HISTORICAL SUSTAINABILITY OF GROUNDWATER IN INDUS BASIN OF PAKISTAN

Ghulam Zakir Hassan[1] Catherine Allan[2] and Faiz Raza Hassan[3]

ABSTRACT

Pakistan is bestowed with one of the world's largest contiguous irrigation canal network, major part of which lies in Punjab Province under Indus Basin. This network was started to be constructed by British during early nineteenth century. The continuous expansion of the irrigation system over the past century significantly altered the hydrological balance of the Indus River Basin (IRB) in Pakistan. During pre-irrigation era, water table in different doabs (the land between two rivers) in Punjab province was very deep but the system of canal irrigation was put in operation, the problems of waterlogging become the major challenge which led to the need of parallel system of drainage network. This situation created the need of drainage of agricultural lands in the country. Although some drainage was installed before World War II, little attention was paid to the growing waterlogging and salinity problems. To alleviate the twin menace of waterlogging and salinity, Water and Power Development Authority (WAPDA) was established in 1958 and Salinity Control and Reclamation Program was conceived, planned and implemented by adopting surface as well as subsurface drainage projects in the country. First Salinity Control and Reclamation Project (SCARP-I) was implemented in 1960-63. Currently, in Punjab which is the largest groundwater consumer amongst the provinces, groundwater is contributing about more than 45% towards irrigation requirements through pumping by approximate 1.2 million tubewells putting this natural gift beyond the limits of its consumers. The farmer's tubewells are pumping groundwater to meet 40 to 50 % of crop water requirements at farm-gate which has put the aquifer under stress especially in sweet groundwater zones consequently putting this natural gift beyond the limits of human utilization. To meet the ever increasing demand of food and fiber, cropping intensity has increased from 67% to 150% or even more in some areas which is a major driver for dependence on groundwater. Besides irrigation uses groundwater is the major source of drinking, industrial and commercial requirements in many areas the unplanned and over pumping has caused intrusion of saline water into fresh groundwater areas. Punjab Government, Irrigation Department has established a Groundwater Management Cell to carryout various research studies and to devise the management interventions in the Province. Research study carried out in Vehari district of Southern Punjab has indicated that by increase of depth to water table from 40 ft. to 70 ft. the cost of pumping per acre-feet has increased 125%. In urban areas, this threat is very severe for example in Lahore City, the annual average rate of fall is 2.5 ft. Its quality is also deteriorating at many places due to one or the other reasons. In this paper findings of various studies have been outlined to identify the critical areas and to suggest some management options for the replenishment of this fast depleting natural resource in Punjab. Potential site for artificial recharge of aquifer has been identified and possibility of aquifer recharging through flood water has been explored.

Keywords: Groundwater, Irrigation, Artificial Recharge, Punjab, Pakistan

[1] PhD Scholar Charles Sturt University, Australia and Director and Irrigation Research Institute (IRI), Government of the Punjab, Irrigation Department, Library Road, Lahore 54500, Pakistan. * Correspondence author: zakirjg@gmail.com

[2] Assistant Professor, School of Environmental Sciences, Charles Sturt University, NSW, Australia

[3] Assistant Director, Irrigation Research Institute (IRI), Government of the Punjab, Irrigation Department, Library Road, Lahore 54500, Pakistan.

1. INTRODUCTION

Pakistan is highly dependent on water resources originating in the mountain sources of the upper Indus for irrigated agriculture which is the mainstay of its economy. Hence any change in available resources through climate change or socio-economic factors could have a serious impact on food security and the environment. In terms of both ratio of withdrawals to runoff and per-capita water availability, Pakistan's water resources are already highly stressed and will become increasingly so with projected population increases. Potential changes to supply through declining reservoir storage, the impact of waterlogging and salinity or over-abstraction of groundwater, or reallocations for environmental remediation of the Indus River Basin or to meet domestic demands, will reduce further the water availability for irrigated agriculture to ensure the food security in the country.

