparent in physical model and shall be adopted in future for the similar low head projects limiting delays and cost incurred in the physical model testing.

***Keywords**: Surge, FLOW-3D, Numerical Model, Taunsa, RANSE*

1. Introduction

Maximum elevation that the flow will achieve due to a sudden rejection of load in a hydropower facility is an important parameter to hydraulic engineers. The information is required in setting the maximum height of sidewalls to prevent overflow in the headrace channel as well as to understand the surge propagation upstream in headrace channel to schedule the opening of gates of the main barrage and balance the discharge through the barrage and power channel.

In Pakistan, physical model studies are the only practical medium available to understand and analyze the three dimensional and time-dependent complexities of the fluid flow phenomenon. Physical models can only be setup at the final design stage and their execution is expensive. However, the avant-garde computational flow dynamics has emerged not only as an alternative analysis

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and design tool but can also be employed to analyze phenomenon that are not possible to assess with physical testing.

2. Literature Review

A monoclonal wave exhibiting a rapidly varying flow may result in a hydropower project due to sudden closure or opening of the powerhouse control structure such as the sluice gates or wicket gates. This hydraulic transient analysis is of immense importance especially during the design phase of the hydropower project. The rising wave can easily overtop the banks of the fore-bay or the headrace channel and damage appurtenant structures of the hydropower facility. Moreover, studying the propagation of wave through the headrace channel and into the reservoir is required to assess the effect of rapidly varying flow in the headrace on the reservoir water levels.

Several mathematical methods exist for one-dimensional determination of surge for different conditions i.e. for straight channels, for propagation of surge on a gradient, analysis of reflected surges and the Johnson method. The first three methods are simplifications of the original problem and are based on several assumptions. These methods do not truly represent the original problem and these conditions are rarely met in practice. Similarly, the Johnson method can be arduous as the computation proceeds since numerous surges will be produced and propagated. Hence it becomes inaccurate and difficult to assess the surge using these methods.

Other time dependent analysis increase the complexities of the problem by introducing additional independent variable of time since the resulting equations become partial differential equations instead of ordinary differential equations. Method of Characteristics and Implicit and Explicit Finite-Difference Methods have better accuracy and rigor but are time-consuming and cannot be applied fully to original conditions. In special cases, such as analysis of hydropower projects comprising of open headrace channel with tailrace tunnel (Closed conduit), implicit methods are preferred for the closed conduit. Such complexities can only be modelled using a powerful software package like FLOW-3D, based on numerical solution schemes that can accurately predict fluid flow using the concept of fluid volume tracking.

FLOW-3D was developed at the Los Alamos National Laboratory in the 1960s and 1970s as a general purpose computational fluid dynamics simulation package. FLOW-3D uses an Eulerian framework in which volume tracking technique models the free surface. This method, based on fluid volume fraction analyses the amount of fluid in each cell and is robust enough to handle the breakup and coalescence of fluid masses.

FLOW-3D uses several models to numerically simulate turbulent flows. For this case study, the Renormalization group (RNG) k-epsilon turbulence model was used with a no slip or partial slip wall shear boundary condition. The RNG turbulence model uses statistical models to solve the turbulent kinetic energy (k) and the turbulent kinetic energy dissipation rate (Є), renormalizing the Navier Stokes Equations to use cater for the effects caused by smaller scale motion.

FLOW-3D employs the Volume-of-Fluid (VOF) technique developed by Hirt and Nichols in 1981 to deal with interfaces between two fluids and to model. VOF depends on the volume fraction which is assigned value of either 1 or 0 depending the cell is occupied by the fluid or not. It is governed by the following convection transport equation:

$$\frac{\partial F}{\partial t} + \frac{\partial F u_j}{\partial x_j} = 0$$

A detail on VOF method related issues can be found in Bombardelli et al. (2001) while its development can be referred to C.W. Hirt et al (1981). The free surface is not only unknown in 3-D computations, but it also acts a boundary for the problem. A sharp representation of interface is necessary to be maintained apart from locating the free surface in a 3-D Eulerian grid, doing it effectively in terms of computational time.

Case Study of 135MW Taunsa Hydropower Project

Taunsa Hydropower Project has been sited along right bank of Taunsa Barrage across Indus River in Pakistan. It is a run of the river, low head hydropower scheme envisaged to provide power to the national grid. Table 1 summarizes the salient features of the project.

Table 1. Salient Features of 135MW Taunsa HPP

Type of Turbine	Horizontal Bulb
Mode of Operation	Run of the River
Installed Capacity	135 MW
Gross Head	6.0m
Rated Head	5.8m
Design Discharge	3,155.5 m^3/sec
Turbine Units	9 Units
Headrace Width	203m
Headrace Length	1100m
Vertical Gate Height	16m

FLOW-3D analysis is often limited by computation power available. For numerical simplicity in this case, the three-dimensional model was setup based on only one hydropower unit and not the complete power-station. FLOW-3D can effectively use the symmetry conditions of the project layout without affecting the accuracy of the surge analysis. A 3D model was used since flow has three-dimensional characteristics.

3.1 Model Preparation

The model for Taunsa hydropower project was prepared in AutoCAD and imported in stereo-lithographic format which is used for rapid prototyping, 3D printing and computer-aided manufacturing. Three dimensional models were prepared for the headrace, transitions, powerhouse and tailrace. Figure 1 illustrates the 9 unit powerhouse with gates open. Figure 2 shows the detail of transitions of a single unit with bulb turbine housed inside.

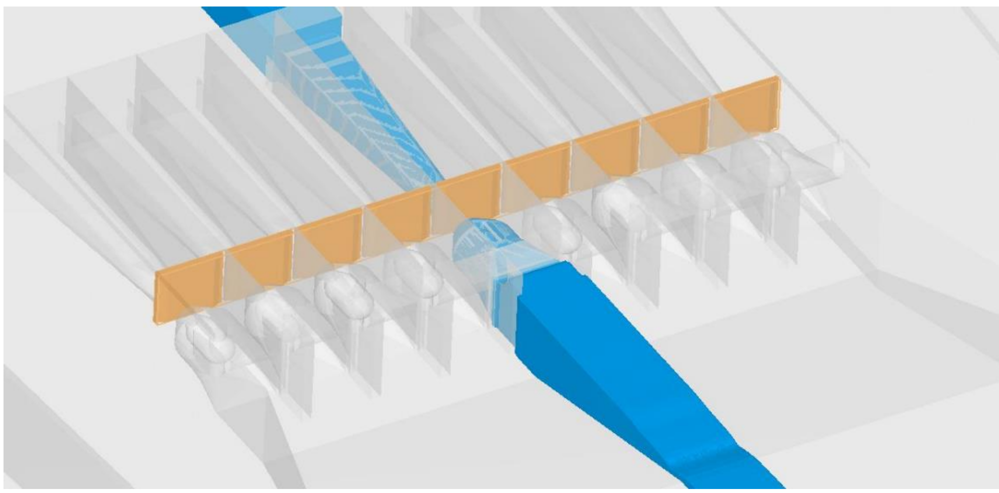

Fig. 1. Isometric View of Taunsa HPP Model

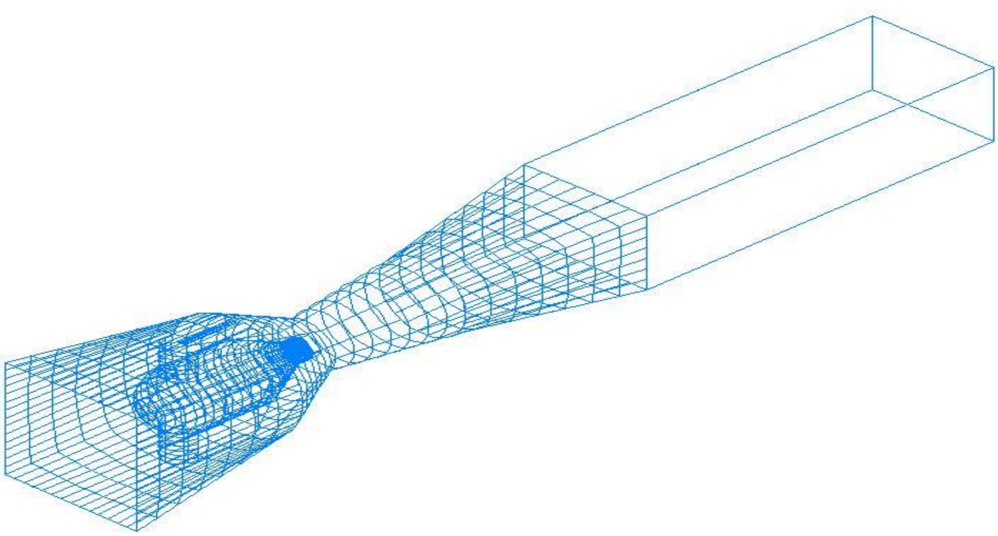

Fig. 2. Wireframe of a single in-take and draft tube with bulb turbine

3.2 Meshing

Meshing is a consequential part of the analysis process which not only determines the numerical accuracy of the model but also the memory and time required for the simulation. Meshing was done and refined in FLOW-3D model setup options. FLOW-3D has an advantage of FAVOR; Fractional Area/Volume Obstacle Representation Method which allows modeling of complex geometries based on equations formulated as functions of the area and volume porosity.

As specified before, for simplicity as well as increased accuracy, meshing was done for one unit. This is a common practice since for large models, noumber of total active cells are limited by computer memory. For Taunsa Hydropower Project, the extents, number of cells and cell sizes are tabulated in Table 2.

Table 2. Summary of meshing in FLOW-3D

Total active cells		2320000	
Dimension	**Extent (m)**	**No of cells**	**Cell size (m)**
X	400	400	1.00
Y	18.5	50	0.37
Z	29	116	0.25

Cell sizes for the mesh were selected based on two factor. First consideration in this regard is the model accuracy. In case of surge analysis, height of surge (z-direction) is the most important. Hence, smallest cell size has been selected for z axis. Second consideration is CPU memory and computation time. Increasing the number of cells requires greater computation power and longer simulation time. Average simulation time in for Taunsa HPP was 15 hours. Keeping in view the two factors, minimum cell size was selected so that full computation power was being employed.

3.3 Boundary Conditions

Boundary conditions have a huge impact on the final results of the simulation. It is necessary to assess the boundary conditions that best replicate the real-time conditions and actual simulation. Boundary conditions applied for the problem are specified below:

X minimum	Specified Pressure Boundary
X maximum	Outflow Boundary
Y minimum	Symmetry Boundary
Y maximum	Symmetry Boundary
Z minimum	Wall Boundary
Z maximum	Symmetry Boundary

The upstream boundary condition consisted of a specified pressure to maintain a prescribed reservoir elevation. The downstream boundary utilized the FLOW-3D outflow boundary condition. A symmetry boundary condition was applied along right and left side of the mesh section to take advantage of the inherent symmetry in the problem and thereby decrease computational time while maximizing spatial resolution. Boundary conditions used have been explained below:

Symmetry Boundary: There is no mass flux (flow) through a symmetry boundary. There is also no shear stress or heat transfer applied at this boundary type. It is useful for reducing the size of a simulation when symmetry exists by cutting the simulation at the symmetry plane.

Wall Boundary: The wall boundary is similar to the symmetry boundary in that mass flux across the boundary is not allowed. However, with a wall boundary, heating and viscous stresses can be applied.

Specified Pressure Boundary: This boundary type sets a pressure condition. The pressure can be constant by setting a value in the dialog box, or time dependent by selecting the pressure button.

Outflow Boundary: This boundary type is useful for surface waves because they are able to leave the flow region without reflecting back into the domain. This boundary type looks at flow conditions just inside the mesh and matches them to allow fluid to freely dissipate through the mesh extent.

3.4 Case Study Scenarios

Two flow scenarios have been analyzed for the case study as tabulated in Table 3. During normal flow operation, initial water level elevation of 135.94m will be maintained in the headrace channel and 130.25m in the tailrace channel during full operation of 9 units. The model is allowed to operate freely for 30 seconds after which the gates are shut at 1.4m/s to close the orifice in 5 seconds in order to replicate sudden closure conditions. Type B surge or the rejection surge occurs as a result of sudden decrease in power output. Similarly during flood flow operation, initial water level elevation of 136.25m will be maintained in the headrace channel and 133.26m in the tailrace channel. Other conditions are kept same as in normal flow conditions.

Table3: Flow Conditions for Taunsa HPP

Flow Condition	U/S water level (m)	D/S water level (m)
Normal Flow	135.94	130.25
Flood Flow	136.25	133.26

3. Results

The rejection surge occurs as a result of sudden decrease in power output. Figure 3, 4 and 5 illustrate the surge inception and propagation at different times after load rejection in the extent just upstream of the gates. The points of flow direction reversal can easily be tracked for the upstream advancing surge. This is a feature that is only possible with computational flow dynamics analysis since it is not possible to observe these phenomenon in physical model testing.

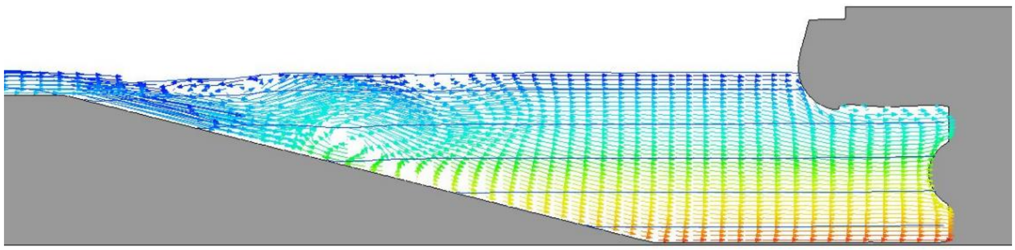

Fig. 3. Flow through the power unit at full operation

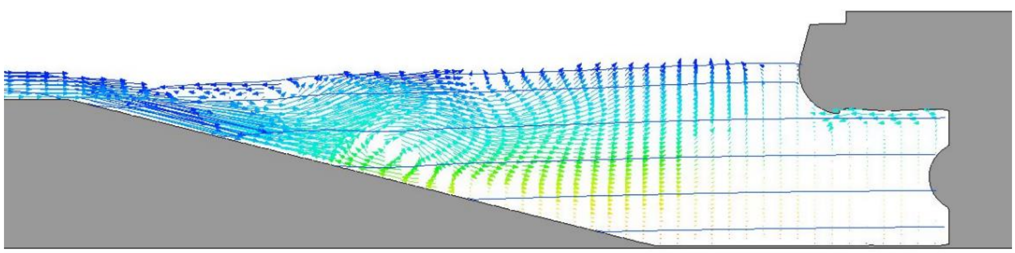

Fig. 4. Surge inception at time of load rejection

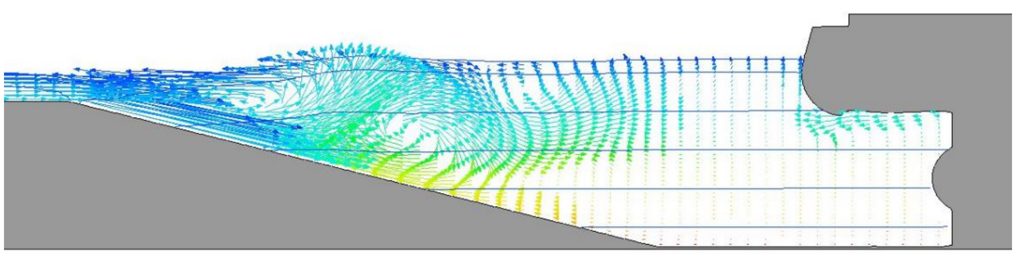

Fig. 5. Flow reversal after 10 seconds of load rejection

In figure 3, flow vectors at full flow conditions are illustrated by arrows. This shows an uninterrupted movement of fluid. After load rejection, a *region of fluid immobility* starts to develop as observed from figure 4. This region acts a cushion against incoming discharge and reverses its direction which results in surge inception. Figure 5 shows the region of fluid immobility develops upstream with time as surge wave begins to achieve greater elevation. The phenomenon holds true for both normal flow conditions and flood flow conditions.

4.1 Normal Flow Conditions

As the surge moves upstream, change in flow depth will ensue. FLOW-3D can track the change in elevation of free surface efficiently for any spatial location of the model. Changes in surface elevation with time were observed for three locations i.e. at turbine unit entrance, 85m upstream of the entrance and at headrace entrance.

The temporal and spatial change in free surface elevation at 3 locations has been shown in Figure 6. Table 4 shows the summary of results which depict a maximum surge of 2.25m at unit entrance. Time of arrival of first wave has also been tabulated. The surge is expected to reach the headrace entrance in 260 seconds after gate closure with an average velocity of 4.84m/s. As the surge wave moves upstream, the height of wave dampens.

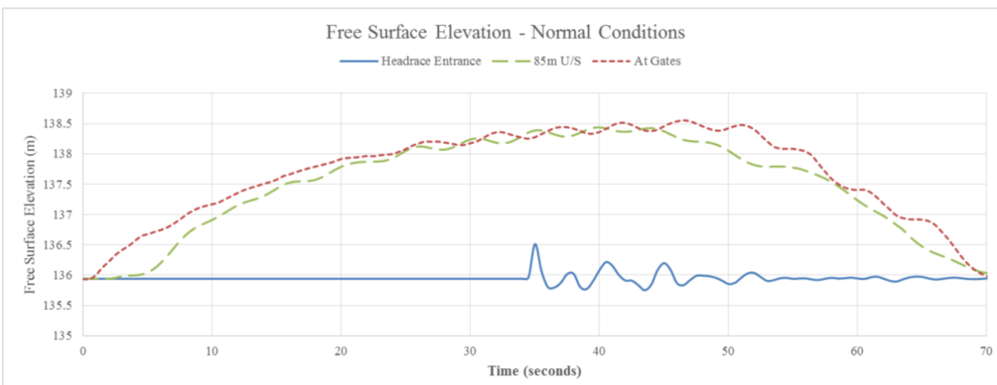

Fig. 6. Change in water elevation vs time after load rejection for Normal Flow Conditions Taunsa

Table 4. Summary for Normal Conditions

Location	Max Surge	Surge Elevation	Time (sec)
Unit Entrance	2.25m	138.19m	7
85m U/S	2.21m	138.15m	14
Headrace Entrance	0.53m	136.47m	260

4.2 Flood Flow Conditions

In case of flood flows in Taunsa hydropower, an upstream water level of 136.25m is maintained in the headrace with a corresponding tail-water level of 133.26m in tail-race. Other conditions are kept same as in normal flow conditions. The surge is expected to reach the headrace entrance in 206 seconds with an average surge velocity of 6.7 m/s. Maximum surge elevation of 138.4m (2.21m) is observed at the power unit entrance. The results have been tabulated in Table 5. Figure 7 shows the change in free surface elevation at the three selected locations vs time after load rejection from the power unit.

Table 5. Summary for Flood Conditions

Location	Max Surge	Surge Elevation	Time (sec)
Unit Entrance	2.21m	138.39m	6
85m U/S	2.00m	138.20m	12
Headrace Entrance	0.32m	136.52m	206

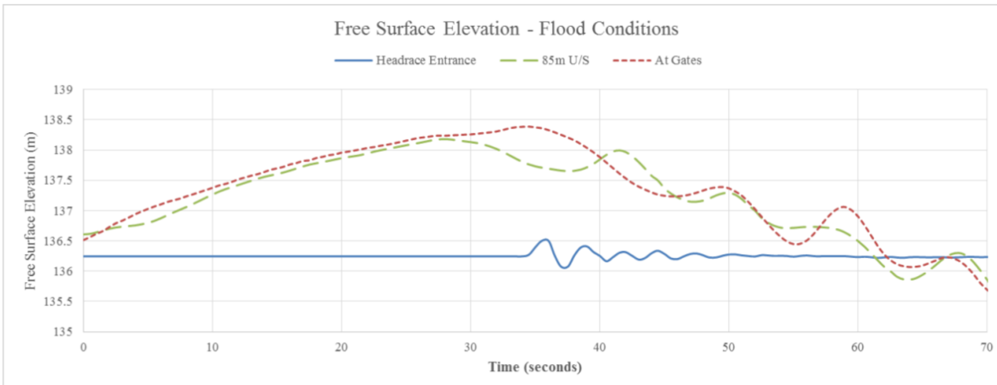

Fig. 7. Change in water elevation vs time after load rejection for Flood Flow Conditions Taunsa Headrace

It is observed that the surge travels faster and achieves a lower maximum free surface elevation for the flood flow conditions compared to the Normal Flow Conditions.

4. Conclusion

Observations of the surge inception and propagation are in line with the theory and assumptions specified by VenTe Chow and other authors. For upstream advancing surge, when the surge wave reaches any point in the headrace, the water elevation behind the wave approximately equals the maximum elevation of the surge wave. The simulation results were compared with the mathematical formulae mentioned above as well as the physical testing model carried out at Irrigation Research Institute, Nandipur, Punjab. The results of the physical model testing were within ±2% of the results achieved with simulations in FLOW-3D. This has built greater confidence in modelling using computational flow dynamics especially for modelling in field of power generation.

Applications of computational flow dynamics have been increasing in engineering applications over recent times. The computer numerical models are a cost-effective alternative to physical modeling techniques offering more flexibility during design and analysis and can offer insights into phenomenon that are not apparent in physical model testing. However, CFD analyses limited by computational power. The present 3D detailed analysis of a single unit required more than 24 hours of computation per simulation to examine a 70-second time-history. A longer time-history is often more desirable.

The analysis of Taunsa hydropower headrace channel using computational flow dynamics is a step-forward in supplementing the results from mathematical modelling and conventional physical model testing in Pakistan. It is not only a robust analysis software solution but can be employed as efficacious tool in the design process of hydraulic structures where it can offer extensive flexibility to assess and compare different proposed designs and their efficiencies. This design support can save a lot of time and money by the optimization process before final designs are physically tested at Irrigation Research Institute, Nandipur.

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TEMPORAL VARIATION IN ABLATION RATE OF PASU GLACIER IN THE KARAKORAM RANGE, PAKISTAN

Asim Rauf Khan[3], Muhammad Ashraf[4]

Abstract

Glaciers of the Upper Indus Basin are the most important contributors to the annual river runoff. An understanding of the glacier behavior provides insights to water availability in the short and long term to fulfill Pakistan's requirement for agriculture and energy. Field investigations of glaciers provide information crucial to hydrologic modelling of river basins such as the Indus. The study examines the results of field investigations carried out on Pasu Glacier from 2010-2015. In this study, stake were drilled at two locations on Pasu Glacier in Hunza Valley and ablation measurements were recorded. In addition, discharge measurements were carried out on Pasu outlet. Snout surveys were also conducted. Such field observations as carried out in this study supplement the physically based numerical models to assess the changes accurately and provides contemporary glacier dynamics.

1. Introduction

The glacier system in the Upper Indus Basin, which consist of Karakoram and Hindu-Kush Himalaya (HKH) regions, is the largest glacier system outside the polar region. There are more than 5000 glaciers in this region also called as the Upper Indus Basin. Therefore, it has attracted many researchers to focus their studies in this region and found the contrasting mass balance regimes for these mountain ranges. Hewitt (2005) and Kääb et al. (2012), for example, found the stable or slightly positive mass balance in the Karakoram Range that is in contrast with predominantly negative balances of glaciers in the rest of the Hindu-Kush Himalaya (Cogley, 2011). Kääb et al. (2012) reported that the larger glaciers are expanding in several areas of the central Karakoram, accompanied by numerous glacier surges. However, other observations indicate that in the Karakoram and adjacent mountain ranges, most glaciers are still losing mass (Haritashya et al 2009). These states of the glaciers effects the hydrology of the basin by increasing melt water initially due to shrinking of glaciers but reduced runoff later due to store of precipitation in the expanding glaciers, and can also generate local hazards. Archer and Fowler (2004 & 2006) suggested that these differences could be caused by increases in precipitation and a simultaneous trend toward higher winter temperatures and lower summer temperatures. Such a combination, associated with the role of the elevation and elevation range of the glaciers across the Karakoram, may have caused the expansion of large, flat glaciers and probably reduced melt water production. If the observed trend of

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slightly cooler summer temperatures continues, melt water from high elevations will be reduced and the low-lying glacier snouts could compensate for the missing amount (Mayer et al., 2010).

Knowledge of the glacial ablation, melt gradient and hydrological response of Karakoram glaciers to climate change is critical, since their melt water contributes to fresh water resources of the country. However, due to logistical constraints and sparse field observations of glaciological and meteorological conditions in the Karakoram in context of spatial and temporal scale in particular at high altitudes have made it difficult to understand the changes in glaciers due to changing climate. Therefore, researchers analyzed the remote sensing data and different GIS techniques to asses these changes (e.g., Gardelle et al., 2012, 2013; Kääb et al., 2012). Large gaps remain in our understanding of the important drivers of glacier change in this region, including regional atmospheric conditions, local topography and glacier debris cover, as well as interactions between them. The field observations supplement the physically based numerical models to assess the changes accurately and provides contemporary glacier dynamics. The prevalence of debris cover has a strong potential influence on glacier behavior in the Karakoram, as field studies have shown that debris cover can significantly alter the ice ablation rate compared to that of clean ice (e.g., Østrem, 1959; Fujii, 1977; Inoue and Yoshida, 1980). Ice melt is enhanced beneath debris cover less than a few centimeters thick, due to increased absorption of solar radiation. Conversely, ice ablation decreases exponentially as the thicknesses increases above this depth, due to insulation of the ice from atmospheric energy sources.

The glacier was studied previously under the Pakistan Snow and Ice Hydrology Project (PSIHP) of WAPDA in collaboration with a Canadian University for ablation gradient estimates during the August, 1989 and again in August, 1990. During August maximum relative contribution of flows occur into the River Indus due to the glacier melt because maximum snow cover disappears below equilibrium line.

The study was resumed after a lapse of about twenty years to see the variations in melt rates, ablation gradient and meteorological parameters in 2011, 2012 and 2013. Stakes were installed at the same locations that were observed previously and the temperatures are compared for the same duration as it was studied in 1990 to avoid any biases during the comparison of melt rates and gradient. The field study results will help in modelling of glacier melts by providing the actual measured ablation gradients.

2. Study area

Pasu glacier is located in the central Hunza sub basin of Upper Indus Basin (UIB) in the Karakoram Mountains range (Figure-1). Pasu Glacier can be categorized as a medium sized glacier of the Upper Indus Basin (UIB) with an area of 60 km^2.

It is a highly crevassed glacier having length of about 22 km. It is located at latitude 36°27'28"N and longitude 74°52'57"E about a 1 km distance towards west from the Karakoram Highway (KKH) on way from Gilgit to Khunjerab Pass (Figure 1).

The melt of glacier enters into a proglacial lake of about 450 m in length, which can be categorized as end moraine dammed lake. Flows from the lake are drained towards west into a Hunza River that is a major right bank tributary of the River Indus. The total catchment area of Pasu Glacier is 99 km^2 out of which 60% is the glaciated area (Figure-2). The glaciated area of Pasu Glacier is 1.3% of the total glaciated area of Hunza River Basin that area is reported about 4463 km^2 (Akhtar et al., 2008).

Flows from the Hunza, Braldu and Shayok are dominated by melt water from glaciated areas. About 80-90% of the discharge occurs after the snow cover has disappeared from the areas below about 4500 m a.s.l. The major contribution to the flow from the glaciated areas occurs in month of July and August.

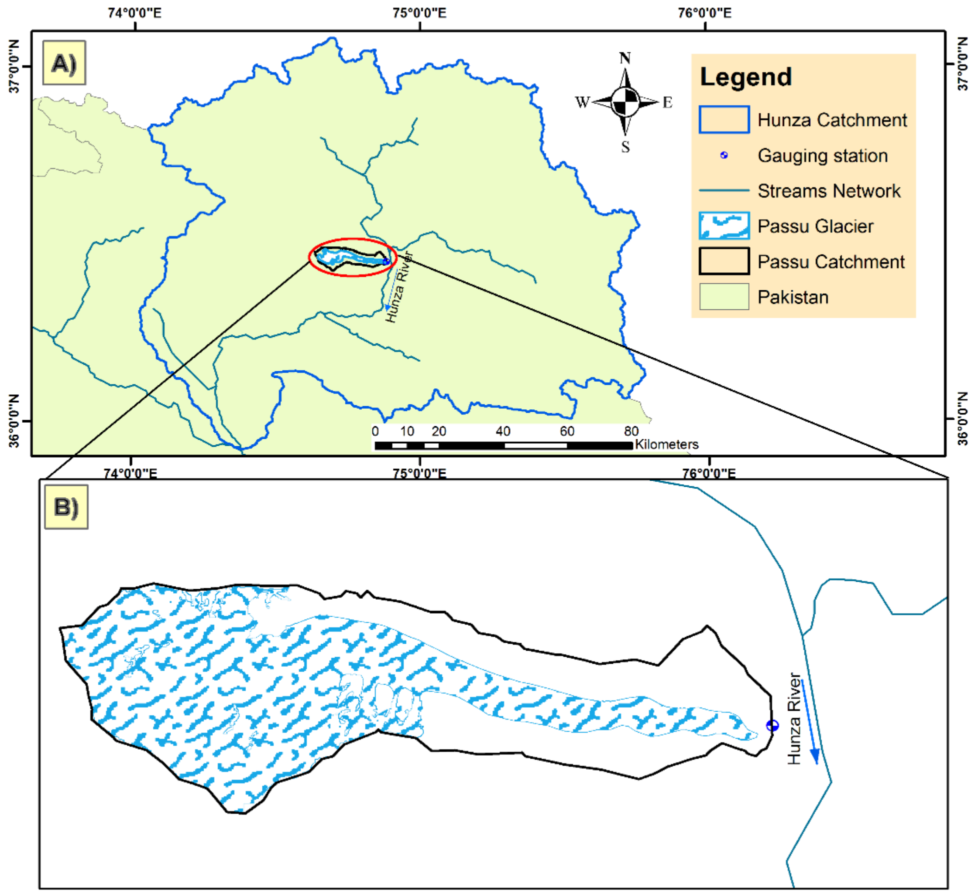

Figure 1: Location Map for Pasu Glacier A) Location of Pasu Glacier in Hunza River Basin, B) Pasu Catchment and Glacier boundaries and gauging location.

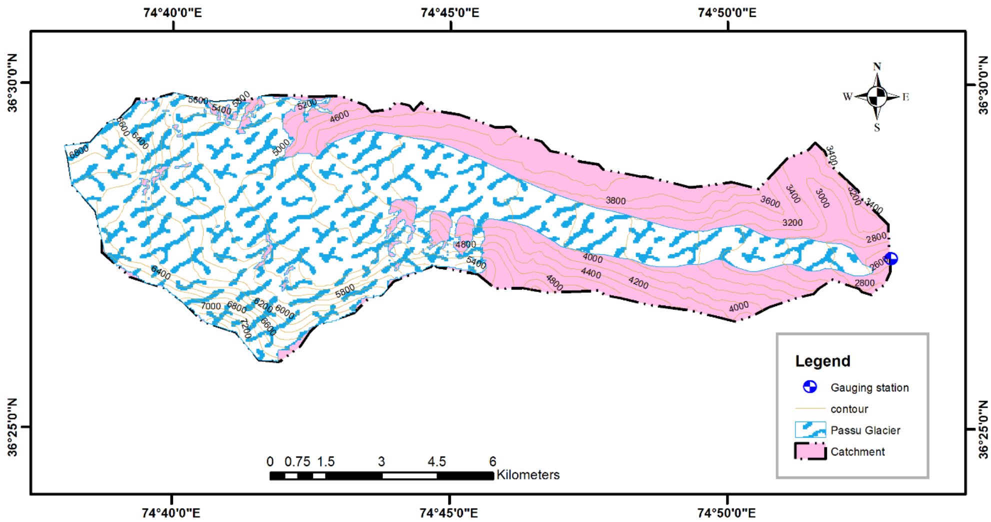

Figure 2 Pasu Catchment and Glacier Boundaries.

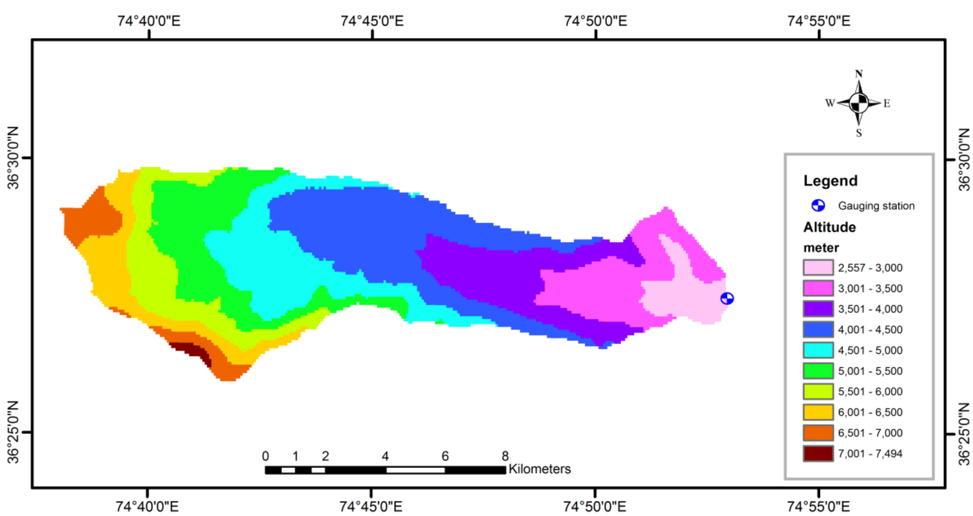

Figure 3 Altitudinal Zones of Pasu Glacier.

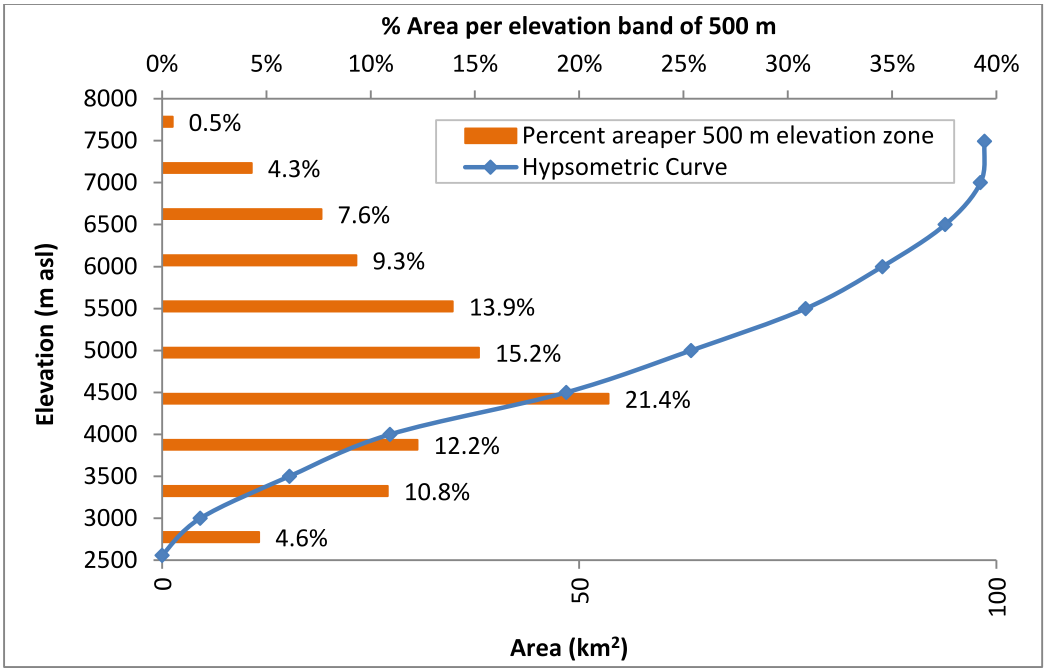

Figure 4 Hypsometric Curve of Pasu Catchment

The Shuttle Radar Topographic Mission (SRTM) digital Elevation Model (DEM) data was used to delineate the catchment boundary and altitudinal zones of the glacier and its catchment. A major part of the glacier falls within the elevation range of 4000-6000 m.a.s.l. and the terminus or snout of the glacier falls in the elevation range of 2500-3000 m.a.s.l (Figure-3). Most of the area of the Pasu catchment, i.e. 78.3%, lies in the elevation zone of 2500 to 5500 m.a.s.l (Figure-4). The remaining 21.7% area of the catchment lies at very high altitudes of 5501 to 7494 m.a.s.l.. Similarly, 84.1% of the glaciated area in the Pasu catchment lies within the elevation zone of 2557 to 5500 m.a.s.l. This elevation zone is the "active hydrologic zone" that mainly contributes to runoff. Only 15.9% area of the glacier lies above the elevation of 5500 m.a.s.l.

3. Material and methods

Ablation measurements were carried out by installing the stakes on glacier perpendicular to the glacier flow i.e. along the cross sectional direction of the glacier. For this purpose, two stake profiles were installed, one at Pasu Snout (four no. of stakes at a mean elevation of 2650 m.a.s.l) and other at Pasu Ghar (three no. of stakes at a mean elevation of 3450 m.a.s.l). Ablation data was collected on daily basis during the month of August in the years from 2011 to 2013. Ablation at each stake installed on Pasu Snout (PS) profile and Pasu Ghar (PG) profiles was recorded for the period 11-29 August in 2011, for the period 8-31 August in 2012 and for the period 3rd August to 7th September in 2013. Day wise and stake wise ablation rates were calculated by averaging the daily stakes ablation and the averaging the monthly ablation of each stake, respectively. Ablation gradients of the glacier was also calculated from the net ablation rates and average elevations of profiles for each study year. The average snow water equivalent (SWE) was considered 0.9 g/cm^3 to estimate the ablation rates.

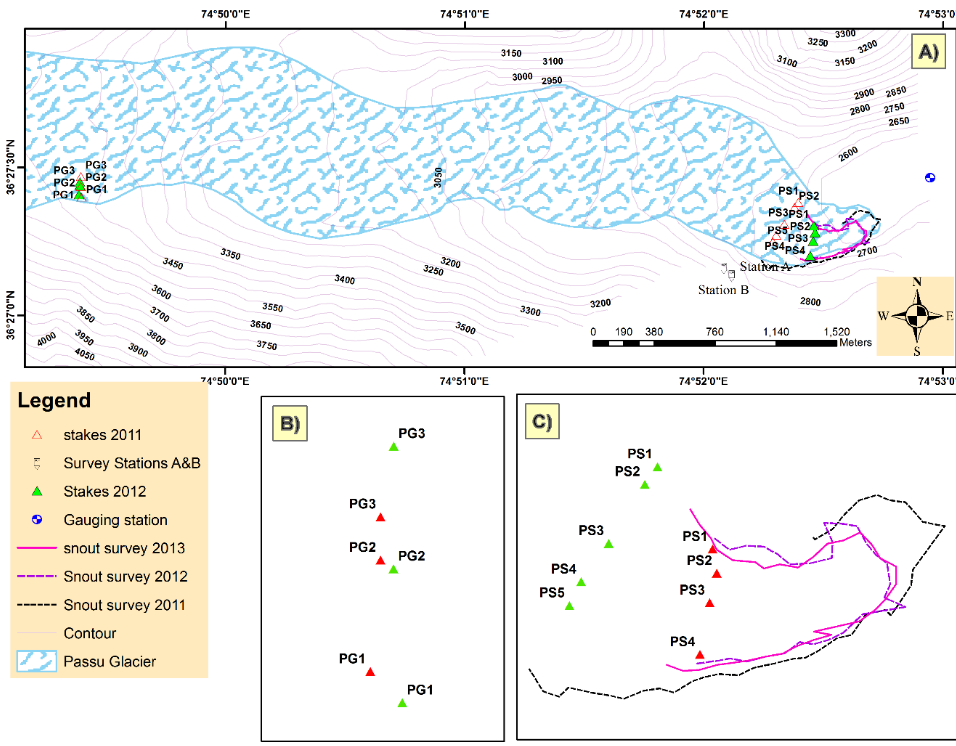

Figure 5. Location of stakes on Snout (PS) and Pasu Ghar (PG), **B)** Stakes location at Pasu Ghar during 2011 and 2012 **C)** Snout boundaries and stakes location and Pasu Snout (PS) during 2011, 2012 and 2013.

Three meteorological stations were established for recording air temperature, relative humidity during 2011-2013. One on-ice meteorological station was established near the Pasu Snout Profile, while another off-ice station was established on the south lateral moraine (3450 m.a.s.l.) of the glacier at Pasu Ghar. For both stations, the equipment was placed inside the Stevenson screen which was fixed approximately 1.2 m above ground/ice surface. In addition, manual readings were also taken to check the Automatic Weather Station (AWS) readings.

The rating curve for the low flow season was developed just downstream of the lake outlet by wading and for the high flows season it was developed at the KHK Bridge, which is about 1-km downstream of the lake (Figure 7). Regular discharge measurements were carried out for developing rating curve using the area-velocity method.

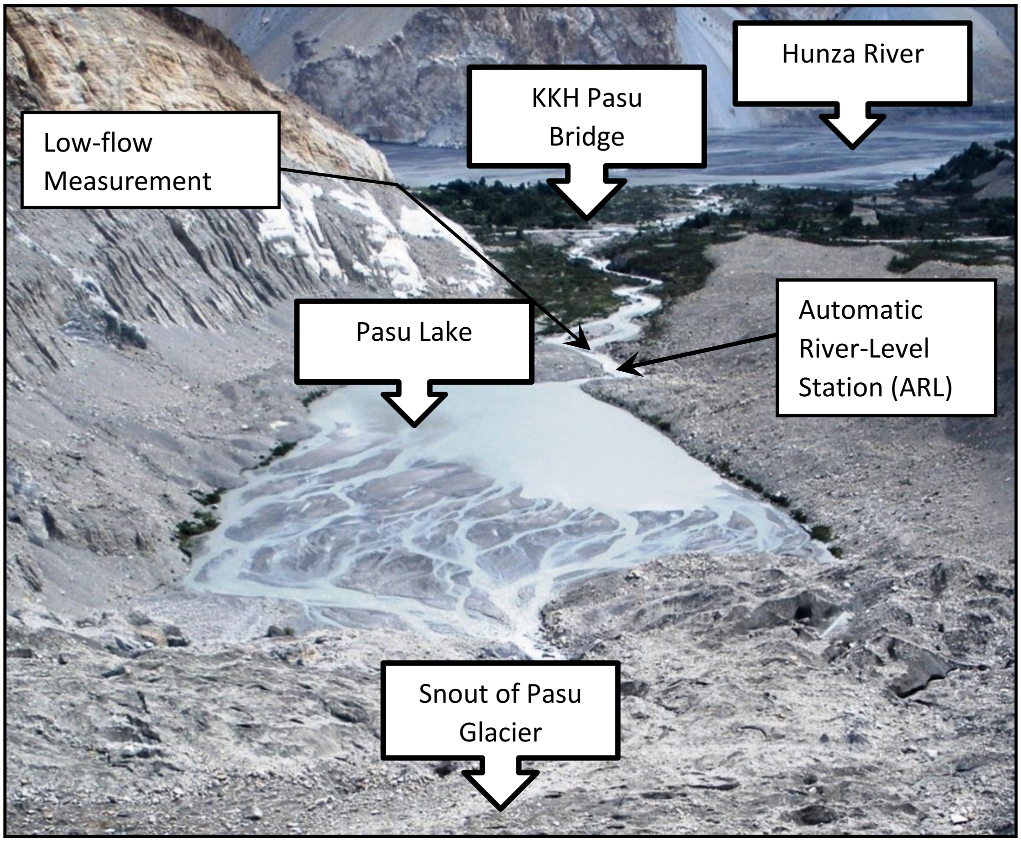

Figure 6. View of Pasu Lake, snout and channel from lake to River Hunza

An Automatic River Level (ARL) Station was installed at the outlet of Pasu Glacier just downstream of the channel issuing from the lake formed by the end moraines of the glacier (Figures 6 & 7). The discharge observation system for Pasu Glacier was installed in October 2010. The ARL equipment included Pressure Transducer and Data Logger from SEBA Corporation.

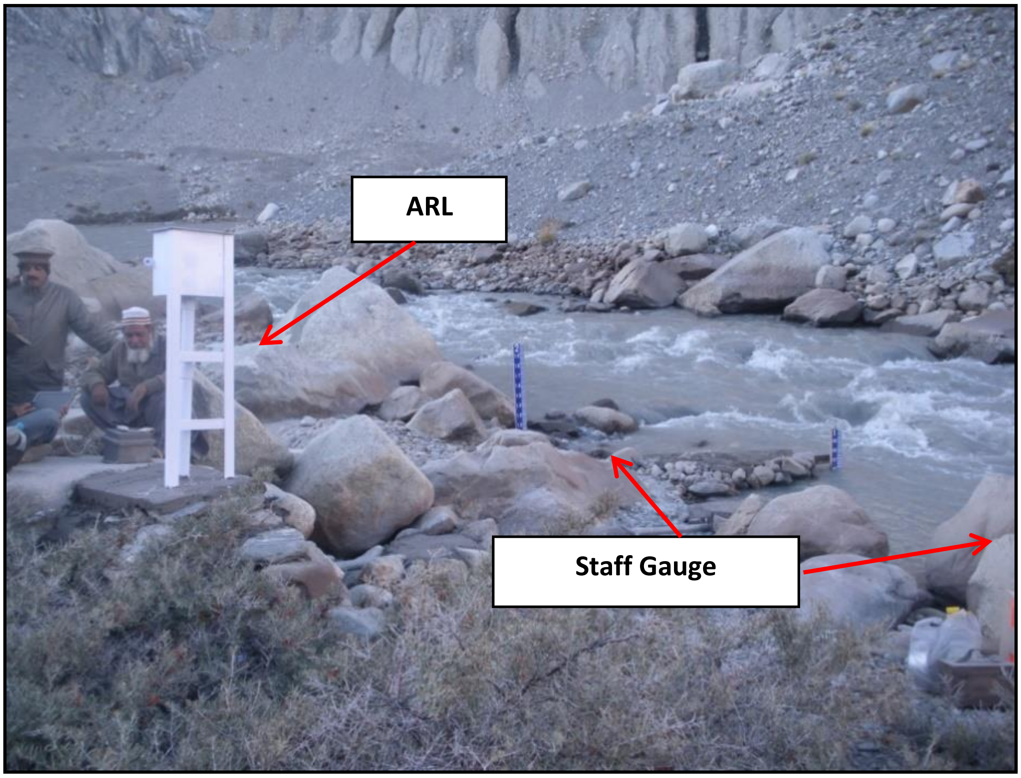

Figure 7. Automatic River Level and staff gauges site.

4. Results and discussion

4.1. Ablation Rates

Ablation at each stake installed on Pasu Snout (PS) profile and Pasu Ghar (PG) profiles was measured during August in the each selected year. The stake-wise and day-wise mean ablation rates were also calculated at both sites. Figure 8 shows the net ablation rates during 1990 and 2011 to 13. The maximum ablation was measured during 1990 at both profiles. The ablation rates measured at both profiles during the recent study period were less than measured in 1990. The minimum ablation rate was measured in 2012. The ablation rate at Passu Ghar was 35% lower than the ablation rate at Passu Snout in 1990. Whereas, it is about only 20% less than the ablation rates at Passu Snout.

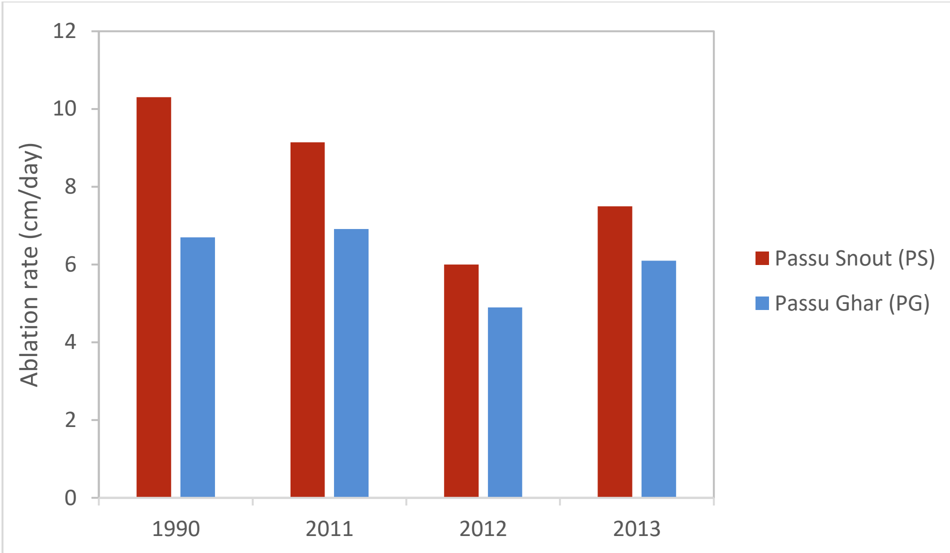

Figure 8. Ablation rates (w.e) at Passu snout and Passu Ghar

The ablation gradients for each year have been calculated between the two stake-profiles (i.e. PS and PG). Compared with the results of the field study of August 1990 when the ablation gradient was 0.554 cm/day/100-m, the values in 2011, 2012 and 2013 have been much lower being 0.294, 0.14 and 0.18 respectively (Table-1). Ablation gradients in 2011, 2012 and 2013 were 47% and 75% and 67% less than that in 1990, respectively.

Table 1. Ablation Gradient at Pasu Glacier

#	Description	August 1990	August 2011	August 2012	August 2013
1	Net ablation at PS profile (NAS) cm-day	10.3	9.14	6.0	7.5
2	Net ablation at PG Profile (NAG) cm/day	6.7	6.91	4.9	6.1
3	△ ABL = (NAS-NAG) cm/day	3.6	2.23	1.1	1.4
4	Elevation PS (ES) m.a.s.l	2850	2677	2635	2634
5	Elevation PG (EG) m.a.s.l	3500	3436	3428	3426
6	△ ELV (EG-ES) m	650	759	793	729
7	Ablation Gradient cm/day/100-m between the PS & PG profiles	0.554	0.294	0.14	0.18

4.2. Temperature vs Ablation rates

Temperature and humidity data were recorded for Pasu snout and Pasu Ghar during day time in 2012 and 2013. Figure 9 shows the comparison of the temperatures of 1990 with 2013 for both profiles. Daily temperature and the ablation rates calculated at Pasu Ghar and Pasu snout during August-September 2012 and 2013, respectively.

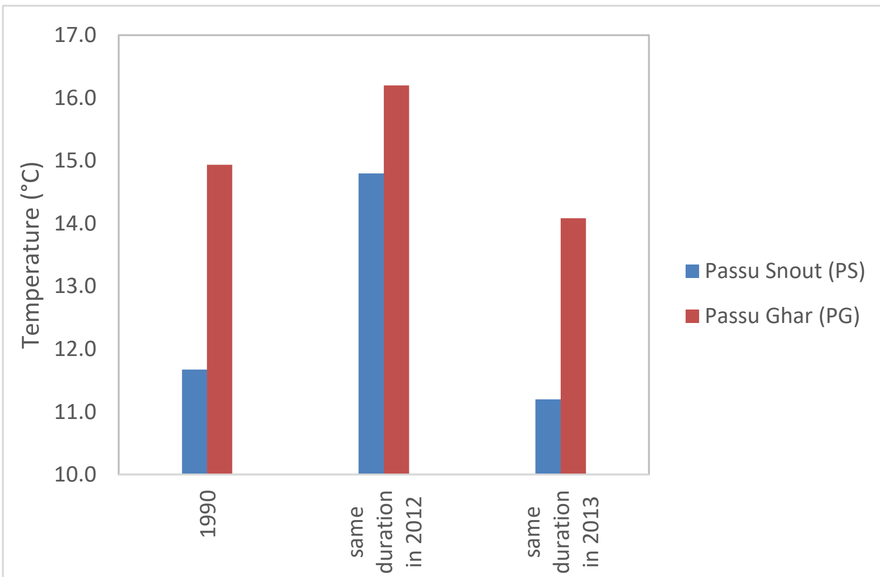

Figure 9 Comparison of temperature at both profiles

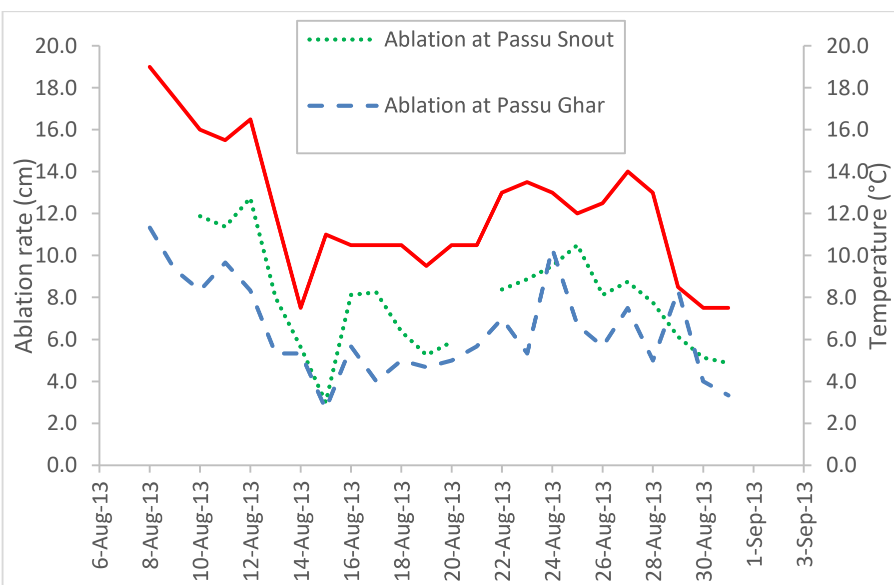

Figure 10 Temperature and ablation rates during August 2013.

Instead of the stable terminus position great variation in ablation and low ablation gradient was measured in recent study years at both profiles. This can be explain by the presence of a thick debris cover which inhibits melting., so that annual ablation totals tend to be highest on the upper part of glacier ablation zones, where debris cover is thin or absent, and decline with altitude as the average debris thickness increases (Nakawo et al., 2000). This reversal of the ablation gradient on the lower part of glacier ablation zones means that, during times of negative mass balance, debris covered glaciers tend to lose less mass from the terminal zone than from higher parts of the snout. Consequently, glacier shrinkage can result in a thinning and reduction in the gradient of the snout without significant change in the position of the terminus (Naito et al., 2000). Conversely, times of positive mass balance are associated with thickening and (Benn and Oven, 2002).

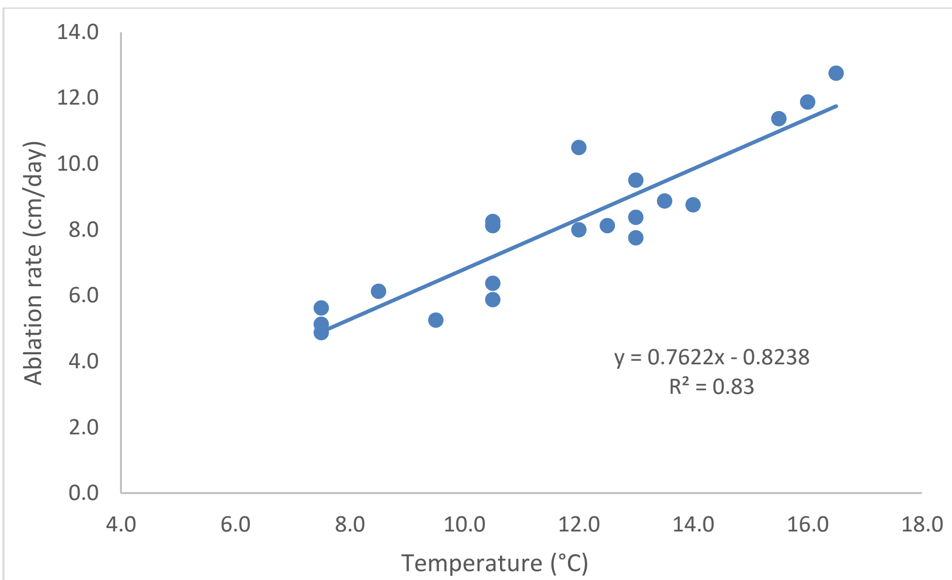

Figure 11: Relationship between Ablation rate and Temperature at Pasu snout (data: 10-31 August 2013)

4.3. Discharge versus Temperatures

The maximum average daily discharge of 62.6 and 60.5 cumecs were recorded on August 21- 23 in 2012 and August 11 in 2013, respectively. The discharge reaches to its peak around 4:00 PM. During the month of August, the total volume of melt was calculated 96 and 88 Mm^3 in 2012 and 2013, respectively. Higher melt volumes in August during 2012 can be explained by the prevalence of higher temperatures as compared with 2013. The comparison of the off-ice Passu Ghar temperatures of 2012 with 2013 shows that 15% higher temperatures resulted in 9% increase in melt volumes. Total volume of water generated by Pasu Glacier from October 2010 to September 2011 was 317 million m^3 with the bulk of water coming in five summer months of May–September (GMRC, 2015). The calculated annual melt water production of about 135 million m^3 was calculated for Hinarche Glacier (42.3 km^2 area), which is about 50% of the flows of the Pasu Glacier. Whereas, the area of the glacier is about 70% of the area compared with Pasu Glacier. Glacial melt water production is about 300 million m^3 per year for the entire valley under balanced conditions (Mayer et al. 2010).

The mean daily discharge and the temperature data are well-correlated (Figures 11&12). The data used for the development of relationship was obtained from automatic river level and weather stations at Pasu snout. The data is recorded on hourly basis, which is averaged to convert into mean daily. The exponential relationship of flows and temperature shows a good correlation with coefficient of determination (R^2) of 0.57 (Fig. 11).

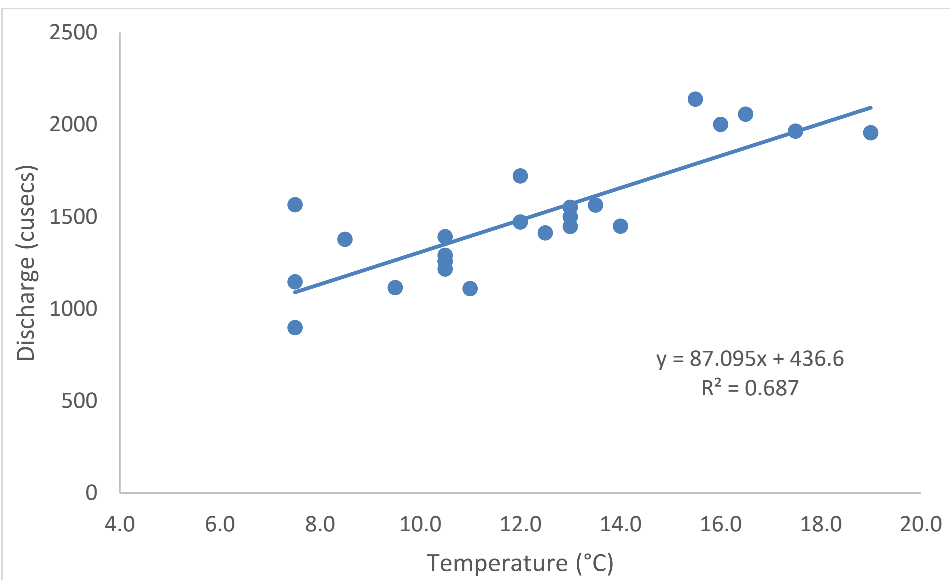

Figure 12 Relationship between Discharge and the Temperature at Pasu snout (August 8-31, 2013).

5. Conclusions

The study provides the variation of the ablation rates, temperatures, ablation gradient and the temperature for the month of August during the field activities from 2011 to 2013 at Passu Glacier. The following conclusion can be drawn from the study results:

i. The ablation rate at Passu Ghar was 35% lower than the ablation rate at Passu Snout in 1990. Whereas, it is calculated about only 20% less than the ablation rates at Passu Snout in recent study years.

ii. Compared to similar observation carried out in a study conducted in 1990, the ablation gradients have been decreased by 47% and 75% and 67% in 2011, 2012 and 2013, respectively.
iii. Temperature showed very good correlation with and ablation rates. Similarly, discharge also showed better relationship with mean daily discharge.
iv. Higher temperature in 2012 resulted in a more melt from the glacier, whereas ablation rates were less as compared with the flows and melt rates of 2013, respectively.
v. The melt rate not only depends upon the temperature but also the temperature gradient plays important role in total melt volumes.
vi. Snout Surveys indicate that the glacier has receded in 2012 relative to its position in 2011. Site observation showed that a part of glacier at its terminus detached from the main body of the glacier. However, the glacier snout position was unchanged in 2013. In the most recent snout survey for Pasu Glacier conducted in November 2015, the glacier has advanced by 20 meters relative to its position in 2013.
vii. Glacier field investigation are extremely important in understanding glacier dynamics and provide crucial data on melt rates and temperature gradients which could be used in hydrologic modelling for climate change impact studies.

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ASSESSMENT OF WATER QUALITY AND EFFICIENCY OF PUBLIC DRINKING WATER FILTRATION PLANTS IN LAHORE

Anza Farooq, Dr. Abdullah Yasar, Dr. Amtul Bari Tabinda, Arrfa Sikandar, Zara Anjum [5]

Abstract: The quality of water that human beings consume is of great importance. Pollution or contamination free drinking water is a necessity as contaminated water can cause different types of diseases. Talking about drinking water quality of Lahore city the most important contaminant is arsenic. The objective of this study is to assess the quality of drinking water by comparing source water with the water from filtration plants installed by government. In order to find out whether filtration plant removes the harmful contaminants or not especially arsenic, physiochemical and bacteriological parameters are analyzed. The result of this study demonstrates that filtration plants do work well to remove contaminants as most of the physical, chemical and bacteriological parameters such as pH, alkalinity, total hardness, chlorides, electrical conductivity, total dissolved particles, total and fecal coliform are within the limits standardized by World Health Organization and National standards of Pakistan for drinking water quality. Only two out of thirteen samples of filtered water showed arsenic contents higher than the limits prescribed by WHO that are Takoni ground sanda and FCC block gulberg with both having 25 ppb. The filtered water exceed in nitrates for Anand road upper mall, Bagh munshi ladha and Shah Jamal with values of 57.1, 55.1 and 51.8 mg/l respectively whereas the standard limits for nitrates is ≥ 50 mg/l. The main source of drinking water is tap water so main water borne disease is cholera and mostly it occurs in infants. It is concluded, that the quality of water is not so worse but still people should use filtered water instead of tap water. Out of all three sources of drinking water filtered water had best quality and is recommended for use, government should take initiatives to inform public about the importance of safe drinking water.

Introduction: The main extensively spread substance in our planet is water. Among other natural resources, water takes up a unique place. Water plays a vital role in our environment and in our own life. It is available everywhere. Out of all the water present on earth, the most important is fresh water. Freshwater can never be replaced by anything else so human life is unfeasible without it. The special qualities of water gave birth to a false impression of its resources and people started to consider it a free gift of nature. Under these preconception or misconception, a custom has arisen of careless mindset in the use of water. People started to consider under this misconception that very little expense is required for the purification of wastewater and protection of water's natural bodies (Shiklomanov, 1998).

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About 1400 million km^3 is the entire volume of water present on Earth out of which 35 million km^3 that is only 2.5 percent is present as freshwater. Most of the freshwater comes about in Antarctica and Greenland in the type of permanent ice or snow and some part is present in the deep groundwater aquifers that contain saturated rocks and water pass through them easily. The chief source of water for human use are rivers, lakes, soil moisture and fairly shallow groundwater basins or wells. Only about 0.01 percent of the entire water on earth and about one percent of all of the freshwater are present in the form of usable fraction out of all water resources. The distinction between evaporation and precipitation on land is groundwater recharge and runoff that is roughly 47000 km^3 annually (Gleick, 1993).

It is fundamental human right and vital for heath that every human being have access to safe drinking water. Drinking water standards can differ among countries and regions of a country in nature and structure. Across the world, there is no applicable approach. For the formulation of national standards few things are to be considered that are quality of available water, quality of available services and quality of the present infrastructure (World Health Organization, 2004)**.** Along with the formulation of laws and regulations, the government should take steps for making their nation aware about the importance of water and its sustainable use. Pakistan is a part of South Asia. Like other South Asian, countries Pakistan also faces the problem of safe drinking water. All over South Asia, it has been a finding through different studies that urban and rural water pipelines are regularly infected with human fecal organisms (Tambe et al, 2008).

Lahore is one of the main cities of Pakistan. In Lahore, the underground water layer's typical vision is that it is a single continuous and free source of water. For Lahore's domestic, industrial and commercial usage, water is pumped out from this underwater source. To meet the drinking water needs the groundwater is pulled up from a distance downward of about 120 to 200 meters. About 715 millimeters is the annual average rainfall of Lahore city. Due to urbanization, however the recharge of this rainwater to underground source in city areas is negligible. In common, the main reason for the speedy reduction of groundwater in the city is that the groundwater's discharge is higher than its recharge. The main cause of contamination and quality deterioration of surface and groundwater is that all municipal waste from Lahore city, collected in a complex network of 14 main drains and then directly released into the River Ravi devoid of any treatment. Usually the quality of shallow groundwater considered meager as these tube wells badly affected by leakage from sewerage or drainage network. At depth of almost more than 200 meters, the quality of pumped groundwater is relatively good because of this factor WASA takes out water from this depth or more. According to different research articles, observation is that pumped ground water in Lahore has higher arsenic levels almost more than 50 parts per billion. In Lahore the presence of arsenic is much higher in concentration than the WHO standard, then that of its surrounding areas. This high concentration contaminates the groundwater and is present at low water tables that are up to 30 meters deep. Air pollutants derived from kiln factories is the chief man made source of arsenic. The other possible source is the fertilizers (Qureshi & Sayed).

The government has installed many water filtration plants at different areas of Lahore including residential as well as commercial in order to fulfill the community's need of safe drinking water. Many communities and societies have also set up their own water filtration plants from where people can get safe drinking water that is free of cost (Yaqub et al, 2014). As assessed from above the drinking water of Lahore contaminated with arsenic and other pollutants, this research deals with the quality of drinking water by examination of its physiochemical and bacteriological parameters. The quality of drinking water is assessed at source end tube wells and public water plants or more precisely drinking water filtration plants. It includes two different types of data that is secondary data for water quality parameters of source taken from WASA and the other one is primary data for water quality parameters of tap water and filtered water.

Out of a list of hundred tube wells, thirteen were randomly selected for analysis. Of these thirteen tube wells, samples were taken from tap water and public water plants or drinking water filtration plants of their respected areas or communities. That makes a total of twenty-six water samples for primary analysis. Afterwards both the filtered water and tap water samples analysis compared separately with the secondary data of source water. Water quality was evaluated by focusing on the following biological, physical and chemical parameters that included turbidity, pH, conductivity, and total dissolved solids TDS, salinity, chlorides, nitrates, phosphate Total hardness, Alkalinity, fecal coliform, total coli forms and Arsenic. The quality of water was also compared with the health of people of the selected communities. For analyzing the health, a questionnaire was designed and conducted with the doctors that practice in these selected communities.
The objectives of this research are:

1. To compare variations between sources, tap and filtered water samples.
2. To determine purity of filtered water by biological and physiochemical analysis.
3. To analyze the health of people after installation of drinking water filtration plants.
4. To analyze the obtained data to suggest the future prospect for improving the drinking water conditions for public use.

Materials and methods: The data for analysis of source water was taken as secondary data from WASA, Lahore. However, for the analysis of filtered water samples were collected from sampling sites. Grab sampling method was used. Afterwards, collected samples were transported to lab for further analysis according to the procedures and methods mentioned in Mamta Tomar's Quality Assessment of Water and Wastewater and some procedures according to APHA guidelines.

After the selection of sampling sites, a route was made for the collection of samples. All samples collected on the same day and transported to Lab for analysis. It was believed that this procedure will be able to thwart microbial growth, flocculation and lessen any adsorption on container surfaces (Huang et al. 2013; Behera et al. 2012). The physicochemical parameters such as temperature, pH, salinity, TDS, and EC were recorded on-site by using pH, EC and turbidity meters. Other physiochemical and biological parameters were analyzed in lab. In lab first of all samples were analyzed for arsenic, fecal coliform and total coliform. Afterwards, the samples were preserved at 4° C. The samples were collected in one-liter PET bottles that were cleaned with distilled water. Before collecting water the tap was allowed to run for about 2 minutes and then bottles were rinsed with the sample to have proper sample. The bottles were labeled properly to avoid any confusion.

The parameters selected for examination of the quality of drinking water included five physical parameters that were pH, conductivity, turbidity, TDS and salinity. The parameters for chemical analyses included arsenic, chlorides, nitrates, total hardness and alkalinity. Other than physiochemical analysis, biological analysis was also conducted for fecal coliform and total coliform.

Results and discussion: The pH which is a physical parameter for water quality is important as its value higher than 8 is not appropriate for efficient disinfection, on the other hand pH values less than 6.5 can play role in enhancing the corrosion in household plumbing system and water mains (Haydar ,2009). As per Who standards and National Standards for drinking water quality, the standard range of pH for drinking water is between 6.5 to 8.5. The range of pH for selected sampling location of filtered water is between 7.1 and 7.6 whereas that of secondary data tube well water is between 7.8 and 8.3. Both the results show that the values are within range. The color of all the samples was clear and the taste was acceptable.

There are no standards specified for electric conductivity of drinking water in National Standards and WHO. The data for source water show that the range of EC is 353 to 881 and that of filtered water examined is 160.9 to 583. Total Dissolved Solids for both secondary data for source water and that of primary data for tap water were found to be within the prescribed limit of World Health Organization Standards and National Standards that is less than 1000 mg/l. In aquifers, the Total Dissolved Solids rises with the deepness because of less new recharge water to dilute existing groundwater and longer time for ions to dissolve (Gray, 2008).

The values for filtered water samples examined are within the range of 111.9 to 465.The standards for turbidity by WHO and national standards of Pakistan are same that is less than 5 NTU. Both the data for source water and that examined for filtered water show that all results are within limit.

In drinking water sources, turbidity is capable of badly interfering with the effectiveness of disinfection of water as it provides guard for microbes, and most of the treatment methodology is bound for the removal of particulate matter. Turbidity can cause visible cloudiness in water that in turn causes depressing brunt on consumer acceptability. In groundwater sources as it is pumped out, the clay, chalk particles or some oxides such as reduced iron results in turbidity. However, in surface waters turbidity contains attached microbes that are threat to health. From the access of dirty water from exterior of the system and because of the fracas in the sediments and bio films in the supply, system there is turbidity (WHO, 2011).

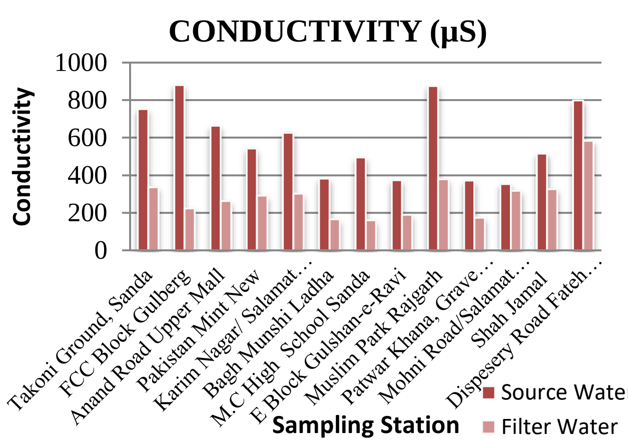

Figure 1: Comparison between conductivity of source and filter water

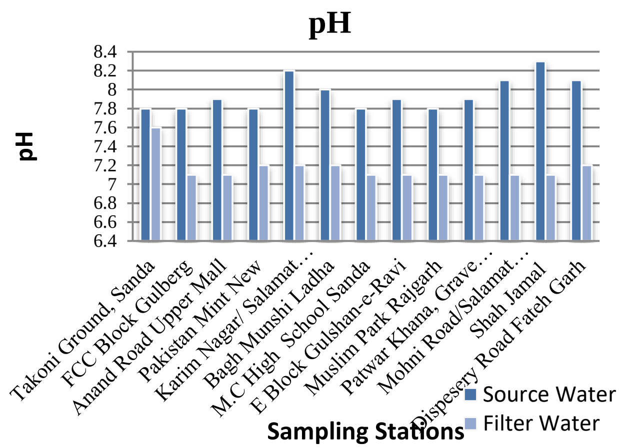

Figure 2: Comparison between pH of source and filter water

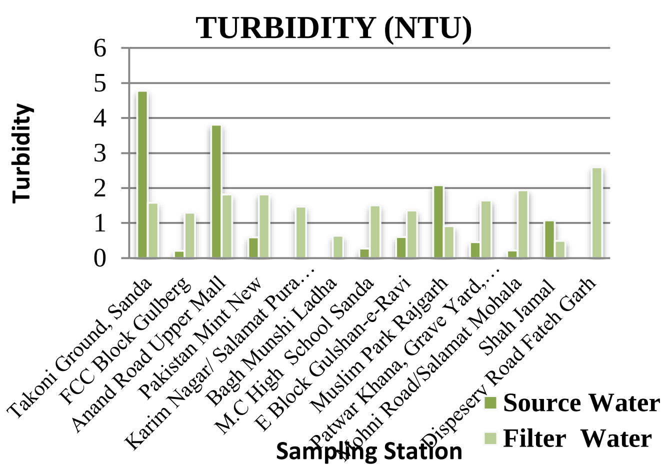

Figure 3: Comparison between turbidity of source and filter water

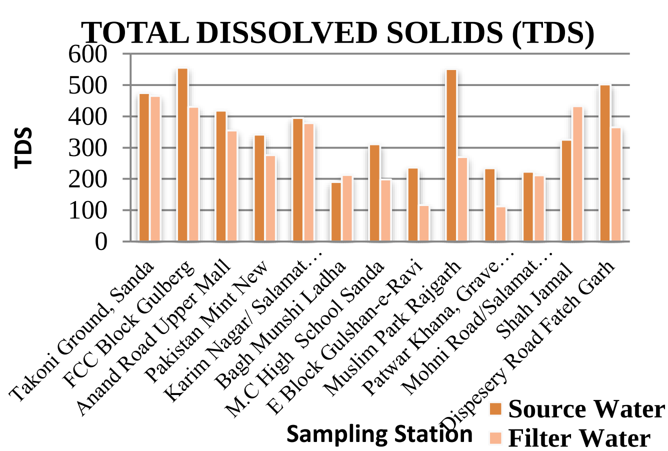

Figure 4: Comparison between TDS of source and filter water

There are about two different forms of environment in which arsenic is naturally present in groundwater, these environments are closed aquifers in semi-arid and arid areas; second are those water bodies that resultant from alluvium and are reducing speedily (Smedley & Kinniburgh, 2002). As per WHO standards, the standard value for arsenic is 0.01mg/l or 10 ppb whereas according to national standard the guidelines are 0.05mg/l or 50 ppb. The data for source water show that the range of arsenic in selected areas is 34.5 to 100.1ppb that is five times higher than national standards and almost ten times higher than WHO standards. Whereas that examined for filtered water ranges between 10 and 25 ppb that is within the national standard limits but higher than the WHO standards. The sources of drinking water that contain arsenic in quantities 10µg/l or more are principal source of arsenic intake. In part of the world where main parts of diet are soups and other related dishes is said to have more intake of arsenic with food than with drinking water (WHO, 2011). From water supplies intake of arsenic is able to cause cancer in skin (Smith et al, 1992).

The WHO standards for chlorides are 250 mg/l whereas a national standard is less than 250 mg/l. The data for source water has chloride content is the range of 17 to 64 mg/l and that of filtered water examined show range between 39.05 and 99.4,both are within the standards. The WHO standard for Alkalinity is not specified. However, the national standard for alkalinity is less than 500 mg/l. The data for source water has Alkalinity content in the range of 114 to 418 mg/l and that of filtered water examined show range between 131 and 254, both are within the standards. The phosphate content of filtered water examined is between the ranges of 0 to 0.23. On the other hand, the data of phosphate content for source water is not available. There are no standard value for phosphate in drinking water by both WHO and national standard.

The WHO standard for nitrates is 50 mg/l whereas a national standard is less than 50 mg/l. The data for source water has chloride content is in the range of 1.6 to 23.3 mg/l and that of filtered water examined show range between 37.1 and 57.1. It is very hard to remove the nitrates and nitrites from water sources or supplies. The most commonly used disinfection techniques can only convert nitrites to nitrates i.e. from more toxic to less toxic state. The source of nitrites and nitrates in the supply lines or in some cases source is the contamination of sewage water or sometimes, agricultural runoff (WHO, 2011). It was found that if increasing the contact to nitrates then the mortality rate of cancer will increase in both genders when taking in account gastric and prostate cancer (Morales-Suarez-Varela, 1995).

As per WHO standards and National Standards for drinking water quality, the standard range of total hardness for drinking water is less than 500. The range of Hardness for selected sampling location of filtered water is between 190 and 370 whereas that of secondary data tube well or source water is between 110 and 308. People consuming drinking water can observe changes in its hardness.

Talking about communities the consumer satisfactoriness of hardness concentration in drinking water may differ from one another. Talking into consideration the calcium ions then the threshold of taste of water depends on its related anions and is commonly in the range of 100 to 300mg/l. However, in case of magnesium the range is most likely to be lesser than that of calcium (WHO, 2011). It is good that the results of fecal and total coliform for all the samples collected from public water plants or drinking water filtration were within the limit standardized by WHO and national standard for drinking water quality of Pakistan.

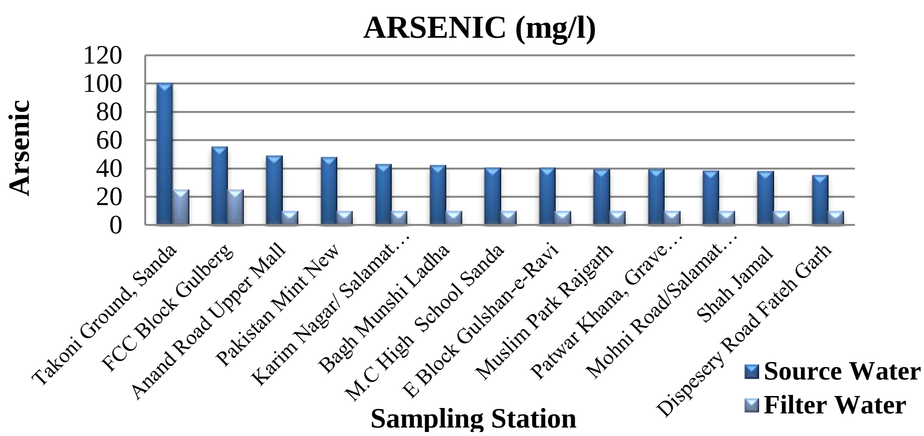

Figure 5: Comparison between arsenic of source and filter water

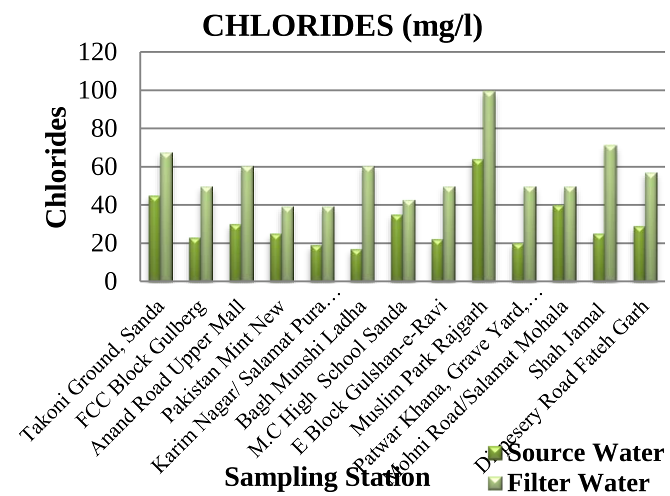

Figure 6: Comparison between chlorides of source and filter water

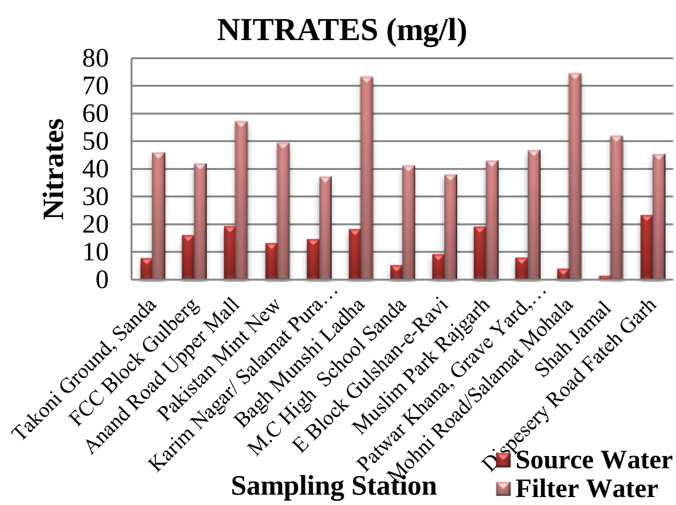

Figure 7: Comparison between nitrates of source and filter water

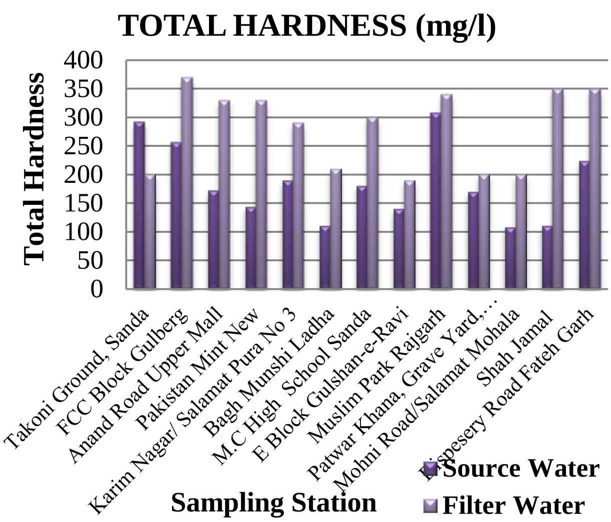

Figure 8: Comparison between total hardness of source and filter water

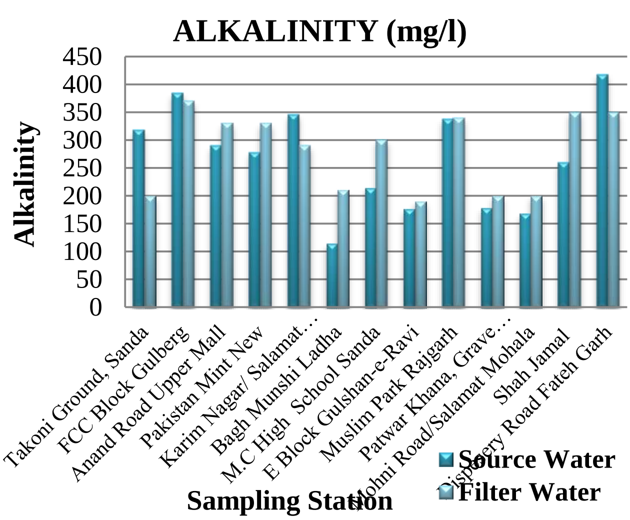

Figure 9: Comparison between alkalinity of source and filter water

CONCLUSION

It can be concluded, after the examination and analysis of both the primary and secondary data related to the drinking water quality's physiochemical and bacteriological parameters of different sources of water of the selected communities' shows that most of the parameters are within limits standardized by the World Health Organization and National standards for drinking water quality

Pakistan. First of all the result primary data of quality of filtered water from public filtration plants depicts that its most of physiochemical and bacteriological parameters such as pH, electrical conductivity, turbidity, total dissolved particles, chlorides, total hardness, phosphates, fecal coliform, total coliform and alkalinity are within limit of WHO and National standards. Only some samples of filtered water exceed the limit. In case of arsenic, all samples are within limits of national standards but two samples that are Takoni ground sanda and FCC block gulberg exceed the WHO standards. Whereas in case of nitrates, three samples that are Anand road upper mall, Bagh munshi ladha and Shahjamal exceed limit by both WHO and National standards. The main water borne disease is cholera and mostly it occurs in infants. It can be concluded that the quality of water is not so worse but still people should use filtered water instead of tap water.

RECOMMENDATIONS

The installation of public water plants or drinking water filtration plants is a good initiative by the government, the quality of filtered water is far much better than that of tap water.

More plants should be installed to achieve the goal of safe drinking water and improvement of health of people settled in Lahore.

The main difficulty analyzed during research is that there are filtration plants but only minimum percent of its communities is taking benefit from it so there is a need to disperse information about its importance and to bring awareness about the use of filtered water to get rid of most of the water borne diseases. For this purpose program should be launched for the communities after installation of drinking water filtration plants.

As most of the people in the communities having filtration plants use tap water with deteriorating quality combined with the declining levels of water due to decrease of recharge of its source because of urbanization and so it cause solemn risk of health for the communities using it for drinking water. Local communities should be conscious of the resource of water they have and its importance so they would be able to use it responsibly without damaging or wasting it.

According to WASA Lahore, the filtration plants have not completed three years of service yet and during sampling, it was observed that people just do not care about the filtration facility they have, as some of the plants were damage and not functioning. So to prevent this type of damages and contamination hazards, an appropriate routine monitoring system must be adopted.

The presence of nitrates in excess amount and the bacterial contamination especially of fecal coliform confirm the sewage contamination of water supply lines. In order to avoid sewage contamination care should be taken the leaking or broken pipes should be change and repaired timely. Other than this, the supply and sewerage lines should be kept at a distance and if possible then they must be laid on opposite sites.

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INDUSTRIAL WASTE WATER QUALITY OF GUJRANWALA AREA

By

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ABSTRACT

The basic objective of this study was to investigate the quality status of the city effluents from Gujranwala; a hub of several industries in Pakistan. The samples were collected by conducting field visit at different locations where effluent from different industrial units is discharged at wastewater discharge outlets. Mainly this study involved determination of waste water quality parameters at different locations. The values of different parameters like chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), pH, turbidity, electric conductivity (EC), Carbonates (CO_3^{-1}) and Bicarbonates (HCO_3^{-1}) varied for the different industries as 337-617mgl^{-1}, 115-301 mgl^{-1} , 385-820 mgl^{-1}, 195-537 mgl^{-1}, 0.2-1.8 mgl^{-1}, 5.63-8.8 mgl^{-1}, 18-540FTU, 389-9950µs/cm, 0-390 mgl^{-1}and 60-750 mgl^{-1}, respectively.

The measured values of different parameters were compared with those of National Environmental Quality Standards (NEQS) for precise assessment of the quality. The analysis of the parameters showed that almost all of the samples were unfit according to NEQS. This situation is indeed a serious threat for the environment and biodiversity and hence for the stakeholders in the region have to start wastewater monitoring program with the help of local wastewater management authorities. Based upon the effluent quality data, wastewater treatment plants should be installed to make the water clean which later on can be used for other purposes e.g., agriculture. It is fact that that the highest amount of the industrial effluent is coming from the tanneries and textile industries followed by ceramic and ghee industries, respectively. Excepting ghee industries,

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all other releases are extremely toxic and therefore demand immediate remedial action.

Keywords: Groundwater, effluents, parameters, chemical analysis, electrical conductivity, environment

INTRODUCTION

The project area of the Gujranwala city (WASA Gujranwala Jurisdiction) is about 15,000 acre. Gujranwala city is divided into three zones as Zone-I, Zone-II and Zone-III and four towns.

There are 16 Nos. disposal stations, from where domestic sewage is being pumped to salvage carriers, or in the Mian Singh Minor. Total sewage network comprises of 9” to 60” dia. with approximate length of 380 km. About 12,000 acres area of the town is served with pipe sewers and open drains. About 3,500 acres area is not served with pipe sewers or drains. The text is reviewed and sited from (Nisar et al,. 2012).

In the high density area of the Gujranwala town type-I and type-II drains have been constructed in the streets. These drains are receiving domestic sewage from the houses. The drains are connected to the sewer on the major streets. During rain the storm water entering into the drain are causing overflow in the sewer and flooding the streets.

Municipal effluents are one of the major reasons for rapidly degrading environment in the metropolitans of developing countries lacking in wastewater treatment facilities. The industrial activities have already caused substantial air and water pollution leading to adverse effect on the vegetation as well as to the human beings and aquatic life (Mubin et al., 2002). The quality of water can be assessed by chemical analyses using the parameters like conductivity, alkalinity, hardness, total dissolved solids, chlorides as well as dissolved oxygen (Makia et al., 1999). Disposal of the untreated wastewater into drains and ultimately into the rivers, deteriorate the water quality and harms aquatic life Khurshid et al. (1999) reported that due to discharge of the untreated effluents from industries, the dissolved oxygen (DO) level is decreasing whereas biological oxygen demand (BOD) and total dissolved solids (TDS) are increasing in the river Ravi. The use of industrial and municipal wastewater in agriculture is a common practice in many parts of the world (Sharma et al., 2007; Ahmad et al., 2010). Rough estimate indicates that at least 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater (Scott et al., 2004). The major objectives of wastewater irrigation are that it provides a reliable source of water supply to farmers and has the beneficial aspects of adding valuable plant nutrients and organic matter to soil (Liu et al., 2005; Cheunbarn and

Peerapornpisal, 2010). Wastewater effluent at least for irrigation use, could be a valuable source to augment this dwindling water supply, and should not continue to be wasted. Reuse of wastewater effluent could both decrease the disposal of water to the environment and reduce the demand on fresh water supplies (Jasem et al., 2003). Textile industries consume large volume of water and chemical for wet operation of textile. The quantities and characteristics of effluent discharged vary from mill to mill depending on the water use and the average daily product (Saha, 2007). One of the burning problems of our industrial society is high consumption of water. Many approaches have been taken to reduce water consumption, but it would be more appropriate to recycle wastewater into high quality water (Schroder et al., 2007). The present study aims to assess the quality of industrial effluents in district Gujranwala Pakistan where industrial wastewater is causing serious threat to environment. Ten parameters were chosen to assess the water quality of industrial wastewater namely chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), pH, turbidity, electric conductivity (EC), carbonates (CO_3^{-1}) and bicarbonates (HCO_3^{-1}). For example, BOD is measured to estimate the organic strength of the wastewater. Wastewater with high organic material and low DO may pose a risk to freshwater bodies by adversely impacting their oxygen content and endangering aquatic species (fish etc.) that depend on higher oxygen levels for their survival. Provide references that show these parameters to be effective in evaluation wastewater and for making recommendation of its treatment for recycling or reuse. Moreover, the use of wastewater for agriculture purpose without any treatment is affecting the health of the human beings as well as deteriorating the groundwater quality. The water is directly pumped out from the drains and being used in the fields for growing vegetables and field crops. The present study would help assessing the wastewater quality status in order to develop data base for of the competent authorities and its incorporation into developmental plans for treatment and / or safe disposal of Gujranwala wastewaters.

MATERIALS AND METHODS

Study area:
Study was conducted in district Gujranwala which is situated in the Punjab Province of Pakistan. The population of the region is 3,401,000. Due to its extensive road and rail links, the region has flourished with manufacturing and agricultural sectors.

Management of industrial wastewater

The city of Gujranwala also has set up several commercial and industrial centers allowing the manufacturing of ceramics, iron safes, metal utensils, textiles, steel, sanitary and tannery production. Main crops in the region are sugarcane, melons, rice and grains for international export. People grow vegetables by using effluent drained in to ditches near fields and because the drain water is easily accessible to the farmers.

Sampling strategy

A sampling plan was prepared to evaluate the results of water quality parameters of industries in the study region. Random samples were taken from twenty industries in the city situated at different places. The randomly selected industries were ghee industries, ceramic industries, flour mills, leather industries and textile industries. The designation sample numbers for these industries presented in Table 1. Wastewater samples were collected in 500 ml size microbiological examination bottles. Then each of the samples was tested against 10 parameters including chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), pH, turbidity, electric conductivity (EC), carbonates (CO_3^{-1}) and bicarbonates (HCO_3^{-1}).

These Industrial wastewater samples were collected from the outlets that represented effluent from all sources of wastewater in each industrial operation. After taking samples, the bottles were tightened properly to protect from any type of leakage. Storage of the samples was done by cooling to near freezing temperature during storages, even then holding time was kept to minimum. The samples were chilled to 20°C before analysis. For the samples, the industries were selected randomly to get accurate results. There is no systematic system for the disposal of industrial effluent in drain water which is later on used for agricultural purposes. For wastewater quality parameters, different equipment can be used to find different parameters. We used a Fenway Meter for finding the dissolved oxygen and pH. To find the Electric Conductivity and Total Dissolved Solids, the equipment used was Hanna Meter. A Lovi Bond Meter was used to find the Chemical Oxygen Demand. Carbonates and Bicarbonates were found by titration method (Koca et al., 2011). The values of Total Suspended Solids were detected using Filtration Method. Turbidity was found by using Turbidity Meter and Biochemical Oxygen Demand was found by using the 5-Day BOD test.

RESULTS AND DISCUSSION

After a laboratory analysis of various samples and careful examination of the data, results are being reported for retrieving useful information. Results are outlined to quantify and evaluate the impact of untreated industrial effluents for different levels of wastewater quality.

Total suspended solids (TSS) and total dissolved solids (TDS):

In National Environmental Quality Standard (NEQS) Pakistan, the permissible value of total suspended solids (TSS) for industrial water is 150mg/l as against the observed mean value of TSS of 577 mg/l from the industries and it ranges from 385 to 820 mg/l. The higher TSS values are for leather industries. In fact, all of the observed values of TSS much higher than standards values suggesting a poor quality of the wastewaters from the industries. In case of the TDS, the NEQS standards of industrial effluent are 3500 mg/l. However, the TDS value of the leather industry in study region is much higher than the set standards. The mean value for leather industry is 6303 mg/l. The value for all the industries ranges from 195 to 6537mg/l. The moderate results for the values of TDS were from the Flour Mills.

Chemical oxygen demand (COD), biochemical oxygen demand (BOD) and dissolved oxygen (DO):

The standard values of dissolved oxygen (DO) is 2 mg/l. Results show that DO value for all the industries falls between 0.2 mg/l to 2.5 mg/l. The maximum value for DO among all of the 20 samples was 1.8 mg/l. The minimum value of DO was 0.2 mg/l. While in case of biochemical oxygen demand (BOD), the NEQS value should not exceed 80 mg/l for industrial wastewater. The mean value of BOD is 202 mg/l. The maximum value for BOD among all of the 20 samples is 301 mg/l. The minimum value of BOD is shown in the sample which is 115 mg/l. The value of chemical oxygen demand (COD) for NEQS is 150 mg/l whereas the mean value for COD in the study region is 430 mg/l. The value for all the sampling points ranges from 251 to 658 mg/l. The maximum value of COD among all of the 20 samples was 658 mg/l. The minimum value of COD is 132.