The Indus River Basin supplies water to the largest contiguous irrigation system in the world, providing water for 90% of the food production in Pakistan, which contributes 25% of the country's gross domestic product. But Pakistan could face severe food shortages intimately linked to water scarcity. It is projected that, by 2025, the shortfall of water requirements will be around 32%, which will result in a food shortage of 70 million tones. Recent estimates suggest that climate change and siltation of main reservoirs will reduce the surface water storage capacity by 30% by 2025 and the irrigated agriculture will be hampered badly. Water has always played an important role in the economic development of Pakistan and is likely to continue to do so in the future. Agriculture is the single largest sector of Pakistan's economy, accounting for around a quarter of the country's gross domestic product. Agriculture employs about 44% of the labor force, supports the 75% of the population, and accounts for more than 60% of foreign exchange earnings for the nation. Agriculture in Pakistan mainly, perhaps more than anywhere else in the world, is dependent on irrigation.

At the same time, agriculture in Pakistan is being reshaped rapidly. Contract farming is increasing, more progressive and commercial farmers are emerging, high-value crops are displacing food grains, and increasing prices for agricultural commodities are attracting people to agriculture. Taking advantage of these new agricultural opportunities requires new forms of water control, regulations and management options. Solutions will require a paradigm shift in water-resource development and management strategies (Bhutta 1999).

Irrigation dominates water use in Pakistan and is expected to continue as the major user of both surface water and groundwater resources in the future as well. As development proceeds and the population and the country's economy both grow, competition for water resources will become a major concern. Present water use for municipal and industrial supplies in the urban sector is of the order of 5.3 billion m^3 (BCM). The demand for municipal and industrial supplies in urban areas is expected to increase to ~14.0 BCM by the year 2025. It is projected that, in 2025, per capita water availability in Pakistan will be reduced to less than 600 m^3 which would mean a shortfall in water requirements of ~32%, which will result in a food shortage of 70 million tones by the year 2025 (ADB 2002).

2. INDUS BASIN IRRIGATION SYSTEM

The surface irrigation system of the province is not in a capacity to meet with the ever increasing water demands of all sectors. Surface-water resources in Pakistan are based on the flows of the Indus River and its tributaries (Jhelum, Chenab, Ravi, Sutlej, and Beas to the east and the Kabul River to the west). The Indus River has a total length of 2900 km and a drainage area of ~966,000 km^2. The inflow to these rivers is mainly derived mainly from snow and glacial melt and partly from rainfall in the catchment areas. Outside the Indus Basin, most of the rivers are ephemeral streams, which only flow during the rainy season and thus do not meet the water needs of the Indus system inside the basin as do the other rivers. The Indus Basin is underlain by an extensive unconfined aquifer that covers ~16 million ha of surface area, of which 6 million ha are fresh and the remaining 10 million ha are saline (Haider et al 1999). The average safe groundwater yield is estimated to be ~6 BCM, whereas extraction for the agriculture, domestic, and industrial sectors is of the order of ~52 BCM. Thus, the remaining groundwater potential is ~11 BCM (PWP 2001). However, evidence, such as increasing salinity in the groundwater due to redistribution of salts in the aquifer and declining groundwater levels, confirms that the potential for further groundwater exploitation is very limited. Therefore, the aquifer protection and augmentation by different means and methods is imperative for the sustainable use of groundwater in the Indus River Basin on long-term basis.

3. CHALLENGES OF WATER MANAGEMENT IN THE INDUS BASIN

3.1 Low Storage Capacity and Poor Irrigation Infrastructure

Pakistan has very limited water storage capacity, that is, only 15% of the annual river flow. The per capita water storage capacity in Pakistan is only 150 m^3 compared with more than 5000 m^3 in the United States and Australia, and 2200 m3 in China. The dams of the Colorado and Murray Darling rivers can store 900 days of river runoff, South Africa can hold 500 days in the Orange River, and India can hold between 120 and 220 days in the Peninsular rivers. In contrast, Pakistan can barely store 30 days of water in the Indus Basin (Briscoe and Qamar 2005). If no new storage is built in the near future, canal diversions will remain the same, and the shortfall will increase by 12% in the next decade. The Pakistan Water Sector Strategy estimates that Pakistan needs to raise its storage capacity by 22 BCM by 2025 to meet the projected requirements of 165 BCM. Therefore, it is of paramount importance that Pakistan gives serious attention to building new storage facilities. It is unfortunate that, even after completion of Terbela, no decision could be taken on the construction of any significant new storage capacity.