Turbidity, pH and Electric Conductivity (EC):

The mean value for twenty samples of industries for Turbidity is 180 FTU which ranges from 19 to 540 FTU. The maximum value of Turbidity among all of the 20 samples was 540 present. The minimum value of Turbidity is shown in the sample which was 19. The NEQS for pH ranges from 6 to 9. It can be concluded that some of the samples are slightly acidic. The sampling values vary from 5.63 to 8.8 mg/l. We found the maximum value of pH among all of the 20 samples which is 8.8 mg/l. The mean value of EC was 2819 micro-s/cm. The value of EC ranges from 285 micro-s/cm to 9950 micro-s/cm. The minimum value of conductivity is shown in the sample which is 285 micro-s/cm. The highest values of EC were in leather industries.

Bicarbonates and Carbonates:

The mean value for twenty samples of industries for Bicarbonates is 435 mg/l. The value for all the sampling points ranges from 60 to 750 mg/l. The maximum value of Bicarbonates among all of the 20 samples was 750 mg/l. The minimum value of Bicarbonates is for sample which is 60 mg/l. The mean value for twenty samples of industries for Carbonates is 49 mg/l. Most of the sampling points were observed carbonate nil. The maximum values were observed 370 and 210mg/l in textile and highest 390mg/l in leather industry.

CONCLUSIONS AND RECOMMENDATIONS

Flour industry had minimal adverse impacts of wastewater releases whereas the Ghee mills showed moderate effects that can be rectified and/or treated within the factory premises through minor arrangements by the owners. Tanneries were the worst of all other industrial units; they demand serious attention of the planners before it is too late. Special treatments processes are required to be installed at industrial units in order to avoid polluting all the drains, waterways, surface and groundwater.

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Figure 1 Green Lush Crop due to irrigation with industrial and domestic waste water in Gujranwala Area.

Another View Green Lush Crop due to irrigation with industrial and domestic waste water in Gujranwala Area.

Figure 2 Field Channel Carrying Domestic and Industrial Waste Water in Gujranwala Area.

Figure 3 Another Small Field Channel Carrying Domestic and Industrial Waste Water in Gujranwala Area.

Figure 4 Main Drain Carrying Domestic and Industrial Waste Water in Gujranwala Area.

Figure 4 Pump is installed in Main Drain for Pumping Domestic and Industrial Waste Water for irrigating the crops in Gujranwala Area.

Figure 5 Pumping of Domestic and Industrial Waste Water from Main Drain for irrigating the crops in Gujranwala Area.

Figure 6 Domestic and Industrial Waste Water carrying Main Drain Passing through the Agricultural Lands.

Figure 7 Another view of Domestic and Industrial Waste Water carrying Main Drain Passing through the Agricultural Lands.

Figure 8 Field Channel carrying Domestic and Industrial Waste Water and Passing through the Agricultural Lands.

Figure 9 **Another Field Channel carrying Domestic and Industrial Waste Water and Passing through the Agricultural Lands.**

Figure 10 **Collection of Groundwater Sample from Hand Pump for Analysis in Gujranwala Area.**

Figure 11 Collection of Groundwater Sample from Hand Pump for Analysis in Gujranwala Area.

Figure 12 Healthy and Lush Green Vegetables grown with Industrial and Waste Water in Gujranwala Area.

GROUND WATER RECHARGE AND NATIONAL CONTEXT

By

Engr. Riaz Nazir Tarrar[11]

1. Introduction

1.1. Global water availability scenario

Over geologic time, a number of large sized fresh groundwater aquifers were created on the earth. These aquifers resulted from perennial groundwater recharge in the regions underlain by favourable sub-surface conditions dominated by alluvial soils. There are at least 37 such large aquifers located in a number of countries around the World.

It is estimated that out of total global water, only about 2.5% is freshwater (refer Annex-01). Its further distribution is: surface water 1%, groundwater 30%, and virtually un-utilizable, glaciers and ice caps 69%. Therefore, it can be realized that groundwater is the primary utilizable source of water for the benefit of mankind.

1.2. Natural processes for Groundwater recharge

These comprise direct recharge of: natural precipitation; river flows; continued seepage from mostly unlined irrigation water conveyance systems; and heavy seepage losses in uneven irrigated lands. Various ‘Process for Groundwater Recharge’ are illustrated in Annex-02.

1.3. Stressed groundwater aquifers on earth

Since time immemorial, the humans have been tapping groundwater for their consumption through natural springs and wells etc. However, with the start of Industrial Revolution around 18th century, demand on groundwater started progressively increasing due to cumulative impact of: population growth; development of artificially irrigated agriculture for providing food and fibre requirements of growing population and industrial raw material; and almost uncontrolled utilization in industrial process. An appreciation in this regard can be had from the sole fact that the global population of about 1 billion in 1804 was around 7 billion in 2012 and projected to reach 8 billion in 2025 and 9 billion in 2048 (refer Annex-03).

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A recent research study conducted by the scientists covering 37 large aquifers brought out that:-

i. Eight (8) of them were 'overstressed' due to being sucked dry with almost no natural replacement to offset the usage. Unfortunately, most of the these aquifers were located in the world's driest places, with very little natural replenishment.

ii. Five (5) other aquifers were 'highly stressed'.

iii. Situation would only worsen with climate change and population growth.

iv. Arabian aquifer system, providing water for more than 60 million peoples, was the world's 'most overstressed'. Aquifer of Indus Basin in Pakistan and North Western India were the second most overstressed. Nurzuk-Djido Basin aquifer in Northern Africa was the third most overstressed.

1.4. Over Exploitation of aquifers

Most of aquifers were being sucked dry through merciless over-exploration by the mankind. In this process: -

i. China was draining some of its rivers dry and mining ancient aquifers, which may require thousands of years to recover.

ii. By 2025, about 2/3rd of world population could be living under water stressed condition.

Through man-made actions, groundwater quality over the last 60 years or so has substantially deteriorated because of: -

i. Excessive application of chemical fertilizers for agriculture.

ii. Dumping of untreated industrial / domestic water and waste into natural bodies which historically formed fresh groundwater recharge sources.

iii. Intrusion of saline into fresh groundwater aquifers due to mining

2. Artificial groundwater recharge

2.1. Need

To support various human and production activities, global extraction of groundwater is increasing day by day. On the other hand, existing natural groundwater recharge sources are unable to replenish the aquifer thus leading to extensive mining. If this imbalance continues, it may not be difficult to imagine the plight of humanity in not too distant future. In a water-scarce society, we can no longer continue with this level of uncertainty, especially since groundwater is disappearing so rapidly.

It is, therefore, imperative that artificial groundwater recharge be resorted to urgently without waiting for 'fait-accompli'. Particularly, in the most overstressed aquifer zones like Indus Basin, prolonged inaction may lead to dire consequences.

2.2. Basic planning considerations

Artificial recharge (sometimes called planned / induced recharge) is a way to store water underground in times of water surplus to meet demand in times of shortage. Some factors to be considered for planning artificial recharge schemes are:-

i. Availability of water source including: -
    a. Quantity
    b. Quality (after reactions with native water and aquifer materials)
ii. Clogging potential of the sub-strata.
iii. Availability of underground storage space relative to water level.
iv. Transmission characteristics of the aquifer.
v. Applicable methods (injection or infiltration).
vi. Cultural / social considerations.

2.3. artificial recharge Methods

Artificial recharge methods can be classified into two broad categories: (i) direct methods; and (ii) indirect methods. Schematic representation of some methods adopted under these categories are shown in Annex-04.

2.3.1. Direct Methods

i. Surface spreading techniques comprising:
    a. Flooding
    b. Ditches and furrows
    c. Recharge basins
    d. Run-off conservation structures
    e. Stream-channel modification
    f. Surface irrigation: Basically, this aims at increasing agricultural production by providing dependable watering of crops during gaps in scarcity period. Wherever adequate drainage is assured, surface irrigation should be given first priority as it gives the dual benefit of augmenting groundwater resources.
ii. Sub-surface techniques comprising:
    a. Gravity-head recharge wells
    b. Connector wells
    c. Recharge pits
    d. Recharge shafts

2.3.2. Indirect Methods

i. Induced recharge
ii. Injection pumping wells
iii. Collector wells
iv. Infiltration galleries
v. Aquifer modification involving: -
    a. Bore blasting
    b. Hydro-fracturing
vi. Groundwater conservation structures comprising: -
    a. Sub-surface dams / underground barriers
    b. Fracture-sealing cementation technique

2.4. Limitations Of Various Recharging Techniques

There are certain limitations in various groundwater recharging techniques, which are mentioned in Annex-05 and summarized below:

i. Sources: Rain water storage tanks; springs; sustainable groundwater aquifers; potential artificial recharge; storage dams; and percolation from rivers / irrigation system.

ii. User Scale: Family: village; town; and very large areas such as canal commands, etc.

iii. Limitations: Failures in periods of scant rainfall or dry season; need for sustainable aquifer yields; need for large sacrificial areas; and monitoring / management difficulties over very large areas.

3. National Groundwater Scenario

3.1. Groundwater Potential And Utilization

Most of the groundwater resources of Pakistan exist in Indus Plains extending from Himalayan foothills to Arabian Sea and are stored in alluvial deposits. These Plains are about 1,600 km long covering an area of 21 Mha (52 Ma) and blessed with large unconfined aquifer, which has now become an essential supplemental source of irrigation water. Over last 100 years or so, this aquifer was created by: direct recharge of natural precipitation; river flows; continued seepage from mostly unlined water conveyance / distribution channels; and heavy application losses in uneven irrigated lands.

Out of its estimated potential of about 62 BCM (50 MAF), the present average exploitation is about 55 BCM (45 MAF) with about 80% being withdrawn by about 1 million small capacity private tube wells. The balance developable potential, however, creates misconception, as the aquifers are not continuous. For instance, in Balochistan, groundwater, extracted through dug wells, tube wells, springs and Karezes is the main dependable source of water for irrigation of orchards and other cash crops. It is estimated that, out of a total available potential of about 1 BCM (0.9 MAF), about 0.6 BCM (0.5 MAF) is already being utilized, thus leaving a balance of 0.5 BCM (0.4 MAF in isolated pockets for further utilization. Simultaneously, in certain confined /

closed river basins it has been exploited almost to extinction. Factually, excessive mining of fresh groundwater aquifers in Indus Plains have already made this precious source inaccessible in 5% and 15% irrigated areas of Punjab and Balochistan, respectively.

3.2. Excessive Mining

Mining has caused alarming lowering of groundwater tables in Indus Plains. ‘Comparative Groundwater Table Behaviour of Provincial Irrigated Areas From 1981 – 2014’ is shown in Annex-06. It can be noticed that over the study period, areas under water table depths above 12 m (40 feet) have increased substantially as indicated below: -

i. Punjab: from 0 to 17.20%
ii. Sindh: from 0 to a nominal 0.02% including reduction in waterlogged areas. However, it has been accompanied by a range of problems such as low farm yields, impediment to rural sanitation facilities and large prevalence of human and animal diseases.
iii. KPK: from 0 to 24.7%
iv. Balochistan: from 0 to about 0.3% but with accompanying problems similar to Sindh

3.3. Quality And Its Deterioration

3.3.1. Quality

Quality of groundwater ranges from fresh with salinity of less than 1000 total dissolved solids (TDS) near main rivers to highly saline 3000 TDS and above in the canal commands. General distribution of fresh and saline groundwater in the country is well known and mapped (refer Annex-07) as it influences the options for irrigation and drinking water supplies. Accordingly in 12 Mha (29.3 Ma) of Indus Basin Irrigation System: 5.75 Mha (14.2 Ma) are underlain with groundwater having salinity less than 1000 TDS; 1.8 Mha (4.54 Ma) with salinity from 1000 to 3000 TDS; and 4.3 Mha (10.6 Ma) with salinity more than 3000 TDS.

3.3.2. Deterioration

Quality of groundwater in the Indus Plains varies widely according to its spatial distribution. Variation with depth is also quite significant and relates to the pattern of groundwater movement in the aquifer. About 77% of the area in Punjab province has access to fresh groundwater. However, there are large numbers of saline groundwater pockets in central Doab areas of canal command areas of Punjab. In addition, Cholistan area in southern Punjab is well known for highly brackish water, which cannot be used for drinking purposes. In some parts of Punjab, there are also reports of high fluoride content (7-12 mg/l) and high concentrations of arsenic (50 ug/l) in the groundwater.

In Sindh province, about 28% of the area has access to fresh groundwater. Large areas are underlain by poor quality of groundwater. In the lower parts of the Indus Plains, area of fresh groundwater is confined to a narrow strip along the Indus River. Excessive pumping of this layer is causing salt water intrusion into these limited fresh groundwater areas. This situation has already resulted in abandoning of over 200 public tubewells located in fresh groundwater zones of Sindh province.

3.4. Economic Cost Of Pumping Groundwater

Pakistan is facing an acute shortage of surface irrigation supplies as canal water is not fulfilling the crop requirements. Therefore, farmers are supplementing crop water supplies by pumping groundwater all over the country. Due to excessive groundwater pumping, water table levels are dropping day by day. Particularly in some areas of Balochistan, Punjab and KPK provinces, the water tables have gone so deep that small farmers cannot use groundwater as its pumping has become very costly.

3.5. Lack Of Groundwater Management Approach

Groundwater in Pakistan is under increasing threat from over-exploitation, pollution and lack of proper management to match the demand and supply patterns of this natural resource base. On the other hand, no groundwater management approach has been developed to control over-exploitation and consequent threats to its fresh water aquifers.

3.6. Situation Analysis Of Water Resources In Lahore

3.6.1. Study of 2014

An almost horrifying scenario has been created by over-exploitation of groundwater in Lahore. To assess this situation, WWF-Pakistan, in collaboration with Cleaner Production Institute (CPI) and WWF-UK, launched a project funded by European Union, entitled “City-wide Partnership for Sustainable Water Use and Water Stewardship in SMEs in Lahore, Pakistan”. An important component of this project, concluded in late 2014, was to conduct a study on “Situation Analysis of the Water Resources of Lahore: Establishing a Case for Water Stewardship”. Scope of this study also included water accounting for city of Lahore and identified gaps in the current knowledge.

An essential part of this study was to identify key risks and the problems faced by the city of Lahore both in terms of water quantity and quality. It provided basic information about the physical water and institutional water management situation and risks (physical, reputational, regulatory and institutional) of Lahore as identified below: -

i. Wastewater in Lahore is collected through a network of 14 open main drains and discharged into River Ravi without any treatment. At the same time, around 100 industries located along the banks of Hudiara Drain are highly pollutive including textile processing units, carpets, etc. This has created an alarming situation regarding water quality of Ravi River (refer Sub-Section 3.62)

ii. Current water supply for domestic, industrial and commercial uses is estimated to be 3.79, 0.92 and 0.77 MCM/day, all of which is extracted from the ground water and aggregates to 1996 MCM (about 1.6 MAF) per year.

iii. Total current groundwater extraction for agriculture is estimated as 1.71 MCM/day aggregating to 623 MCM (about 0.5 MAF) per year.

iv. Population of Lahore is expected to increase to about 221 million by 2025, out of which 84% are projected to live in the urban areas creating more pressure on the water, sanitation, energy, transport, education and health sectors.

v. a. Due to excessive pumping, on the average groundwater table has already gone below 40m (130 feet). It is projected to drop to 70m (230 feet) by 2025 and further to 100m (330 feet) or more by 2040, if current extraction pace continues.

b. Besides excessive mining of groundwater, this will significantly deteriorate its quality due to: recharge from polluted Ravi water; and intrusion from the adjacent saline aquifer.

vi. Current (2014) annual water balance shows an output of 2619 MCM (about 2.1 MAF) against input of 2317 MCM (about 1.9 MAF) thus showing a net deficit of 248 MCM (about 0.2 MAF) as per supporting details in Annex-08.

vii. To overcome this deficit which is going to increase in future, imposing ban on boreholes and dug wells, defining limits of withdrawal and imposing groundwater extraction fee are considered inevitable.

viii. Groundwater recharge increase could be consciously aided by rain water harvesting techniques especially in new housing colonies. However, for long-term sustainability of drinking water quantity and quality, groundwater supplies should be supplemented by surface water supplies including artificial recharge.

ix. The possible surface water sources that can be tapped for artificial recharge are River Ravi and BRBD Canal.

x. Once quality concerns are addressed including recharge from highly polluted Ravi water, there will be a need to strike a balance between recharge and usage by implementing laws and regulations at all levels.

3.6.2. Ravi Water Quality Assessment Around Lahore

During 2009-10, a study was conducted to assess the water quality of Ravi River around Lahore. For this purpose, four (4) sites were selected (refer Annex-09) along the river at Ravi Syphon; Shahdara Bridge; Mohlanwal Village; and confluence of Hudiara and Sattukatla drains. Twelve (12) water samples were collected from these sites at intervals of two months. These were then analyzed for physical (colour, odour and turbidity), chemical (pH, TDS, Cl, F, NO_3, Cu, Zn, Ni, Pb) and bacteriological (E. coli) parameters. Results were then compared with WHO, US-EPA and Pak-EPA criteria for drinking water supply (refer Annex-10).

Main findings of this study were: -

i. Turbidity, Pb and Ni (except Ravi Syphon) were exceeding the permissible limits.
ii. E-colis were present in all samples and exceeded the permissible limit of 0 in 100 ml.
iii. pH, TDS, Cl, F, NO_3, Cu and Pb levels of samples were within the permissible limits.
iv. Surface water pollution was caused by disposal of untreated municipal and industrial effluents dumped into Ravi.
v. Pollution levels were increasing along the direction of river flow with minimum at River Syphon and maximum at the confluence of Hudiara and Sattukatla drains.

3.7. Socio-Economic And Environmental Impacts Of Groundwater Mining

Declining groundwater tables due to mining and land degradation as a result of poor quality groundwater use for irrigation has seriously affected the social fabric of Pakistani society. Drying up of Karez systems in Balochistan have increased the livelihood burden on women due to immigration of spouses for income supplementation. Similar conditions also exist in the Cholistan area of Punjab where women have to walk miles to bring fresh drinking water from canals / ponds as groundwater is very deep and hazardous to health.

Soil salinity remains a hazard for the Indus Basin and threatens the livelihood of farmers, especially the small-scale ones. Due to very large investments in SCARPs, extent of salt-affected lands has decreased to about 4.5 Mha from about 6.0 Mha in 1980s. However, simultaneously, land degradation has reduced the production potential of major crops by about 25%.

3.8. Groundwater Management Status in Pakistan

Until recently the management of groundwater in Pakistan did not receive much attention because the resource was in abundance and therefore the focus remained primarily on its development. The spectacular expansion of agriculture helped lifted millions out of poverty. However, the situation began to turn serious when such unregulated exploitation brought many aquifers under severe stress and threatened the sustainability of this resource.

Major reason for these negative developments is that the management of groundwater could not keep pace with its development. Over the last three to four decades, Pakistan tried several direct and indirect management strategies to control over-exploitation of groundwater but these remained ineffective.

In 1980s, licensing system was introduced to restrict installation of private tubewells in the critical areas (where either groundwater was falling at faster rate or its quality was deteriorating). At provincial level, groundwater regulatory framework for Punjab province was prepared in 1990s with assistance of the World Bank. National groundwater management rules were also drafted under Provincial Irrigation and Drainage Authority (PIDA) Act in 1999-2000. Similar law was also developed by Balochistan Government (Balochistan Groundwater Rights Administration Ordinance, 2001). These rules suggested demarcation of critical areas, provision of licenses for the installation of tubewells especially in critical areas and registration of all tubewells. This regulatory framework was submitted to the provincial governments for implementation. However, like many other laws, these could not get the attention of the governments and the problem of groundwater management went abegging.

Despite plethora of laws and policies developed by government, no serious effort was made for implementing them. In addition to historical neglect, the provision of human and financial resources for the groundwater management remains very limited. Unlike the management of surface water resources there has been no effort to manage aquifers that span beyond administrative provincial boundaries. Another complication in the management of groundwater is that no single organization is responsible for managing the total resource base.

4. National Groundwater Recharge Situation

4.1. Need For Artificial Recharge Schemes

In the light of foregoing, current groundwater related situation can be summed up as below: -

i. In the areas underlain by fresh groundwater around 50% farmgate irrigation requirements are being provided by this source.

ii. In this process, groundwater aquifers are being seriously mined to depths of 12m (40 feet) and above in most of the canal commands. Resultantly: cost of pumping groundwater is getting out of the reach of small formers; and quality of groundwater is deteriorating due to salty water intrusion from the adjacent brackish aquifers.

iii. Groundwater recharge from existing sources is insufficient to maintain equilibrium between output and input. This factor is jeopardizing the sustainability of various ground water aquifers with dire economic and social consequences.

Therefore, it needs no emphasis regarding urgent need to take up indirect recharge schemes in various fresh groundwater areas not only to replenish the threatened aquifers but also ensure their sustainability.

4.2. Present Planning Status For Artificial Groundwater Recharge Schemes

4.2.1. Recharge Potential in Irrigated Areas

Realizing that no management approach had been developed to control over-exploitation of groundwater, IWASRI carried out a study to identify areas of groundwater depletion and suggest measures for their sustainability. Groundwater table data of irrigated areas of Punjab and Pakhtonkhwa underlain by useable groundwater was analyzed for aquifer depletion over the period of June 1981 to 2014. In turn, this provided an area-wise estimate of groundwater recharge potential.

The study revealed following levels of groundwater depletion, and consequent recharging capability in various irrigated areas of upper Indus Basin: -

i. Punjab:

   a. Maximum of about 46 MAF in Bari Doab
   b. Over 14 MAF in Chaj Doab.
   c. Over 7 MAF in Thal Doab

ii. Over 10 MAF each in Bannu and D. I. Khan Plains of Khyber Pakhtunkhwa.

The study recommended that programmes of artificial recharge be undertaken in these highly depleted aquifer areas.

4.2.2. Recharging Through Flood Flows

It is gathered that following proposals have been studied / identified in Punjab: -

i. Creation of an underground reservoir in Bari Doab: Pre-feasibility level

ii. Utilizing abandoned reach of Mailsi Canal upstream of SM Link: Pre-feasibility level

iii. Construction of collapseable fibre glass weirs at suitable locations on Punjab rivers: Conceptual level

The need is not only to pursue the above proposals, but to initiate focused planning for pursuing artificial groundwater recharge schemes, wherever feasible.

5. Conclusions and Recommendations

5.1. Conclusions

i. Groundwater is a major source of supply for the mankind as it constitutes about 30% of the estimated global surface / other freshwater availability.

ii. Due to rapidly increasing global population and related developmental activities, fresh groundwater aquifers are being sucked dry through merciless meritless exploitation by the mankind.

iii. A recent scientific study of 37 major groundwater aquifers over the world brought out that: 8 were ‘overstressed’, and 5 others were highly stressed.

iv. Amongst overstressed aquifers, Indus Basin was ranked second, due to uncontrolled exploitation.

v. Groundwater recharge from various natural sources is unable to cope with the extractions resulting in serious mining of groundwater. In order to restore this imbalance, resort to artificial groundwater recharge measures has become inevitable.

vi. Present national groundwater utilization scenario is very alarming as indicated below: -

   a. Average annual groundwater utilization of about 56 BCM (45 MAF) is mostly through 1 million private tube wells, which accounts for about 50% of farmgate irrigation water requirement.
   b. Total developable potential is estimated around 62 BCM (50MAF), which shows a theoretical balance of about 6 BCM (5MAF). This, however, creates misconception as aquifers are discontinuous. Consequently, most of the sizeable fresh water aquifers have already become overstressed.
   c. Mining has caused alarming lowering of groundwater tables in canal irrigated areas. A study of this trend over the period of 1981-2014 shows that irrigated areas with water table depths above 12m (40 feet) have increased: from 0 to 17% in Punjab; and 0 to 25% in KPK. These drop in water tables have increased pumping costs to the extent that this source is becoming inaccessible to small formers.
   d. Groundwater quality is also deteriorating due to: intrusion from the adjacent saline aquifers; excessive use of chemicals / fertilizations and recharge from contaminated water from untreated municipal / industrial effluents.
   e. Current groundwater quantity / quality availability and utilization situation is alarming and requires top priority attention for addressing the issues.

5.2. Recommendations

i. Groundwater in Pakistan is under increasing threat from over-exploitation, pollution and lack of proper management to matter the demand and supply patterns of this natural resource base. On the other hand, no groundwater management has been developed. This deficiency should be urgently addressed through: creating awareness among stakeholders, particularly the farming community; consolidation of plethora of existing laws and policies of the government and ensuring their strict implementation.

ii. As the existing natural recharge is not matching with over-drawl, a basic plank of management should be artificial groundwater recharge.

iii. Presently there seems no focus on artificial recharge schemes except a few conceptual / pre-feasibility level studies to utilize flood flows. This activity, therefore, needs acceleration at national level through taking up planning of artificial groundwater recharge schemes, wherever feasible.

iv. a. A case in point is precarious groundwater situation in Lahore. Currently, there is: an annual deficit of about 248 MCM (0.2 MAF) between output and input; and this imbalance has already lowered groundwater table to 30m (100 feet), which may touch 70m (230 feet) by 2025.
  b. To arrest this alarming trend, groundwater supplies be supplemented by surface water particularly through artificial recharge.
  c. Rain water harvesting be introduced, particularly in new housing schemes.
  d. Surface water recharge schemes through flood supplies may consider: creating a reservoir on the river between Lahore and Ravi Syphon; running excess supplies in BRBD Canal; and installation of direct injection wells in Lahore Branch Canal to utilize the supplies rendered surplus through conversion of large irrigated areas to residential colonies around Lahore.

6. References

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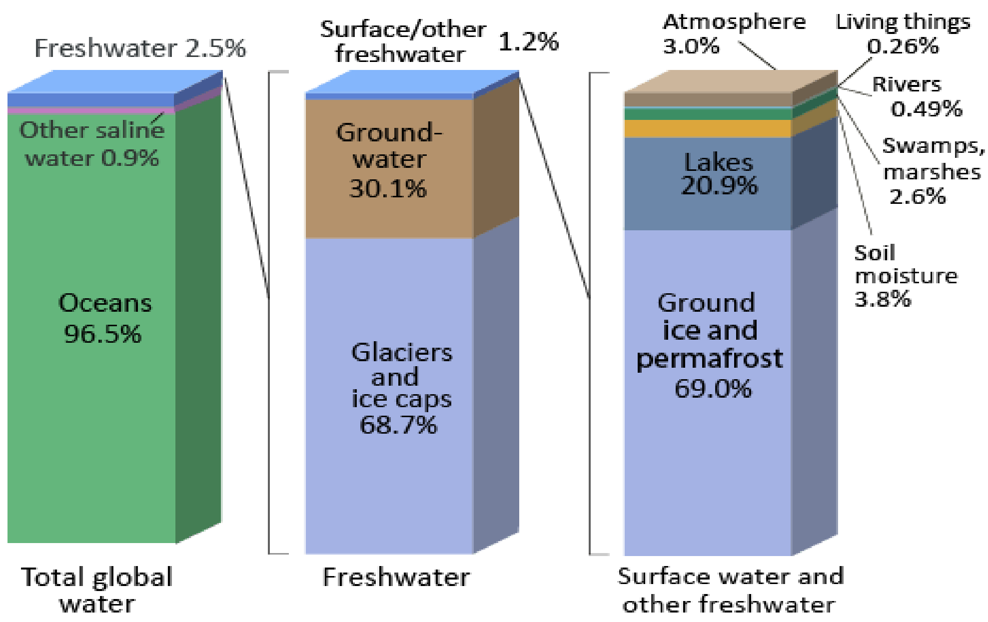
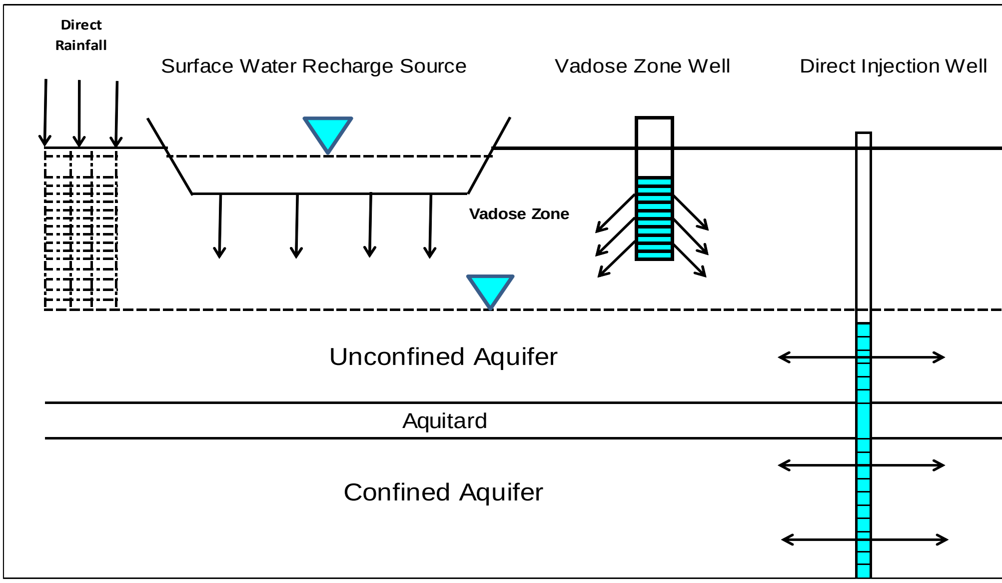
ANNEX-01: GLOBAL WATER DISTRIBUTION

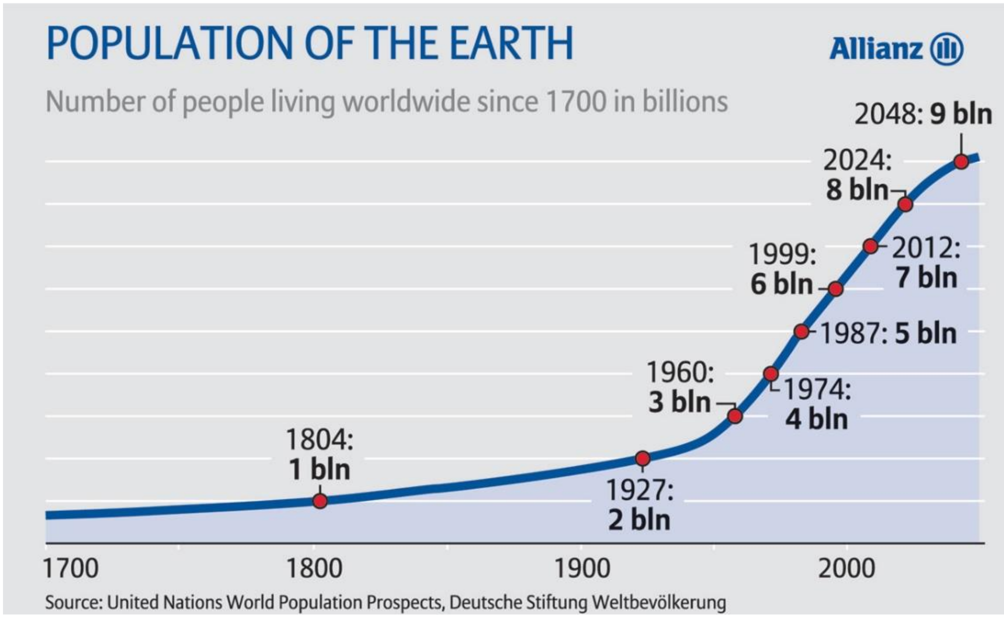


Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.
NOTE: Numbers are rounded, so percent summations may not add to 100.

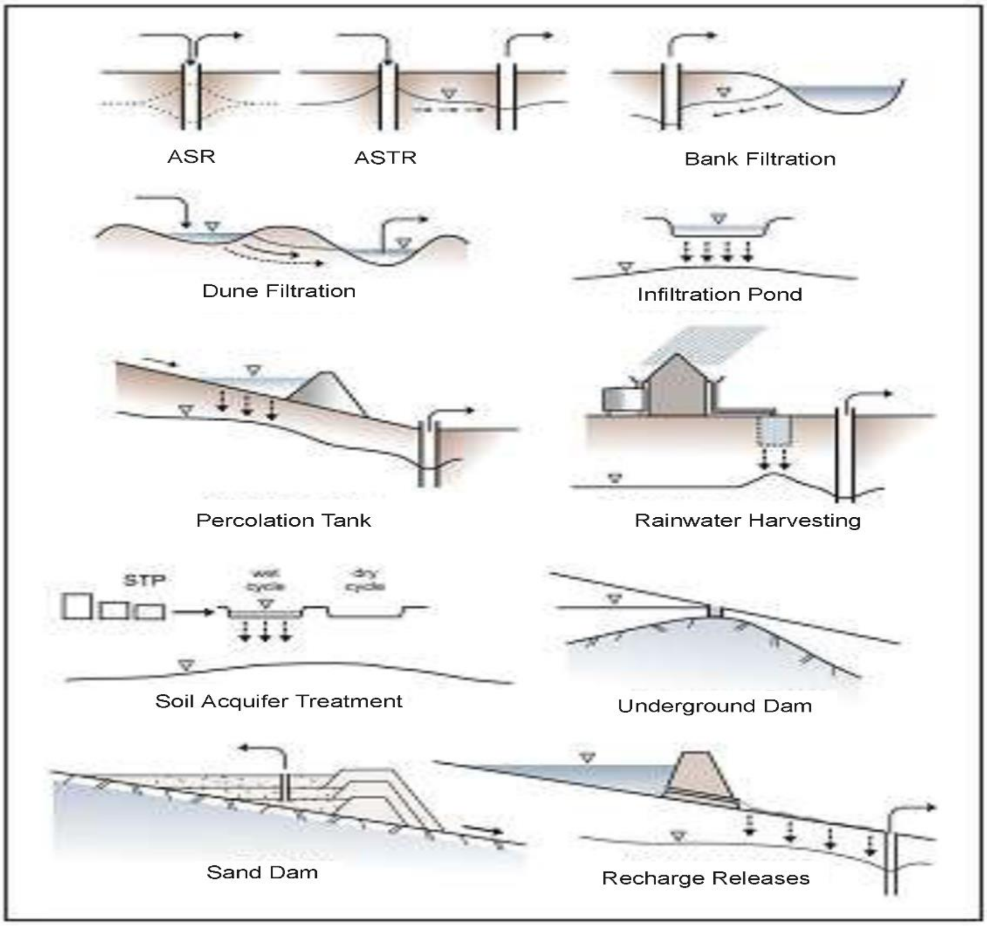
ANNEX-02: PROCESSES FOR GROUNDWATER RECHARGE



ANNEX-03: POPULATION OF THE EARTH



ANNEX-04: SCHEMATIC REPRESENTATION OF VARIOUS DIRECT AND INDIRECT AQUIFER RECHARGE METHODS



ANNEX-05: LIMITATIONS OF VARIOUS GROUNDWATER RECHARGING TECHNIQUES

Source	User Scale	Limitations
Rain water storage tank	A family	Fails in periods of drought spell
Springs	Family/Village	Can also fail in dry season
Ground water	Village/Town	Needs sustainable aquifer yields
Artificial Recharge	Village/Town	Need aquifer with potential to accept recharge
Dams	Village/Town	Needs large area likely to be submerged
Percolation From Rivers / Irrigation Systems / Reservoirs	Large Plains	Monitoring and management spread over very large areas

ANNEX-06: COMPARATIVE GROUNDWATER TABLE BEHAVIOUR OF PROVINCIAL IRRIGATED AREAS FROM 1981 TO 2014

Table 1: Groundwater Table Depth in Irrigated Areas of Punjab (June 1981-2014)

Watertable Depth (m)		1981	1999	2010	2011	2012	2013	2014
<1.5	**M ha**	0.957	0.62	0.20	0.633	0.651	0.669	0.439
	%	9.6	6.2	2	6.3	5.95	5.6	1.5
1.5 to 3.0	**M ha**	3.219	1.89	1.11	1.344	1.650	1.956	2.08
	%	32.3	18.9	11	13.5	14.9	16.3	17.3
3.0 to 4.5	**M ha**	2.269	2.92	1.56	1.506	1.888	2.269	2.531
	%	22.8	29.3	16	15.1	17.0	18.9	21.1
4.5 to 6.0	**M ha**	1.478	1.47	1.73	1.423	1.601	1.778	1.800
	%	14.8	14.8	17	14.3	14.55	14.8	15.1
6.0-12.0	**M ha**	2.040	3.06	5.37	5.061	4.104	3.147	3.087
	%	20.5	30.8	54	50.8	38.5	26.2	25.7
>12.0	**M ha**					1.092	2.183	2.062
	%					9.1	18.2	17.2
Total		9.96	9.96	9.96	9.967	12.002	12.002	12.002
		100	100	100	100	100	100	100

Table 2: Groundwater Table Depth in Irrigated Areas of Sindh (June-2014)

Water Table Depth (m)	Area	1981	1999	2010	2011	2012	2013	2014
1.5	M ha	1.023	2.21	0.324	2.158	1.194	0.902	0.595
	Percent	17.9	38.5	6	37.7	20.95	15.3	9.8
1.5 to 3.0	M ha	3.482	2.87	3.78	2.557	3.780	4.217	3.938
	Percent	60.9	50.0	66	44.6	66.3	71.7	64.8
3.0 to 4.5	M ha	0.632	0.35	1.08	0.537	0.499	0.507	0.773
	Percent	11.0	6.1	19	9.3	8.8	8.6	12.7
4.5 to 6.0	M ha	0.324	0.17	0.28	0.248	0.137	0.178	0.287
	Percent	5.7	2.9	5	4.3	2.4	3.0	4.6
6.0-12.0	M ha	0.260	0.14	0.27	0.236	0.088	0.081	0.114
	Percent	4.5	2.5	5	4.1	1.5	1.4	1.9
>12.0	M ha					0.001	0.448	0.001
	Percent					0.02	0.07	0.02
Total	M ha	5.72	5.74	5.74	5.74	5.74	5.74	5.74
	Percent	100	100	100	100	100	100	100

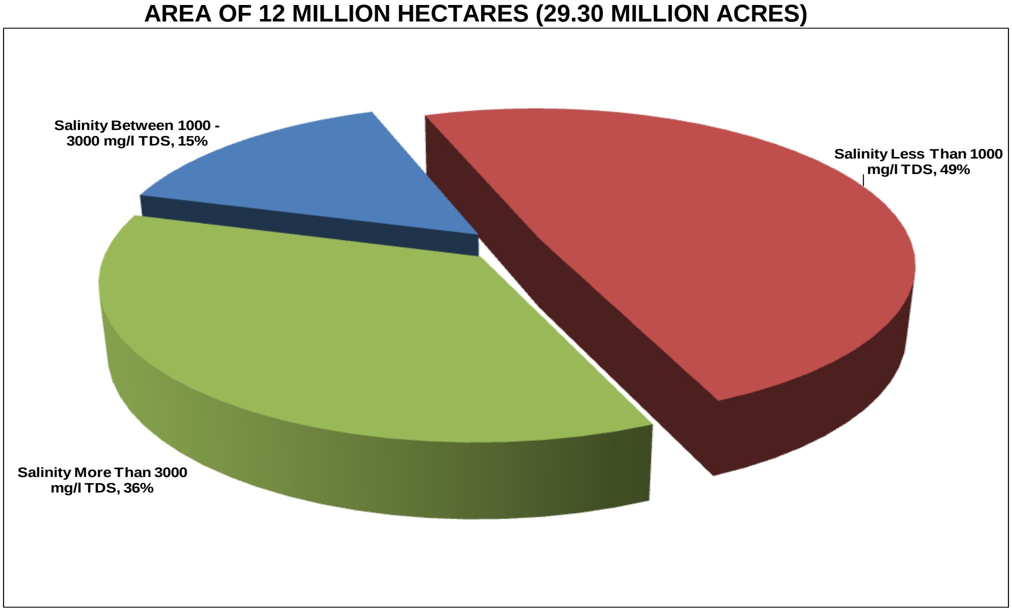
Table 3: Groundwater Table Depth in Irrigated Areas of KPK (June 1981-2014)

Watertable Depth (m)	Area	1981	1999	2010	2011	2012	2013	2014
<1.5	M ha	0.026	0.032	0.027	0.020	0.060	0.041	0.028
	Percent	8.0	6	5	3	4.4	3.0	2.1
1.5 to 3.0	M ha	0.015	0.153	0.122	0.087	0.240	0.302	0.278
	Percent	26.4	27	21	15	17.4	22	20.2
3.0 to 4.5	M ha	0.010	0.082	0.094	0.102	0.195	0.192	0.214
	Percent	14.6	15	16	17	14.2	14.0	15.6
4.5 to 6.0	M ha	0.041	0.068	0.061	0.067	0.123	0.119	0.123
	Percent	10.3	12	10	11	9.0	8.6	9.0
6.0-12.0	M ha	0.22	0.230	0.284	0.312	0.314	0.340	0.391
	Percent	40.8	41	48	53	22.9	24.8	28.5
>12.0	M ha					0.442	0.380	0.339
	Percent					32.2	27.6	24.7
Total	M ha	**0.539**	**564.9**	**587.5**	**587.5**	**1.374**	**1.374**	**1.374**
	Percent	**100**	**100**	**100**	**100**	**100**	**100**	**100**

TABLE 4 Groundwater Table Depth in Indus Command Irrigated Areas of Balochistan (June 1981-2014)

Watertable Depth (m)	Area	1981	1999	2010	2011	2012	2013	2014
<1.5	M ha	0.037	0.079	0.01	0.140	0.060	0.028	0.014
	%	36.8	19.8	2.4	35.1	15.82	5.9	7.5
1.5 to 3.0	M ha	0.036	0.127	0.156	0.126	0.165	0.272	0.171
	%	62.9	31.9	39.0	31.6	43.4	57.7	88.3
3.0 to 4.5	M ha	0.0002	0.193	0.084	0.031	0.073	0.081	0.008
	%	0.2	48.3	21.0	7.7	19.1	17.1	3.9
4.5 to 6.0	M ha			0.03	0.027	0.021	0.023	0.0003
	%			7.5	6.7	5.6	4.8	0.2
6.0-12.0	M ha	0.116		0.120	0.075	0.065	0.067	0.00026
	%	100		13.0	0.019	16.9	14.2	0.1
>12.0	M ha					0.0012	0.002	0.000008
	%					0.3	0.3	0.004
Total	M ha		**0.399**	**0.399**		**0.381**	**0.381**	**0.381**
	%		**100**	**100**		**100**	**100**	**100**

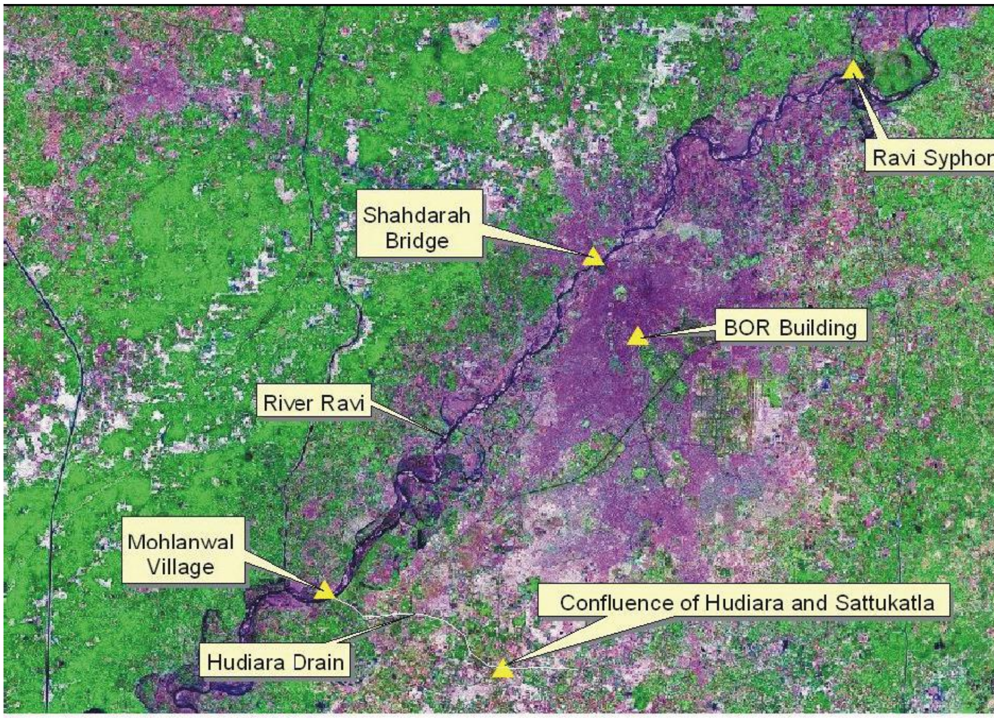
ANNEX-07: GROUNDWATER QUALITY IN INDUS BASIN IRRIGATION SYSTEM - TOTAL AREA OF 12 MILLION HECTARES (29.30 MILLION ACRES)



ANNEX-08: SUMMARY OF WATER BALANCE OF LAHORE CITY

Source		**(MCM/day)**	**(MCM/year)**
Output			
	Domestic	3.79	1384
	Industrial	0.92	335
	Commercial and Institutional	0.76	277
	Agriculture	1.71	623
	Total Output	7.17	2619
Input			
	River Ravi	5.31	1937
	Irrigation System	0.40	146
	Rainfall (urban areas+non-urban agricultural fields	0.38	138
	Groundwater return flow from agricultural fields	0.41	150
	Total Input	6.50	2371
Output-Input		0.67	248
	Total surface water use in Lahore	3.00	1094
	Total wastewater generated in Lahore.	8.0	2920

ANNEX-09: WATER QUALITY ASSESSMENT OF RIVER RAVI AROUND LAHORE -SCHEMATIC MAP SHOWING POWER SAMPLING SITES



ANNEX-10: INTERNATIONAL AND NATIONAL CRITERIA FOR DRINKING WATER QUALITY

	TDS (ppm)	Cl (ppm)	Fl (ppm)	NO_3 (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)	Pb (ppm)	E.coli
WHO Criteria	<1000	250	1.5	50	2	3	0.02	0.01	0 in 100 ml
Pak-EPA Criteria	<1000	<250	≤ 1.5	≤ 50	2	5	≤ 0.02	≤ 0.05	0 in 100 ml
US-EPA Criteria	1000	250	2	10	1	5	-	0.015	-

WATER RESOURCES DEVELOPMENT CREATES JOB OPPORTUNITIES

By

Dr. Izhar-Ul-Haq

Abstract:

Water is not only necessary for living beings but also for plants. Agriculture depends on water to ensure food security. Water turns the wheel of Industry and it is a renewable source of hydropower. Construction of dams to store water for domestic use, agriculture, flood mitigation and hydropower, barrages and canals for irrigation provide jobs to the people. Down stream industries and the trickledown effect further creates opportunities for employment. Introduction of irrigated agriculture in India changed the civilization from nomadic to settled life. Water supplied in the unsettled areas would not only provide the job opportunities but also eliminate the militancy.

1. Introduction

"We created every living thing from water" (Al Quran)

The ability of the people of the Hilly Flanks, China, the Indus Valley, Oaxaca, and Peru, to harness the natural resources helped them in creating civilizations of their own.

Arabs developed in the 8th century A.D. because of the expansion of the agriculture based on irrigation in Iraq and Egypt using different techniques.

The opening of the Suez canal and Panama canal transformed the meanings of geography to a great extent, not only for the countries adjacent to these canals but for the whole world as well.

The Mediterranean Sea was at first an impediment to travel as were the Atlantic and the Pacific Oceans, but once a technology was created for coping with these natural impediments, they became highways for commerce and war. The dominance of Europe in the world arena, after 17th century, is the story of success.

2. Construction of Canal Irrigation System in India by British

The construction of the modern canal irrigation system in the Punjab by the British was a great feat of engineering and administration and the best use of the soil and water. The British canal irrigation system brought a change in the social and economic lives of the people of the Western Punjab.

The British were aware of the geography, the abundance of water and vast tract of land in India. They built canal irrigation system, institutionalized it, organized it and had set up unique rules of administration. The total tax revenues increased 75% between 1870-1901. The canal irrigation of the Western Punjab, "transformed this region from desert waste, or at best pastoral savanna, to one of the major centers of commercialized agriculture in South Asia".

This modern irrigation system brought a revolution in agriculture and Punjab's agricultural output had increased manifold. The canal irrigation system brought fruition in the form of canal colonies, and one of the biggest plain land settlement in the world, and, "transformation of 6 million acres of desert into one of the richest agricultural regions in Asia. It was a stupendous engineering feat that was seen as the colonial state's greatest achievement. The British spent about 5,000,000 Pounds to construct the Upper Jhelum, Upper Chenab, and Lower Bari *Doab*. Before the introduction of the modern irrigation in the Western Punjab, its agriculture was based on (*sailabi*) inundation and (*barani*) rainfall. The basic objective of the modern canal irrigation was to bring under cultivation the vast waste crown land.

The Lower Chenab Canal with total length of 2700 miles, having yearly net revenue of the canal, about 40% of its capital cost (more than two million Sterling Pounds) was one of the most successful irrigation systems in the world. The area that was brought under cultivation was two million acres. The second canal colony, the Lower Jhelum Canal, in the tract of *doab*, land between the two rivers, Jhelum and Chenab, was established in 1902. The Triple Project, comprising the Upper Jhelum, Upper Chenab and Lower Bari Doab canals, was completed in 1915 with the cost of 7 million Sterling Pounds. The total length of the canal was 3400 miles and the area irrigated was two million acres.

Individual efforts were also made in respect of building canals, like that of Reynell Taylor, Deputy Commissioner of Dera Ismael Khan, established a canal project, which brought 20,000 *big has* (10,000 acres) of jungle under cultivation.

Engineering mastery of earth and water was nowhere more evident in the empire than in the irrigation canals of India. Chenab Canal had 250 foot wide bed with the "depth of almost 11 feet of water, and discharges 10,800 cubic feet per second or about fourteen times the amount ordinarily discharged by the river Thames at Richmond. At both sides of the canals were roads, only for the official use, then the trees and then a road for the common travelers.

Before the colonial rule in the Punjab, most of the population lived semi nomadic lives, in summer at the bank of rivers while in winter they migrated to the bar area, *rahna* (where there is water and pastoral land for the animals). It was a cycle of seasonal migration. After the canals construction, *chaks* were chalked out with wide bazar, streets, hospitals, schools and pastoral land, totally different from the older villages, *mozas*, having narrow streets and no facilities that were available in the *chaks*. The British administration directly affected the rural life and helped People in living a settled life, with a sense of the rule of law.

There was no permanent solution to cope with the menace of famine before the establishment of canal irrigation system but when once established with modern communication system of railways and roads, and responsible government, the effects of famine got diminished to a great extent. When peasants were given rights of ownership, they cultivated the land with much labour, resulting in the permanent supply of food and the communication system. Railways, roads and telegraph greatly helped in controlling the effects of famine. Thus the modern canal irrigation system transformed the lives of the people of the Punjab from nomadic to the settled one and undoubtedly the manifestation of settled life in the form of increasing civility and polish and falling down rate of crimes did appear in canal irrigated Punjab.

The colonial agriculture in the Punjab based on canal irrigation contributed a lot in the field of ending of internal warfare among semi-nomadic tribes and banditry, and changed their life pattern.

3. Construction of Indus Basin Replacement Works

Indo Pakistan water dispute was resolved on signing of Indus Basin Treaty by the two countries. Indus Basin Treaty led to the construction of Indus Basin replacement works. These comprised of two large dams Mangla and Tarbela, five barrages and eight inter river link canals. This was the largest civil engineering project ever let out in the history of construction industry. The projects were meant for providing the replacement water allocated to India. In addition of ensuring the agricultural water supply these projects provided enormous development and employment opportunities. Millions of peoples worked on the construction and supply of material for these projects.

These water projects brought green revolution in Pakistan. Agriculture and the allied industry thrived and became the mainstay of Pakistan's economy.

Hydropower provided by the two storage dams Mangla and Tarbela provided cheap hydropower. This triggered the industrialization in Pakistan. Heavy mechanical and electrical industries were established at Wah. Textile Industry and power looms flourished in seventies and eighties.

3.1 Construction of Mangla Dam

During construction of Mangla Dam Project from 1963 to 1967 at peak 600 Pakistani Engineers and 80 Foreign Engineers worked on supervision of the project. The contractor's manpower comprised of 13000 Pakistani and 500 expatriates. Table 1 presents manpower at Mangla Dam during construction.

Table-1 (Manpower at Mangla Dam)

Description of Manpower	No. of Manpower	Remarks
CONTRACTOR'S MANPOWER		
Pakistani	13,000	At the peak of work
Expatriate	500	At the peak of work
ENGINEER'S MANPOWER		
Pakistani	600	At the peak of work
Expatriate	80	At the peak of work

During Raising of Mangla Dam Project from 2006-2010, at peak Pakistani work force was 4674 and Chinese were 74. Table-2 presents the manpower engaged during raising of Mangla Dam Project.

Table-2 (Contractor's Manpower at Mangla Dam Raising Project)

Description of Manpower	Period	No. of Manpower	Remarks
Pakistani	Jan-2006	2817	-
	June-2008	4674	Peak Demand
Chinese	Jan-2006	74	
	June-2008	43	

3.2 Construction of Tarbela Dam Project

During construction of Tarbela Dam Project from 1968-75 Pakistani workforce at peak was 15800 and the expatriates were 800. Table-3 gives the contractor manpower deployed during construction of Tarbela Dam Project.

Table-3 (Contractor's Manpower at Tarbela Dam)

Description of Manpower	Period	No. of Manpower	Remarks
Pakistani	1969	5,000	First year of the project
	1972	15,800	Peak Demand
Foreigners	1969	250	First year of the project
	1970	800	Peak Demand

3.3 Trained Man Power

After completion of Tarbela dam no mega dam was started. Most of the trained manpower went abroad especially Middle East. Their foreign remittances have been more than the cost of the Indus Basin Works.

4. Daimer Basha Dam Project

In order to meet the food and fiber security of its population, Pakistan needs urgently at least one large storage project. Feasibility and design of Diamer Basha Dam has been completed. Council of Common Interests has approved the project. Govt. is arranging funds for its construction. Land has been acquired for the project and infrastructure is almost complete at site.

4.1 Construction Stage

Implementation of the project will open a large number of gainful employment opportunities for professionals in the multifaceted technical and managerial positions and also para technical and skilled manpower. Estimated peak direct employment of WAPDA and Consultants during construction will be 2045 personnel. With corresponding employment of 11520 by construction contractors, it will aggregate to 13,565 persons.

4.2 Operation and Maintenance (O&M) Stage

Estimated personnel requirement for O&M stage will be 1260.

4.3 Indirect Employment after Execution of the Project

As part of trickle-down effect, very large employment will be generated at the regional and national scale in the secondary and tertiary level of economy. In particular, the impact in industrial and agriculture sectors will be marked. Through additional energy delivery at the consumer end either additional industrial units will be established or the idle capacity of the existing units utilized. Similarly, additional provision of storage water at the canal heads of IBIS will either enable cultivation of additional areas or increase the crop yields. By adopting these criteria an estimate of indirect employment attributable to DBDP has been made as described in the following paragraphs:

4.4 Power Generation and Resulting Employment

In Pakistan, there are 233,162 industrial units consuming 17,603 GWh or about 26% of the electricity supplied by WAPDA from a total generation of 67,480 GWh. These units provided employment opportunities to 9.47 million peoples among a total employed labour force of 45.18 million for the year 2008. These industrial units include: Mining and Quarrying; Manufacturing; Construction; and Electricity and Gas distribution. DBDP will provide additional generation of 19,208 GWh. Assuming the present trend, about 26% of this annual generation (4994 GWh) would be utilized by the industry. Assuming 15% conveyances losses this comes to 4245 GWh at the consumer end. Presently, the industry is providing employment to a person for an energy of about 1800 kWh. At this rate, the additional industrial employment could become available to about 2.36 million peoples.

4.5 Agricultural Benefits and Resulting Employment

Live storage capacity of DBDP will be 6.4 MAF with average additional water availability at canal head of about 6.15 MAF. Assuming 44% irrigation efficiency, additional water available for crops will be 2.71 MAF. Based on the average water requirements of 2.21 acre foot per cropped acre about 1.23 million acres additional area could be matured from the water available from DBDP. As typical cropping pattern requires 29 man days input per cropped acre the project will provide 35.67 million man-days or employment to about 0.1 million persons per annum of additional employment.

4.6 Subsidiary Employment

Additional employment under subsidiaries is roughly estimated as 40,000 persons per year.

4.7 Total Employment

Total expected additional individual employment after execution of the project comes to 2.5 million persons per annum as per breakup in Table-4.

Table-4 (Expected Indirect Employment after Execution of Diamer Basha Dam Project)

Sr. No.	Economy Sector	Estimated Employment Generation			
		Attributing Factor	Project Contribution At Consumer end	Persons / Unit (No)	Total (No)
1.	Industrial (Additional Generation)	Expansion	4245 GWh [a)]	1800 KWh [c)]	2,360,000
2.	Agricultural (Additional Water)	Additional Cropped Area	1.23 MA [b)]	29 Man-days	100,000
3.	Subsidiaries		-	-	40,000
Total					**2,500,000**

Say 2.5 million

a) Applying a loss of 15% to 19208 GWh annual energy generations attributable to the project and assuming that 26% of this will be utilized in industry.

b) Additional cropped area / year.

c) Energy delivered per person at consumer end.

5. Flood Canals

During high flow season about 3 months, 30 MAF water on average goes downstream of the last barrage kotri into sea. In order to make use of a part of this water three flood canals: Greater Thal Canal (irrigate area 1,739,000 acres, Phase-I, 355,000 acres), Kachhi Canal (irrigate area 7,13,000 acres, Phase-I, 102,000 acres) and Rainee Canal (irrigate area 412,400 acres, Phase-I, 113,690) were started in 2002. Phase-I of these canals has been completed. Barren lands of Thal, Kachhi and Thar have been brought under plough providing employment opportunities to lacs of people.

6. Gomal Zam Dam Project

Gomal Zam Dam Project on river Gomal in South Waziristan conceived in 19^{th} century was built from 2004-14. It would store 1 MAF of water and produce 17MW of hydropower. It would irrigate 163,100 acres of virgin land. It would provide working opportunity to 15000 persons. It would alleviate poverty and bring prosperity to the FATA backward area. It would tie down the people to land and eliminate militancy.

7. **Mirani Dam**

Mirani dam is located on Dasht River in South West Baluchistan. It would store 0.152 MAF of water and irrigate 33,200 acres of land. This would provide job opportunities to 4000 people and ensure food security to the poor people in the area.

8. Neelum Jhelum Hydro Power Project

Direct employment provided by N.J.H.P.P is 1000 Pakistani workers and 500 Chinese workers in addition to supervisory and management staff. It also provides jobs to the manufacture and suppliers of the material.

9. Kurram Tangi Project

It is located on Kurram river in North Waziristan. It would store 1 MAF of water and produce 84 MW hydropower. GoP with the USAID grant has started construction of K2 weir which would irrigate 84,380 acres of land, provide job opportunities to people and reduce militancy in North Waziristan.

10. Virtual Water

Not only every living thing is made up of water but most of eatable and other things are the product of water. One cup of coffee requires 140 liters of water to produce it. One liter of milk requires 1000 liters.

Wood from which our furniture and home is made, requires water to grow and provides opportunities for employment. Table No.5 gives the virtual amount of water required to produce the product.

Table-5 (Water requirements for various items)

Items	Water Requirements
One cup of Coffee	140 Liter
One Liter of Milk	1000 Liter
One Kg Wheat	1350 Liter
One Kg Rice	3000 Liter
One Kg Maize	900 Liter
One Kg Beef	22000 Liter

Conclusions & Recommendations

- Without water there is no life. It not only ensures our food and fiber security but also provides necessities of life.
- The irrigation system introduced by the Britishers in the sub-continent ushered in a new era of civilized life. The density of the population is the highest in irrigated area than that of non-irrigated areas.
- Construction of Indus Basin Replacement work provided job opportunities to lacs of people during construction. Trickledown effect provided jobs to millions of people.
- If we provide agriculture in the non-settled areas, it would not only reduce poverty but also militancy.

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GROUNDWATER MANAGEMENT THROUGH ARTIFICIAL RECHARGE-A POTENTIAL FOR JOBS

By

Ghulam Zakir Hassan[1], Ghulam Shabir[2] and Faiz Raza Hassan[3]

ABSTRACT

Groundwater is a precious nature gift a vital role for the existence of life on the planet. This natural resource is being utilized for drinking, agricultural, industrial, livestock, commercial and other uses and is continuously under threat. Irrigated agriculture contributes over 90% of Pakistan's food production. Agriculture is the largest single sector which contributes 22% of GDP and creating employment for about 45% of the overall labor force. Agriculture sector generates over 60% of foreign exchange. In Punjab which is the largest groundwater consumer amongst the provinces, groundwater is contributing more than 45% towards irrigation requirements through about 1.2 million tubewells. Artificial recharge of aquifer an option for groundwater management will lead to generation of work and new jobs which will also contribute to our economy. Aquifer is being depleted at the alarming rate and quality at some places is deteriorating with the passage of time which is taking the groundwater beyond its normal methods of utilization for mankind. In the present study efforts have been made to identify the critical areas (areas under threat) in the Punjab province and potential sites for artificial recharge to augment the underground reservoir have been pointed out. Major activities carried out include the drilling of exploratory boreholes at critical sites in field, infiltration rates, soil and water investigations, monitoring of groundwater quality and levels and other investigations to demark the potential sites. On the basis of field surveys and laboratory investigations, criteria consisting of different parameters for potential sites for artificial recharge to replenish the groundwater reservoir has been developed and potential sites have been identified. Old Mailsi Canal has been identified as potential site for artificial recharge where artificial recharge has been planned. Flood water has been found a significantly important source contributing to aquifer recharge which caused watertable rise of 1-2 ft in Rechna Doab during flood 2014. Groundwater management has been identified as a potential source of jobs for professionals as well.

Key Words: Groundwater, Artificial Recharge, Aquifer, Punjab, Pakistan, Jobs

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Introduction

Serious water scarcity situation may occur in Pakistan and the country may suffer badly if necessary measures are not taken from today for the management of water resources. Since last many years, rapid increase in population has resulted in over extraction of groundwater especially in the urban areas to meet with human demands due to which underground watertable is depleting at alarming rates. Also in rural areas, surface water is insufficient to meet with the demands of agriculture sector due to continuous increase in food requirements. It is worth mentioning that groundwater is contributing about 40% of total water being used for irrigation purposes in the Province, while almost more than 95% demands for drinking water are being met from groundwater. The un-planned pumpage of groundwater is also causing salt-water intrusion into fresh groundwater due to which sweet groundwater resource is becoming scarce. This needs formulation of long term policy framework and comprehensive planning to guard against fast depleting groundwater resources. This critical situation needs to be addressed for our future generation and country's economic growth. During monsoon rains, when lands are generally saturated and need no canal irrigation, the surplus canal water can be injected into aquifer after necessary de-silting and treatment. The rainfall water in suitable depressions and natural drains can also be used for recharging purpose. Realizing the intensity of problem, the Groundwater Management Cell (GWMC) of Physics Directorate, Irrigation Research Institute has been assigned the task of conducting research studies on artificial recharge of groundwater aquifer.

It is a great misfortune that about 40 MAF precious surface water annually goes waste to the sea due to insufficient number of large dams. On the other hand, more than one million tubewells are extracting groundwater on continuous basis. The rate of natural re-charging (approx. 30 MAF annually) is lower than the rate of extraction (50 to 55 MAF annually). This situation has resulted in tremendous depletion of groundwater levels; for example in Lahore, where more than 425 WASA tubewells are extracting about 755 Million gallon of groundwater per day for drinking purpose, while natural re-charging of groundwater aquifer is almost negligible due to construction activities and pavements of streets and roads. The only source to recharge Lahore aquifer is Ravi River which remains nearly dry except during monsoon season; groundwater table in Lahore city has depleted down to around 100 ft or even more in some cases.

The Present study describes the preliminary work done on the subject matter during financial years 2009-12. Suitable points with respect to water quality and groundwater levels were chosen for physical survey. On the basis of field surveys and investigations, potential sites for recharging the aquifer artificially had been identified. Research activities have been carried out in the province of Punjab especially in critical areas (groundwater highly depleted areas).

Artificial recharge can take place through direct and indirect methods and most of the country use artificial recharge to obtain different objectives like (i) the maximization of storage (including seasonal, long-term, and drought or emergency water supplies), (ii) physical management of the aquifer, (iii) water quality management, (iv) management of water distribution systems, (v) ecological benefits. In urban areas natural recharge has been reduced due to urbanization and rainfall water goes to surface drains or enters the sewerage system and causes the problem of flooding and/or choking the disposal network during rainy seasons. This water can be diverted and injected to underground reservoir and can prove very helpful in recharging the aquifer.

The Indus Basin Irrigation System (IBIS) of Pakistan is the largest irrigation system in the World. It consists of Indus River and its tributaries, 19 barrages/headworks, 12 links canal, 45 major canals command, Distributaries/Minors and watercourses by **Chaudhary, S.A. (2010), Qureshi, et al (2009)**. The length of the canal system is 58, 450 km. IBIS was developed about a century ago for irrigating the fertile lands at cropping intensity of 75% by **Qureshi, (2009)**. The Punjab Irrigation system is the major irrigation system of IBIS comprises 14 barrages/headworks, 24 main canals (6085 km long) and 2794 distributaries (29546 km long) and drains network by **Asrar. (2010)**.

Preliminary Investigation for selection of Potential sites

On the basis of field surveys and investigations, critical reviews of groundwater levels were carried out and potential sites for recharging the aquifer artificially had been identified. Research activities have been carried out in the province of Punjab especially in critical areas (groundwater highly depleted areas).

Efforts were made to select the potential sites for conducting the experimentation on artificial recharge on the basis of some scientific reasoning. Keeping in consideration the available data, status of groundwater in the province was reviewed.

General criteria for selection of potential sites for installing the exploratory boreholes were set which is presented in table 1.

Table1: General Criteria for selection of Potential sites for Artificial Recharge

Sr. No	**Parameter**	**Value**
i.	Depth to groundwater table	> 50 ft
ii.	Groundwater Quality(EC)	< 1.5 ds/m
iii.	Average annual rain	(approximately 16 inches)

Sr. No	Parameter	Value
	fall (min)	
iv.	Surface water availability	Existing
v.	Ground water extraction	Intensive farmers tubewells
vi.	Soil strata of the area	(min. seepage rate of 10^{-7} cm/sec as in the medium sand strata)
vii.	Water catchment area	Possibly less polluted area
viii.	Staggering of bore hole sites	Along canals (water bodies)
ix.	Field area Characteristics	Depression along canals and wet land within river system

OLD MAILSI CANAL

Mailsi Canal had been off taking from Islam Headworks since 1928. This channel having length from RD 0+000 to RD 160+241 (32.05 Miles) falls within the jurisdiction of Islam Headworks Division. It is an earthen channel with non-perennial system. The Design parameters of Mailsi Canal is given in table 2. The project area is shown in figure 1.

Table 2: Design parameters of Mailsi Canal

Sr. No.	Description	Content
1	Bed width	155 ft.
2	FSD	10.30 ft.
3	Discharge	4883 Cusecs.
4	Free Board	2.50 ft.
5	Longitudinal Slope	0.10 Per 1000 Rft.
6	Width of left bank	25 ft.
7	Width of Right bank	15 ft.
8	Total Length (RD)	160+241 (32.05 Miles)

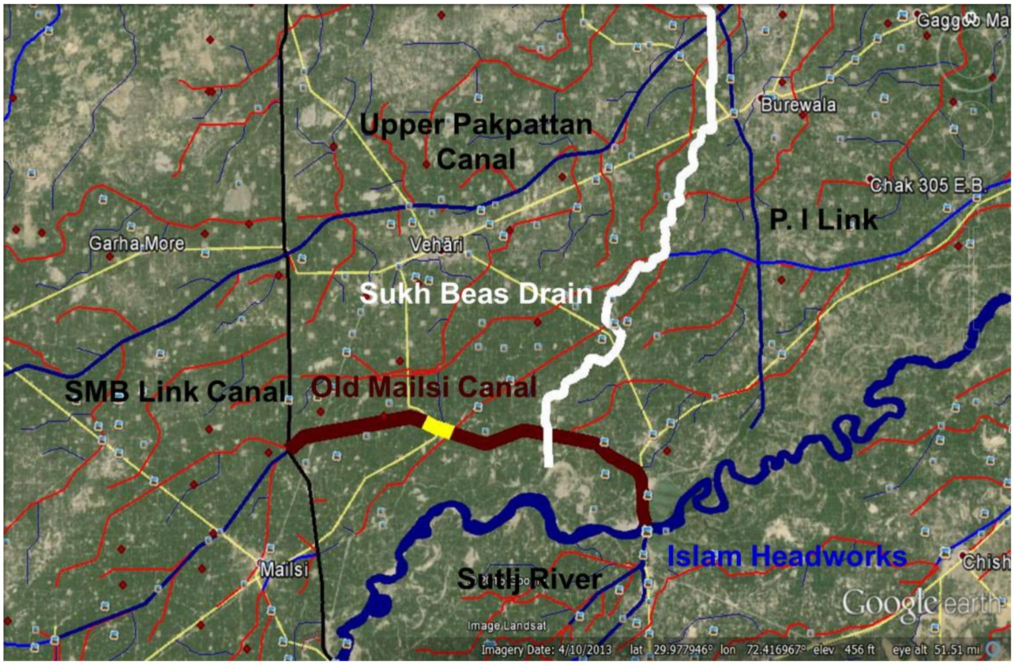

Figure 1: Location of Old Mailsi Canal

CURTAILMENT OF MAILSI CANAL

During the year in 1960, due to Indus Water Treaty all rights of River Sutlej were given to India. River Sutlej was dried since 1965 and canal irrigation supply has been arranged by constructing Links Canals in Pakistan. Due to non-availability of water supply in River Sutlej at Islam Headworks, Mailsi Canal was curtailed from RD 0+000 To RD 129+505. Upper reach was closed and abandoned at site. Remaining tail portion of Mailsi Canal from RD 129+505 to RD 160+241 off taking from RD 250+420 / R of SMB Link and takes their due share from SMB Link. Karam Branch was off take at RD 76+150 / L of old Mailsi Canal. Due to curtailment of Mailsi Canal, all system transferred with their share to SMB Link i.e. “Mailsi Canal Lower, Karam Branch Lower, Mailsi Disty, Dhamaki Disty, Alam Minor, , Chattar Disty, Lower Dhallu Disty, Mian Minor , Nawaz Disty” lies with in jurisdiction of Islam Headworks Division and Dhallu Disty Upper , Burana Disty takes their share from Allah Abad Disty at RD 85+500 Tail lies under the jurisdiction of Western Bar Division.

Water levels were monitored from piezometers continuously and then hydrographs of depth to watertable have been prepared as shown in Figure 2. Measurement of groundwater level plays a vital role in groundwater recharge estimation. The figure indicates that values of depth to watertable of all points were increasing.

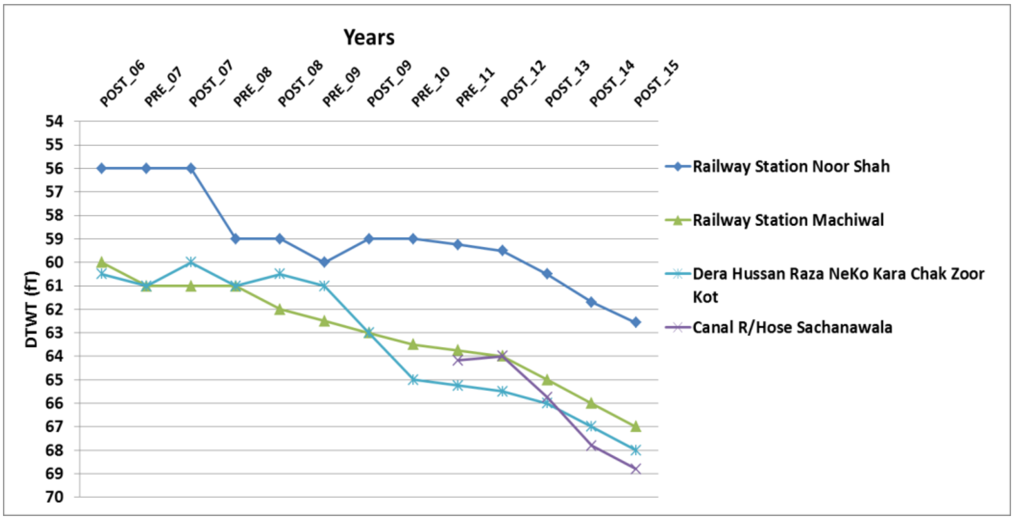

Figure 2: Hydrograph of the selected sites in the project area

Working of a farmer tubewell and view of open well indicating deep water level in the vicinity of old Mailsi canal are shown in figure 3

Figure 3: Working of a farmer tubewell and view of open well

Recharge Method

Artificial recharge is the planned human activity for augmenting the amount of groundwater available through works designed to increase the natural replenishment of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction. A variety of methods have been developed and applied to artificially recharge groundwater reservoirs in various parts of the world. Selection of the feasible methods is important and can be challenging. The methods may be generally classified as i) the direct surface recharging techniques, ii) indirect recharge techniques and iii) combination of surface and subsurface methods including subsurface drainage (collector wells), basins with pits, shafts, and wells etc. by **OAKFORD, (1985).**

Artificial recharge can be accomplished through various direct methods like spreading methods, through injection wells or through pits and shafts. Spreading methods include flooding method, natural channel method etc. The local field conditions including the physiography and hydrogeology of the area have to be carefully considered before selecting a method for artificial recharge.
Direct methods can be divided into surface recharge and subsurface recharge techniques. In surface recharge, water moves from the land surface to the aquifer by means of infiltration through the soil. The surface is usually excavated and water is added to spreading basins, ditches, pits and shafts and allowed to infiltrate. Generally, surface recharge methods are dependent on the contact time the water has with the soil. Direct surface methods, in comparison to other methods, involve low construction costs and are easy to operate and maintain. Sub-surface recharge methods include recharging the water directly to groundwater by means of recharging wells or shafts. Few techniques of direct methods are spreading basins, recharge pits and shafts, recharge wells, percolation tanks etc.

Indirect methods for artificial recharge include installing groundwater pumping facilities near connected surface water bodies to lower groundwater levels and induce infiltration elsewhere in the drainage basin. Indirect methods include modifying aquifers to enhance groundwater reserves as well. Enhanced streambed infiltration is creating a system of wells near a surface water body. One line of wells is set parallel the bank of a river and a second line of wells are located a short distance from the river. Conjunctive wells are screened in both a shallow confined aquifer and a deeper artesian aquifer. Water is pumped from the deeper aquifer and if its potensiometric surface is lowered below the shallow water table, water from the shallow aquifer drains directly.

Groundwater recharge broadly describes the replenishment of water to a groundwater flow system. Recharge, an integral part of the hydrologic cycle, is the process by which water moves to the groundwater and then away from that area though saturated materials by **DELIN, et al (2007)**. Groundwater is a far more important resource than is often realized. Excluding the water locked in glaciers and icecaps, about 97 percent of the World's fresh water is groundwater while streams, rivers and lakes hold only about 3 percent by **BOUWER, (1978). IRI, (1999)** conducted a study on artificial recharge under semi field conditions at Field Research Station Niazbeg. In an Interim report No IRR-Phy/538 March 1999, it was concluded that, choking of strainer is the major problem during recharging of ground water artificially by gravity well. It was suggested that water should be treated to make it free of silt and physical debris etc. before injection to groundwater storage.

RAMA, (1989) worked on the possibilities of underground storage of surplus flood water in India. He described that generous rainfall during the months of July-August-September causes floods in Gangetic basin, followed by shortage of supply during dry months. The physiography and topography of the region provides a very limited scope for surface storage. There exists the possibility of storing some of the surplus run-off of the rainy season in underground reservoirs, for use during the dry period. The scheme envisages emptying the existing natural reservoirs which are normally always full and which are likely to fill by themselves after they are emptied, without any extra engineering. The artificial part of the scheme consists in generating productive consumption, by intensive irrigation, for the large quantity of water withdrawn. The emptied reservoir is expected to absorb a part of the flood pulse also. The scheme is likely to have maximum potential in the Gangetic plain. The most promising reservoirs, meeting the above criteria, appear to be the sandy aquifers connected with the beds of seasonal streams.

FIROZUDDING, et al (1989) worked on induced recharge to deep aquifer for augmenting the water supply scheme. They found that there is mounting concern regarding the problem of developing adequate water supplies to Ambala urban area as the locally available ground water supplies through tubewells will not be able to meet the growing demands. They examined the results of the studies carried out to delineate the water table aquifer along the riverine tract of Dangri River, the geometry and the productivity of the aquifer, its capacity to hold the required amount of water and possibilities of induced recharge for the river. It is estimated that a quantity of 2.66 MCM can be pumped out from the aquifer during the dry season. The estimated induced recharge from the river to the aquifer is about 0.833 MCM during the monsoon season. A possibility of development to the extent of 7.30 MCM of the deeper aquifers occurring below 150 m depth has also been discussed as an additional source to augment the water supply. The results of their investigation showed that the highly permeable granular zones, which can act as the most favorable zone for induced recharge, occur in the area around Khelan, Babial and Kajkipur along the riverine tract of Dangri River with average saturated thickness of about 14 meters. It is suggested to construct a well field in this area, with an average discharge of 726 m /day from each well. The well field should be laid parallel to the river on its western bank at a distance of 100 m from the river keeping spacing of 300 m between two shallow tubewells of 30 m depth. The corresponding drawdown in the center of the well field is calculated to be 7.77 m. About 10986 m/day of ground water can be withdrawn during summer months which can be utilized for augmenting the water supply to Kamala urban area. This amount of water can be withdrawn without desaturing the zone tapped in shallow water table aquifer. It is expected that with intensive development, water levels will go down in these areas as the system tends to be in dynamic equilibrium thereby creating additional storage space for induced infiltration. It has been estimated that a quantity of 0.833 MCM can be recharged by induced infiltration during monsoon season from the Dangri River. Further augmentation of water supply to Ambala town to the tune of 7.30 MCM of water per annum can be attempted by tapping the deeper aquifers in the depth range of 150 to 450 m bgl through a well field of 10 tubewells with a pumping rate of about 2000 m /day at each well. **IRI, (2009)** installed sixty number of exploratory boreholes (3” dia and 100 feet depth) in the field at various critical sites to explore the aquifer characteristics and soil stratification for identifying the potential sites for artificial recharge of aquifer. Soils samples from all these sixty sites were collected and analyzed for determination of profile lithology. Based on the analysis of soil samples, borelog were prepared. Groundwater samples from existing nearby sources were also collected and analyzed to ascertain the quality of groundwater. **IRI, (2013)**installed 50 piezometers at various depth (50, 100 and 150 feet) in the shape of batteries along Ravi River from downstream of Ravi Syphon to Mohlanwal to study the effect of pollution underlying the aquifer towards the Lahore. Borelogs were prepared for the determination of profile lithology. **Ahmad, (1974)** pointed out that the various sources from which recharge occur were the link canal, Main canal system, water courses, irrigation field, rivers and rainfall. He further added that the annual groundwater recharge for Rechna, Chaj, Thal and Bari Doabs was worked out which was found to be 3.2, 3.7, 1.6 and 2.1 inches respectively.

The impact of recharge will change groundwater regime. Change in groundwater storage is directly indicated by the rise or fall of water levels. As a result of recharge project a groundwater mound will develop which can change the groundwater flow, its rate and direction. A network of piezometers is proposed for installation along the recharge canal.

The stream channel method for underground storage of flood water is selected. Water recharging through a channel involves operations that increases the time and area over which water is recharged from a naturally losing channel. This involves both upstream management of stream flows and channel modifications to enhance infiltration. Upstream reservoirs enable erratic runoff to be regulated and to limit stream flows to rates that do not exceed the absorptive capacity of the downstream channel. This method however requires extra effort for digging of a stream of appropriate size which can store and recharge the targeted volume of water during specific period after meeting evaporation losses. Islam Headworks will be used to regulate the flow of erratic flood water entering into the canal to rates that do not exceed the absorptive capacity of the canal. Abandoned Old Mailsi Canal with capacity modification will be used storing and recharging the aquifer.

The average depth of the pond is 10 feet. This pond usually remains full of water. However, size of the water pond shrinks when water in it infiltrates and evaporates. Flood water will pass through this pond to the Old Maisli Canal through Headworks. The pond provides flexibility to store and release water even after the flood events. It will also help settle sediment and allow relatively cleaner water to flow into the recharge canal. The configuration and No. of ponds proposed in the project area.

Seepage Rate

Seepage rate is determined at the bed of Old Malisi Canal at different RDs with Double Ring Infiltrometer. The result of seepage rate is given in table 1. Figure 4 shows the performance of Infiltration test.

Table 3: Infiltration Test Results at Old Mailsi Canal Performed by Infiltrometer (Double Ring)

Test. No	Canal RD	Test Location	Soil Type/ Soil Strata	Infiltration Rate		Remarks
				cm/sec	ft/day	
Test No 1	RD 14	Center of Canal Bed at Mauza Khan Garh	Sandy	0.001	3.78	Test was performed at the depth of 0.5 feet below existing bed level
Test No 2	RD 29	Center of Canal Bed at , Mauza Karam shah	clayey	2E-04	0.02	Test was performed at the depth of 1 feet below existing bed level
TEST No 3	RD 45	Near crossing of Canal and Drain, Chak 65, on left side corner in the Bed of Canal	clayey	3E-04	0.03	Test was performed at the depth of 0.5 feet below existing bed level
Test No 4	RD 62-63	Mauza Hassan Shah on the Bed of Canal	clayey	0.001	0.06	Test was performed at the depth of 1 feet below existing bed level

Figure4: Field testing (Infiltration Rate)

Volume of water will recharge (MAF in 60 day) with different seepage rate is given in table 4 and graphically represented in figure 5.

Table 4: Recharge Calculation

Seepage rate (ft/day)	**Volume of water will recharge (AF/day)**	**Volume of water will recharge (MAF in 60 day)**
0.01	4.25	0.0002548
0.02	8.49	0.0005095
0.03	12.74	0.0007643
0.06	25.48	0.0015285
1	424.59	0.0254752
2	849.17	0.0509504
3	1273.76	0.0764256
3.78	1604.94	0.0962963
4	1698.35	0.1019008

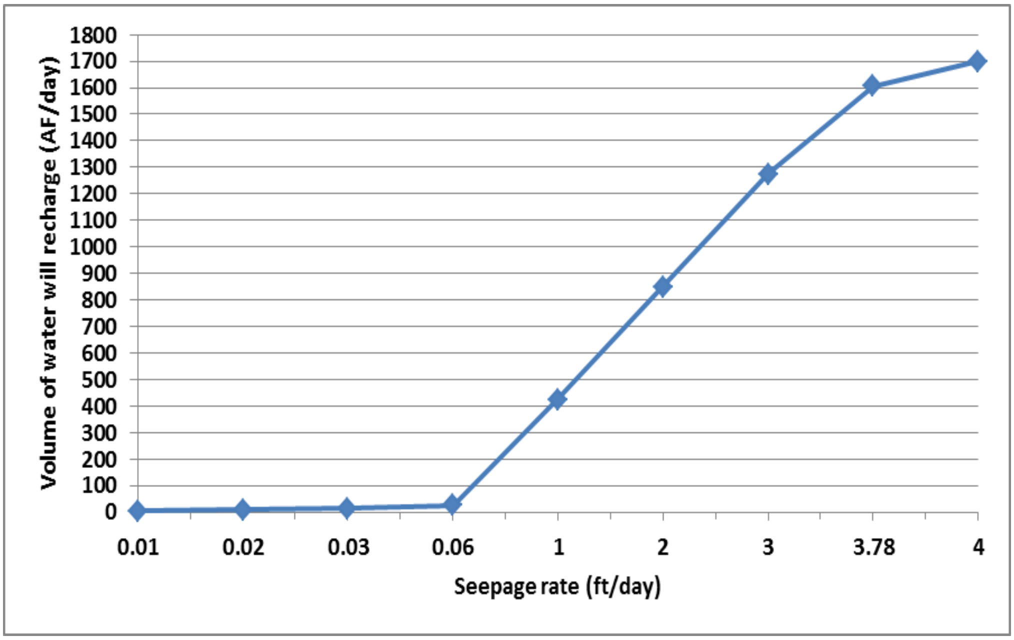

Figure 5: Graph B/w Seepage Rate and Volume of water Recharge

Project Area

The project area is facing shortage of surface water. The groundwater levels are declining in the area at a rate more than 2 feet per year. The agriculture of the area is facing shortage of irrigation water supplies. The study area has been selected for artificial groundwater recharge project on the basis of availability of surplus flood water, infrastructure for controlled diversion of flood water, recharge channel, suitable geologic characteristics of the formation and agricultural land for use of water. The Model Study Area of Old Mailsi Canal is shown in figure 6.

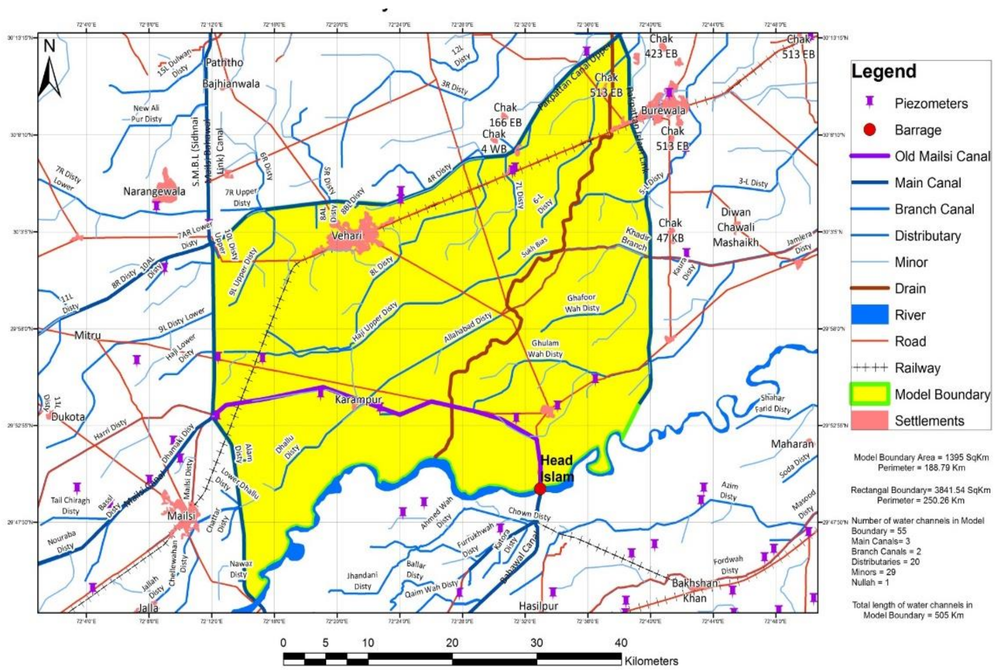

Figure 6: Model Study Area of Old Mailsi Canal

Nineteen exploratory boreholes installed in the model area as shown in Figure 7. The Depth to watertable (DTWT) ft in Model Area is given in table 5. Contour of Groundwater Levels (GWL) ft in Model Area is shown in figure 8. Pictorial view of Groundwater monitoring in field has been shown in figure 9.

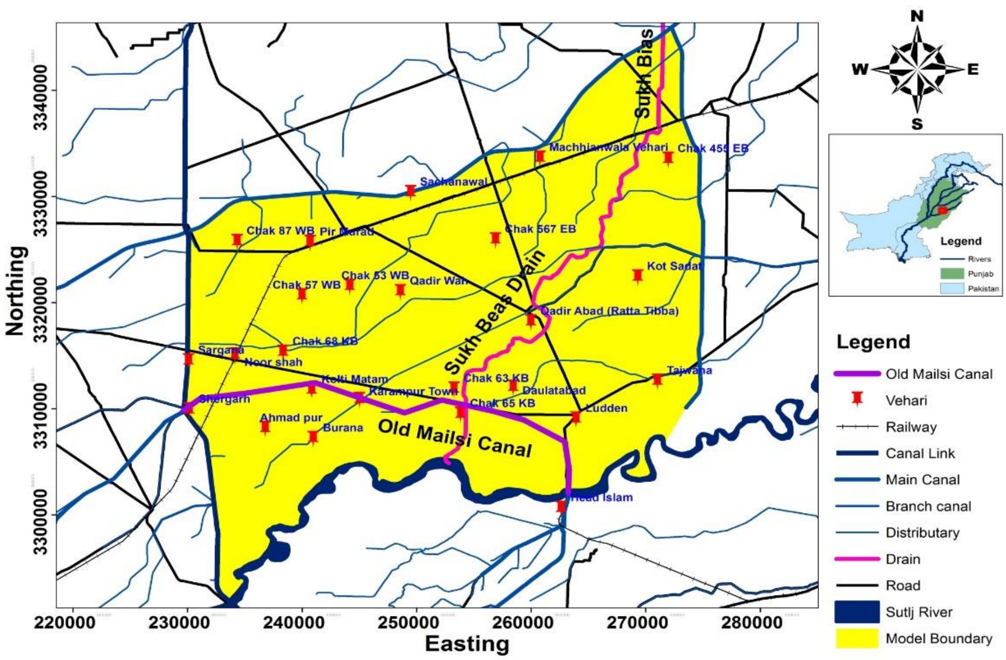

Figure 7: Location of Piezometers in Model Area

Table 5: Depth to watertable (DTWT) ft in Model Area

Sr. No.	Address	DTWT (ft)
1	Govt. High School 557-EB, Machhianwala Vehari	64.09
2	Govt. Primary School, Qadir Wah	71.85
3	Govt. Model Primary School, Qadir Abad (Ratta Tibba)	67.46
4	Govt. Higher Secondary School, Ludden	49.15
5	Govt. Model Primary School, Tajwana New	40.88
6	Govt. Boys Middle School, Daulatabad	63.98
7	Govt. Elementary School, Chak 65 KB	59.35

Sr. No.	Address	DTWT (ft)
8	Govt. Girls Primary School, Chak 63 KB	70.32
9	Rural Health Centre, Karampur Town	62.28
10	Basic Health Centre, Burana	52.95
11	Govt. Boys Middle School, Ahmad pur	57.98
12	Govt. Boys Primary School, Chak 68 KB	69.5
13	Govt. Primary School, Chak 57 WB	66.14
14	Govt. Elementary School, Chak 53 WB	66.09
15	Govt. Middle School, Chak 87 WB, Multan Vehari Road	56.45
16	Govt. Elementary School, Pir Murad, Multan Vehari Road	63.04
17	Govt. High School, Chak 567 EB	69.75
18	Govt. High School, Kot Sadat	68.52
19	Govt. High School, Chak 455 EB	63.26
Average value		62.27

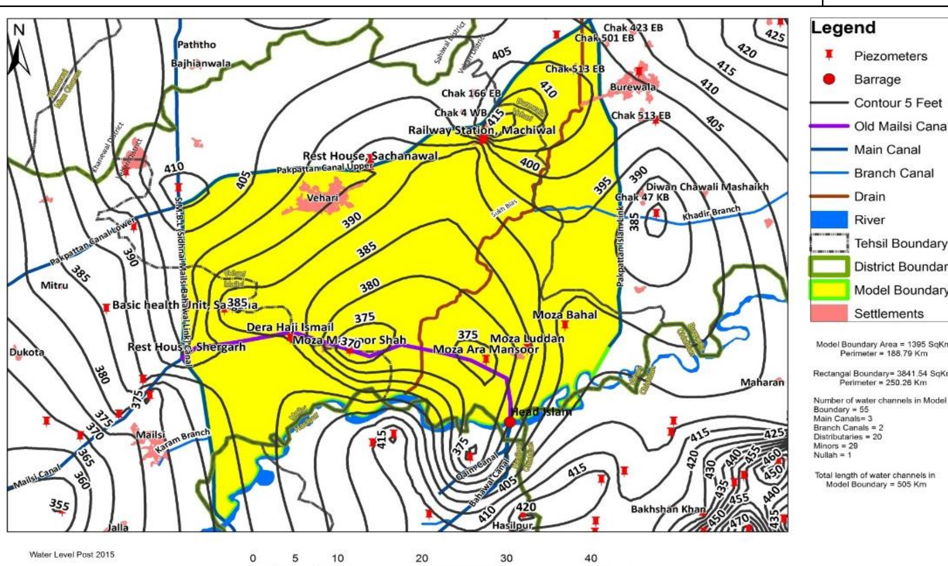

Figure 8: Contour of Groundwater Levels (GWL) ft in Model Area

Figure 9: Groundwater monitoring in field area

Groundwater samples were collected from different sources and analyzed for calculating the Electrical Conductivity (EC). The analyzed samples would be rated as “fit” or “unfit” as per irrigation water quality criteria is given in table 6.

Table 6: Groundwater quality in Model Area

Sr. No.	Types of Bore	Adress	TDS (ppm)	EC (us/cm)	pH	Temp	Remarks
1	Electric pump	Rest House, Head Islam	376	752	8	19	Fit
2	Tubewell	Main Mukhtar Doltana. Moza Luddan	494	987	7.5	29	Fit
3	Hand pump	Moza Bonga Azam	454	906	7.5	29	Fit
4	Hand pump	Basti Main Hakam	626	1254	7.3	28	Fit
5	Hand pump	Moza Tajwana	557	1113	7.4	28	Fit
6	Tubewell	Moza Bahal	522	1045	7.4	27	Fit

Sr. No.	Types of Bore	Adress	TDS (ppm)	EC (us/cm)	pH	Temp	Remarks
7	Hand pump	Moza Lal Deh	525	1051	7.4	28	Fit
8	Electric pump	Sadar Petrol Pump, Multan Road, Vehari	580	1158	8	29	Fit
9	Hand pump	Railway Station, Machiwal	452	900	7.9	40	Fit
10	Tubewell	Nadeem pathan, Moza Akbar shah	302	603	8.3	23	Fit
11	Hand pump	Near junction of Canal and Drain, Chak 65	409	820	7.7	25	Fit
12	Tubewell	Dera Khan Muhammad Kala, Kalas Mohal, Moza Ara Mansoor	352	704	8.1	29	Fit
13	Tubewell	khair Muhammad Grho, Moza Hassan Shah	307	613	8.2	28	Fit
14	Electric pump	Madina ul alam adibaia, adda chak 63 KB	360	780	8	29	Fit
15	Electric pump	Basti Abbas, Moza Hassan Shah	257	514	8.3	27	Fit
16	Turbine	Sajad Shah, Moza Hassan Shah	295	590	8.3	29	Fit
17	Tubewell	Manzoor Shah, Moza Hassan Shah	294	588	8.3	30	Fit
18	Tubewell	Noor Shah,	303	606	8	28	Fit
19	Electric pump	Sargana Petrol Pump, Moza Sargana	284	568	8.2	28	Fit
			(ppm)	**(us/cm)**			
20	Tubewell	Ghulam Sarwar, Moza qadir wah	395	790	8.1	27	Fit
21	Electric pump	Liquat Ali, Basti Murad Pur, Moza Mastafa Abad	656	1312	7.9	29	Fit

Water Balance

Irrigation network system is consisted main Canals, its distributaries/ minors and water courses which not only supplies surface water for irrigation purpose but also contributes to aquifer recharge through seepage.