3.2 Increasing Gap in Supply and Demand

The population of Pakistan is increasing at a rate of 2.8% and is projected to increase to 250 million by 2025. The percentage of the urban population will increase from its current 35 to 52% by 2025. As a result, water demand for domestic, industrial, and non agricultural uses will increase by ~8% and is expected to reach 10% of the total available water resources by the year 2025 (Bhutta 1999). In Pakistan, water availability already fell from 5000 m^3 per capita in 1951 to just 1100 m^3 per capita in 2005 and is expected to fall to as little as 800 m^3 per capita by 2025 (WWF Pakistan 2007). Available land per person for cultivation is also decreasing. Moreover, agriculture is threatened by severe waterlogging and salinity, in the areas where groundwater is brackish, due to a lack of drainage facilities and good-quality irrigation water. Therefore, a multidimensional approach needs to be applied for sustainable development of land and water resources.

3.2 Low System Efficiency and Crop-Water Productivity

The overall irrigation efficiency is only 30% (Bhutta and Smedema 2007). The average yields in Pakistan are low for wheat and rice, at 2276 kg/ha and 1756 kg/ha, respectively. There is great variability in crop yields, with some farmers achieving yields of 3874 kg/ha for wheat and 3545 kg/ha for rice. In addition to water shortage, lack of inputs, poor irrigation practices, and secondary salinization are the other major factors in low crop yields. The productivity of water in Pakistan is about the lowest in the world. Maize yields in Pakistan are very low, which means that there is tremendous scope for substantial improvement. In terms of water productivity, maize has a factor of 9, between the lowest, in Pakistan (0.3 kg/m3), and the highest, in Argentina (2.7 kg/m3). The flip side of current low water productivity is the enormous potential for radical improvement and increased production for Pakistan, which can bring much more jobs and livelihood opportunities per drop of water (Qureshi et al 2004). At the same time land productivity can also be improved to boost up the crops yields. Agro ecological zoning and revisiting the cropping patterns can also improve the system efficiency.

3.5 Unsustainable use of Groundwater

During pre-irrigation era, water table in different doabs (the land between two rivers) in Punjab province (Figures 1 and 2) was very deep at about 160 m (Ahmed. N, 1995). Seepage from the irrigation system and percolation from irrigated fields caused the water table to rise continuously, reaching critical conditions for a substantial area especially in the Punjab province. This led to the dual menace of waterlogging and salinity and crops were seriously affected over a wide area. Over the past three decades, farmers have largely taken the problem of surface water scarcity into their own hands, and "solved it" by sinking hundreds of thousands of tube wells to feed their thirsty crops. The number of private tube wells increased from 10,000 in 1960 to ~0.6 million in 2002 (Qureshi et al 2003) and more than 1 million in 2007 (World Bank 2007). Investment in these private tube wells is of the order of 30–40 billion rupees (US$ 500 million), whereas, annual benefits in the form of agricultural production are to the tune of US$ 2.3 billion. Over 2.5 million farmers, who exploit groundwater directly or rent irrigation services from neighbors (Shah et al 2003). The management challenge is to stabilize the groundwater table at levels where the cost of pumping is affordable without deteriorating the quality of aquifer water as well. Overexploitation of groundwater has already caused severe water table decline in most canal command areas in Punjab. The average decline in the groundwater table is 0.5 to 1.0 meter per year in different areas of the Punjab province. Continuous use of brackish groundwater has led to the secondary salinity causing the soil degradation in some areas as well. Overexploitation of groundwater in rain-fed areas has made them less resilient to drought, resulting in social, economic, and political problems of the tinny farming communities. Groundwater in both rural and urban areas is declining especially in the sweet zones, and the areas having less canal water available for irrigation purpose. Therefore, the irrigation and drainage projects have attained a vital role in the growth and development of Pakistan. Keeping in view the importance of irrigation and drainage projects in Pakistan, Asian Development Bank in 2004 has classified these projects under the subsector agricultural and natural resources under their sector and thematic classification system which were previously clustered with rural development projects (ADB 2008). Lack of holistic management policy, over-depletion of aquifer, reduced recharge due to urbanization, lack of awareness among the consumers, less efficient irrigation methods, secondary salinity, intrusion of saline water in to fresh water etc. have emerged as the challenges which have put question mark on the sustainable use of groundwater in the Indus Basin.