Aquifer always tends to achieve equilibrium state provided there is no change in recharge and discharge components for a considerable period of time. The difference between all inflows and outflows of the area is equal to net change in storage per unit of time. If net change in aquifer storage is positive, watertable will rise but in case of negative change in aquifer storage, watertable will decline. Negative balance means that discharge rate is higher than recharge rate. In case net change in storage is zero, the watertable will neither fall nor rise. The net recharge in the aquifer measured by using water balance method has been represented in Table 7.

Table 7: Water Balance in Model Study Area

Components		Kharif	Rabi
Recharge (MCM)	Rainfall	64.611	18.149
	Main/Br Canal	63.159	0
	Distys/minors	43.553	0
	Water Course	68.988	0
	Field Irrigation	84.51	0
	T/W Irrigation	98.341	171.157
Total Recharges(MCM)		423.16	189.306
Discharge(MCM)		312.19	543.355
Net balance (MCM)		110.97	-354.05
Water Level Drop (ft)		0.26	-0.83
Porosity 25%		1.13	-3.62
Avg Water Level Drop per year (ft)		-1.24	

Layout Plan for Recharging of Old Mailsi Canal

Upto RD 45+000 of the Old Mailsi Canal is proposed to be rehabilitated according to its design parameters. An infiltration rate of 3 ft/day is used. Variable flood events are expected at the proposed location of the project. Therefore, the designed project layout can recharge 2 to 3 times more than the designed quantity of water. To store and release water in the canal and drain to the designed level, as many as 2 regulated retention structures are provided. Moreover, 60 recharge wells are provided to be installed in the bed of selected part of channel to accelerate the recharge process. Layout of Proposed Recharging Setup is shown in figure 10 and view of recharge well in figure 11.

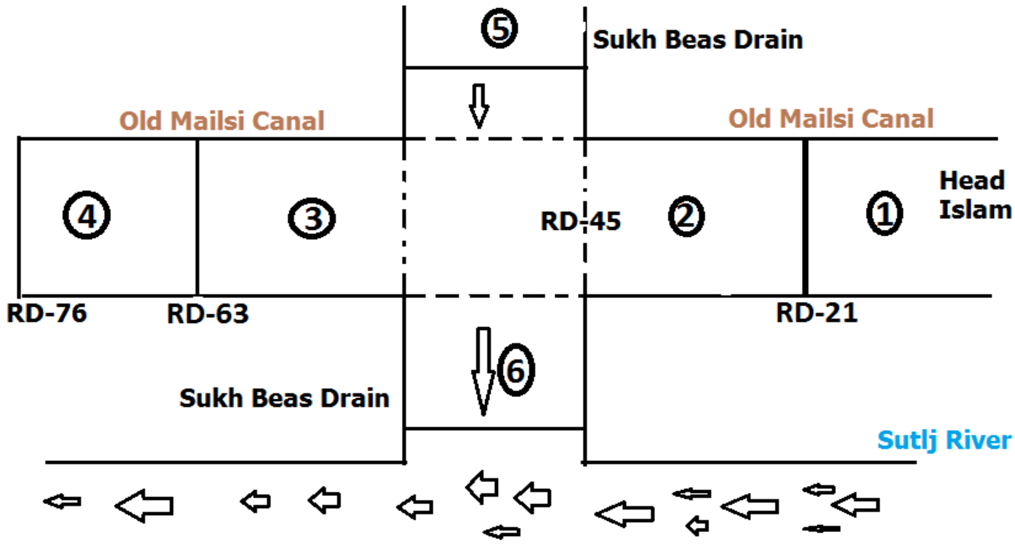

Figure 10: Layout of Proposed Recharging Setup

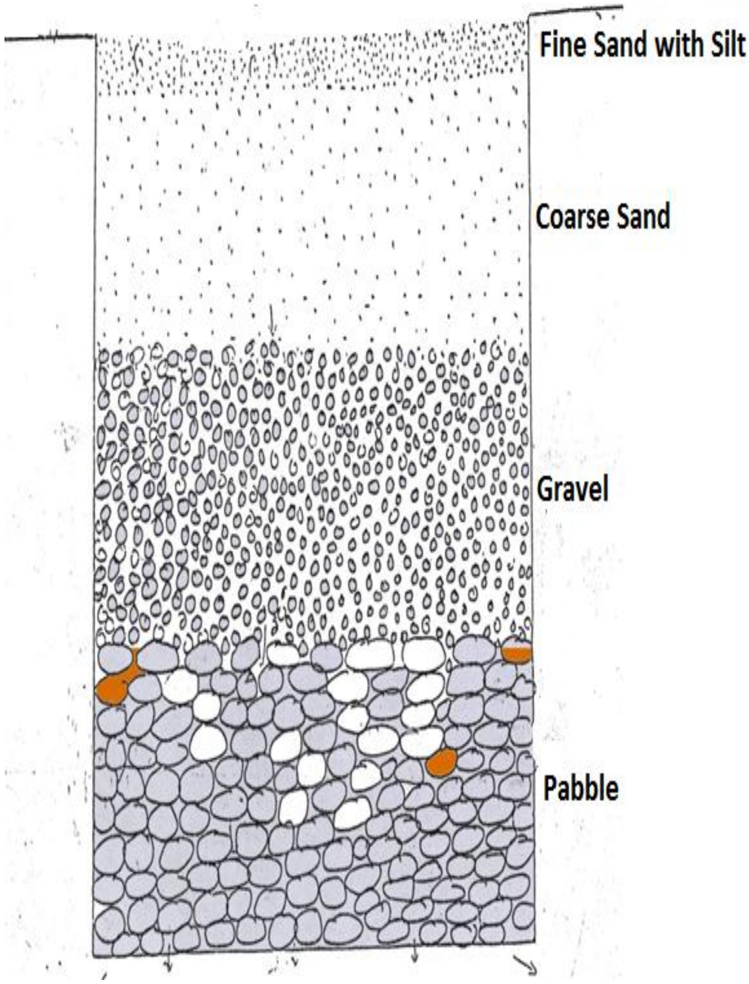

Figure 11: View of Recharge Well

Expected Jobs Creation

Sr. No.	Name of Activity	Nature of Jobs Expected
1	Survey/ Estimation	Engineers, Sub Engineers, Surveyors and Rod Man
2	Implementation/Execution of Project	Labour, Technical and Management Staff
3	Monitoring/Management of the project	Consultants/Experts, Scientists and Engineers Technical and Management Staff
4	Post Project	Farm Labour, GW monitoring teams, A management setup same as for surface water management, GW modelling experts, socio-economists, Environmental specialists

Conclusions

In Punjab province of Pakistan groundwater is contributing about more than fifty percent towards irrigation requirements beside other uses. As for surface water management thousands of human resources are involved in its operation. Irrigated agriculture contributes over 90% of Pakistan's food production. Agriculture is the largest single sector which contributes 22% of GDP. Creating Employment about 45% of the overall labour force. Agriculture sector generates over 60% of foreign exchange.

As fifty percent crop water requirements are met from groundwater, artificial recharge of aquifer-an option for groundwater management will lead to generation of work and new job which also contributes to our economy.

i. There is urgent need for recharging as watertable is continuous declining (about 60-80 ft) in the model area
ii. The Cropping Intensity in the area is high Annual-129% (Kharif-63%, Rabi-66%).
iii. Water for recharging is available (during flood at Islam Headworks).
iv. People gave their consent and showed interest for water resource development.
v. Head regulator of the canal is existing at Headworks Islam.
vi. Land for recharging of Old Mailsi Canal bed is available. No land acquisition is involved.
vii. The only limitation is encroachment on the banks of the canal by local community. Kachi Abadi including shops and houses in scatter form on the both bank of the canal. Canal bed is being used for cultivation.

Field experimentation on artificial recharge can be carried out to derive further conclusions and useful results. Artificial recharge is the main source of augmenting the aquifer. For this purpose flood water management, rainfall harvesting and experimentation of artificial recharge on selected potential sites is urgently required. Detailed modeling for this purpose is required.

Acknowledgements

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RAINWATER HARVESTING POTENTIAL IN POTHOOHAR, PUNJAB

By

Dr. Muhammad Nawaz Bhutta and Dr. Saleem Sarwar

Summary

The Pothohar region is situated in northern part of Punjab province. Total area is 23438 km^2 which is administratively divided into four districts. The altitude varies from 300 to 600 m. Annual average rainfall varies from 487 mm to 1766 mm. Total Pothohar area is 5.4 Mac. Out of which 40% area of the land is covered by Range land, 18% by rainfed irrigation, 23% covered by irrigation and about 19% area is bare land. Total annual runoff from Pothohar area is estimated as 2.6 MAF. The Government of Punjab has constructed 55 small dams in the Pothohar region, to store water for agricultural production. Present storage of all the existing small dams is 0.21 MAF. Small dams are irrigating about 60,000 ac. In addition Rainwater Harvesting Schemes (RHS) are irrigating 86,740 ac. In the Pothohar Region where good agricultural land is not a limiting factor and about 2.4 MAF of runoff water is wasted by flowing over steep slopes, causing soil erosion and damaging the water ways and dams,

Optimum utilization of every drop of available water is becoming increasingly important with the ever-increasing population to meet their food needs. Rainwater harvesting is an option to capture the water, reduce erosion and utilise fertile land for agriculture and high value crops. About 8707 sites for Rainwater Harvesting Schemes have already been identified. Construction of these schemes would contribute in enhancing the crop production and reducing the erosional hazard. RHS are operated and maintained by the beneficiaries/farmers. Additional area of more than 241,235 ac will be brought under agriculture and high value crop.

1. Introduction

The Pothohar region is situated in northern part of Punjab province. The area being hilly in nature includes the great Salt Mine Range. The river Indus flows in western side of the plateau and River Jhelum flows in the eastern side. The area is administratively divided into four districts, Attock, Chakwal, Jhelum and Rawalpindi. The altitude of this highland varies from 300 to 600 m, the topography of the area does not allow any canal system to be constructed for utilizing the river flows. The location map is shown in Figure 1.

1.1 Climate

Annual Normal rainfall Isohyetal Map is shown in Figure 2. The months of significant rainfall are July, August and September. About 45 % of the rainfall occurs in these months. Rainfall analyses were carried out for Jhelum, Chakwal, Mianwali, Gujjar Khan, Islamabad, Cherat, Dhrabi and Talagang station. The rainfall station, operating agency, length of record and mean annual rainfall are given in Table 1. There is a large spatial rainfall variation in the Pothohar region. Annual average varies from of 553 mm in the south western to 1766 mm at Murree in the northeastern area.

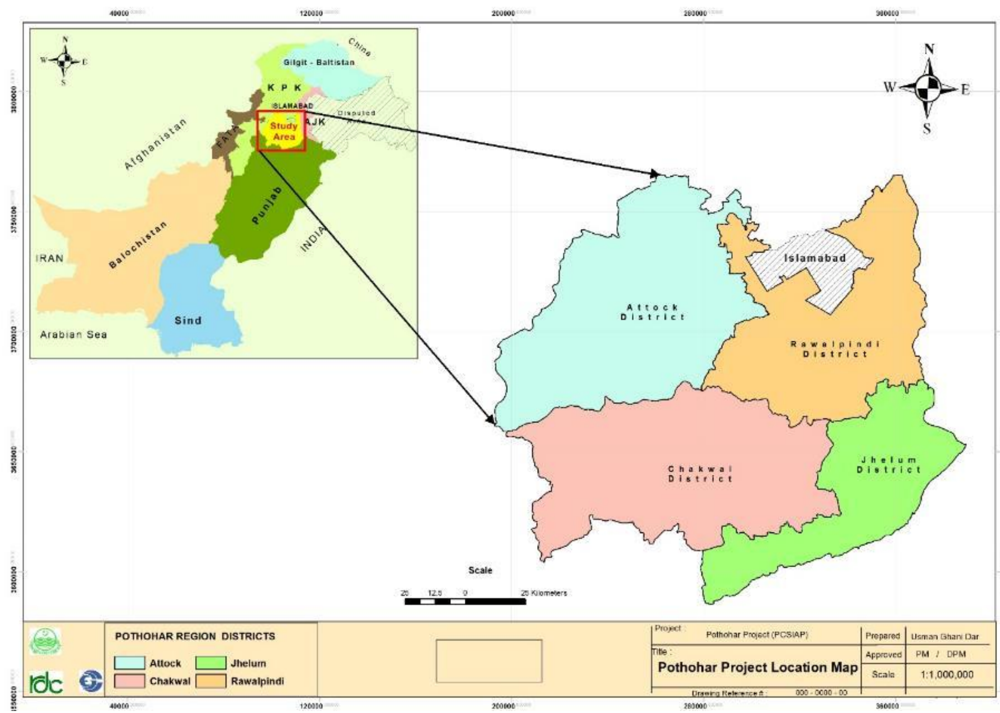

Figure 1: Location Map of the Project Area

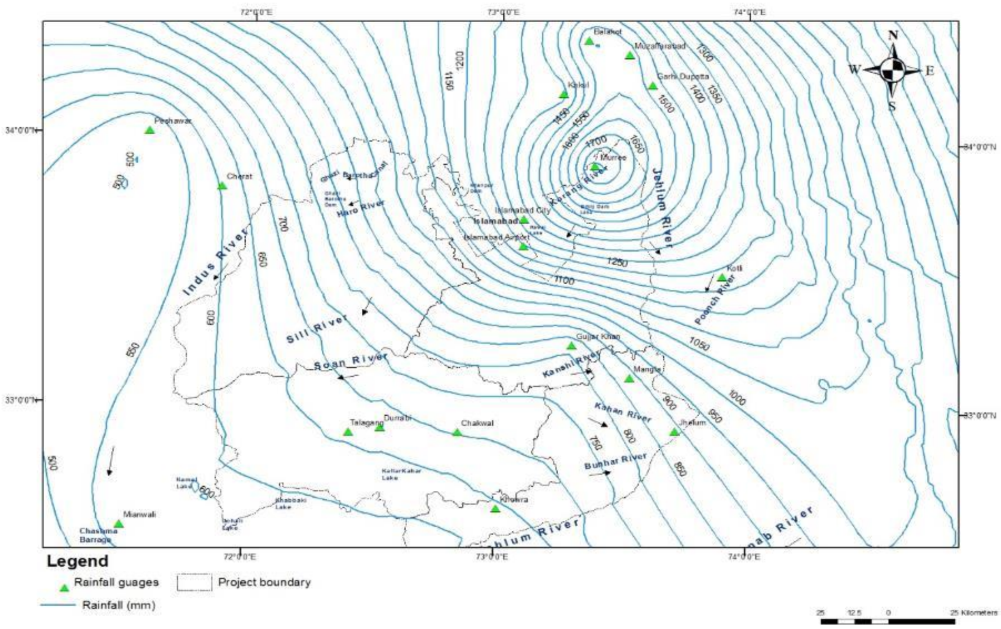

Figure 2 Isohyetal Map of The Pothhar Region

Table 1: Mean Annual Rainfall at Various Rainfall Gauges in the Pothohar Region			
Gauging station	**Year of record**	**Operating Agency**	**Rainfall (mm)**
Gujjar Khan	1954-2009	WAPDA	814
Murree	1954-2010	PMD	1766
Islamabad	1954-2014	PMD	1172
Jhelum	1954-2014	PMD	866
Chaklala	1985-2013	PMD	1189
Mianwali	1983-2012	PMD	576
Chakwal	1983-2013	PMD	787
Cherat	1992-2006	PMD	586
Dhrabi	1983-2013	Irrigation	553
Talagang	1983-2013	Irrigation	557

The maximum mean monthly rainfall (348 mm) occurs in Murree in the month of July while minimum rainfall (1.81mm) occurs in the Chakwal in the month of November. The mean monthly rainfall for various gauging stations in the Pothohar region is shown in Figure 3.

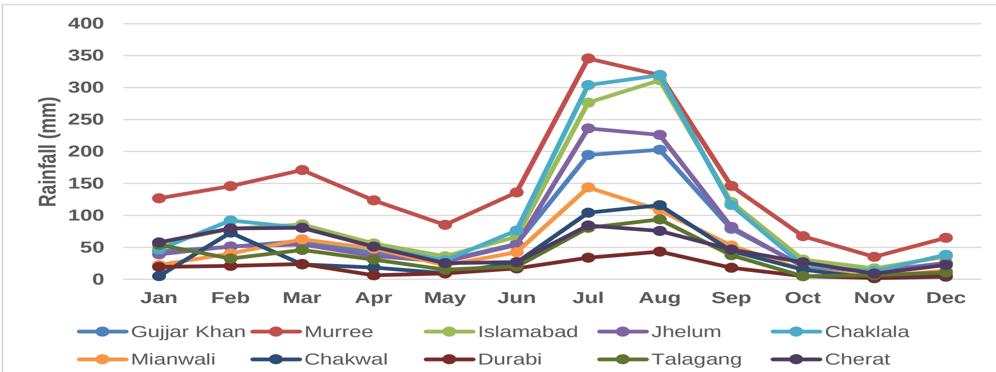

Figure 3: Mean Monthly Rainfall in the Pothohar

The absolute mean monthly temperature in the valley ranged from 1° C in January to 40° C in June.

The maximum evaporation recorded in the month of June is 363 mm and the minimum recorded value is 75mm in the month of December. The average annual evaporation in the Rawalpindi is 2097 mm which is slightly less than Chakwal having total annual evaporation of 2179 mm. The maximum and minimum evaporation at Rawalpindi are 366 and 59 mm for the months of June and February respectively.

1.2 Soil Characteristics of The Project Area

The major type of the soil in the area is loamy soil (Calcareous Loamy Soils, Calcareous Silty Soils - Gullied Land and Calcareous Loamy and Clayey Soils) having 32% of the total area. Mountainous Land with nearly Continuous are 28%. The various soil classes of the Pothohar region are given in Table 2.

Table 2: **Soil Types with area in the Pothohar Region**

SOIL TYPE	**AREA**	
	Km^2	**percent**
River	137	0.6
Non Calcareous Clayey Soils	22	0.1
Calcareous Clayey Soils	228	1.0
Calcareous Loamy and Clayey Soils	2921	12.9

Table 2: **Soil Types with area in the Pothohar Region**

SOIL TYPE	**AREA**	
	Km^2	**percent**
Calcareous Loamy Soils	1978	8.7
Calcareous Sandy Soils and Dunes	32	0.1
Calcareous Silty Soils - Gullied Land Co	2490	11.0
Gullied Land and Bad Land	831	3.7
Unidentified	364	1.6
Sand Dune and Sandy Soils	43	0.2
Seasonally Flooded Soils	70	0.3
Salt - Effected Soils	661	2.9
Rough Broken Land	2972	13.1
No calcareous Loamy Soil	636	2.8
Mountainous Land with Patchy Soil Cover	1967	8.7
Mountainous Land with nearly Continuous	6151	27.2
No calcareous Silty Soils	1138	5.0
Total	**22641**	**100.0**

1.3 Land Use

The area can be divided into three major physiography units: 1. Mountains 2. Undulated hills and 3. Terrecial plains.

The 40% area of the land is covered by Range land, 18% by rainfed irrigation, 23% covered by irrigation and about 19% area is bare land. The irrigated land is mostly found on flat plains and gentle slopes, forming terraces and comprising post flooding or irrigated croplands, rainfed crop land and mosaic crop land. Maize, wheat and rice are the main crops grown in the area. Fruits, including apples, apricots, peaches, walnuts, almonds, plums, pears, cherries, strawberries, citrus and guava are grown under irrigation. Sugarcane is a new introduction and is cultivated in limited areas. Vegetables are also grown in the area.

2. Water availability

2.1 Surface Water Availability

Rainfall is the only source creating runoff in the Valley. Several major streams/nullahs bring flows towards the low-lying areas. Small Dams Organization (SDO) of Punjab Irrigation Department has carried out studies on some of its existing dams and established monthly rainfall-runoff relationships as per observed rainfall-runoff recorded and developed regression equations for the three zones (SDO, 1987).

Zone A: BishanDaur River at Missa Runoff $=0.983 \times 10^{-7} \times (\text{Rainfall}+112.6)^{3.5}$

Zone B: Sill River at Chahan Runoff $= 0.9222 \times 10^{-2} \times (\text{Rainfall}+21.3)^{1.6}$

Zone C: Ling River at Kahuta Runoff $=0.428 \times 10^{-2} \times (\text{Rainfall}+32.5)^{1.5}$

The analysis to determine runoff is carried out using US-SCS method for Zone C for the authenticity of the equations developed by SDO. This method takes into account various factors affecting runoff from a given amount of rainfall such as soil, vegetation, forest cover, density of vegetation and degree of wetness of watershed, represented by Curve Number CN.

The estimated water availability by using both the methods shows good agreement, therefore, water availability was carried out for other two zones using regression equations developed by Small Dam Organization due to insufficient daily rainfall data that is required for the SCS method.

Zone A

Zone A comprises of the Rawalpindi region having catchment area of 2317 Km^2. Soan River and Korang River are the two major tributaries in this region. The length of the longest stream in this region is about 70 Km. Islamabad (City and Airport) and Murree are the two rainfall stations in the region. The mean annual rainfall at Islamabad is 1462 mm and 1744 mm at Murree. Maximum rainfall occurs in this region. July is the wettest month in the Murree with 336 mm rainfall and minimum rainfall occurs in the month of December.

The mean monthly runoff calculated by above equation is shown in Figure 4. The annual average flow in the valley is estimated about 1.03 BCM (0.84 MAF). Maximum runoff is generated in the month of July and August having 0.81 BCM (0.65 MAF).

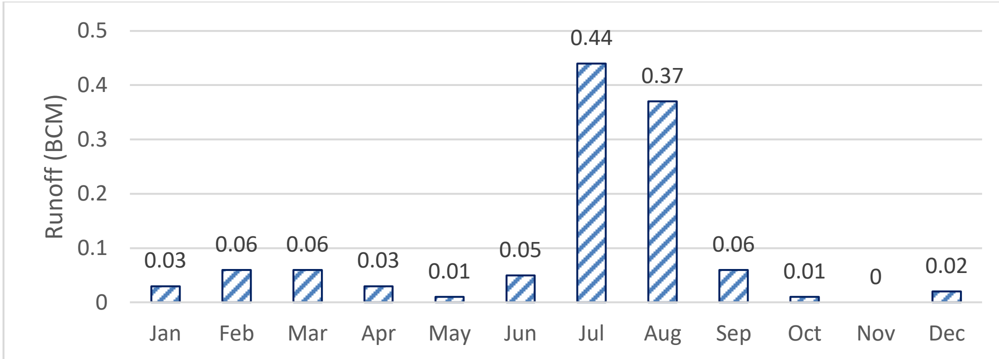

Figure 4 Mean Monthly Runoff for Zone A

Zone B

Zone B comprises of Attock and Chakwal districts with catchment area of 13927 Km^2. Zone B is the largest zone in the Pothohar region and rainfall is comparatively less in this region compared with other 2 zones. Sill River, Haro and Soan River are the major tributaries in this region.

Rainfall data of two rainfall stations on the southern side of the Zone B are used. Mean annual rainfall at Cherat, Talagang and Dhrabi gauging stations are 586 mm, 573 mm and 553 mm respectively. July is the wettest month at all these stations.

The mean monthly runoff calculated bu above formula is shown in Figure 5.The annual average runoff in the valley is estimated to be 1.74 BCM (1.40 MAF). Maximum runoff is generated in the month of July and August having 0.60 BCM (0.49 MAF).

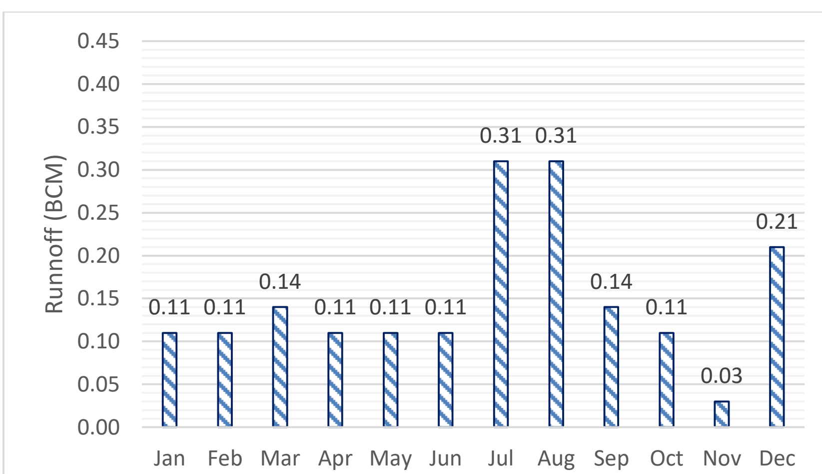

Figure 5 Mean Monthly Runoff for Zone B

Zone C

District Jhelum lies in the Zone C, while some part of District Rawalpindi and Chakwal also lie in this region. The total area of this zone is about 7194 Km^2. Kanshi, Kahan and Bunha are the major tributaries in this region fall in the River Jhelum on the eastern side of this zone.

Chakwal, Jhelum and Gujjar Khan rainfall data (1983-2013) was used to determine the mean monthly runoff in this zone. Mean annual rainfall at these stations is 653 mm, 876 mm and 787 mm respectively from 1983 to 2013.

The mean annual runoff computed by the above formula for this zone is 0.42 BCM (0.34 MAF). The wettest month is July with 0.11 BCM (0.09 MAF) and October to January are the driest months with 0.01 BCM (0.01 MAF) runoff (Figure 6).

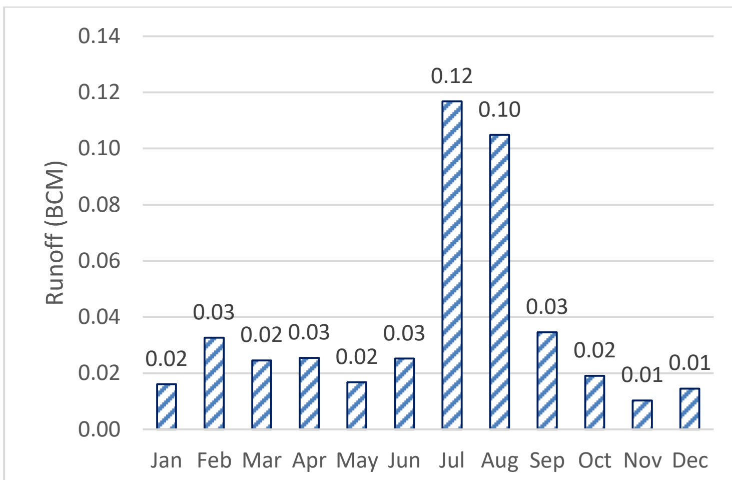

Figure 6 Mean Monthly Runoff of Zone C

The runoff generated in zone A, Zone B and Zone C with average annual rainfall and area is given below. The total runoff generated is about 3.19 BCM (2.5 MAF). The runoff is based on actual rainfall updated upto year 2013 (Table 3).

Table 3 Annual Runoff for Pothohar

Zone	Average Rainfall (mm)	Area (km^2)	Runoff (BCM)
A	1481	2317	1.03
B	773	13927	1.74
C	546	7194	0.42
Mean/Total	933.33	23438	3.19

2.2 Occurrence of the Groundwater

The moderately thick aquifer is present in the two pockets, along the River Jhelum and River Soan. Groundwater depth in the region varies between 6 meters to more than 40 meters. Soan Valley situated in southwestern side of the region has also groundwater aquifer. The depth of the tubewells in the Soan Valley varies from 55 to 92 m (180 to 300 ft). The existing watertable in the central part of the valley and other sub-valleys ranges from 6 to 25 m (20 to 80 ft), while in the piedmont area and along the foothill it ranges from 25 to 49 m (80 to 160 ft).

There was decline of groundwater in the Soan Valley due to excessive abstraction of groundwater. During the inventory of 138 water points, information about the water table at the time of well installation and under existing conditions was also collected from the owners of 54 inventory points and declining rate per year has been estimated for the area, which ranges from 1 to 19 m (0.3 to 43.3 ft) per year with an average of 1.84 m (5.84 ft) per year. The minimum, maximum and average water table decline rate/year in different Union Councils have been worked out as tabulated in Table 4 (NESPAK, 2007).

Table 4 Decline Rates (m) of Watertable in Soan Valley

Sr. No:	Union Council/ Sub-valley	Number of Observation Points	Minimum Decline (m)	Maximum Decline (m)	Average Decline/ year (m/yr)
1	Uchhali	29	0.07	13.21	1.90
2	Khura	8	0.25	4.95	2.61
2a	Biyak/Kalial Sub-valley	2	0.70	1.98	1.10
3	Khabakki	2	0.36	1.01	0.69
4	Jaba	9	0.17	7.01	1.35
5	Naushahra	NA	NA	NA	NA

For the sustainable use of groundwater ponds, mini dams and RHS shall be developed in the area.

3. Water Resources Development

3.1 Small Dams

The Government of Punjab has constructed 55 small dams in the Pothohar region, to store for agricultural production. A summary of number of dams constructed in different periods is given in Table 5.

Table 5 Storage of Small Dams				
Division	**Gross Storage (MAF)**	Storage per ac of Command Area (ft)		
		Mean	**Maximum**	**Minimum**
Fateh Jang	0.04	4.2	14.2 (Kanjoor)	0.98 (Ratti Kassi)
Rawalpindi	0.02	2.7	5.6 (Misriot)	1.18 (Dhok Sanday Mar)
Jhelum	0.03	3.3	7.0 (Dungi)	1.32 (Salial)
Chakwal	0.11	3.0	9.9 (Pira Fatehal)	0.5 (Gurabh)

Annual crop water requirement is estimated as 1.5 ft per year, whereas storage in small dams is much higher. This indicates inefficient use of very precious water.

The gross storage of all the existing small dams is 0.21 MAF. The maximum gross storage of dams is in Chakwal district with 0.11 MAF while minimum water tapped lies in district Rawalpindi with 0.02 MAF. The small dams are irrigating about 60,000 ac.

The Construction of small dams has enhanced the land use, crop intensities and crop yields. There is a shift of cropping pattern from the traditional cropping towards high value crops in the command areas of these small dams due to water availability. The watertable in these areas has risen and has become accessible for pumping. The number of dug wells has increased. Ashraf et al. (2007) carried out study in the Rawalpindi Division of the Pothohar Region to determine the impact of small dams on the agriculture and groundwater development. They found that besides supplying water for irrigation, these dams have many indirect benefits. They recharge the groundwater, provide water for domestic and municipal purposes, control erosion and floods in hilly and plain tracts, help develop fish culture and also provide recreational activities (Ashraf et al., 2000).

According to ICOLD definition most of these dams are large dam. Condition survey of these dams has identified the following issues:

i) Dams have comparatively less problems and short comings can be made up easily except on few dams which have serious spillway problems.

ii) Irrigation channels have following major problems:

a. Some of the canals are either not built or have not become functional.
b. R.C.C pipes used for gravity flow are either under size or have serious leakage problems.
c. P.R.C.C pipes used in syphons are the major bottleneck in recently completed dams as these have not been manufactured according to the specifications.

d. Hardly any water sharing system exists. Influential farmers may get more water than their share.

iii) Command area of many dams is far away from the reservoir and bringing water to command area has become challenge.

3.2 Rainwater harvesting schemes

Optimum utilization of every drop of available water is becoming increasingly important with the ever-increasing population to meet their food needs. Efficient use of land and water is the key to the economic crop production. In the Pothohar Region where good agricultural land is a limiting factor and where rain water is wasted by flowing over steep slopes, causing soil erosion and damaging the water ways and dams. Rainwater Harvesting Schemes (RHS) would contribute in enhancing the crop production and reducing the erosional hazard.

The Pothohar Region have a total command area of 5.4 million acres (2.2 Mha). In addition to small dams about 86,740 ac are being irrigated by existing rain water harvesting structures (Table 6).

Table 6 Completed Rainwater Harvesting Schemes

	Rainwater Harvesting Structures	Dug Wells	Tube Wells	Turbines	Total
Number	2154	4,112	399	187	-
Area irrigated (ac)	54460	20,560	7,980	3,740	86,740

It has been estimated that annually 2.4 MAF water is lost as surface runoff from Pothohar Region. The conservation/collection of runoff and its utilization is of paramount importance in this area. Therefore, the surface runoff if taped and stored at proper locations could help to achieve the goal of self-sufficiency in food. RHS can help in this regard.

In the Pothohar region the RHS has been constructed since 1978 and has completed various multi-sectoral development projects. It included construction of small RHS, mini dams and ponds etc. Various public sector institutions are engaged in the development of barani (rainfed) areas of Pothohar Plateau. A total of about 7150 interventions have been constructed including 2455 RHS, 4112 dug wells, 399 tube wells and 187 turbines for harnessing water resources to provide supplemental irrigation supplies to rainfed areas. Despite piece meal efforts of various institutions, only 0.2 MAF rainfall runoff is being utilized out of potential of 2.6 MAF. Proper harvesting of this balance of 2.4 MAF is inevitably required for regional economic growth. RHS are operated and maintained by the beneficiaries. No government funds are needed for O&M.

4. Potential New Sites for rain water harvesting

A total of 8707 sites for rainwater harvesting structures (mini dams and ponds) have been identified for construction in four districts of Pothohar (Table 7). Out of these Attock district contains maximum number of potential sites (2,596 new sites: 970 mini dams+1626 ponds) while Rawalpindi district contains minimum number of potential sites (1,431 new sites: 799 mini dams+632 ponds).

Table 7 District wise Summary of Potential Sites

District	No. of Rural UC	Mini Dam	Ponds	Total
Rawalpindi	**119**	**799**	**632**	**1431**
Chakwal	**59**	**864**	**1449**	**2313**
Attock	**61**	**970**	**1626**	**2596**
Jhelum	**42**	**1033**	**1334**	**2367**
Total	**281**	**3666**	**5041**	**8707**

Recently a survey of 34 potential sites of RHS has been carried out. RHS storage capacity, command area and cost of construction has been estimated. The storage size of schemes varies from 10 AF to 100 AF and called small with size of 10 - 30 AF, medium with size of above 30 – 60 AF and large with size of above 60 to 100 AF (Table 8). Survey has indicated that potential RHS small size are 41 percent, medium size 38 percent and large size 21 percent. Construction will all 8707 RHS will provide additional storage of 0.364 MAF and command area of 0.241 Mac (Table 8).

In addition it will have the following additional benefits:

i. Recharge groundwater aquifer;

ii. Provide fishing opportunities;

iii. Improve the environment; and

iv. Reduce erosion/help watershed management.

Table 8 **RHS ESTIMATED COSTS**										
Sr. No.	Storage Category	RHS Surveyed				Storage of 8707 RHS (AF)	Command Area of 8707 (ac)	Average Cost/RHS (Million Rs.)	Cost of 8707 (Million Rs.)
		No	percent	Mean storage (AF)	Mean Command Area (Ac)				
1	Small (10-30 AF)	14	41	18	12	64,534	43,023	5.40	6,588
2	Medium (30-60)	13	38	47	31	156,470	103,204	6.82	7,714
3	Large (60-100)	7	21	80	53	143,409	95,009	9.99	6,090
Total		**34**				**364,414**	**241,235**		**20,392**

4.1 Agriculture Development and Benefits

Considering water and land resources as constraining factors, 50% of command area will be served with high efficiency irrigation system (HEIS) and drip irrigation is the option. The rest 50% will receive surface / flood irrigation. The crop production is envisaged to be achieved through bringing barren land under cultivation and practicing of cropping pattern with high return crops including orchards and high value crops on 50% of the command area which is proposed to be served with HEIS and traditional crops on 50% of area proposed to be served with conventional irrigation. Irrigation water will be provided to field crops through improved water channel with minimum water losses. The water saving measures will include improved water courses, land levelling, improved irrigation agronomic practices such as bed and furrow planting and minimum tillage etc. This will minimize the losses even under conventional surface irrigation. Cropping intensity of 145% has been proposed keeping in view the water availability, soil suitability, climate conditions, present cropping pattern and intensities in Pothohar region, marketing and socio-economic conditions and profitability etc. The ultimate annual cropping intensity of 145% will be achieved within a period of four years observing linear trend. The Pothohar valley has been declared as olive valley and government is giving great emphasis on introduction of olive and grapes cultivation in the valley .In consistence with government policy, orchards and high value crops comprising of olive(3%), grapes(9%), citrus(10%), peaches(5%), guava(5%), fig(3%), vegetables tunnels(3%) and flowers consisting of rose petal(4%), rose cut flower(4%), gladiolus(2%) and tube rose cut flower(2%) have been included in the cropping pattern. The crops will attain the ultimate yields during 5th year and afterwards taking this level constant, no projection has been made upto project life. The plan will result in increased cropped area, crop yields, production and farm incomes ameliorating the livelihood of farmers.

The ultimate objective of an irrigation project is the economic exploitation of soil and available water resources, increase of cropped area, crop yields and enhanced production of food, cash crops and high value crop / fruits / vegetables for achievement of self-sufficiency, exportable surplus and better standard of living of farming community. With the implementation of the project, it is assumed that cropping pattern and intensities of 145% including some percentage of high value crop will be practiced. Similarly improvement in crop yields is proposed from one and half to about two folds in traditional crops. The NVP values range from Rs. 959,000 to Rs. 5,756,000 depending upon the scale of CCA of each rainwater harvesting structure. The NVP per acre of CCA comes to about Rs. 95,954.

4.2 Project Cost and Economic Analysis

The overall estimated cost of 8707 RHS is Rs. 20.39 Billion (Table 8).

The economic analysis involves the appraisal of agricultural development scenarios via, the existing situation “without project” and the future “with project”. The project benefits are the difference between net-farm incomes for “with” and “without” project conditions. The economic cost of the project is taken from financial cost for economic cash flow statement and operational and maintenance cost is calculated as 1.5% of total cost. The agriculture net benefits have been taken as difference of with and without project. Fisheries benefits have been taken as 10 % of agriculture benefits. Economic cash flow has been prepared at 12% discount rate. The life assumed as 30 years. Incremental benefits have been calculated by taking the difference of total benefits and total cost. Economic parameters have been worked out on incremental benefits to indicate the feasibility of investment.

Net present worth (NPW), benefit cost ratio (B/C Ratio) and economic internal rate of return (EIRR) have been calculated for each RHS to examine the economic feasibility of implementing the schemes and are as under:

Net present value – NPV ranges from Rs. 959,000 to Rs. 5.756 million.

Internal rate of return – IRR ranges from 14% to 21%

Cost benefit analysis (BC ratio) is in the range of 1.5 to 2.8

As per economic analysis, all the RHS are economically viable and feasible for implementation. Sensitivity analysis also indicates that all the RHS are economically feasible and endorse the above results.

5. References

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SAFE DRINKING WATER; AN ONGOING CHALLENGE IN LAHORE

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WWF-Pakistan[12]

Abstract

This paper gives an overview of the situation of water resources in the city of Lahore, with special reference to water pollution, contamination and the problem of over abstraction along with health repercussions in communities. The water borne diseases are being reported at the district level, and with the passage of time, the number of cases reported in the health facilities of Lahore and Faisalabad is increasing as well as the water table levels are dropping. Also the presence of Arsenic in the groundwater is another threat being faced by the communities of Punjab, in particular Lahore. As studies conducted by different organizations and tests conducted by Pakistan Council of Research in Water Resources (PCRWR), shows higher levels of Arsenic and Fecal Coliform present in drinking water. The paper also talks about the initiative of WWF-Pakistan in collaboration with Coca Cola Beverages Pakistan Limited, “Increasing the supply and access to safe drinking water in Lahore, Pakistan”. Under this initiative, water filtration infrastructures are being installed in the communities of Lahore, selected on the basis of present water facilities and water quality. Also this paper provides further recommendations to cater current facing threats to communities.

Introduction

In Pakistan, water is not being managed properly, resulting various diseases in the population due to drinking water. If viewed in the context of global climate change, increase in population of the city of Lahore, water scarcity is a problem that has economic, social and environmental consequences. Pakistan, in developing countries is the one; facing severe food and water crises in the 21st century. High usage by domestic as well as industrial sectors, major cities like Lahore is already short of clean drinking water. Over abstraction and added water pollution to water resources further deteriorate water quality hence causing common yet frequent diseases among water consumers. (Aziz 2005).

Drinking water must be free from components which may adversely affect the human health. Such components include minerals, organic substances and disease causing microorganisms. A large portion of the population in developing countries suffers from health problems associated with either lack of drinking water or due to the presence of microbiological contamination in water (Haydar, 2009).

It has already been known that Pakistan is now a water stressed country[13] with average per capita water availability at 964 m^3 per annum[14]. As Lahore being the

[12] World Wildlife Fund

second largest city of Pakistan and capital of Punjab province, have a history of groundwater over abstraction with continuously decreasing rate of groundwater, causing decrease in water levels. In the city, water supply demand has been increased as a large number of population flows in annually from other cities and villages. As well as, industrialization is the other cause of unsustainable water use. Since, development including paved and carpeted road has reduced the recharge by ground, the River Ravi which was considered a main source of recharge to groundwater remains almost dry except in the monsoon season and the pollution added to it sourcing from industries and urban waste through drains. Groundwater conditions in Lahore is likely to worsen in near future if the situation remains persistent (Mahmood 2013).

Problem Statement

Pakistan's population has a current water supply coverage of 79% (Aziz 2005). This inadequate supply of water also poses health risks to the consumers because of its poor quality. Erratic water supply is common in Lahore and outbreaks of gastroenteritis and other waterborne diseases have become a normal feature. Estimates indicate that more than three million Pakistanis suffer from waterborne diseases each year of which 0.1 million die. (Haydar, 2009).

With rapid urbanization, the chemical aspects of water quality have also become a cause of increasing concern as toxic chemicals in industrial effluents pose a high risk to human health. Unfortunately, little attention is being paid to drinking-water quality issues and quantity remains the priority focus of water supply agencies. There is a lack of drinking-water quality monitoring and surveillance programmes in the country. Weak institutional arrangements, lack of well-equipped laboratories and the absence of a legal framework for drinking-water quality issues have aggravated the situation. Above all public awareness of the issue of water quality is dismally low.

Ground water resources bear the greatest burden, as over 60% of Pakistan obtains drinking water by means of hand or motor pumps. This significant demand on already scarce ground water has resulted in declining water table levels, which often reach lower saline levels in water tables in most areas. Acute shortages, coupled with pollution caused by industrial and public wastewater has given rise to health problems and decreasing agricultural production. Patients admitted to hospitals nationwide, suffer from water related diseases, such as typhoid, cholera, dysentery and hepatitis, which are responsible for one third of all deaths. The total costs associated with waterborne disease are estimated to be more than 1.8 % of the country's GDP, according to the World Bank. (WWF-Pakistan, 2007)

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[13] The threshold of water scarcity <1000 m^3/capita (Ref: International decade for Action 2005-2015. www.un.org/waterforlifedecade/

[14] Economic Survey of Pakistan, 2013-14

Data received from the Directorate of Health, Information System (DHIS), where data is received from health facilities from districts, enters the MIS cell where it is entered into DHIS software in every district of the Punjab. This data is scrutinized and examined in detail by the Provincial MIS cell and provide viable information about health cases reported. In those reports the top 5 diseases in districts, includes Diarrhea/Dysentery.

Data from 2011 to 2014 shows incidences per 1000 population in different districts in figure below.

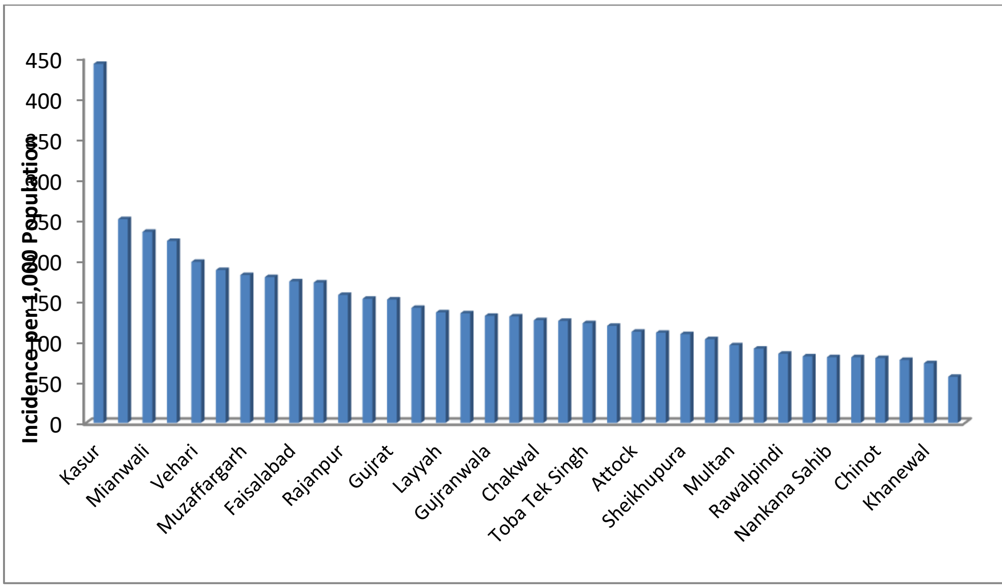

Figure 1: Incidences of Diarrhoea/Dysentery per 1000 population in Major Cities of Punjab in 2011

Source: Annual Report, Directorate General Health Services Punjab, by the District Health Information System (DHIS), 2011

As the Figure 1 shows, there are 70 incidences in city of Lahore, but significantly higher in District Kasur.

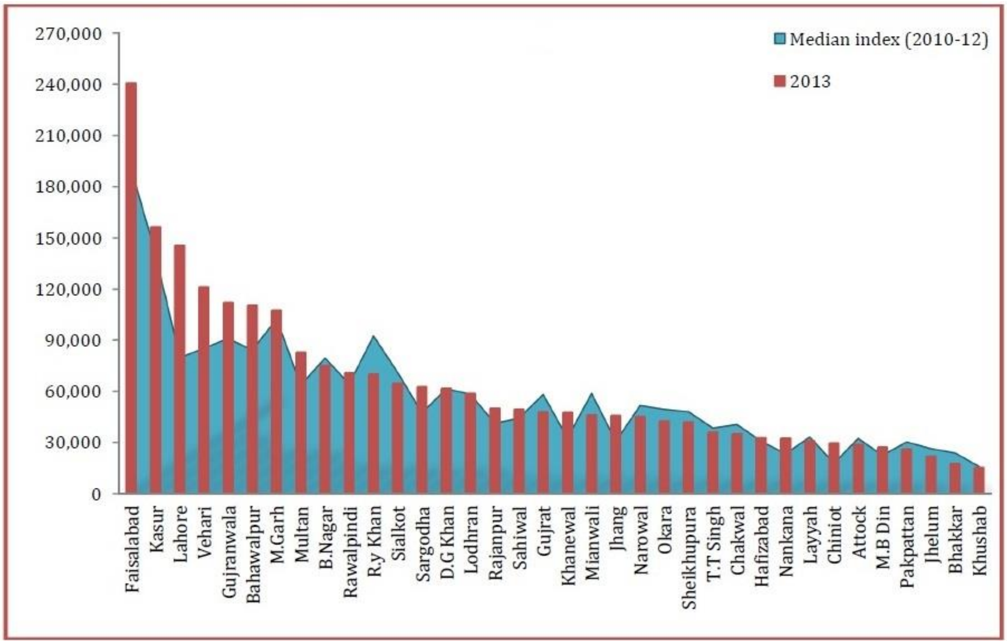

Figure 2: Incidences of Diarrhoea/Dysentery in Major Cities of Punjab in 2013
Source: Annual Report, Directorate General Health Services Punjab, by the District Health Information System (DHIS), 2013

Figure 1 indicates the incidences in year 2011, but as reported, Figure 2 point outs the higher number of incidences reported in year 2013, in 2 major cities in Punjab. Where Lahore and Faisalabad reported less cases in previous years, in year 2013 it is much higher in Lahore, and highest in Faisalabad. Incidences reported were around 240000 in Faisalabad, 160000 in Kasur and 150000 in Lahore District.

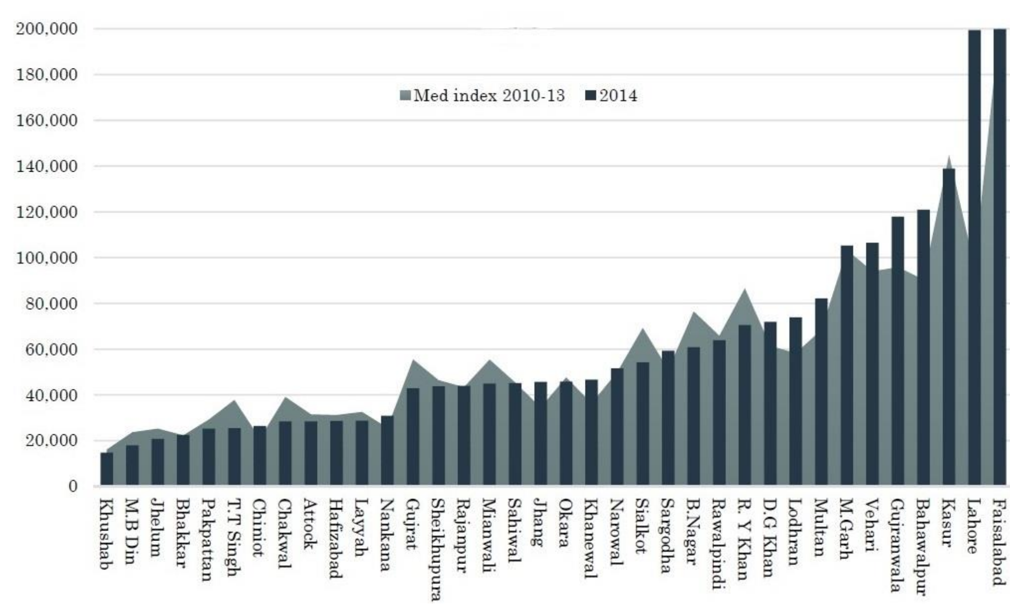

Figure 3: Incidences of Diarrhea/Dysentery population in Major Cities of Punjab in 2014
Source: Annual Report, Directorate General Health Services Punjab, by the District Health Information System (DHIS), 2014

As already discussed, number of cases reported in Lahore and Faisalabad were less in previous years, but data from recent years shows that there are higher number of patients coming in with Diarrhea. Cases reported in Lahore were less than Kasur, from 2011-2013, but as Figure 3 shows, cases in Lahore are now more than the cases in Kasur District.

The National Water Quality Monitoring Programme (NWQMP) was initiated by Pakistan Council of Research in Water Resources (PCRWR) in 2002. It was the premier project of the year which generated the first detailed water quality profile of 23 major cities of the country. The NWQMP continued for five years (2002-2006). This report is the final and fifth technical report of 2005-06 and presents the results of the final phase of the monitoring program. During this phase, 357 water samples from 364 selected water sources were collected, adopting the uniform sampling criteria and analyzed for 79 physico-chemical parameters, including trace, ultra-trace elements and bacterial indicators. The analytical findings were compared to World Health Organization (WHO) guidelines and Pakistan Standards Quality Control Authority (PSQCA) standards for drinking water.

In Kasur, all sources (10) were unsafe due to bacteriological contamination and high TDS (40%), arsenic (100%), sodium (50%), potassium (10%), fluoride, sulfate (20%) and nitrate (10%).

Lahore, the second largest city of Pakistan has shown an alarming situation of drinking water contamination as all 16 of its sources were supplying unsafe water due to bacteriological (50%) and arsenic (100%) contamination.

In Multan, where all 16 sources were found unsafe due to bacteriological contamination (56%) and arsenic (94%) contamination.

In Rawalpindi, out of 15 sources, 11 were found contaminated by bacteriological contamination (53%) and TDS (7%) and nitrate (47%).

In Sargodha city, only one source, out of a total of 24 locations, was found safe for drinking purpose and the major causes of contamination were bacteriological (83%), arsenic (13%), sodium (54%), potassium (29%), chloride (46%), sulfate (38%), TDS (67%), nitrate (54%) and fluoride (4%).

In Sheikhupura, where all 11 sources were supplying unsafe water to the public mainly due to the presence of bacteriological contamination (45%), excessive levels of potassium, sulfate and nitrate (9%), arsenic (73%), sodium and TDS (27%).

In Sialkot, only three sources out of 10 were supplying safe water and the rest have shown excessive levels of bacteriological (70%) and arsenic (20%) contaminants.

In Federal Capital Islamabad, only 7 sources out of 27 (26%) were found safe and the rest of the 74% were unsafe due to bacteriological contamination.

In Bahawalpur City, all sources (25) were found unsafe due to bacteriological as well as chemical contamination i.e. arsenic (88%), turbidity (32%), iron (68%), sulfate (20%), sodium (12%), lead (8%) and TDS (16%).

In Faisalabad, 3 sources out of 13 were found safe and the remaining 10 sources were found unsafe due to bacteriological contamination, high sulfate and TDS (46%), iron (31%) hardness (23%), sodium (54%), potassium, chlorides (38%) and fluoride (15%).

In Gujranwala, all 14 sources were found unsafe due to bacteriological as well as the chemical contamination of arsenic, nitrate and TDS (7%), while only one (1) source was supplying safe drinking water.

In Gujrat, 4 sources out of 9 were found unsafe due to bacteriological contamination (56%), turbidity (22%) and iron (11%) (PCRWR 2006).

In one study presented at the University College London, London, (Edwards 2010), showed the arsenic intensity levels (Figure 4) in selected areas of Lahore. As acceptable level is 10 ppb, areas in Lahore showed in the Figure 4 are high as described by legend on the bottom right part of the figure.

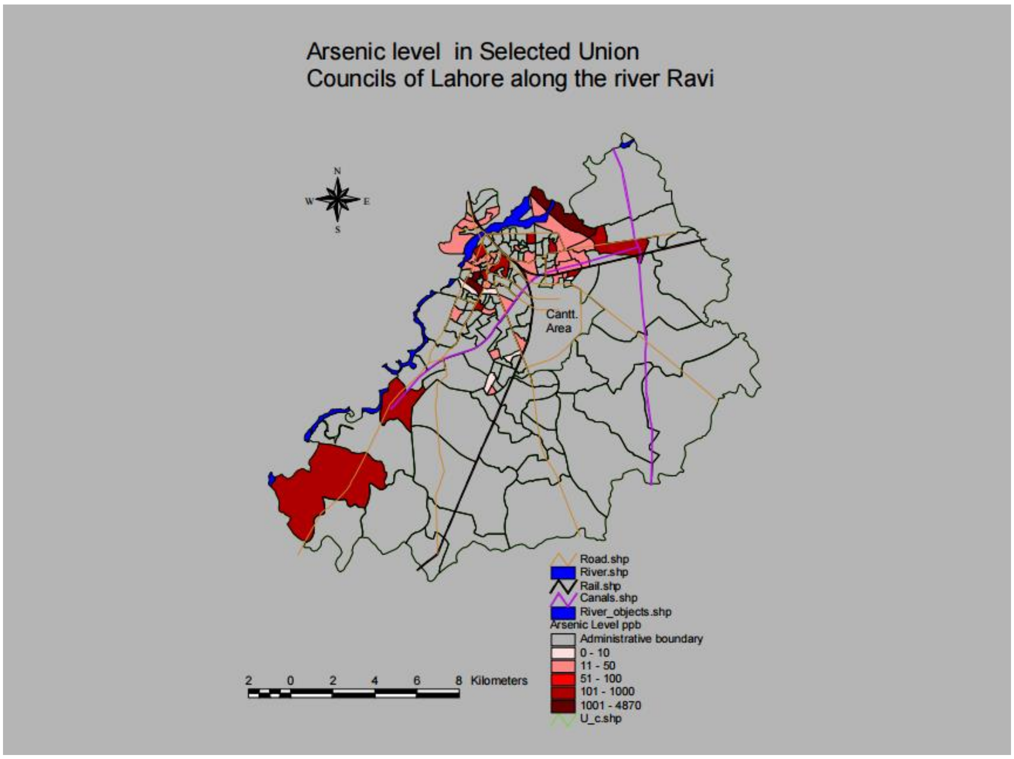

Figure 4: Arsenic level in Councils of Lahore (Edwards 2010)

As described in Figure 5, NDMA and UN Children’s Fund with WASH, plotted arsenic levels after testing in different areas. The following figure show levels in the form of circles in different area. The figure describes more levels in the urban areas, including Lahore, Faisalabad, Multan, Rahim Yar Khan and Bahawalpur.

Arsenic test results - Punjab

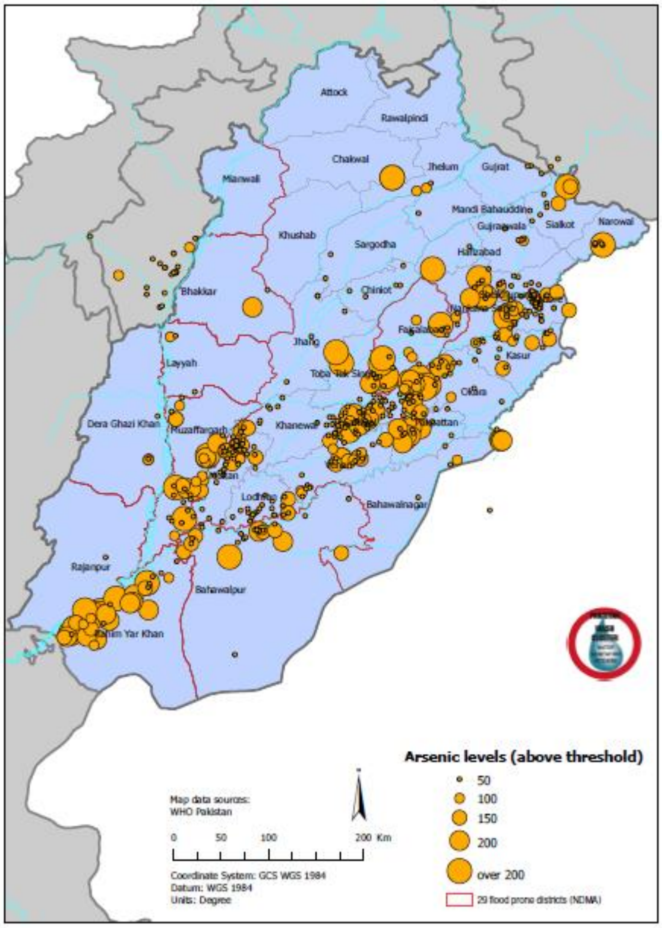

Figure 5: Arsenic levels in Punjab Province NDMA (2012) (http://reliefweb.int/map/pakistan/pakistan-arsenic-test-results-punjab-20-sep-2012)

Initiative by WWF-Pakistan

WWF-Pakistan and Coca Cola Beverages Pakistan Limited have collaborated on their own initiative and cost to work towards increasing access to safe drinking water by installing safe drinking water filtration plants across the city of Lahore. The aim is to work for the selected communities in Pakistan suffering from shortage of clean drinking water. The initiative is being carried out in accordance with the urgency of water shortage situation, the needs of the local communities and the willing participation of the communities. WWF-Pakistan is installing localized solutions, with respect to the particular water availability and accessibility issues at each target site. The capacity of the target communities, with a particular focus on women's participation, will be built to ensure sustained operation and maintenance of all installed drinking water infrastructures.

Under this initiative, 5 filtration plants are in operation, including the areas, Basti Saiddan Shah, Lady Willington Hospital, Glaxo Town, Awan Town and Masti Gate (Walled City). Also the awareness surveys were conducted to mobilize locals along with awareness seminars as a follow-up to surveys, to make people aware of current challenges and threats the communities face.

On the other locations of Lahore, 4 water filtration facilities are under construction that will be completed soon and providing safe water to the communities.

In this collaboration, Pakistan Council of Research in Water Resources (PCRWR) is on board for regular monitoring and testing of water quality. PCRWR collects samples, from the selected area and the type of filtration facility is installed as the report suggests. The water quality test conducted at Basti Saidan Shah, suggested the arsenic level at 23.84 ug/L, whereas the permissible limit by WHO is 10 ug/L. Also, test conducted at Lady Willington Hospital resulted in 26.89 ug/L, but the highest was in the water sample collected form Mochi Gate (Walled City), that was 27.12 ug/L.

Recommendations

- Combined effluents treatment plant at city level should be installed
- NEQS, including water standards, should be implemented
- Identifying areas with poor quality aquifers that should not be tapped for consumption
- Areas with declining water levels, where recharge options need to be considered instead of abstraction.
- Identification of key hot spots around Ravi with respect to groundwater quality and suggesting and implementing relevant mitigation options across the basin
- Communities should be made aware of the over abstraction, conservation and sustainability with special reference to women and children
- Initiatives should be planned for other cities depending on the current water quality and facilities available

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MEETING CHALLENGES OF FLOODS & DROUGHTS

Abdul Khaliq Khan[15],
Shahzad Ghafoor[16],

Abstract

Rainfall and river flows in Pakistan are highly seasonal and unevenly distributed. There are periods of torrential rains and dry months. Rainstorms in urban areas cause flooding and disruption of civic life. Rivers overspill banks and inundate vast areas causing damage to standing crops and infrastructure plus human sufferings and loss of lives.

The impending climate change is going to exacerbate the situation. Events of floods and droughts are estimated to increase in frequency and intensity. This paper reviews the present situation in Pakistan with a foresight on future and makes recommendations on how to alleviate the adverse impacts and adapt to the changing conditions

1. General

Survival of life depends on water. Pakistan is an arid country with large population and accentuated needs for adequate water availability. Nature supplies water through precipitation of air moisture in the form of snowfall on mountains in the north and rainfall in the plains. Supplies of both snow and rainfall are highly uneven in time and space. River flows are mostly dependent on snow and glacier melt with seasonal contributions by rainfall. Last 90 years data shows annual average flow of western rivers at rim stations as 138 MAF. In this period the year 1959 experienced maximum inflow of 187 MAF and generated very high floods. Minimum flow was observed during 2001 when only 97 MAF was recorded and drought conditions developed.

The country suffers frequently from devastations of floods and miseries of droughts. With the passage of time the per capita water availability has drastically reduced. Under a psychology of scarcity of water, when we get the abundance we are not even mentally prepared to deal with it. The nation has to prepare itself to meet the two extreme weather conditions.

2. Snowfall

The bulk of snow fall, derives its moisture from westerly winds, during winter and nourishes the glaciers in the mountains of Hindu Kush, Karakorum and Himalayas. However in summer as well a significant quantity of precipitation culminates as snowfall. Topography largely determines where snowfall to occur. Two outstanding factors are; the great variation of snowfall with altitude and the altitudinal migration of melting temperatures round the year. These two factors

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combine to ensure that only about one third of Upper Indus Basin contributes an estimated 80% of the river's flow.

Much of the snow in areal extent disappears before the rivers show an appreciable increase in flow. This is due to thinning of snow cover below 11,500 ft. (3,500 m) above sea level. This means that much of the melt here is lost to evaporation. The summer period of river flows commences as melting reaches the ablation zones. Monitoring of annual changes in snow and ice cover is therefore very important for weather forecasting in Pakistan.

3. Glaciers

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

4. Rainfall

The rainfall over most of the agricultural area of the Indus Plains averages only 225 mm per year. The Northern Areas from Karakoram Mountains to Himalayas including the Murree Hills receive 1200 to 1700 mm of rain. In the Indus Plains the annual rainfall decreases from the foothills of Himalayas towards south with 1100 mm at Islamabad, 625 mm at Lahore 150 mm at Multan and 90 mm at Nawabshah. Further south, it increases towards the coast with 175 mm at Hyderabad to 300 mm near the south west coast.

During the year, there are very wet months and very dry months. Between the years there are wet and dry cycles. Such variations call for managing the flows and managing the conveyance systems. Remedy is to store from the surpluses and save from the losses. We should build carryover dams with dedicated storage capacities to absorb flood waters and chamfer flood peaks. We should also build flood carrier channels and improve municipal drainage systems to save the urban population from flooding by rainstorms.

5. Weather Cycles

The mainstay of Pakistan's economy is agriculture which in turn largely depends on water. Water security is thus essential for Pakistan. Whereas the water dependent agricultural and industrial produce is important for the economy the safeguards against losses from phenomena like floods and droughts are equally important. Weather abnormalities are part of weather cycles. We cannot stop occurrence of floods and droughts but we can save the society from consequential stresses, human miseries and losses of life and properties.

6. Floods

Flood is a natural event often generated by a thunder and rainstorm. When storm occurs in upper catchment areas, the water flow in rivers rises to flood levels. When heavy rainfall occurs in plain areas with flat topography and improper drainage, the urban areas in particular get inundated. Other causes of floods could be sudden melting of snows and ice, glacier lake outburst, breach of landslide blockage of river and tsunami in coastal areas.

7. Recent Flood Events

During last 55 years, the country has faced 22 high to very high floods. Studies on global warming impacts show that these events will increase in magnitude and frequency. It can be noted from the global temperatures data of recent years' that change has already set in. Flood occurrence frequency has increased in the last decade. Whenever, there is an extra high flood and large scale inundation, the country goes panicky and frenzied. In such environment the plans prepared for meeting emergencies fail. Rush behaviour takes over the much needed state of calm and cool thinking. Modern sciences offer that even such mental states and behaviours can be addressed in the emergency action plans.

8. The 2010 Flood

The 2010 flood was worst of its kind in the recent history. The meteorological setup just before the 2010 flood was unique and much different from the historical events. In early July 2010, a strong pressure ridge started developing near the Ural Mountains in Russia. The pressure ridge became static and formed a barrier named Omega Block by the meteorologists. The stationary pressure ridge directed moisture laden winds south east and there was persistent rain fall in most areas of Afghanistan, northern Pakistan and Kashmir. With an abnormally active jet stream running around the periphery of Omega Block into Pakistan a super charged monsoon developed and the catchment of Chitral, Swat and Indus rivers received torrential rains.

The whole country was devastated in the record breaking rains from 220 to 415 mm. About 160,000 km^2 land was affected. More than 2000 people died and nearly two million people affected. Economic losses touched $ 45 billion.

The 2010 flood is generally regarded as super flood but hydrologically it has a return period of 1 in 50 only. A 200 year flood could be around 15 lac cusecs and its devastation can only be imagined. None of the barrages on Indus River are designed to pass this flood.

Lesson was learnt from the 2010 flood that flood forecasting and warning system for Indus river has limited capability. There was lack of preparedness in the communities especially in those who faced the hazard for the first time. Quick and correct decision making was lacking in the management of flood and evacuation of affectees. Need for real time inundation maps, communication systems and logistics was greatly felt.

Story of devastation caused by 2010 flood is horrifying but the sufferings from several other floods like 1969, 1973, 1988, 1992, 2003, 2007 and then every year from 2011 to 2015 are no less in any way (Table-1). Every time sentiments go high, media yells, writers publish angry notes and soon everything goes quiet and lull.

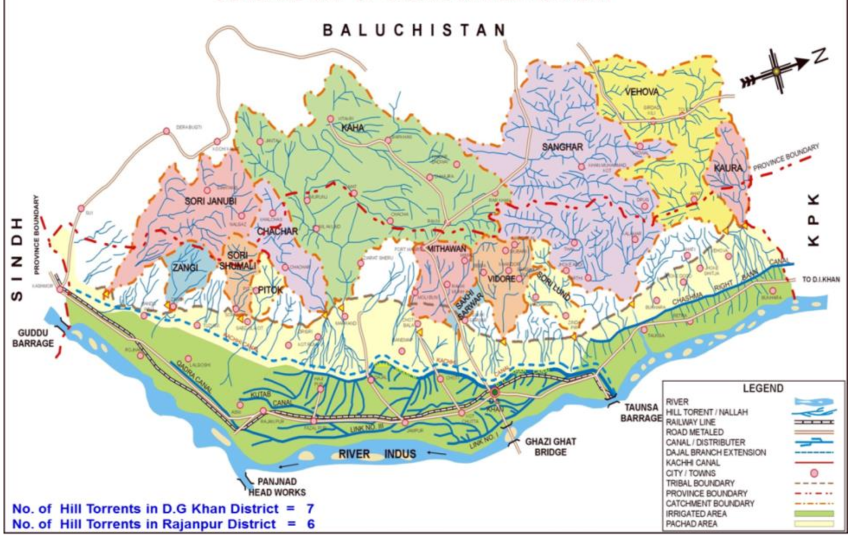
Table 1: RECENT FLOODS IN PAKISTAN

Year	Rainfall	Damages	Other Impacts
2003	Monsoon Rainfall caused flooding in Sindh Karachi (284.5 mm) and Thatta (404 mm)	484 deaths 4476 villages affected	
2007	Monsoon badly affected KP, Sindh & coastal Baluchistan Cyclone Yemyin and rainfall	152 deaths in KP and 815 in Sindh& Balochistan	
2010	Whole country (36 districts) was devastated by record breaking rains (219 to 415 mm) worst in last 80 years.	More than 2000 deaths 20 million people affected	1 million homes affected
2011	Massive floods swept across Sindh due to monsoon rain in September	361 people died; 5.3 million people affected	1.20 million homes & 1.70 million acres of arable land affected
2012	Intense rainfall in September floods in KP, Southern Punjab & upper Sindh.	100 people died	1000 of homes destroyed 1000s of acres of arable land affected
2013	Heavy rainfall in Northern areas, causing floods in August	More than 80 people died	
2014	Massive rains in September in J&K and AJK & Punjab	365 lives lost	4065 villages affected
2015	Floods engulfed many areas of Chitral as a combined outcome of glacial lake outburst and cloud burst in July 2015.	32 fatalities 0.3 million people affected	extensive damage to building and infrastructure

9. Hill Torrents

Flash Flood in piedmont areas are no less important. Hill torrents of Dera Ghazi Khan and Rajanpur districts have a history of bringing flash floods. There are 13 major hill torrents originating from Suleiman Mountain Range and flowing eastwards (Fig.1)

FIG-1: GENERAL MAP OF D.G.KHAN HILL TORRENT



Flash floods generated by these Hill Torrents cause wide spread damages to life, property, communication infrastructure, standing crops and the irrigation canals. The Kachhi canal and D.G. Khan Canal are obstructing the natural surface flows running from hills in the west to river Indus in the east. A very large number of breaches occurred in 2012 flood. Such events shall continue in the future until and unless a site specific project for handling the flood water and a surface drainage system with flood water carrier drains upto the river, alongwith strengthening of right bank embankment of Kachhi canal is implemented.

During 2012, the Vidore Hill Torrent brought a flash flood of 1,45,000 cusecs. Floods in Sanghar, Sori Lund and Kaha hill torrents exceeded 80,000 cusecs. There were cases when the flood waters of two neighbouring hill torrents joined on right side of Kachhi canal and enhanced the damages. Resultantly, the Kachhi canal developed more than 100 breaches. Flood water entered D.G. Khan City and several other towns including Jampur and Rajanpur. Some very important Government buildings and the camps of Atomic Energy Commission were inundated. Such events will reoccur therefore specific remedial solutions must be urgently provided.

The major damages occurred due to 2012 flood are as follow;

Major Damages of 2012 DG Khan Hill Torrent Flood

- Total Cropped Area Damaged 414, 000 Acres
- Total Number of Farmers Affected 11,000
- Total Number of Houses Damaged 3,000

In the right bank areas of Kachhi canal, flood water gets temporarily ponded in front of cross drainage structures and all along the canal in low lying areas. The rapid rise and fall of ponded water develops high pore pressures in the right embankment of Kachhi Canal. A high velocity parallel flow develops along right side embankment of the Canal. These two phenomena cause toe cutting and slides with development of breaches in canal and damages to the structures. Appropriately designed flood protection works must be devised and provided.

High discharge of water exiting the super-passages and siphons of the twin canals finds no freeway on to the river. The obstructed flows overspill the choked and silted up drains and flood carrier channels and spread into urban areas and run over fields of standing crops. (Fig. 2) WAPDA had carried out Feasibility Study of Surface Drainage Project in the 1990's. It should be upgraded and implemented.

FIG 2: COTTON IN KAHA PACHAD

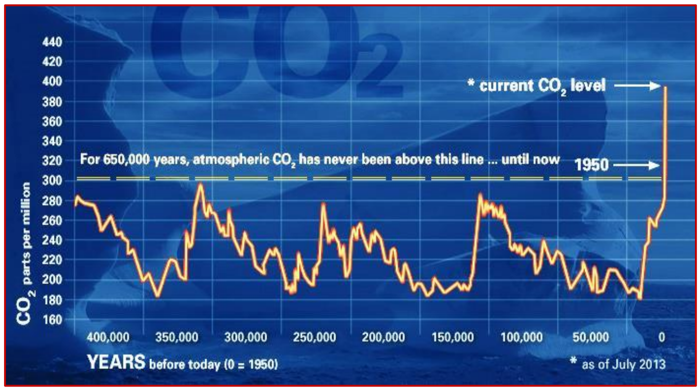
Before Flood

After Flood

10. Climate Change

Global warming is causing climate changes. Carbon dioxide (co_2) content in the atmosphere is an indicator of global warming. The researchers at Vostock laboratory drilled cores from the Antarctica ice sheet for exploring past weather cycles. Their test results have shown that co_2 content varied between a small band of 180 to 300 ppm during last 4000 years. It is now increasing. Please see Fig. 3 for Graph showing Ice Core Test Results.

FIG 3: VOSTOCK LABORATORY TESTS OF DRILLED CORES



The co_2 gas content has started showing significant increase from about 1950. The gas content and atmospheric temperature are sharply accelerating since about year 2000. As a consequence the climate is warming and affecting the weather. It is estimated that the future summers will be longer and hotter. Thunderstorms will increase and the dry spells will be more intense and more frequent. Prudency demands to start dedicated research to monitor the global warming impacts on Pakistan. A Global Change Impact Studies Center (GCISC) has been established under National Center for Physics as an autonomous organization. Prime Minister's Committee on Climate Change has been placed under the GCISC. WAPDA is also upgrading its glacier monitoring set up. There is need to establish research units in Sindh and Balochistan universities for climate change impacts in coastal areas of Pakistan.

It is being observed that there is a marked shift in monsoon with a rainfall shift from NE to NW. Monsoon would seldom reach Chitral height but now it has become a frequent visitor. After 2010 every year has brought flood. Under the scenario of anticipated future weather all our barrages wil be found as under designed.

Barrage on Chenab river is designed for 11 lac cusecs. Exceedence of 11 lac cusecs flood in Chenab river is a high probability. It cannot be ruled out that this magnitude flood will not occur soon. It may even occur this year or next year. Are we prepared to deal with it and avoid devastations in downstream areas. Frequency of past floods in Indus, Jhelum and Chenab rivers is shown in Table 2 & Fig 4. It will be noted that Chenab river has the history of bringing larger number of over 6 Lac cusecs floods; more than Indus.

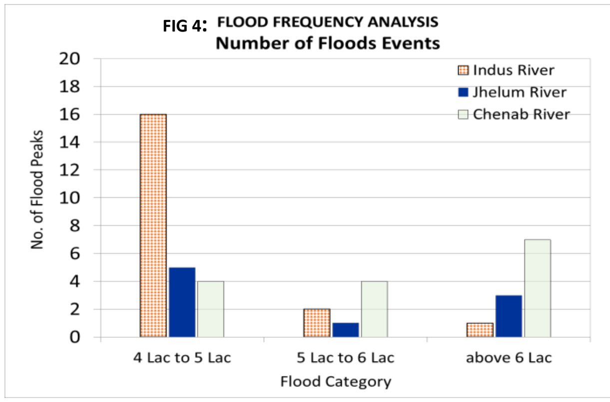


Table 2: FLOOD FREQUENCY ANALYSIS

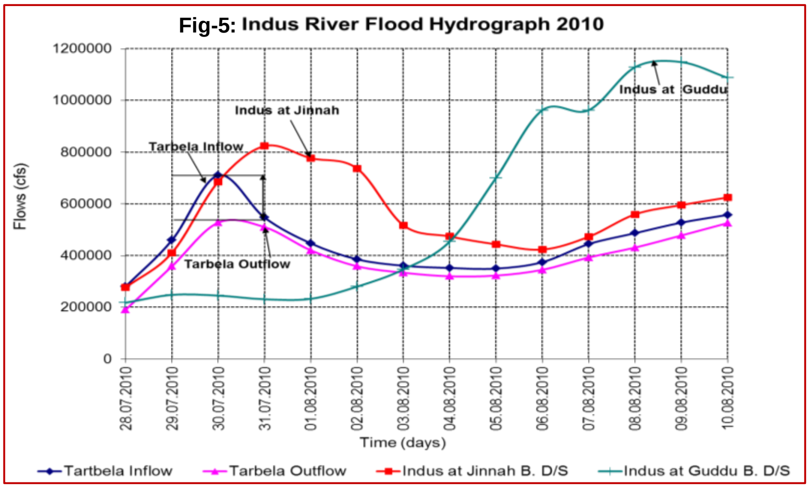
Flood Peaks (cusecs)	Indus River	Jhelum River	Chenab River
1 Lac to 2 Lac	0	9	17
2 Lac to 3 Lac	5	20	13
3 Lac to 4 Lac	28	10	7
4 Lac to 5 Lac	16	5	4
5 Lac to 6 Lac	2	1	4
above 6 Lac	1	3	7

Contingency plans should be prepared separately for Indus, Jhelum & Chenab river floods. These plans should indicate the location of infrastructure in the flood route with special focus to the low lying areas and villages/towns to be affected. These plans should include flood alerts, action points, responsibility lists, guidelines and more importantly the plan B's in events of failure incidents.

Federal Flood Commission (FFC) is supporting projects to enhance flood fighting capabilities of Provincial Irrigation Departments. Interventions for flood management usually comprise of watershed works, river training structures, escape channels, breaching sections and rehabilitation of damaged structures, bridges and culverts. All these efforts do control and direct the flood flows but they do not eliminate inundation of towns and villages. The need of safe passages to shelter places for the affectees has to be addressed. There is urgent need of constructing flood emergency campsites at existing or specially built high grounds in the vicinity of groups of vulnerable villages. The surface/floor level of such campsites should be decided on the basis of high flood levels recorded in the area. The sites should be equipped with sanitary facilities for public health. Trees may be planted to ensure shelter and meet O&M costs to look after these places.

The National Disaster Management Agency's (NDMA) job is complex and comprehensive, dealing with all types of disasters. Floods need specific attention. WAPDA and NDMA should form a Flood Committee to plan the pre flood, during flood and post flood tasks and relief projects for implementation.

During 2010 flood, Tarbela Dam prevented a major disaster downstream. As much as 235,000 cusecs flow was trapped at Tarbela reservoir (see Fig-5). Without this the inflow at Guddu could have been in far excess of its discharge limit which could mean a far greater disaster in Sindh.



11. Droughts

Drought is an insidious hazard of nature. Unlike floods the droughts don't have a clear beginning and end. They just creep in and then gradually fade out. The drought can be defined as a protracted period of deficient precipitation resulting in extensive damage to crops. It is a degree of departure from the average of precipitation or some other climatic variable over some time period.
A great threat from climate change is severe and prolonged droughts. The period 1998-2002 was history's worst drought (in 50 years) in Pakistan (Dr. Kamran Ansari, MEUT Jamshoro).
This drought started in 1997 when El. Nino developed in the Pacific ocean but intensified in 1998 reaching its peak in 2000. Sindh, Balochistan, Afghanistan & India's Rajasthan were affected.

A prominent feature of drought is warmer and drier climate with its impacts manifesting on crops and drinking water. Country specific studies and research are required to prepare adaptation plans for addressing the challenges of drought conditions. A few examples of adaptive measures are;

- Promote and expand rainwater harvesting.
- Construct small storage dams and village ponds to meet local needs of water.
- Introduce water reuse and recycling schemes.
- Change cropping patterns and use drought resistant crops.

- Adjust dates for sowing of crops.
- Adopt high efficiency irrigation system.
- Install desalination plants in coastal areas and near natural lakes.
- In coastal areas build seawalls and storm surge barriers.
- Establish network of mobile units to provide safe water in remote areas.
- Prepare targeted heat-health action plans and appropriate system for provision of such services.

Foremost in drought conditions is that quality and yield of crops is adversely affected creating food problems in the country. Humans and cattle-stock die of hunger and thirst. Study of such problems alongwith specific research is needed to devise adaptation measures. Balochistan has suffered most in the recent decades when there was every second or third year a drought year. Research centers should be established in Balochistan to produce site specific solutions.

12. Conclusions and Recommendations

1. Enhance the existing telemetry and flood forecasting systems.
2. Examine flood control needs at all barrages and canal headworks. Develop contingent plans for flood water to bypass various barrages and bridges where breach section does not exist.
3. Every year In the month of June, inspect all flood protection embankments for their safe performance.
4. Prepare and implement projects to provide flood emergency campsites at selected locations near villages and towns vulnerable to flood inundation.
5. Review the design floods under climate change scenario and modify existing barrages and bridges to handle 1 in 100 year flood.
6. Provide flood management potential in Kalabagh and Mangla Reservoir operations.
7. Examine possible use of wetlands for flood retention and to provide room for river passage. Netherland is doing it on river Rhine and lessons can be learnt.

8. Give priority to the restoration of flood embankments over restoration of aprons and spurs.
9. Provide and upkeep adequate flood fighting material and machinery at critical vulnerable sites.
10. Towns located in flood prone areas should be relocated to safer places.
11. Arrange and ensure that in the event of large flood, the electronic media should not spread wrong news and rumours which may undermine public trust in the state machinery.

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TURNING WATER TECHNOLOGY INTO BUSINESS

Dr. Naveed Alam[17]

Abstract

The most essential ingredients – for the diffusion of water technology and for creating business opportunities in Pakistan – are trained hydrologists and skilled water managers; unfortunately Pakistan does not have them to create and regulate water business. Many institutes in water sector do exist but neither they are equipped with the modern hardware and software nor they are capable to perform their functions effectively and efficiently. Since long, many educational institutes and universities have been delivering water education in a traditional fashion, but, unfortunately, their graduates are not equipped them with the desired national and international marketable knowledge and skills. Water sector in Pakistan has a huge potential by virtue of which we can create hundreds to thousands of job opportunities, but unfortunately neither we are deploying our youth in the right direction nor providing them with the modern knowledge, therefore, they are not able to capture their business share of the world. This paper highlights the urgent need of establishment of modern water institutes as well as rehabilitation and modernization of existing public departments in Pakistan so that they would be able to create jobs for smart and trained hydrologists.

Introduction

Pakistan is lacking behind in water sector owing to the deficiency of skilled hydrologists, which are the essential ingredients of water-based economy and the driving force to move the country ahead; hence, they could be able to fetch the foreign exchange by providing water-based skills, products and services.

A large number of institutes, public and private universities do exist, which deliver water education in a traditional fashion without considering the emerging need of recent time. They are neither equipping their students with the modern and up-to-date knowledge and skills, nor they are capable to providing them the appropriate research platform, nor they are encouraging them to think innovatively.

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The institutional strength does not exist right at the moment in Pakistan; whereas, it did exist in 1970s, when G. D. Bennett was part of team of U.S. Agency for International Development and U.S. Geological Survey (USGS) who taught hydrology in Lahore (Bennett, 1976). During 1960s and 1970s, the Water and Power Development Authority (WADPA) in collaboration with Colorado State University and USGS conducted many theoretical and numerical studies (McWhorter, 1980; Mundorff et al., 1972) and run a number of physical campaigns to discover the geology and hydrology of the Punjab as well as many other areas of Pakistan (Bennett et al., 1967; Greenman et al., 1967; Kidwai, 1963). A number of WAPDA engineers, hydrologists and geologists were trained in the United States of America (USA) under the memorandum of understanding between both the countries, which was originally initiated by the President of Pakistan (General Ayub Khan) in 1961, when he asked to get help from President of USA (John F. Kennedy) for the solution of water problems in Pakistan (Ahmad, 1994). They were also taught many different courses in water sector (i.e., hydrology, geology, water resources management, etc.) including Master's and PhD studies with their research projects relating to the water issues of that era in Pakistan (refer to WAPDA archives).

The World Bank has also conducted many studies to develop and manage the water resources of Pakistan. It has developed many software and hardware to predict the future of Pakistani water resources and subsequently its management (Ahmad and Kutcher, 1992; Alam and Olsthoorn, 2011). It had also started many programs to discover the potential of Pakistani water and its development (Ahmad et al., 1990; Alam and Olsthoorn, 2011). The WAPDA has many useful research reports, data and documents regarding the geology, hydrology and topography of the Punjab and other areas of Pakistan; but all of them are going to waste because of lack of interest on the part of WAPDA. They are not upgrading themselves at par with the international development in water sector. They did not provide them online in public domain so that researchers and students could be able to get benefit from them and to provide further useful insights and share their research experiences. Instead of WAPDA, USGS has published many research reports of Pakistan online and those are freely available at https://store.usgs.gov/.

The public domain codes to manage and develop our existing water resources and to predict the future of our water are freely available online; only need is to explore them for our customized use. For that very purpose, we need skilled and trained hydrologists and efficient water managers. Therefore, this article urges to: (1) develop our institutes at par with the international standards, (2) provide advanced and modern water education in our universities that should equip the hydrologists and water managers with the use and understanding of modern theoretical and numerical developments, (3) promote the culture of transparent and free access of water resources to all sectors of society that may lead to unmatched advancement in water sector, (4) create awareness regarding the use of freeware and public domain codes and software by virtue of which we can save millions of dollars of our foreign exchange that we may spend for the purchase of costly and GUI (Graphical User Interface) codes and/or software, (5) promote local industry to manufacture and assemble sensors and data loggers for the purposes of local and international sales, and (6) provide opportunities in computer and information technologies for onward earning of foreign exchange and for creating a lot of jobs in water sector.

How can we turn technology into business that may lead to jobs in water sector?

1. Use of water technology and knowledge

This article urges that there is no need for the water authorities and institutes to buy costly interfaces (GUIs) because now-a-days a number of codes are available online as freeware; only need is the trained and skilled hydrologists, who could be able to explore them for their customized use.

Fig. 1 shows the presence of a community of open source and free software as developed and promoted by Deltares (https://www.deltares.nl/en/). This presents the way how we can access different free software such as Delft3D, OpenEarth, XBeach, etc. Fig. 2 shows an introduction of a hydrological model – Delft3D. Figs. 3-5 describe the open and free codes of MODFLOW, SWI2 and SEAWAT. Anyone can access them freely and can use them for their own customized need.

We can invoke those free and open source codes and models by using any free programming language, of which Python (https://www.python.org/) is customer friendly and can be used to write input files for those codes and it can also be used to read and visualize the output.

It is pertinent to mention that trained and skilled hydrologist is the only essential requirement to explore the free and open source codes and models; otherwise, it is not possible to use them for our customized need. Our focus should be on the efficient and effective use of such free codes and models; this can lead us to create hundreds to thousands of jobs in water sector, which other way round is not possible to achieve.

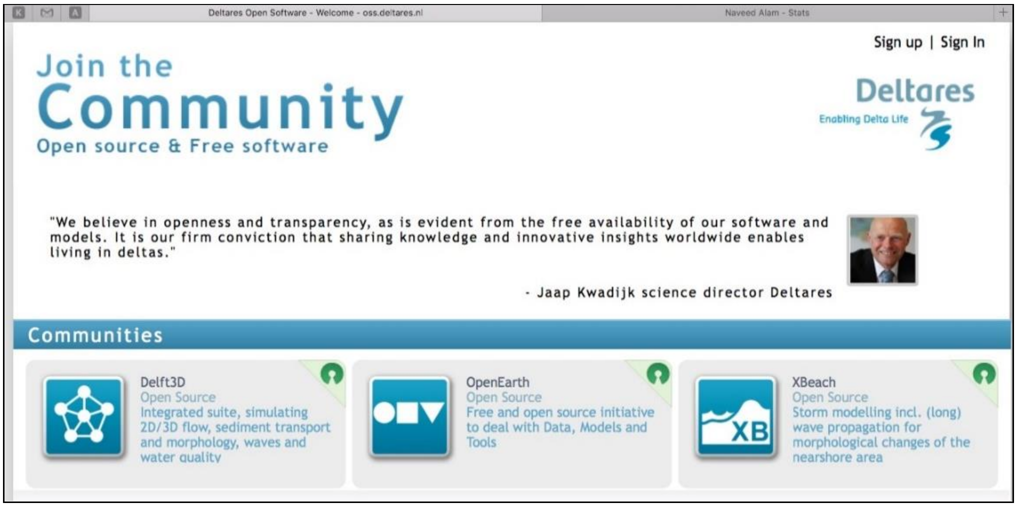

Figure 1: Open source and free software community (https://www.deltares.nl/en/).

The launch of the **Delft3D Flexible Mesh Suite 2016** (Delft3D FM) took place during the

Delft Software Days (DSD-INT 2015) at this year's Symposium 'Next Generation Hydro Software (NGHS)'.

As of 18 November 2015, Delft3D FM is available to all users with a Delft3D Service Package in place.

Our development team is working hard to make all components of Delft3D FM available in open source, both computational engines and Graphical User Interface components (GUI). For now, only DELWAQ, RTC-TOOLS and SWAN are available in open source, which are the computational engines of D-Water Quality, D-Real Time Control and D-Waves, respectively. The key component of Delft3D FM is the D-Flow Flexible Mesh (D-Flow FM) engine for hydrodynamical simulations on unstructured grids in 1D-2D-3D. As long as the 1D-2D-3D architecture of D-Flow FM is subject to change, the access to the D-Flow FM code will be limited to a small group of Partners in Development. We anticipate having D-Flow FM in open source for everyone late 2016, but it could become 2017/2018.

For an introduction to Delft3D FM, please watch the demo videos on our website.

Figure 2: Delft3D – Open source and free software (https://www.deltares.nl/en/).

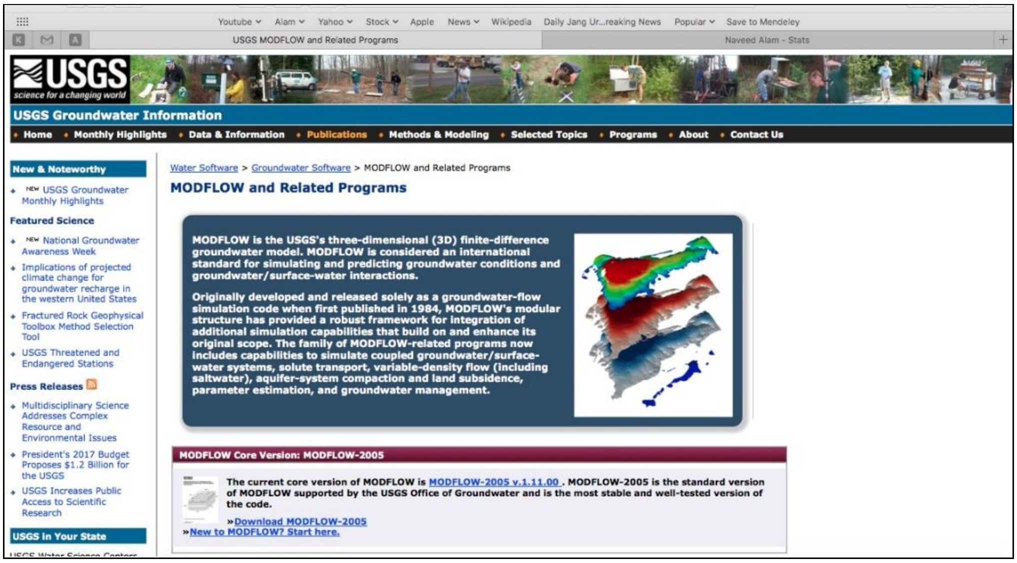

Figure 3: MODFLOW – USGS-based 3D finite-difference groundwater model. It is freely available as a public-domain code (http://water.usgs.gov/ogw/modflow/).

Figure 4: SWI2 – Seawater intrusion package for MODFLOW (https://pubs.usgs.gov/tm/6a46/).

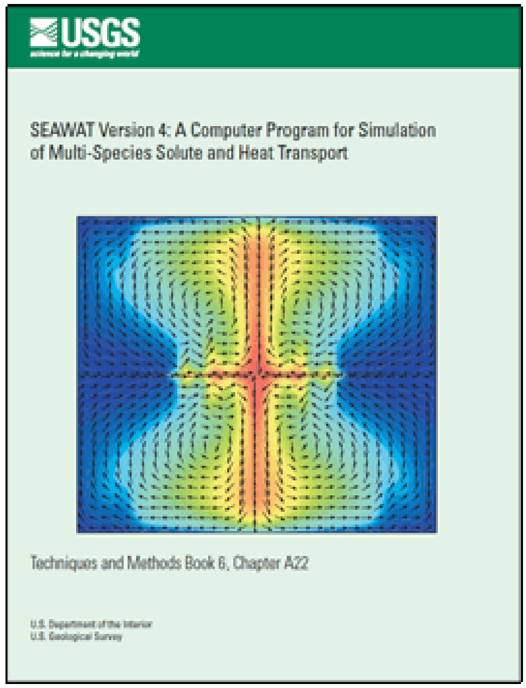

Figure 5: SEAWAT – A computer program for simulation of multi-species solute and heat transport (http://water.usgs.gov/ogw/seawat/).

2. Effective and modern monitoring network

Effective and modern monitoring networks – to measure and record the time series data of hydrological, meteorological information, water table and vertical salinity-depth profiles – either do not exist in Pakistan or this practice had been stopped since 1980s. Whereas, such type of data and information were recorded by the WAPDA in collaboration with its foreign associates [USGS] during 1960s-1980s.

For example, we consider the case of groundwater measurements in the Punjab. The USGS has prepared vertical salinity-depth profiles first time in the history of Punjab in 1960s (refer to Fig. 6). They had run a province-wide campaign to collect water samples at different depths down to 500 m. On the basis of their analyses, they have prepared salinity-depth profiles [maps] for the Punjab. Since then, these maps were neither updated nor revised. Currently, IWASRI (International Waterlogging and Salinity Research Institute) – a subsidiary company of WAPDA – is recording the groundwater measurements. They record the water table measurements and collect the groundwater samples from the existing network of piezometers to analyze their chemical properties only twice in a year. This existing practice of measurements is neither in accordance with the modern international standards nor providing any useful insight about the real situation of groundwater.

Now-a-days, many different categories of data loggers and sensors are available in the market for recording water table fluctuations and for measuring the groundwater salinity over tens to hundreds of meters below the ground surface.

The author has recently conducted an extensive geophysical campaign in the Punjab and collected 600 salinity-depth profiles by using TDEM (Time-domain electromagnetics) technique (Alam, N., 2014). The TDEM technique is an effective method to estimate the vertical salinity distribution of the subsurface; the results can be translated into a model of the geology.

The plan of geophysical survey along with its cross-sectional view is shown in Figs. 7 and 8. For this purpose, a very sophisticated and modern light-weight portable instrument (TEM-FAST; http://www.aemr.net/) was used (refer to Fig. 9). The field procedures involved placing a square loop of wire or antenna at the ground surface. A steady current in the transmitter loop was abruptly turned off to create a magnetic pulse or transient in the ground. The measurements were recorded with the same transmitter loop, and the TEM-RES program (http://www.aemr.net/) conducted the inversion of the TDEM sounding data. The TDEM measurements resulted in the vertical profile of the electric resistivity of the subsurface, which indicated the depth of the water table and thickness of the fresh and brackish groundwater layers (Alam and Olsthoorn, 2014).