4. GROUNDWATER MONITORING AND MANAGMENET

Keeping in view the situation of groundwater in the Province, Punjab Government has taken steps including establishment of a Groundwater Management Cell in Irrigation Research Institute (IRI), approval of Punjab Water Policy and Act, holding of seminars/workshops at grassroots levels with the stakeholders to build their capacity and awareness raising. Different research studies, surveys, investigations etc. are being carried out in province the delineate groundwater challenges and their sustainable solutions. Punjab Irrigation Department has installed about three thousand piezometers in different canal command areas where the groundwater levels are being monitored twice a year. Currently steps are being taken to carry out the tasks like Mapping of aquifer showing areal and vertical profile extent and potential (quality and quantity) and demarcation of hydrogeological zones in Punjab for resource assessment, Filing the gaps to strengthen the groundwater monitoring network in Punjab, development of mathematical groundwater simulation models and preparation of groundwater management plan at basin and sub basin level, strengthening the institutional set up, capacity building and awareness raising among the stakeholders about groundwater management, use of information communication technologies/loggers etc. For this purpose, Punjab province has been divided into different sub-basins keeping in view the hydrogeological boundaries as shown in Figure 3.

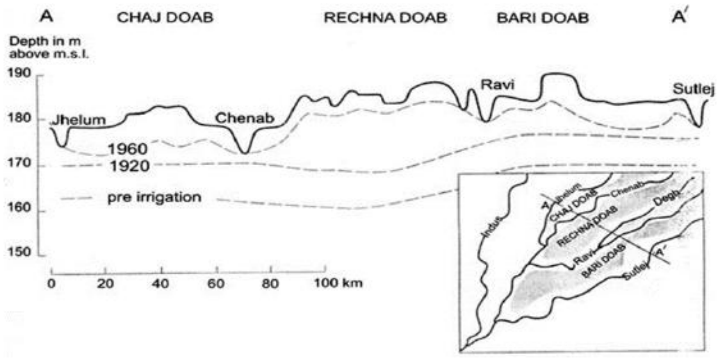

Figure 1. Groundwater table rise in Punjab along section AA/ (Ahmed N. 1995)

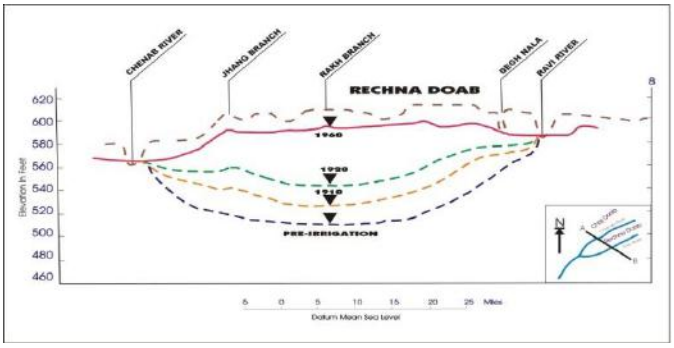

Figure 2: Historical groundwater levels in Rechna Doab, Punjab, Pakistan

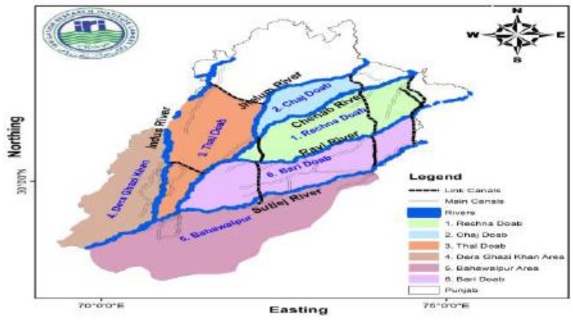

Figure 3: Map showing location of different sub-basins for groundwater management

Observed data on groundwater level and quality are analyzed using different models like MODFLOW and GIS tools. Maps of groundwater quality and levels are prepared to demarcation different zones. A map of depth to water table of Punjab for the year 2018 is shown in Figure 4. IRI (2009) and IRI (2013) conducted a field survey and investigation study by installation of sixty exploratory boreholes in the field at various critical sites in Punjab to explorer the groundwater quality and soil stratification to observe the impact of surface drains and other potential threats for groundwater.

Wherein it was observed that surface water bodies especially drains are playing a vital role in contamination of groundwater. A study was conducted for groundwater investigation in Faisalabad area using Groundwater Model (MODFLOW) where tile drainage and surface drainage networks are functional and groundwater is brackish for which one of the causes is heavy industrial pollution in the area (IRI, 2012).