The described campaign was a major effort; however, a modern and the most efficient utilization of this technique can be made through air-borne TDEM geophysics (Viezzoli et al., 2009; Abraham et al., 2012). These air-borne methods provide a full 3D salinity distribution over entire areas in a few days for a low price per unit length of surveyed area. Such methods are probably the only way to obtain a full 3D image of the brackish and salt water distribution and, therefore, of the situation in which the agriculture of the Punjab finds itself today, i.e., being currently dependent on groundwater for additional irrigation and at the same time being plagued by increasing salinities. This situation warrants a careful management of fresh groundwater that originates from canal leakage in areas in which naturally only salty groundwater is present, i.e., the center of the salty doabs. Such airborne methods are probably essential to come up with consistent areal salt and brackish water management. They are also necessary to monitor area-wide progress or regression over longer periods of time. It is believed, that given the importance of mapping of brackish and salt groundwater, such campaigns deserve or require priority by the Pakistani government. At least our TDEM campaign has shown the feasibility of such mapping (Alam, 2011; Alam and Olsthoorn, 2014).

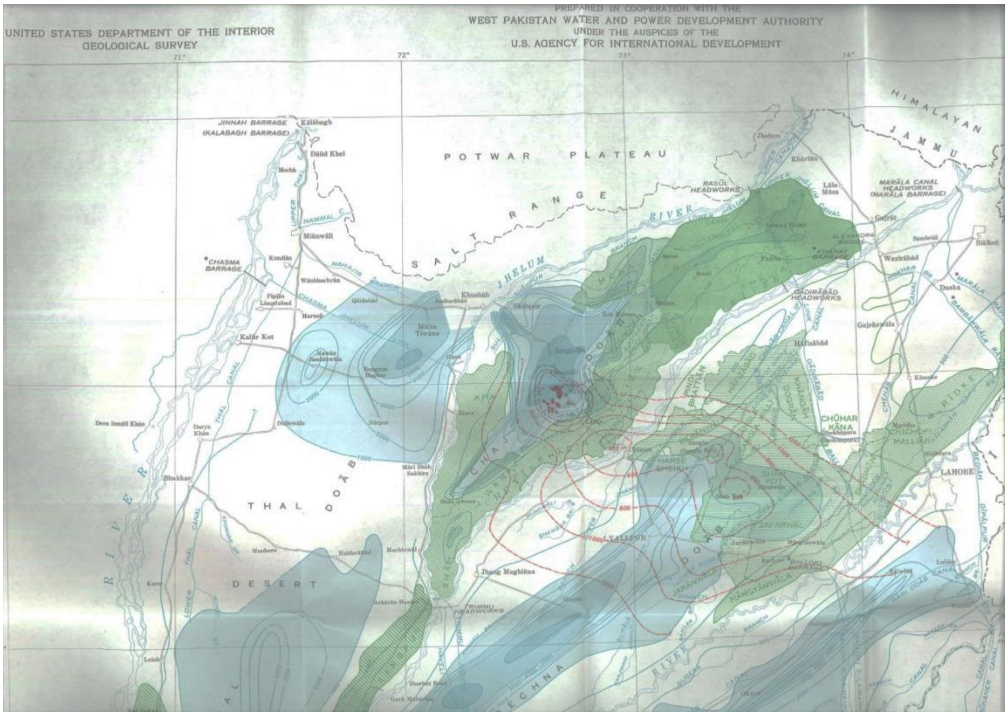

Figure 6: The contour map of groundwater salinity at 30 m below the ground surface in the Punjab (USGS archives).

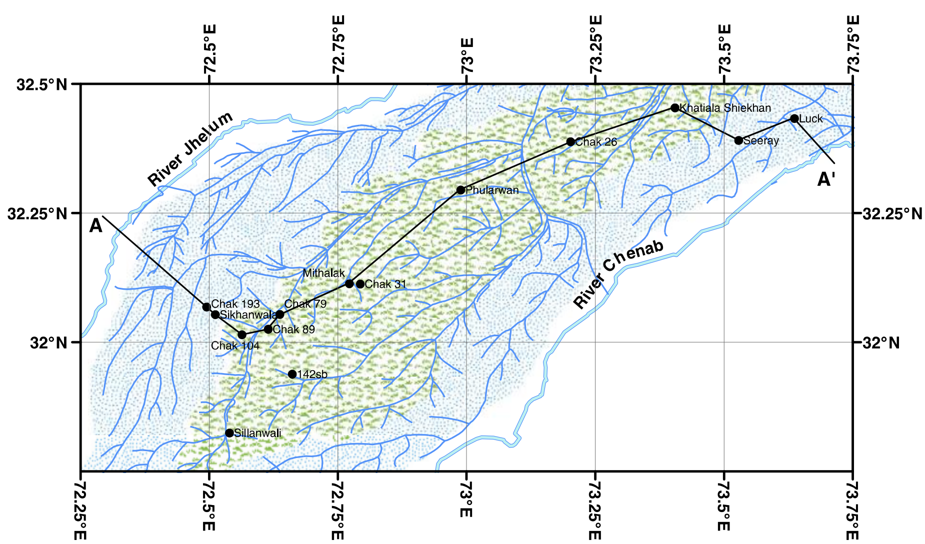

Figure 7: TDEM surveyed sites represented with black dots (Alam, 2014).

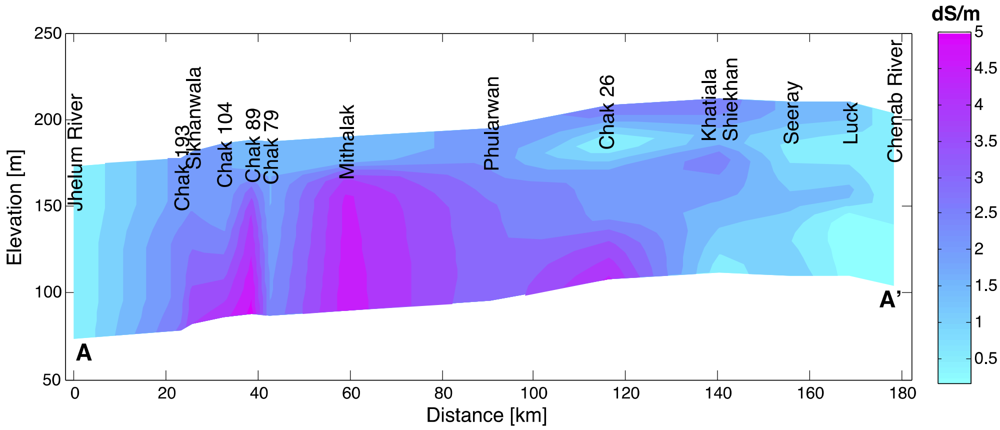

Figure 8: Vertical distribution of the electrical conductivity (EC) of the groundwater, which is profiled along a section AA´(refer to Fig. 7; [Alam, 2014]).

Figure 9: TEM-FAST - Geophysical instrument (http://www.aemr.net/) that was used for an extensive geophysical campaign in the Punjab.

Mobile Water Management is another innovative and game-changing method that can be used for measuring surface water levels and for controlling gates of canals and other types of regulating structures by simply taking a picture with a mobile. It can also be used for water quality tests. It is very cost-effective way to measure and manage water for onward effective, timely and informed decisions (refer to Fig. 10; http://www.mobilewatermanagement.com/). Compared with manual readings, this innovation reduces monitoring costs by 50%. The introduction of mobile-based water measurements and management in the Punjab can create a lot of jobs in the water industry. Only need is to train our students and professionals on modern lines so that they could be able to capture their business share.

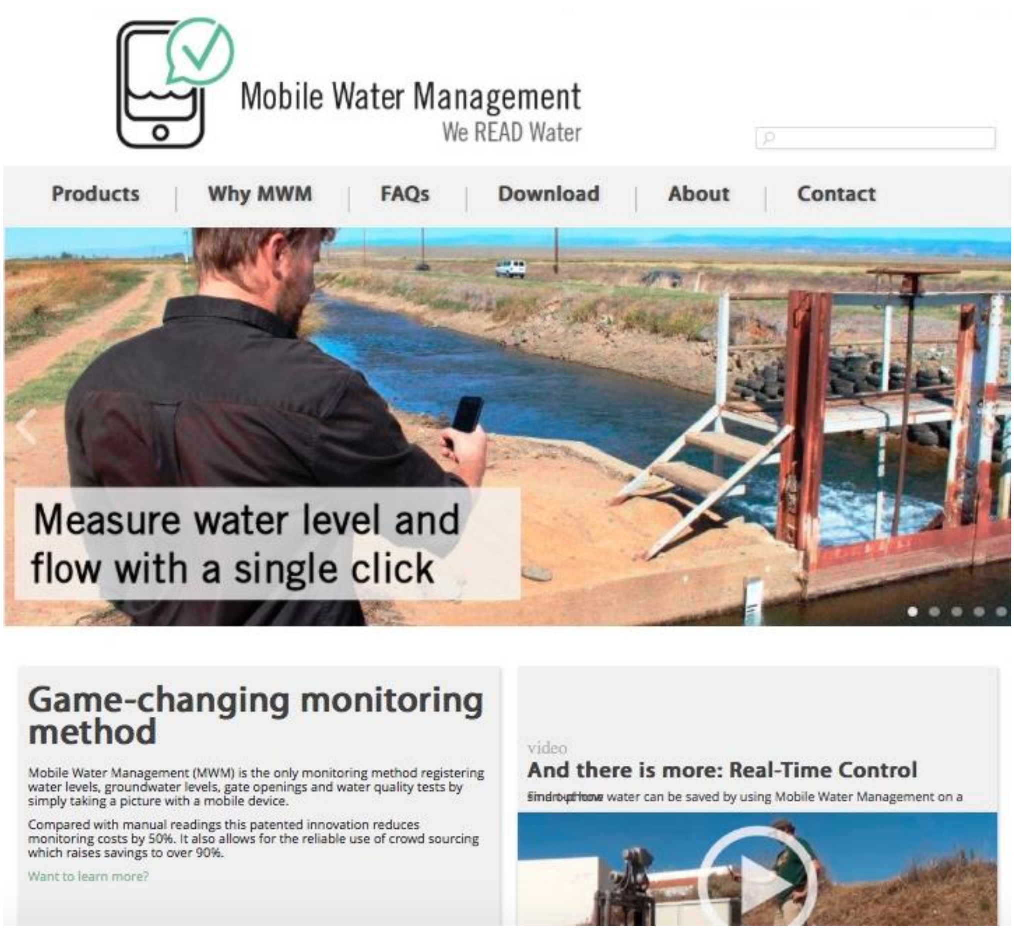

Figure 10: Mobile-based water measurements and management for taking effective, timely and informed decisions (http://www.mobilewatermanagement.com/).

3. Industry and skilled manpower for data measurement

The local manufacturing and/or assembling of equipment (i.e., data loggers, water sensors, software for water measurements) requires skilled and trained hydrologists besides many other professionals. Similarly, data collection, monitoring and interpretation do also need smartly skilled hydrologists.

4. Institute for water education

The Institute for Water Education is an essential requirement to craft hydrologists and water managers who should be capable to invoke open-source and freeware models for their customized use through computer programming. The skilled hydrologists should be able to turn free codes into GUIs for fundraising and for earning foreign exchange.

Those who are interested to start their own companies can utilize the existing facilities of business incubation of LUMS and Plan 9 (refer to Figs. 11 and 12). They should have innovative ideas and capabilities to turn them into useful business, services and products.

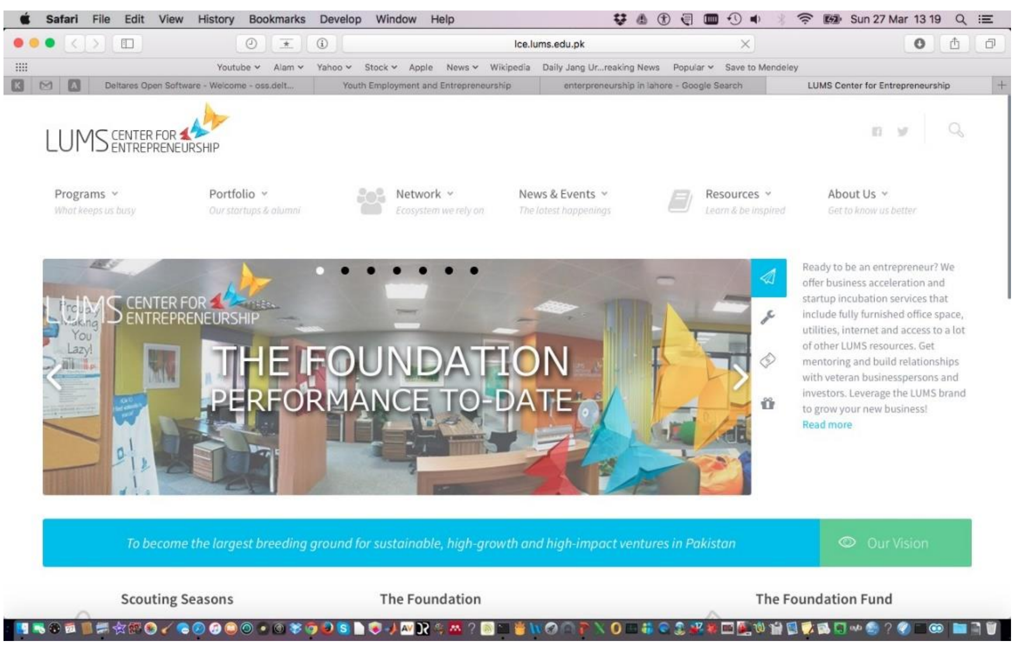

Figure 11: LUMS Center for Entrepreneurship (https://lce.lums.edu.pk/).

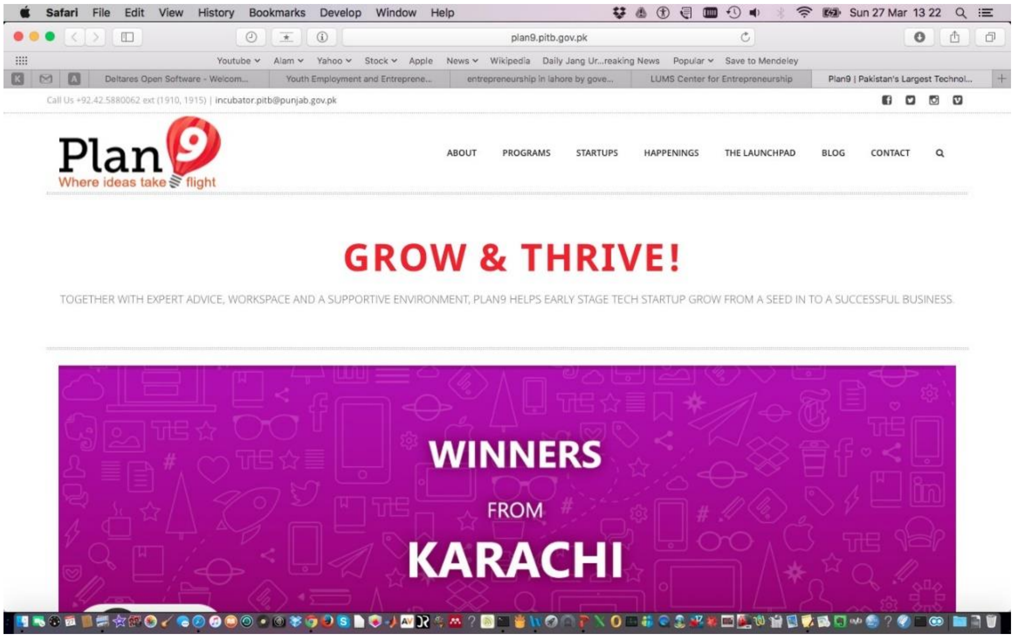

Figure 12: Incubation center for startups (http://plan9.pitb.gov.pk/).

Conclusions

A huge potential does exist in the national and international markets regarding the use of open-source and freeware hydrological codes and models, the efficient and cost-effective water measurements and monitoring for onward effective, timely and informed decisions. Such potential does really require innovation in service delivery; in this regard, our academic and professional institutes together with entrepreneurial skills should create professionals of international standards.

A large number of water institutes do exist in Pakistan but none of them is providing quality education to their students with the desired and essential skills of international level. Because of this, we are loosing our job and business share nationally and internationally.

This article urges the urgent need of such an institute in water sector who could be able to equip their students with the modern skills through quality education. That institute may lead to craft hydrologists and water managers and train them on modern lines so that they could be able to capture their business share by turning water technology into business (refer to Fig. 13).

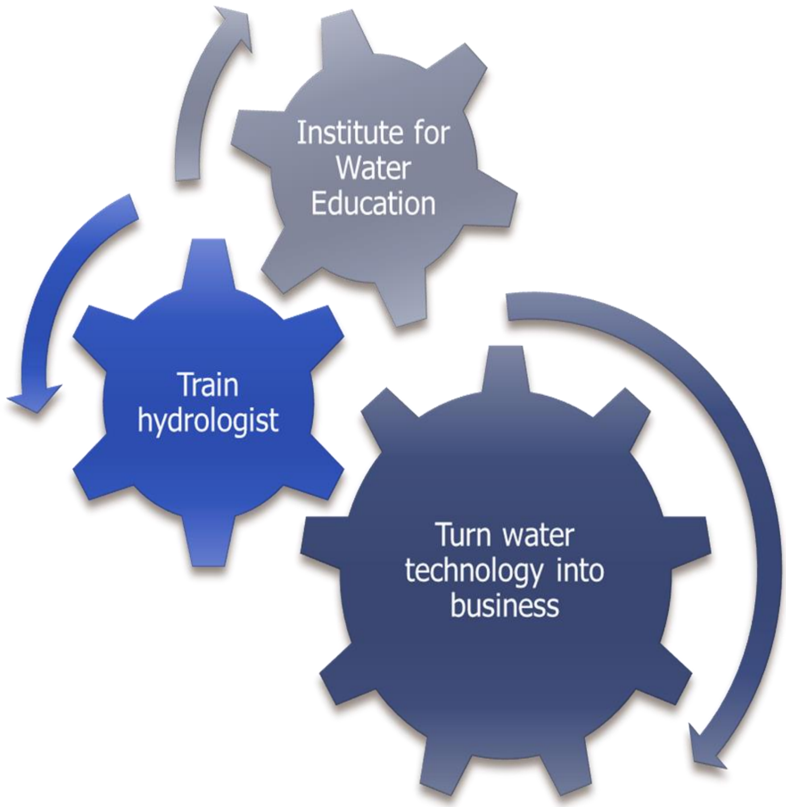

Figure 13: The driving wheels for turning water technology into business.

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THE EASTERN DIVIDE

(AN ECONOMIC ROTULUS ON RAVI, SUTLEJ AND BEAS)

Engr. Usman-e-Ghani[1]

1. ABSTRACT

Water economics is virtually an economics of an unlimited multiplicity. It may be said to be spreading over a range of economics of agricultural and food security to that of the economics of environment and climate change. Still on the other side, it is an economics of super structures as that of the large dams and carriers channels on one side and the complex networks of water courses or those of flood drains on the other.

To each of the dimensions, there exists an inter-relationship of a wide range economic activities, but virtually in such a proportion as that of a part to the whole. The paper under reference may thus be expected to list few of such dimensions which possess their link with the 'Eastern Divide'.A divide because of which the three Eastern tributaries of the Indus Basin River System (i.e. Ravi, Sutlej and Beas) were truncated from the western tributaries (i.e. Indus, Jhelum and Chenab) and were given to India under the provisions of Indus Waters Treaty 1960. The transfer of rights was made for an unrestricted use, depriving the reaches downstream of all the historic flows.

2. KEYWORDS

Ravi, Beas, Sutlej, Indus Waters Treaty 1960, Agricultural Economics, Groundwater Depletion, Environmental Economics.

3. INTRODUCTION

The Indus River System is one of the most significant of all the irrigational river systems in the World in several respects. A number of studies have referred the Indus River System as one of the largest network of the type, which feeds a population of more than 180 million people.The system efficiency has, therefore, remained a subject of numerous studies in the distant and near past. All the dimensions which contribute to any irrigational system have been made foci of research and investigation. Beside, other, these also include the variation in their carrying capacity of the system due to various aspects including the impacts of Indus Water Treaty 1960.

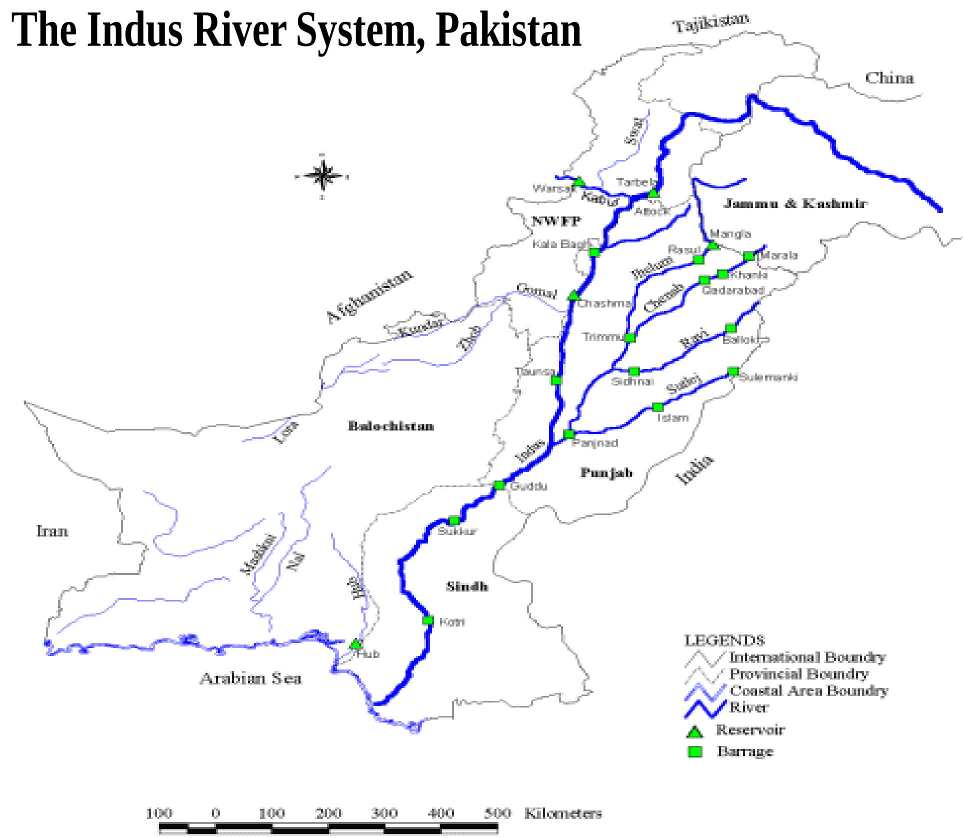

Figure – 1: The Indus River System, Pakistan

It would also be worthwhile to reiterate here that freshwater now is globally a scarce commodity. The optimum utilization of water resources is of utmost importance because the world as a whole is suffering from vast water shortages. The water deficit, emerged and growing rapidly in recent times, largely remains unnoticed. In terms of remedial measures, however, most of the countries are trying to "manage" the water shortage problem instead of "solving" it. Many countries do not have any options and are thus relying on gradually increased import of grain and water related products.

In Pakistan, the water requirements over the next decades are also required to be realistically assessed. Further studies related to the water resource efficiency, as are being intended to be hinted upon through this paper, beside those pertaining to the potential increase in the yields or productivity would hence be required to be appropriately and emphatically undertaken, so that the country may not fall again into the category of grain deficit nations.

4. THE INDUS SYSTEM OF RIVERS

The Indus System of Rivers in the Indus Basin comprises the Indus and its five main rivers i.e. the Jhelum, the Chenab, the Ravi, the Beas and the Sutlej. They all combine into one river near Mithan Kot in Pakistan, which outfalls into Arabian Sea south of Karachi. The boundary of the Indus Basin is clearly defined on the West, the north and north-east, by mountain ridges (watersheds). However, the boundary on the south is not so clearly defined due to absence of hills and active rivers. The total area of the Indus Basin is roughly 350,000 square miles. Most of it lies in Pakistan and the rest is in occupied Jammu and Kashmir, India, China and Afghanistan. The climate in the Plains downstream of the rim stations ranges from semi-arid to arid in the south. Annual rainfall ranges from about 30 inches to about 2 inches in the south. The total annual average discharge of these rivers at the rim stations (where measured) is about 170 MAF (Million Acre Feet).

5. GEOGRAPHY OF RAVI, BEAS AND SUTLEJ (RBS)

Out of the whole of the Indus System of Rivers, a short look at the geography of Ravi, Beas and Sutlej, which are the subject of this paper, is as follows:

Sutlej River in Kinnaur, Himachal Pradesh, India

Sutlej: The longest of the five tributaries, the Sutlej originates near Mt. Kailash along with the Indus and runs a course of **964 miles (1550 km) through the Panjal and Siwalik mountain ranges and enters Pakistan through the plains of Indian Punjab.** The huge 740 feet (225 m) high Bhakra Dam, which Nehru called “the new temple of resurgent India,” is also situated on this river. These eastern tributaries of the Indus known as Panjnad combine at Mithan Kot.

Ravi River, near Chamba

Ravi: This **475 mile (764 km) long river rises in Himachal Pradesh and runs a course of 102 miles (164 km) before joining Chenab in Pakistan after flowing past Lahore.** The Thein Dam (Ranjit Sagar Dam) is located on this river at the tri-section of Punjab, Himachal Pradesh and J&K States and feeds the Upper Bari Doab Canal (UBDC) which irrigates Northwestern Punjab.

The Beas River

Beas: This 290 mile (467 km) long river originates near Rohtang Pass in Himachal Pradesh and flows through Kulu Valley and the Siwalik Range. The Pandoh Dam is **situated** on this and diverts water to Sutlej through the Beas-Sutlej link.

6. INDUS WATERS TREATY 1960

In August 1947 when South Asia was divided into two independent countries there existed one of the most highly developed Irrigation System in the world and approximately 37 Million Acres received irrigation from the flow waters of the Indus System of Rivers. All of the available water supplies were allocated to the various princely States and Provinces in conformity with the principle of equitable apportionment of the waters with preferential right to existing uses. At the time of Independence major portion of the Indus Basin formed a part of Pakistan and out of 37 Million Acres which received irrigation, 31 Million Acres were in Pakistan. The boundary line between the two countries was drawn without any regard to the irrigation works. It was, however, affirmed by the Boundary Commission and expressly agreed by the representatives of the affected zones before the Arbitral Tribunal that the authorized shares of the two zones in the common water supply would continue to be respected.

After protracted negotiations, under the good offices of the World Bank, when the World Bank was convinced that the existing uses in Pakistan could not be met by transfer of flow waters from the Western Rivers and that Storages on the Western Rivers were required for the purpose, the Indus Waters Treaty was signed in 1960. The Bank Engineers had worked out their initial proposals on averages ignoring the special needs of the seasons for the sowing and maturing of the crops when the demands of water are maximum and the flow are minimum. It took Pakistan two years to convince the Bank that Pakistan's contentions were correct that the division of the waters put forward by the Bank would not accomplish the results visualized in its proposal. The Treaty consists of 12 Articles and 8 Annexures (A to H). It is based on the division of the Rivers between the two countries. The waters of the Sutlej, Beas and Ravi rivers named in the Treaty "Eastern Rivers" are for the unrestricted use of India and the waters of the rivers i.e. Indus, Jhelum and Chenab, named in the Treaty as "Western Rivers" are for the exclusive use of Pakistan except for certain specified uses allowed to India in their upper catchments.

Under the Treaty, Pakistan was required to construct and bring into operation a system of works, which would accomplish the replacement, from the Western Rivers, of water supplies for irrigation canals in Pakistan, which on 15th August 1947 were dependent on water supplies from the Eastern Rivers. These replacement works, comprising two storages Dams (One on Indus River and one on Jhelum River), six new barrages (diversion dams), remodeling of two existing barrages, seven new inter-rivers link canals and remodeling of two existing link canals, have since been completed. There was a Transition Period of 10 years during which Pakistan was to receive waters from the "Eastern Rivers" for use in the aforementioned canals.

7. THE AGRICULTURAL ECONOMICS

Agriculture is the largest sector of the economy. With primary commodities accounting to more than 20% of GDP and about 64% of total employment, the sector contributes to more than 60% of foreign exchange earnings. Despite having a considerable irrigation infrastructure, the water on the other hand is a scarce resource. With increasing population and sedimentation of reservoirs, the country is facing serious water shortages. The water availability, which used to be at 5650 m^3/capita/year in 1951, is now being reported as approaching to 1000 m^3/capita/year. It has been estimated to further decline to 800m^3/capita/year by the year 2025 (Draft National Water Policy 2005). Pakistan may thus face water scarcity as a fundamental challenge to its economy and social development in next 5-10 years and we should immediately turn our attention to this challenging issue. If no immediate action is taken, water scarcity would certainly become a critical threat to the future growth of the nation.

With above in the backdrop, it may be agreed that the division of rivers as envisaged through Indus Waters Treaty 1960was a distinct departure from the concept of international law of upper and lower riparian rights (protection of existing uses from the same source). Because of the Treaty Pakistan had to forgo the entire perpetual flow of fresh waters of the three Eastern Rivers (24.00 MAF) which it used to historically receive for irrigation as has been mentioned hereinabove.

From Pakistan's point of view the settlement plan envisaged under the Indus Waters Treaty 1960 had several opportunities and threats as noted hereunder:

Opportunities:

i. After the completion of Indus Basin Replacement Plan Works each country became independent of the other in the operation of its supplies.

ii. Each country is responsible for planning, constructing and administering its own facilities in its own interests and free to allocate its supplies within its own territories, as it deems fit.

iii. This provides strong incentives to each country to make the most effective use of water, since any efficiency accomplished by works undertaken by either country for storage, transfer, reduction of losses and the like, accrues directly to the benefit of that country. The same is true of efficiency achieved in operation.

iv. The independence afforded by the programme also brought benefit of a different kind. The location of works serving each country or territories under its control, and the assurances against interference by either country with the supplies on which the other depends has reduced the chances of disputes and tension.

v. Before the completion of Indus Basin Project works after signing of the Treaty, the entire irrigation system in the Indus Basin was based on run-of-the river supplies. The hydrology of the Rivers is such that about 80% of the total water was produced during the monsoon period July-September. The winter supplies in drought periods became very critical. With the availability of assured supplies made available with the storage of waters in the Reservoirs, waters availability in winter has been assured and is insignificantly affected in drought conditions. Besides total withdrawals and canal heads in Pakistan has increased from about 67 MAF to 104 MAF.

Threats:

The defects of the settlement plan broadly includes following:

i. The traditional sailab (Flood) irrigation which is the most ancient way of using river waters – on the Sutlej, Beas and Ravi would disappear, because when these rivers are fully developed by India the traditional floods would decrease or disappear and the sailab areas would not get the seasonal water, which permitted cultivation. This area is quite considerable in extent.

ii. It was feared that when the Eastern Rivers lost their regular flow the channels would silt up and any subsequent flood would cause great havoc in Pakistan in additional to other environmental effects.

iii. The up-keep of the new link canals and storages would mean a very heavy additional burden on the cost of maintaining irrigation. Besides, storages are not substituted to perpetual flow water as the storages have limited life.

Though we have not been able to take much advantage of above noted opportunities, but on the other hand the threats struck us with the full force. The Indian side, while taking full advantage of the opportunities available to them, embarked on a full throttled program of development over the part of the basin allocated to India. Pakistan on contrary continued with the plans which dominantly lacked the required quantum of luster so as to amicably embark upon the truly productive schemes. The differences of development on either side of the border consequently turned out to be too obvious virtually within no time. The sections of the paper which follow discuss such developments in a bit of broader detail with emphasis on Ravi, Beas and Sutlej.

8. PRE PARTITION UTILIZATION FROM RAVI, BEAS AND SUTLEJ (RBS)

Ravi, Beas and Sutlej are three Eastern Rivers of Indus basin, which have been allocated to India under the Indus water Treaty of 1960 signed between India and Pakistan. The western rivers of Chenab, Jhelum, and Sindh (Indus Main) have been allocated to Pakistan with some nominal use in India.

a) Sutlej River

On this river, Headworks at five places existed before partition in 1947. These were mainly for diversion of river flow for perennial and non-perennial irrigation, depending upon available flow supplies. There was no storage and therefore most of the monsoon's flow escaped lower down. The five headworks were as under:

(a) Rupar Headworks for feeding Sirhind Canal and Bist Doab Canal.

(b) Ferozepur headworks downstream of confluence of Sutlej and Beas.

(c) Sulemanki Headworks.

(d) Islam Headworks and

(e) Panjnad Headworks.

Through Rupar Headworks, partially whole of the perennial river flow was utilized by the canal taking off from this place. The escape during winter season and regeneration below Rupar were however exclusively used by Bikaner Canal, in addition to its Beas share. Only monsoon flows escaped lower down which were later on harnessed by the construction of Bhakra Dam.

Ferozepur Headworks is situated just at the Indo-Pakistan Border and used to feed Dipalpur Canal on Right flank (now lying in Pakistan). This has become redundant after partition.

On the left flank there were two canals viz. Eastern Canal in Punjab and Gang Canal mainly meant for use in Bikaner State. Eastern Canal was a non-perennial Canal depended only on monsoon supplies while Bikaner Canal was perennial canal. The full authorized discharge capacity of Eastern canal and Bikaner Canal was 3320 Cs. and 2720 Cs. respectively. The distribution was governed by tripartite agreement of 1920 and recommendation of a Committee headed by Shri Anderson made in 1935. The canals taking off from Ferozepur headworks mainly depended on supplies of river Beas and also regeneration in river Sutlej (both perennial and non perennial). The pre partition use of Bikaner Canal and Eastern Canal was fixed as 1.110 MAF and 0.494 MAF annually, respectively. The other three headworks viz. Sulemanki Headworks, Islam Headwork and Panjnad Headworks lie in Pakistan and are not relevant to India now.

b) Ravi River

On this river, Madhopur Headworks were constructed in 1902 to feed the Upper Bari Doab Canal (also known as Central Bari Doab Canal). This was a diversion work meant to use the river flow and no storage existed. Part of the command was situated in India and part in Pakistan. The pre partition utilization in India (Punjab) as worked out by Ministry of Irrigation and Power was 1.476 MAF.

c) Beas River

Prior to partition, there was no irrigation structure on this river and the flow was utilized beyond its confluence with Sutlej through Ferozepur head works on Sutlej. Although the Ferozepur Headworks are situated on Sutlej, but the actual utilization from it was that of Beas river. Sutlej pre-partition utilization through Rupar headworks was amalgamated with Bhakra Nangal project and it is now governed by a separate agreement known as Bhakra Nangal Agreement of 1959.

The total pre-partition utilization based on average of 10 Year (1936-46) on Ravi Beas was as under:

Sr.	Name of work/canal	River	Pre-partition utilization (MAF)	Say (MAF)
1	Eastern Canal (Punjab)	Beas	0.494	0.50
2	Bikaner Canal (Rajasthan)	Beas	1.110	1.11
-	(a)Total utilization of Beas river	-	1.604	1.61
3	Upper Bari Doab /canal (Punjab)	Ravi	1.476	1.48
4	Kashmir Canal (J&K)	Ravi	0.035	0.04
-	(b)Total utilization of Ravi river	-	1.511	1.52
-	Grand total (Beas & Ravi)	-	3.115	3.13

9. BHAKRA NANGAL PROJECT BY INDIA

The Bhakra Nangal Project is considered as major development in post partition history of India. A short discussion on the various components of the project follows:

a) Bhakra Dam

Bhakra Dam is a majestic monument across river Sutlej. Its construction was taken up first after independence, for the uplift and welfare of the people of Northern Region. The construction of this project was started in the year 1948 and was completed in 1963. It is 740 ft. high above the deepest foundation as straight concrete dam being more than three times the height of Qutab Minar. Bhakra Dam is the highest Concrete Gravity dam in Asia

and Second Highest in the world. The gross Storage Capacity of the dam is 7.57 MAF with command area of about 6 million acre. The planned upgraded capacity of power production is 1325 MW.

The water stored at Bhakra has a tremendous potential of generating hydroelectric power. There are two power houses namely Left Bank Power Plant and Right Bank Power Plant.

The power houses are connected on either side by underground cable galleries with the switch yard from where transmission lined take off.

b) Nangal Dam

Nangal Dam situated about 13 Kms downstream of Bhakra Dam is 29m (95 ft.) high & comprises 26 bays of 9.14m (30 ft.) each. It is designed to pass a flood 9910 cumecs (350000 cusecs) water. Dam diverts the water of river Sutlej into Nangal Hydel Channel & Anandpur Sahib Hydel Channel for power generation and irrigation purpose. Nangal Pond acts as a balancing reservoir to smoothen out the diurnal variation in releases from the Bhakra Power Plants.

Nangal Hydel Channel is a lined channel taking off from the left bank of river Sutlej just above the Nangal Dam. The natural fall available along the channel is utilized at Ganguwal and Kotla for generating power.

Anandpur Saheb Hydel Channel takes off from Nangal Barrage and along the left bank of river Sutlej almost parallel to and on the left side of the Nangal Hydel Channel. It is 33 Kms long with a discharging capacity of 10150 Cs. It has two power houses at Ganguwal and at Kotla. The total length of Nangal Hydel Channel is 64.5 km.

Pandoh Dam is a diversion dam of the River Beas at Pandoh (at about 21 Km),an earth-cum-rockfill dam,76.20m(250 ft.)high above the deepest foundation. A chute spillway with flip bucket for maximum design outflow of 350000 Cs. has been provided on left abutment. There are five bays in which high pressure top seal type radial gates have been installed for regulating flow of water.

c) Beas Sutlej Link

Beas Sutlej Link Project is the largest tunneling project of India. It comprises of 13.1 Kms tunnel of 25 ft. dia meters, through which water is taken from Pandoh reservoir upto the Baggi Control Works. This tunnel is capable of carrying 9500 Cs. water. The tunnel is concrete lined throughout its length and reinforced in reaches where the rock cover is inadequate. The construction of tunnel involved excavation of over 1.31 million cyd. of rock and 0.55 million cyd. of concrete lining.

Control works have been provided at the exit point of the Pandoh Baggi Tunnel for regulation of outflows from Pandoh Reservoir to meet the fluctuating demands of Dehar Power Plant. A power Plant has also been proposed at Baggi.

Sundernagar Hydel Channel, taking off from the exist portal of Pandoh Baggi Tunnel and outfalls into Sundernagar Balancing Reservoir, is 11.8 km long concrete lined hydel channel. It has got a carrying capacity of 9000 cs. and a silt ejector has also been provided at RD.1364 m. where natural outfall channel is available for discharge of silt laden waters. The channel has been lined with cement concrete.

A Balancing Reservoir with a live storage capacity of 3000 acre ft. has been constructed at tail of the hydel channel to provide balancing storage to take care of the variation between the supply required for the actual load on Dehar Power Plant and discharge in water conductor system. Sundernagar Balancing Reservoir is situated near Sundernagar. An inlet type automatic bell mouth syphon escape with hood over the intake crest has been provided to safe guard the embankments from being overtopped by the water resulting from any contingency, when Dehar Power Plant rejects load suddenly at a time when the reservoir is already full and the hydel channel continues to flow into it.

The last link of the Beas Project Link comprises of Sundernagar Sutlej Tunnel, which is 12.35 kilometers long power tunnel with 28 ft. diameter and having carrying capacity of 14250 cs. The tunnel starts from Sundernagar Balancing Reservoir and terminates into surge shaft from where three penstock headers fan out. The tunnel has been concrete lined throughout its entire length, reinforced in reaches where the rock is poor or where the rock cover is inadequate.

d) Dehar Power Plant

The Dehar Power Plant is located on the right bank of river Sutlej a little upstream of Slapper bridge on National Highway N0.21 There are six generating units of 165 MW each. The water coming out of Sundernagar Sutlej Tunnel enters into R.C.C. Surge shaft. A bypass Tunnel taking off from the surge shaft riser has been provided to bypass surplus water not required by Dehar Power Plant and to contribute water to surge shaft in the case of down surge. At the exit of the Sundernagar Sutlej Tunnel, the tunnel has been trifurcated into 8 ft. diameter steel outlet pipes. Each outlet pipe has been further transitioned into rectangular conduits to accommodate the gates. After generating power at Dehar Power plant, the Beas water is left into river Sutlej. Thus, Beas water meets with the river water at this point and that is why the system is called Beas Sutlej Link.

e) Pong Dam

Pong Dam was primarily envisaged for meeting the irrigation water requirements of Rajasthan, Punjab and Haryana. But presently, it is being used for power generation too. The Dam is located at Pong across river Beas in Kangra district of Himachal Pradesh. It is the highest earth fill Dam so far constructed in the country. The number of instruments of different types has been embedded in the body of dam to observe its behaviours. Rajasthan draws its maximum share of water from Pong Dam.

Five concrete lined tunnels were constructed for river diversion during construction stage. After serving their function as diversion tunnels two of these tunnels have been converted into outlets for controlled irrigation releases and the other three are used as penstocks. Each penstock tunnel has been provided with an emergency gate, operated from the hoist structures, located at top of the dam.

A chute spillway has been provided for passing the flood which is located on the left abutment of the dam. The spillway caters with maximum discharge of 437000 cs. Water is led to ogee shaped crest through an approach channel and controlled by six number radial gates which are operated by electrically driven mechanical hoists with provision for operation by diesel engines in case of power failure.

Pong Power Plant is a reinforced concrete framed structure, located in the stilling basin downstream of penstock tunnels. The power plant has an installed capacity of 360 MW having six units of 60 MW each. Uprating of each unit from 60 MW to 66 MW has been planned. The project has a gross storage capacity of 6.95 MAF.

f) Ranjit Sagar Dam

Ranjit Sagar Dam (Thein dam) is a gigantic Multipurpose River valley Project constructed on river Ravi, 24 km. Upstream of Madhopur Headworks. The construction of Ranjit Sagar Dam is a part of the total plan for the utilization of the water of three eastern rivers namely Sutlej, Beas and Ravi for irrigation and Power generation. Ranjit Sagar Dam is located in a gorge section of river Ravi near village. Thein in J&K state, in seismically active zone of Himalayas constituting the Shivalik range. The Project is an embodiment of inter-state relationship and co-operation amongst the States of Punjab, J&K and Himachal Pradesh. An inter-state agreement between these States was signed in 1979 thereby giving the go-ahead for the execution of the Project. The power production from the project was envisaged as 600 MW with gross storage of 3280 MAF.

Ranjit Sagar lake named after Maharaja Ranjit Singh, the renowned Ruler of Punjab, has been formed upstream of the dam extending upto 22 km with maximum width of 5 km and a depth of 130 m.

10. EXECUTION AND UNIQUE FEATURES OF BHAKRA NANGAL PROJECT

All the major works of the project were departmentally executed by the concerned authorities. The storage of water in the reservoir was started on 15.2.99 and the generation of power was started from August 2000. The unique features of Bhakra Nangal Project are highlighted hereunder:

- The Ranjit Sagar Dam is the highest earth core-cum-gravel shell dam in India.
- The Power Plant has the second biggest Hydro-Turbine in India.
- The Project has the largest dia. Penstock in India.

- The foundation gallery under Rockfill Dam has been provided for the first time in India.

KNOWN RBS DEVELOPMENT BY INDIA (Storage)
• TOTAL = 33 MAF • PAK USES (1947) = 16 MAF • INDIAN USES (1947) = 08 MAF • D/S FLOWS = 09 MAF

KNOWN RBS DEVELOPMENT BY INDIA (Power Generation)
• RAVI = 3500 MW • BEAS = 4000 MW • SUTLEJ = 7000 MW

11. THE ECONOMICS OF GROUNDWATER

The nature of the ground water in the Indus Basin is such that there are adjoining pockets of both sweet water and brackish water. In some cases the water in upper layer is sweet and in the lower level is it brackish. If not carefully exploited there is always a fear of inter mixing of brackish water with sweet water zone. As such its exploitation in conjunction with the river flow waters was not considered in working out the Replacement Plan under the Treaty. Consequently, a look at the impact of such a missing is highlighted in the table below, which indicates the ground water scenario of the city of Lahore, located on the bank of River Ravi, which is one of six tributaries of the Indus system of Rivers:

POPULATION AND GROUNDWATER ABSTRACTION				
YEAR	**POPULATIO NOF LAHOREDIS TRICT (MILLION)**	**ABSTRACTION BY MUNCIPLE/WASA(Mm^3 /YEAR)**	**ABSTRACTIO N BY PRIVATE AND OTHERAGEN CIES (Mm^3/YEAR)**	**TOTAL ABSTRACT ION (Mm^3/year)**
1980	3.06	232	92.20	324.20
1990	4.09	366	160	526
2000	5.45	495	225	720
2010	8.50	650	309.37	959.37
2015	9.70	721	361	1082

Such an extent of depletion certainly asks for immediate measures to redress the issue. By every passing day the gravity of the problem would increase. It may be noted too that the indication through the Table above has been placed only for the city of Lahore. The entire region under the influence of Ravi, Beas and Sutlej exhibit a similar trend and could for then be explored in the relevant part of the studies/literature.

12. THE ECONOMICS OF ENVIRONMENT

Environmental ethics on global and regional scales is inextricably coupled with development ethics. The Rio Declaration notes:

> *"Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature".*

The United Nations World Commission on Environment and Development declares:

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*

THE POLLUTED WATERS
• Presently River Ravi is a sewage carrier. All the seepage from it is nothing but sewage. • Half of total waste IRS is dumped into Ravi. • Flow of sewage in River Ravi is slowly polluting the groundwater reservoir under Lahore. The direction of Ground water flow in the area is from River Ravi towards Centre of the City due to water level difference. • Through the result of water sampling it has been clarified that the source of pollution at these tubewells is seepage from River Ravi. • Mixing of shallow and deep groundwater, especially in the centre of the city reveals that the aquifer is highly vulnerable to pollution. • Mixing of sweet and saline water layers in the unconfined system. • *Because of Ravi Lahore has changed, <u>losing its vigor that</u> was its identity. Though this has got much to do with IWT 1960 but lack of concern, ill management and municipal pollution have rather transformed river into a sewage channel.* • Same holds for the city of Bahawalpur located on the bank of River Sutlej.

Science, technology, industry, democracy, human rights, freedom, preference satisfaction, maximizing benefits over costs, consumerism - all are supposed to be bound by professional or management ethics - as all of them are seriously implicated as cause of the environmental crisis of today. Development of today may be based upon the enlightened myths - whether one may consider agricultural development, forests cut, rivers dammed and diverted for water, lands fenced, minerals extracted, or highways and subdivisions built - but the next hundred years may not be similar to that of the last hundred years. None of even the developed nations have yet fully settled into a sustainable culture on their landscapes. On the scales on the other hand, 'sustainable' still means 'fair' or 'just', much against the pure ethics of eco-justice. The box above is indicative of Ravi, Beas and Sutlej region viz-a-viz the water aspect.

13. IMPACTS ON WATER INFRASTRUCTURE

The section on Prepetition Utilization of waters of Ravi, Beas and Sutlej has lightly touched upon the extent of infrastructure which was in place at the time of partition.However, because of later developments subsequent to demarcation of boundary lines across the newly created studies the structures on the downstream side of the border was deprived of the water flows which use to flow through the beds of respective channels these structures were somehow or the other work to get the flow of water from the Western Rivers, through the link canals planned for the purposes. Because of changed in design parameters including the Sindh factor and the other regime criticized it was just missed that entirely the new set of flow criticized were bound to be encountered.

This was just the one dimension of the impacts of changed water flow scenario on the infrastructure which was existing over each of the channel of the Western Rivers. Several other aspects were also bound to make contribution to the regime criticized which include the pattern of siltation/sedimentation, etc. and there subsequent impact on bound each of the infrastructure as well the studies and analysis to this effect, which are initially required to be done would be able to elaborate these aspects in further detail as the discussion in this respect would be a detailed work by itself.

14. QUANTIFICATION AND COST RERUNS

Finally, it would be imperative and initial to job that the quantification of all the impacts as noted hereinabove is required so as to initial the measure to mitigate the ill facts of the eastern divide. This would be required to be coupled with estimation of cost re-run which are being borne since the time when the flow pattern started changing these cost re-run should also be included with social cost which the area of impact was made to experience. Likely migration, changing's in the pattern of sowing and cultivation.

The change in methods of irrigation would also be required to be included in the estimation of cost re-run side by side they enhanced volume of work required for the up keep of the channels and the respective infrastructure would also be required to be included in such estimates. With economics and jobs falling in conjunction with each other it would emerged that the quantum of cost re-run would be enormous the studies to this effect certainly be helpful to found the solution to the problems so as to recollect the economic benefits and related array of jobs which use to exist over the area of impacts of the pattern divide.

15. FUTURISTIC OPTIMISM

The issues highlighted above carry a big potential for adding to the regional and global harmony. The instruments which could be used in this respect may take the guidelines from the postulates of various international understandings as has been hinted upon here under:

Customary/Common Water Law– 1

• Bilateral or multi-lateral treaties
• General principles and conventions
  ▪ 1911 Madrid Declaration
  ▪ 1966 Helsinki Rules
  ▪ 1991 ILC
  ▪ 1997 UN Convention

Customary/Common Water Law– 2
Principles for allocation: 1. Absolute sovereignty 2. Absolute territorial integrity 3. Optimum development of the basin 4. Community of property (Equitable and reasonable use) 5. No appreciable harm

Customary/Common Water Law– 3
Reasonable and Equitable Use: (Article 10 – 1997 UN Convention) 1. Geographic, hydrographic, hydrologic, climatic, ecological 1. Social and economic needs 2. Effects of the use on another state 3. Existing and potential uses 4. Conservation, protection, development and economy 5. Availability of alternatives

16. CONCLUSION

Having inferred from the discussion above that the Indus Waters Treaty 1960 is a unique Treaty, as it has divided the rivers between the two countries, whereas such treaties in general accounts for sharing of the waters. However, to make an attempt for the balance, that framers of the Treaty intended to limit the capacity of India (being upper riparian) to manipulate, at will, the waters of Western Rivers. This is evident from the following excerpts from the proposal of the World Bank dated 5th February, 1954:

i. It is desirable, so far as practicable, to avoid control by India over waters on which Pakistan will be dependent and to enable each country to control the works supplying the water allocated to it and determine in its own interests the apportionment of waters within its own territories.

ii. The Chenab river rises in India, and before it enters Kashmir, provides a substantial flow that could be diverted for use by India. Assurance by India that the flow of this river will not be disturbed, is essential.

The recent developments in Indo-Pakistan relations have again provided an opportunity to both the countries to address the water related issue with the spirit of goodwill. For the sake of life on Eastern Rivers the measures are too important to be considered. As, the peace in the subcontinent is distinctively related to the honour which India should extend to the Indus Waters Treaty 1960, the true implementation of the Treaty, in its letter and spirit, would be the bare minimum. Any attempt by India to jeopardize the Treaty would only respect in hampering the peace initiative. Hence, for looking into the issues of Eastern Rivers, the other multilateral instruments are required to be resorted upon as shown in the box hereunder.

IMPORTANT LEVELS
▪ *Complete implementation of Indus Waters Treaty 1960.* ▪ *Referral to various conventions on Climate Change, like UNFCCC, etc.* ▪ *Resort to various groundwater agreements and conventions for international aquifers.*

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EFFECT OF OVERPUMPING ON SHALLOW GROUNDWATER AQUIFER – A CASE STUDY

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ABSTRACT

This study was conducted in Sadiqabad Area, District Rahim Yar Khan, where the native groundwater is mostly saline. The flow of regional groundwater from EW to SW direction and alluvial deposits underlying project area behaves one of unconfined aquifer. The average elevation of project area is 260 ft with annual potential ET 69 inches (1750 mm). Fatima has installed 19 Tube wells at total depth=140 ft, having discharge of one cusec. The Piezometers between two tube wells were installed by hand percussion method. The soil sampling was conducted after every 10 ft and a water sample was collected after 60 ft depth. TDS of water and pH remains in ranges of about 400-500 and 7.5-7.75 (safe limit) was noted at the time of experiment. The soil of upper layer (0-60 ft) loam to fine sand, coarse sand below 60 ft and the profile up to 225 ft was found within safe limit. Overall water quality behavior with respect to depth is mixed, however in TW-19, 18, 4 salt concentrations in upper layer (100 ft) is higher as compare to lower but in TW-17 middle layers are higher. The tubewells was installed at depth 150 ft and Observation wells beside tubewells at 250 ft. A bunch of 5 Observation Wells of 225ft=68.59m, 200ft=60.97m, 175ft=53.35m, 150ft=45.73m, 100ft=30.48m were lowered within single ore hole to monitor water level fluctuations in different layers of aquifer. Groundwater withdrawal/day was calculated on behalf of discharge, withdrawal was assumed as actual water requirement of Fatima Fertilizer. The water requirement of company January-March 20113 was 1100-1300 m3/hr, April is very low was note. Water requirement-incremental trend was found January-March (winter to summer) and more water requirements from May-July was noted. The concentration of Iron (Fe) and Arsenic was found higher in water than others. The TDS incremental trend showed that water quality was deteriorated since last 24 months (Dec. 2011-Nov. 2012) and an average increase of TDS observed 94mg/l. Water table depth is major indicator to find aquifer sustainability, water table in area is decreasing with time, Jan 2012-Nov.2013 more than 1/2 meter water table was decreased, this decreasing trend showed that in 2025 water table depth will further lower of about 3m (if current scenario of discharge/recharge persists). In April 2025, TDS level of existing tubewells of Fatima at APL Site will touch TDS=1000mg/l, TDS (Dec. 2020, April 2025)=799.32mg/l,1001.34mg/l. Groundwater level ill touch 77.55m at APL Site, the average groundwater level with reference bench mark=98m and water table depth will be (98-77.5) 20.5m

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(67ft). The casing pipes of tube wells at APL are lowered upto depth of 80ft, in such scenario tube wells will not respond beyond water table depth of 67ft. Ground surface level in Dec. 2020, April 2025 will be 77.79m,7545m. Over-pumping in skimming well has caused reduction in well discharge, the strainer may expose to air and suction break occur in bore hole. Safe operational hours/day is 30%, in shallow aquifers (like APL, about 8 hours/day) and potential for safe operational hours from existing tube wells (16 numbers) at APL is about 128 tubewell hours (16 tubewells for 8 hours). The real requirement of Fatima is 316 average operational hours (May) but higher in June-July, total 40 tube wells will needed for proper devise rest schedule.

Key Words: Aquifer; Over-pumping; Water table; Fatima Fertilizer; APL; Borehole; Tube well; Piezometer; Device Rest Schedule; GIS; pH; TDS; EC.

1. **INTRODUCTION**

Groundwater (subsurface water) is an important hidden water resource [1]. Subsurface water resources have been particularly utilized in the areas of low rainfall and alluvial low land coastal plains [2]. In the drier and inland parts of the world, groundwater is also a major source of fresh water available for agriculture, mining including other domestic activities apart from human consumption. In many parts of the world, population of the regions relies on groundwater supplies since surface water resources such as lakes and rivers are scarce [3]. In most cases, the subsurface water brought to the surface using pumps specially made for various aquifer systems or conditions. High yielding aquifers, lower yielding aquifers and reticulated air systems are three types of pumping used most often [4]. Pumping of groundwater solves many immediate problems faced by those living in lowly developed and low rainfall regions but there have been many negative effects pumping such as pollution of aquifers, seawater intrusion and so on. Coastal regions including those in Australia have experienced saltwater intrusion into coastal aquifers resulting significant deterioration of the subsurface water quality [5-7]. Excessive pumping has led to other long term effects that have been less reported. As this review suggests, there are other longer term critical effects that have been not so well reported and one of the aims of this paper is to highlight other equally important long term effects of pumping from groundwater.

Pumping of groundwater requires much investment by authorities but more critically, it requires well-informed planning such as location of the bores, methods of construction etc. Feasibility studies needed before the well construction, to understand the aquifer condition, water quality and disposal options. The ignoring of the initial planning and construction can lead to difficulties in long-term consequences [4].

Fatima Fertilizer Company (Fatima) financed a study to Pakistan Council of Research in Water Resources (PCRWR) on “Effect of Over pumping on Shallow Groundwater Aquifer.

Fatima has established their fertilizer-producing factory in Sadiqabad, district Rahim Yar Khan, where native groundwater is mostly saline. Keeping in view, the groundwater quality constraint, administration of the Fatima has installed 19 tube wells along the Ahmedpur Lama (APL) Minor (about 20 km north to factory) to meet their water requirement 1500-2000 m^3/hr (15 to 20 cusec). Two water storage reservoirs; one at APL site and another at factory site to regulate the supply of water at required destinations. The native groundwater of the APL site area is saline however; being the adjacent of River Indus and seepage from minor has developed a thin film of fresh water over the native saline water. In such scenario, it is a great concern to maintain the water balance (flow of water in and out of a system).Ahmedpur Lama Minor is non-perennial (seasonal) irrigation distributary. There must be less recharge during its closure period and over pumping in this period may disturb the interface. It is determined fact that “Once the interface is disturbed, its recovery is very difficult”. In this scenario, judicious use of water could not be compromised. Therefore, this study was continued round the year to collect the data for groundwater quality and water table fluctuation to draw solid conclusions.

1.1 **Scope of Study**

The mandate of the study was fixed to record monthly water table depth, water quality sampling from, 19 tube wells, 02 reservoirs and 08 observation wells. The observation wells (Piezometers) were installed by PCRWR. Total 04 times during study period, water samples collected from tube wells and reservoirs were analyzed for detailed analysis, whereas in subsequent months, water samples were analyzed for chemical tests only. Water samples collected from reservoirs were analyzed for TBC (CFU/ml) and Chemical Oxygen Demand (COD) which measures the oxygen equivalent consumed by organic matter. Actually, it is measurement of organic compounds in water.

2. **STUDY AREA**

2.1 **General Description**

The study area is located in district Rahim Yar Khan and falls in Unit-III of SCARP-VI. Main settlement of the in the area is Sadiqabad Town, which is located by latitude 28^o 18’ N and longitude 70^o 8’ E, in the most southern part of the Punjab province. Sindh province lies in the southern at a distance of about 45 km from the project site. River Indus is located at about 33 km in west from the project site. The double track Karachi-Khanewal-Lahore railway line and Karachi-Peshawar highway passes along the project site. Boundary Map of Pakistan (Fig. 1a), Boundary Map of project area (Fig. 1b) and Location Map of Tubewells (Fig. 1c), Tubewells with coordinates (Easting+Northing) are given in Fig. 1d.

2.2 Climate

The climate in the project area is arid. High temperatures, low and irregular rainfall, low relative humidity and high evaporation rates are the salient features of the climate of the area. May and June are the hottest months with mean maximum temperatures up to 42^{o} C. The extreme maximum temperature may be as high as 49^{o} C. January is the coldest month with a mean minimum temperature of 4^{o} C. The winter is generally frost free, but sometimes frost occurs for a short spell during the month of January. Average annual wind velocity is low to moderate and damaging winds are uncommon, although in Kharif occasional sandstorms occur. Mean annual precipitation is 156 mm, of which more than half falls in July and August.

2.3 Topography

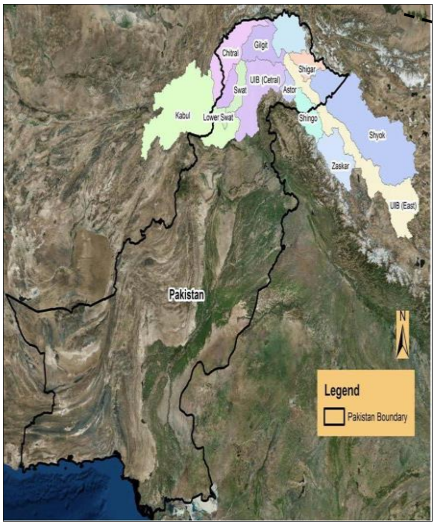
The topography of the project site and its surrounding area is plain and slopes in south to southwest direction with a gradient of about 1 in 5000. The average elevation of project area is about 260 feet above sea level.

2.4 Geology and Geo-Hydrology

The project area is part of the Indo-Gangetic plain, formed by the filling up of geosynclines created during the orogeny of the Himalayan Mountains. Most of the alluvial material, which was mainly carried by the rivers of the Indus Basin, has been deposited during the Pleistocene in a marine environment. This is the reason that the project area away from the River Indus is underlain by a strongly saline aquifer.

The area is underlain by predominantly sandy deposits of alluvial origin. The available borehole records show that 70 to 90 percent of the deposits consist of well sorted medium sand. Layers of fine to very fine sand and silt-clay layers are encountered at varying depth and places. Coarse sand layers are also found at depths in the borehole logs, which indicate that the alluvial deposits may become coarser at greater depths.

Since, the encountered clay layers in the project area are of varying thickness and extension, therefore the alluvial deposits underlying the project area behaves as one single unconfined aquifer. The regional groundwater flow is from east-west to south-west direction.



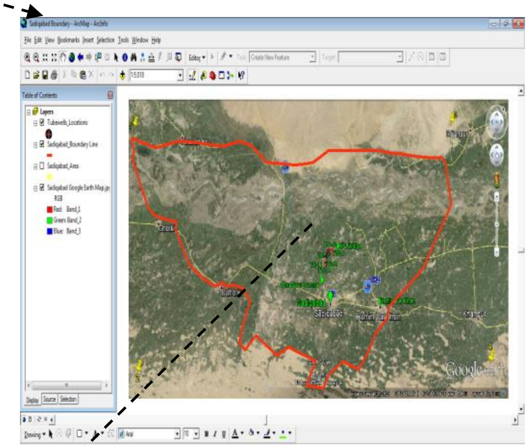


Fig. 1a: Boundary Map of Pakistan

Fig. 1b: *Boundary Map of Sadiqabad Area District Rahim Yar Khan*

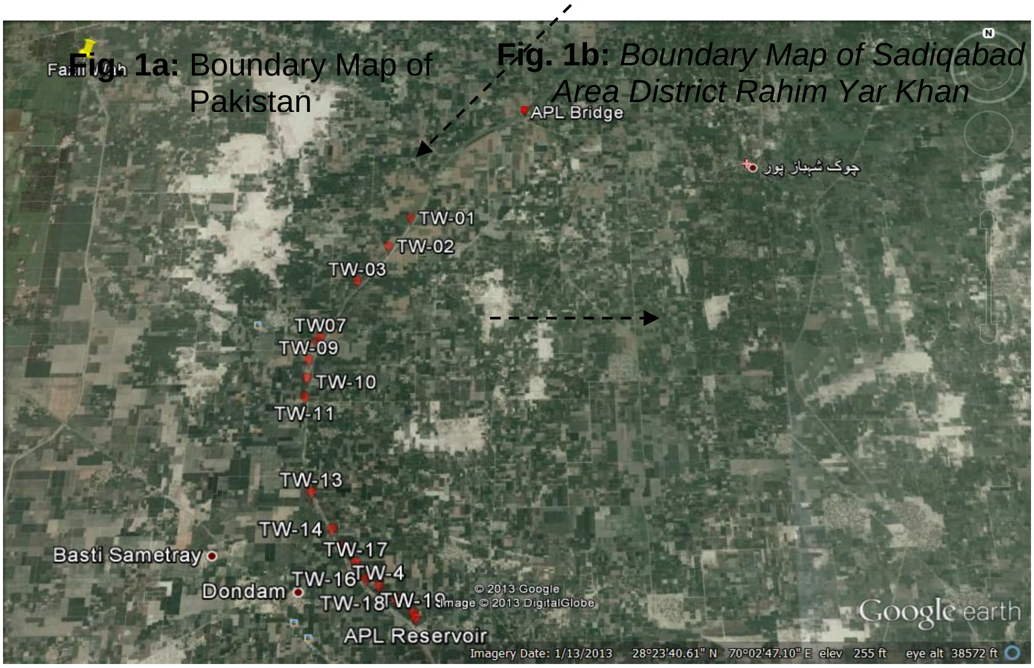


Fig. 1c: *Location Map of Tubewells*

Fig. 1d: *Tubewells with Coordinates*

TW#	Northing	Easting
1	$28^0 24' 39''$	$70^0 01' 51''$
2	$28^0 24' 24''$	$70^0 01' 40''$

3	$28^{0}24'06''$	$70^{0}01'25''$
4	$28^{0}21'46''$	$70^{0}01'43''$
5	$28^{0}22'01''$	$70^{0}01'29''$
6	$28^{0}23'45''$	$70^{0}01'12''$
7	$28^{0}23'38''$	$70^{0}01'08''$
8	$28^{0}23'36''$	$70^{0}01'06''$
9	$28^{0}23'27''$	$70^{0}01'03''$
10	$28^{0}23'18''$	$70^{0}01'03''$
11	$28^{0}23'09''$	$70^{0}01'03''$
12	$28^{0}22'32''$	$70^{0}01'07''$
13	$28^{0}22'26''$	$70^{0}01'09''$
14	$28^{0}22'10''$	$70^{0}01'20''$
15	$28^{0}22'03''$	$70^{0}01'25''$
16	$28^{0}21'49''$	$70^{0}01'37''$
17	$28^{0}21'56''$	$70^{0}01'32''$
18	$28^{0}21'41''$	$70^{0}01'51''$
19	$28^{0}21'35''$	$70^{0}01'59''$

2.7 **Irrigation System**

Annual potential evapotranspiration is about 69 inches (1750 mm), which greatly exceeds the rainfall. Irrigation is therefore essential to supplement the rainfall and has been practiced for many centuries. Older forms of irrigation were gradually superseded when an extensive system of canal irrigation was introduced over a century ago. The project area receives irrigation supplies through Panjnad Canal off-taking from Panjnad Headworks.

3. **OBJECTIVES**

- ❖ Evaluation of current status of water quality, water table depths, available fresh water column, interfaces of saline and fresh groundwater.
- ❖ Life of the tube wells/aquifer will be assessed on the basis of current discharge/recharge.

- Devise rest schedule & recovery time will be included in final report.

4. METHODLOGY

The study is aimed to evaluate the sustainability of the aquifer. Water quality and quantity are the important parameters to be studied. Water quality behavior was studied by water sampling from tube wells, whereas the water quantity was studied by observation of water table depth with respect to time.

4.1 Water Quality Monitoring

Fatima Fertilizer Company has installed 19 tube wells along Ahmedpur on both the banks (left & right). Total depth of tube wells is about 140 ft and discharge of 1.0 cusec. The effluent of tube wells is collected in a reservoir at tube wells site, from where it is again pumped and collected in reservoir at Factory site. Water samples were collected from all 19 tube wells individually, reservoirs at tube well (APL) and factory (Plant) sites. PCRWR collected monthly data for water table depth, water quality sampling from, 19 tube wells, and 02 reservoirs. Four times during study period, the samples of tube wells and Reservoirs were analyzed for detailed analysis, whereas in subsequent months, water samples analyzed for chemical tests only. Water samples collected from APL and site reservoirs were analyzed for TBC (CFU/ml) and Chemical Oxygen Demand (COD) which measures the oxygen equivalent consumed by organic matter. Actually, it is measurement of organic compounds in water.

4.1.1 Water quality and soil texture of bores

The observation wells (piezometers) in between two tube wells were installed by hand percussion method. The soil samples were collected after every 10 ft; similarly water samples were collected at every 10 ft below water table level. Results are given in table-1. Water table was below 50 ft, the water samples were collected after the depth of 60 ft. TDS of water remains in the range of 400 – 500, whereas pH ranges between 7.5 – 7.75. Both the parameters are within safe limits for drinking water. The soil of upper layers (0-60 ft) is mostly loam to fine sand, whereas mostly coarse sand below 60 ft.

Table-1: *Soil Texture and Water Quality of bores for Pierzometers*

<table>
<tr><th rowspan="2">Pz #</th><th rowspan="2">Depth (ft)</th><th colspan="2">Water quality</th><th rowspan="2">Soil Texture</th></tr>
<tr><th>TDS</th><th>pH</th></tr>
<tr><td rowspan="9">Pz-1</td><td>10</td><td></td><td></td><td>Silt loamy</td></tr>
<tr><td>20</td><td></td><td></td><td rowspan="3">Fine sand</td></tr>
<tr><td>30</td><td></td><td></td></tr>
<tr><td>40</td><td></td><td></td></tr>
<tr><td>50</td><td></td><td></td><td rowspan="3">Coarse sand</td></tr>
<tr><td>60</td><td>492</td><td>7.43</td></tr>
<tr><td>70</td><td>425</td><td>7.45</td></tr>
<tr><td>80</td><td>438</td><td>7.70</td><td>sandy loam</td></tr>
<tr><td>90</td><td>431</td><td>7.76</td><td>Coarse sand</td></tr>
</table>

	100	523	7.54	
Pz-2	10			Fine sand
	20			
	30			
	40			
	50			Coarse sand
	60	382	7.75	
	70	381	7.70	
	80	428	7.74	
	90	406	7.50	
	100	428	7.63	
Pz-4	10			Fine sand
	20			
	30			
	40			
	50			
	60	526	7.50	Coarse sand
	70	528	7.55	
	80	399	7.49	
	90	474	7.52	
	100	397	7.73	Sandy loam
Pz-4	10			Fine sand
	20			
	30			
	40			Coarse sand
	50			
	60	363	7.50	
	70	374	7.55	
	80	412	7.56	
	90	351	7.60	
	100	386	7.56	

4.1.2 **Water quality profile at different depths**

To study water quality profile, observation wells were installed at different depths. The profile, up to depth of 225 ft was studied and found within safe limits, whereas tube wells are installed at depth of 150 ft. Overall water quality behavior with respect to depth is mixed, however in Tw-19, 18 and 4; salt concentration in upper layer (100 ft) is little bit higher as compare to lower but in Tw-17 middle layers are higher.

4.2 **Water table Monitoring**

For water table monitoring, a row of 04 tube wells was selected (map of selected tube wells at Fig. 2). Multiple observation wells (bunch of five) were installed beside the tube wells and a single well in between two wells to monitor the water table level with respect to time.

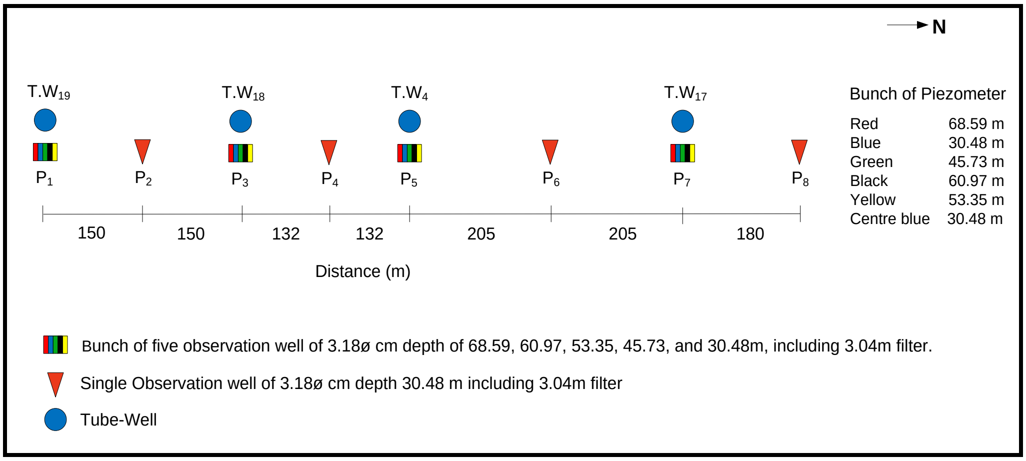


Fig. 2: *Layout of Observation wells (Piezometers)*

The observation wells beside tube wells were installed by using rotary rig machine up to depth of 250 ft. A bunch of five observation wells (PVC pipe of 1.25 inches dia) of 225, 200, 175, 150 and 100 ft (68.59, 60.97, 53.35, 45.73, and 30.38 meters) were lowered in single bore hole to monitor the water level fluctuation in different layers of aquifer. The observation wells in between two tube wells were installed up to depth of 100 ft (single pipe) in a hand percussion bore. Water and soil samples were collected from the wells. The profile of observation well is given in Fig. 3.

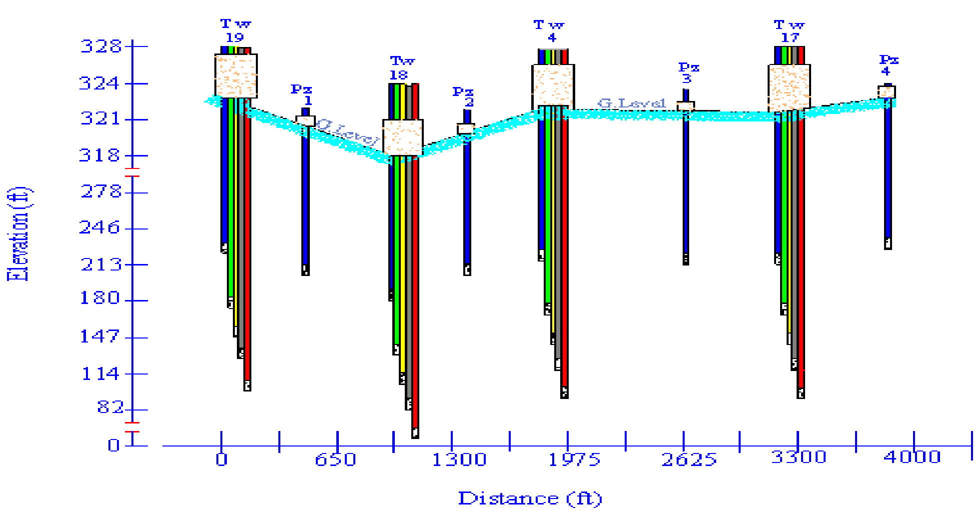


Fig. 3: ***Profile of observation wells (Piezometers)***

4.3 Water Requirement

Groundwater is exclusive source of water utilized by Fatima. For assessment of their actual water requirement (per day), the data for operational hours of tube wells was requisite to management team of Fatima. The tube wells are of 1 cusec discharge each, withdrawal of groundwater (per day) is calculated on the basis of discharge. The withdrawal is assumed as actual water requirement of the company. The average tubewell's operational hours and withdrawal are summarized in table 2. The data of 03 months (January – March 13) revealed that, water requirement of the company ranges from 1100 – 1300 m^3/hr. In the month of April, water requirement was observed very low. According to company administration, plant was closed for annual maintenance during the month of April. Increment trend water requirement is found from January – March (winter – summer), there might be more requirement during the months of May – July. If Fatima may provide more data, better trend line can be drawn.

Table 2: ***Monthly Water Requirement of Fatima Fertilizer Company***

S #	Month	Average operational hrs/day	Withdrawal/ Water Requirement		Remarks
			(m^3/hr)	Cusec	
1	**January, 13**	**252**	**1072**	**10.72**	
2	**February, 13**	**300**	**1275**	**12.75**	
4	**March, 13**	**305**	**1300**	**13.00**	
5	**April, 13**	**144**	**612**	**6.12**	**Closing of Plant for annual maintenance.**

5. **RESULTS AND DISCUSSION.**

5.1 Water Quality.

Water quality sampling was made from all 19 tube wells, reservoirs at tube well (APL) and factory (plant) sites. Water samples were analyzed at Regional Water Quality Laboratory of PCRWR for Physico-aesthetic, chemical, heavy metals and microbial parameters. The results revealed that most of water quality parameters were within permissible limits as per guidelines given in vogue. However, Iron (Fe) and Arsenic was found on higher side as per guidelines given by WHO. The rusty taste of water is observed due to iron concentration. A few tube wells and open reservoirs were contaminated by microbiology. There is incremental trend in total dissolved salts (TDS), which indicates that water quality is deteriorating with passage of time.

The water has been pumped from deeper fluvio deltaic aquifer that contains high concentrations of arsenic [7, 10]. According to Glennon [8], higher temperatures in lower ground levels facilitate in dissolving elements such as arsenic, fluoride and radon that are more prevalent at deeper levels. In Mexico, Raquela [9] reported that subsurface water pumped from well fertilized agricultural lands contain inappropriate levels of toxic materials. It seems that the materials have accumulated over a long period of time.

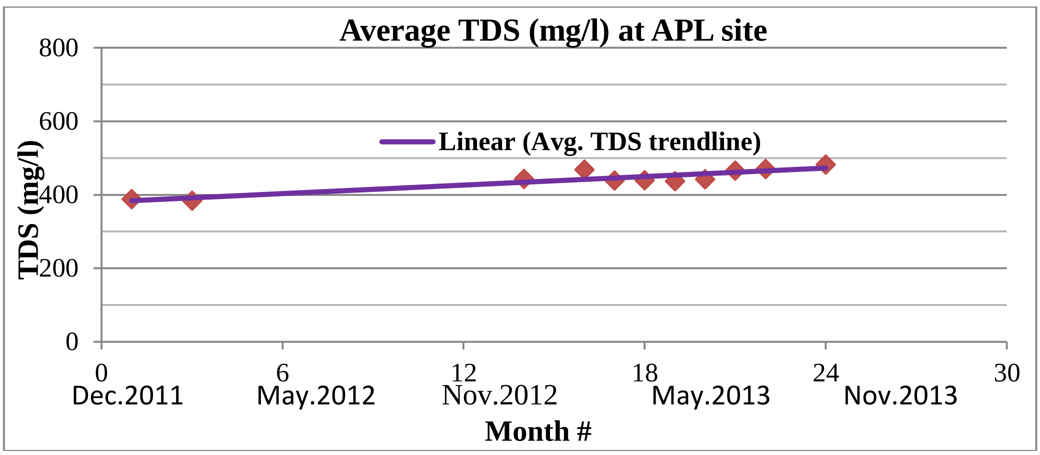


Fig. 4: *Average TDS (mg/l) in Water Effluent of Tube Wells at APL Site*

For calculation of incremental trend, the monthly average of TDS values from all tube wells has been worked out and plotted in a graph using *Microsoft Office Excel 2007.* The values are presented in Fig. 4. Over the record period of 24 months (Dec 2011 – Nov. 2012), an average increase of about 94 mg/l in TDS values was observed. The trend has shown significant threat to water quality. If the exploitation of groundwater is continued with same practice, the aquifer will exhaust with passage of time.

5.2 Water table fluctuations

Water table depth is major indicator to observe the sustainability of aquifer. For regular monitoring of water table fluctuation, observation wells (piezometers) have been installed near 04 tube wells (19, 18, 04 &17) and their middle points. Reduced levels for top of observation wells and ground surface levels have been recorded with the help of engineering level reference to assumed bench mark value. The data for water table was recorded on monthly basis during study period and the data revealed that water tale is decreasing with the passage time. Over the record period of study (January 2012 – November 2013), more than half of the meter, water table level has been decreased. Water level trend has been plotted on the graph using Microsoft Office Excel 2007 and presented in Fig. 5.

Zektser [11] reported that long term groundwater extraction exceeding the aquifer recharge has led to overdraft problems in South Western United States. This region is one of the driest place in North America continent. In the semi-arid region, the large demand for usable water has led to groundwater overdraft in many aquifers. In North West China, the groundwater level has been steadily decreasing because of pumping and a decrease in recharge levels. He attributed the decline in water levels to aquifer overdraft. China, India and Mexico are some of the largest users of groundwater in the world and all facing critical overdraft challenges, where pumping exceeds aquifer recharge. India and Mexico have instituted regulatory measures to reduce groundwater overdraft [12].

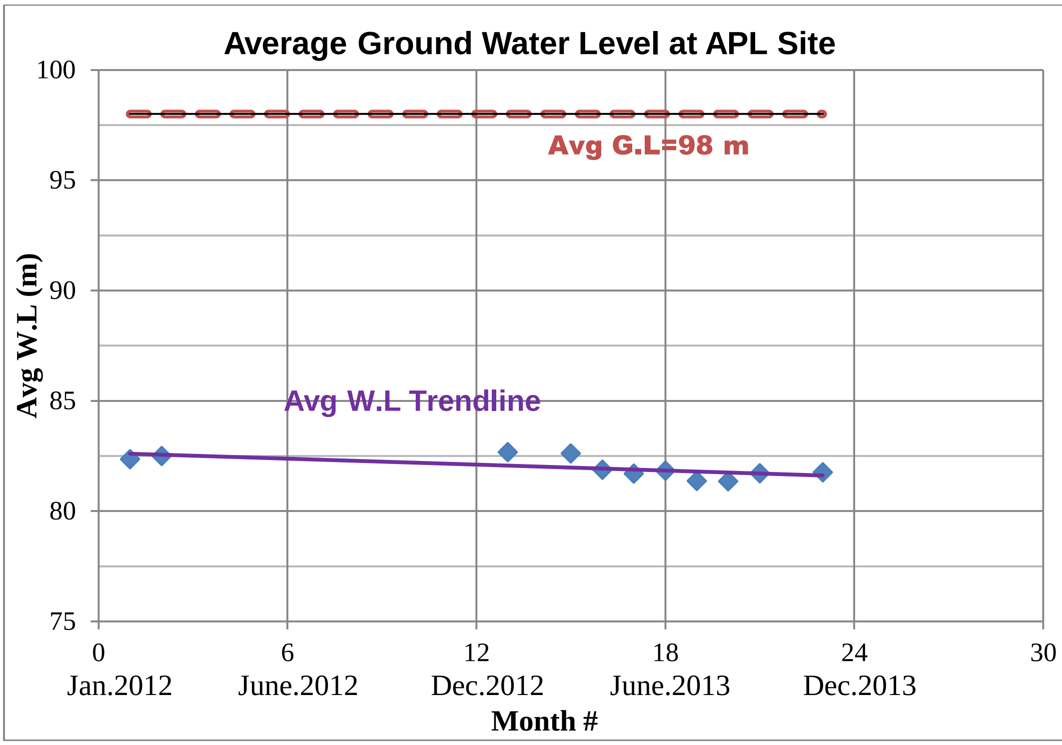


Fig. 5: *Average Watertable Levels During Study Period at APL Site*

Ground-waters levels have been declining due to high water demand in Arusha (Tanzania, South Africa). Some of the impacts of groundwater overdraft are higher pumping costs, land subsidence, depletion of surface water and degraded aquifer water quality [13]. Ongor [14] stated that many of the African countries are most vulnerable to overdraft problems. Although critically vulnerable, there is much less research literature on groundwater use and its long term effects throughout the African continent generally. Depletion of groundwater levels is a global phenomenon and is another issue associated with subsurface water pumping in many countries [3, 15]. Depletion of the groundwater level is defined as long term water level declination caused by sustained groundwater pumping over time [3]. Sustainable water use in the Piedmont region of the Taihang Mountains (North China Plain) is under serious crisis due to the rapid depletion of groundwater caused by pumping [16]. Groundwater depletion has affected major regions of the Middle East, South and Central Asia, North China, North America, Australia [17].

5.3 Estimation of Life of Tube wells/Aquifer

Estimation of the life tubewells/aquifer is major concern of the Fatima Fertilizer Company for their future planning. In the study, PCRWR have tried to explore the over pumping threat on water quality and water table depth, which are the important parameters. It has been already described in section 4.1 & 4.2 that water quality is deteriorating and watertable depth is incresing continuously. For estimation of dead points, projected trend of TDS and watertable have drawn using linear equation of line on Microsoft Excel 2007 (Figs. 6 &7).

5.3.1 Projected TDS (mg/l) at APL Site

Accrding to WHO guidelines, maximum permissible limit of TDS in drinking water is 1000 mg/l. Keeping into considerstion WHO guidelines as a deadline, the projected trend of TDS (mg/l) was drawn (Figure 8). The trendline has roughly estimated that; " In April 2025, TDS level of the existing tubewells of Fatima at APL site will touch to 1000 mg/l". This trendline is bases on existing recharge/discharge scenario and can be affected by unfavourableable (increase in puming, severe droughts) or favourable impacts (decrease in puming, floods, heavy rainfalls.

This trendline can be used to predict the TDS level for any time and can be calibrated with existing data. Further to make the ease in prediction, an equation has been also developed based on gradient of linear line equation.

TDS (mg/l) = 3.884 X No of months + 379.9 ---------- (i)

Where;

December 2011 is Month # 1, desired month will be calculated accordingly.

Example 1:

No of months in Dec 2020 = (Dec 2020) – (Dec 2011) = 9 years or (108 months)

TDS in Dec 2020 = 3.884 X 108 + 379.9 = 799.32 mg/l

Example 2:

No of months in April 2025 = (April 2025) – (Dec 2011) = 13 years and 4 months or 160 months

TDS in April 2025 = 3.884 X 160 + 379.9 = 1001.34 mg/l

5.3.2 Projected Groundwater Level at APL Site

The projected trend of TDS (mg/l) roughly estimated that; " In April 2025, TDS level of the existing tubewells of Fatima at APL site will touch to 1000 mg/l". Accordingly, the trendline of groundwater level was drawn on the basis of data collected during study period. The projected trend of groundwater level roughly estimated that; " In April 2025, groundwater level will touch 77.5 meters at APL site". The average ground surface level with reference bench mark is 98.0 m. Accordingly, watertable depth will be (98 – 77.5) 20.5 m or 67 ft. The casing pipes of tubewells at APL are lowered up to depth of 80 ft. In such scenario, tubewells will not respond beyond watertable depth of 67 ft. Again existing recharge/discharge scenario can be affected by unfavourableable (increase in puming, severe droughts) or favourable impacts (decrease in puming, floods, heavy rainfalls.

This trendline can be used to predict the groundwater level for any time and can be calibrated with existing data. Further to make the ease in prediction, an equation has been also developed based on gradient of linear line equation.

GS Level (m) = - 0.045 X No of months + 82.65 ---------- (i)

Where;

December 2011 is Month # 1; desired month will be calculated accordingly.

Example 1:

No of months in Dec 2020 = (Dec 2020) – (Dec 2011) = 9 years or (108 months)

GS Level in Dec 2020 = -0.045 X 108 + 82.65 = 77.79 m.

Example 2:

No of months in April 2025 = (April 2025) – (Dec 2011) = 13 years and 4 months or 160 months

GS Level in April 2025 = -0.045 X 160 + 82.65 = 75.45 m.

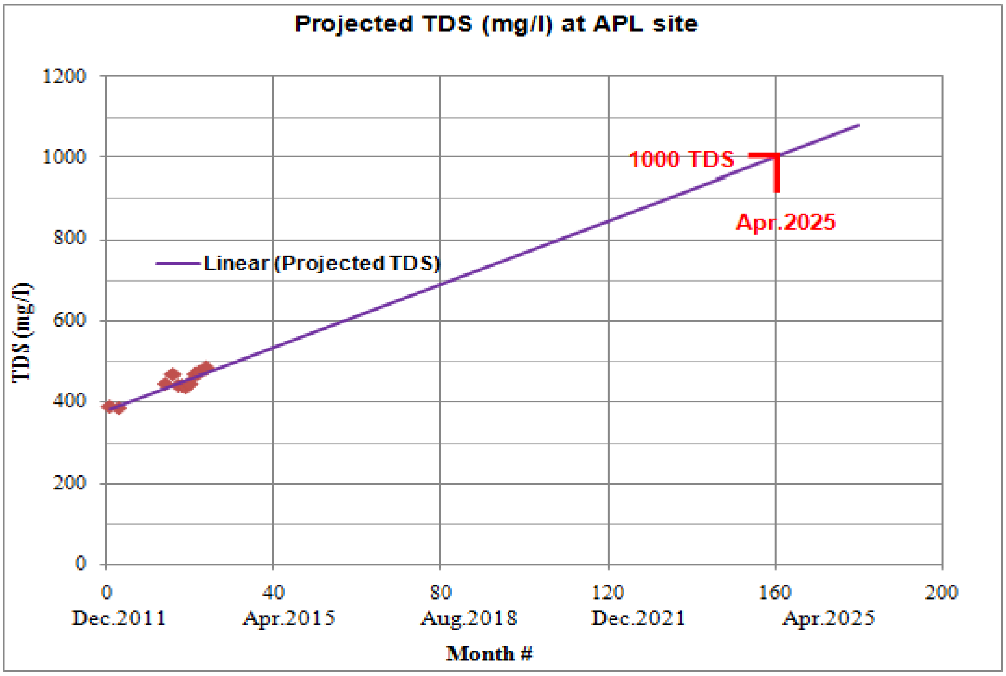


Fig. 6: ***Projected TDS (mg/l) at APL Site***

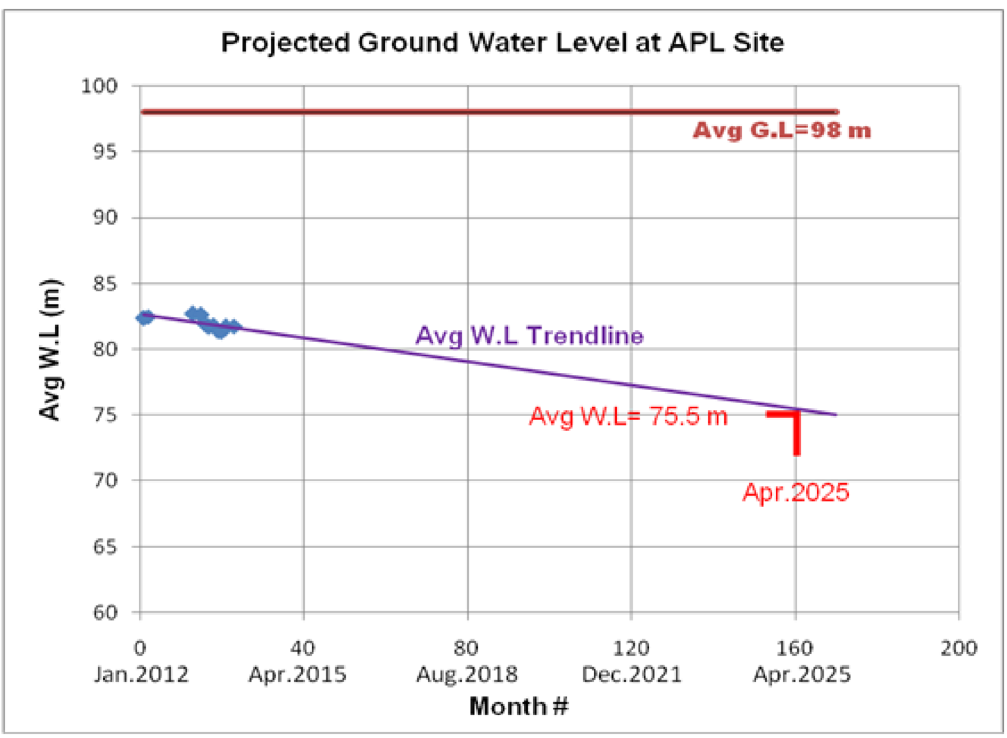


Fig. 7: *Projected Groundwater Level (m) at APL Site*

5.4 Devise Rest Schedule

Numbers of research studies have been conducted on permissible limits of operational hours of skimming wells installed in shallow aquifers in Indus basin. It has been concluded that; “Over pumping in skimming wells has caused reduction in well discharge”. During well operation, as the drawdown exceeds below the depth of the blind pipe, the strainer may expose to air and suction break occurs in this borehole. In this case, the tube well may stop lifting water due to entrapped air in the pump and complete suction break may occur.

Fatima have installed 19 tube wells, out of which three tube wells mostly remain non-functional due to one or other reason and 16 available for operation. The operation of tube wells at APL Site is summarized in table3**.**

Table 3: ***Summary of Tube wells Operation at APL Site***

S #	Month	Total Operational hrs during month.	Average operational hrs per day	Average operational hrs per Tube well per day	Non Functional Tube wells during month
1	Jan. 2013	3800	252	16	3
2	Feb. 2013	8412	300	19	3
3	March, 2013	9465	305	19	3
4	April, 2013	4320	144	8.5	2
5	May, 13	9789	316	20	3

It is obvious that tube well’s operational hours per day are high as about 20, whereas safe operational duration in shallow aquifers (like APL) is 30% (about 8 hours per day). Potential for safe operational hours from existing tube wells at APL site is about 128 tube well hours (16 tube wells for 8 hours). Operation during the month of April is within the limit of available potential, whereas in subsequent months, actual operation is more than doubled as compare to safe potential available.

Keeping into consideration, the actual requirement of Fatima (316 average operational hrs per day (in month of May; which may be higher in June – July) and allowing maximum 8 hrs/day for each tube well, total 40 functional tube wells will be required to establish proper Device Rest Schedule. Due to shortage of number of tube wells, mostly these are operated for 24 hours without any break. In order to give possible rest to tube wells, the schedule has been given in table 4.

Table 4: **Devise Rest Schedule for APL Tube wells**

TW #	Shift # 1 (8.0 AM to 4.0 PM)	Shift # 2 (4.0 PM to 00 Midnight)	Shift # 3 (00 Midnight to 8.0 AM)
1	Running	Stop	Running
2	Stop	Running	Running
3	Running	Running	Stop
4	Running	Stop	Running
5	Stop	Running	Running
6	Running	Stop	Running
7	Stop	Running	Running
8	For emergency requirement (As minimum as possible)		
9	Stop	Running	Running
10	Running	Running	Stop
11	Stop	Running	Running
12	Running	Stop	Running
13	Running	Running	Stop
14	Running	Running	Stop
15	Running	Stop	Running
16	Running	Running	Stop
17	Running	Running	Stop
18	Running	Stop	Running
19	Stop	Running	Running

6. CONCLUSIONS AND RECOMMENDATIONS

PCRWR experts conducted this study with professional sprit, accordingly the conclusions and recommendations has been drawn as follows,

6.1 Conclusions

- Major water quality parameters of all tube wells are within permissible limits as per WHO guidelines for drinking purpose except iron and arsenic. But increasing trend of TDS reflects continuous deterioration of water quality.

- According to current increasing trend in TDS, in 2025 TDS level may touch 1000 mg/l.
- Water table is depth is increasing progressively. The trend shows that, in 2025 water table depth will further lower about 3 meters, which may cause exposure of strainer and suction break of tube wells.

6.2 Recommendations

- Existing tube wells can fulfill 50 percent water requirement of the Fatima. Alternate source (preferably canal water) or other 20 tube wells are required immediately to not only fulfill the water requirement of the company but maintain proper devise rest schedules.
- APL site has become saturated in tube wells installed by Fauji Fertilizer Company, Fatima Fertilizer Company, TMA, NRSP, private peoples. The aquifer is limited; hence further installation of tube wells in the area should be avoided.
- Devise rest schedule is not observed by the company due to some security reasons. But, it is unavoidable. Using some technology (control room at APL Site), schedule may be observed accordingly.
- Water Quality and water table may be regularly monitored to avoid any sudden happening.

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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	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 and S. Tanveer Abbas
10.	Risk Perception towards flooding and environment in low income urban communities	Dr. S. M. Saeed Shah and 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 and 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 and 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 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 and Asghar Hussain,
38.	Protection of Water Quality and its Sustainable Use in Pakistan	Dr. Muhammad Nawaz Bhutta
	2010 – Communicating Water Quality Challenges and Opportunities	
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