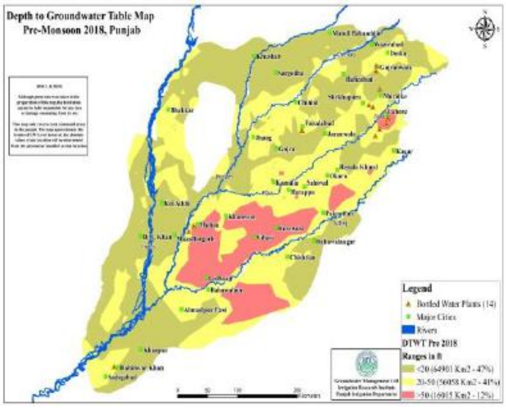

Figure 4: Map showing depth to water table status in Punjab (2018)

Similarly, studies have indicated that groundwater levels are falling at an average rate of 1-2 ft/year in some areas of Rechna Doab (bounded by Ravi River and Chenab River). Recharge potential in Rechna doab during October 2010 and June 2012 was found out as 15.80 and 16.381MAF respectively. Flood water contributes significantly towards recharging the aquifer average rise in Rechna doab during flood 2014 is 2.57 ft/season. Total recharge of GW during flood season 2014 in Rechna Doab was 1.90 MAF (IRI (2015).

5. ARTIFICIAL RECHARGE OF AQUIFER

It has been found that the groundwater budget is Punjab is in danger zone, indicating that we are pumping more than what is being recharged to the aquifer. 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. Similarly, in rural areas with inadequate surface water availability, more cropping intensity, less rainfalls, facing droughts etc. aquifers are also being depleted abnormally. Punjab Government has taken an initiative to conduct experimentation on artificial recharge of aquifer at Old Mailsi Canal in district Vehari of Southern Punjab by diverting the flood. Initial surveys and investigations are being carried out and civil works are in progress to bring the channel at original design. 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.

Under current scenario demands 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. Similarly, flood water during also annually flows to sea, which too can be redirected for artificially recharging the aquifer.

5.1 Preliminary Investigation for Site Selection

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 a potential site for artificial recharge of aquifer can be include the parameters like depth to groundwater table, groundwater quality, surplus surface water available for recharge, soil strata/seepage rates, quality of surface water to be recharged, groundwater pumpage etc. Keeping in view these factors, a site near Islam Headwork on Sutlej River, near Vehari has been identified for recharging the flood water in the bed of old Mailsi Canal.

Table 1: 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)

5.2 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 1 and location of experimental sites is shown in Figure 5.

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 and became abandoned since 1965. It has been observed that the site physically is suitable for groundwater recharge as water table is more than 50 ft deep, soils are fertile and the area is food basket for the province and country, cropping intensity is high up to 129%, groundwater mostly is sweet, flood water can be made available for recharge through the Islam Headworks. There is urgent need for recharging as cost of pumpage has increased many folds, example of one farmer tube-well has been shown in Figure 6. Local stakeholders have shown willingness, suitable place (bed of old canal) is available for any desired artificial interventions for recharging the aquifer. Existing network of piezometers has been upgraded in the proposed study area by filling the gaps to have streamlined monitoring system for groundwater behavior. Depth to water table are being monitored since 2015. Hydrographs of some selected observation wells on biannually basis are shown in Figure 7a and 7b. A map of proposed study area with major features has been shown in Figure 8.

Figure 5: Location of proposed experimental site at old Mailsi Canal

Figure 6: Over-depleted well with high pumping cost in District Vehari, Punjab, Pakistan

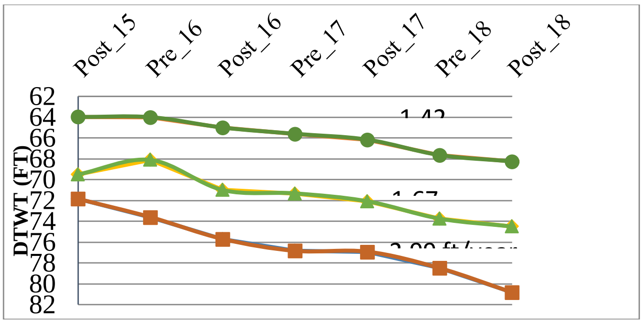

Figure 7,a: Hydrographs of selected piezometers in district Vehari, Punjab, Pakistan

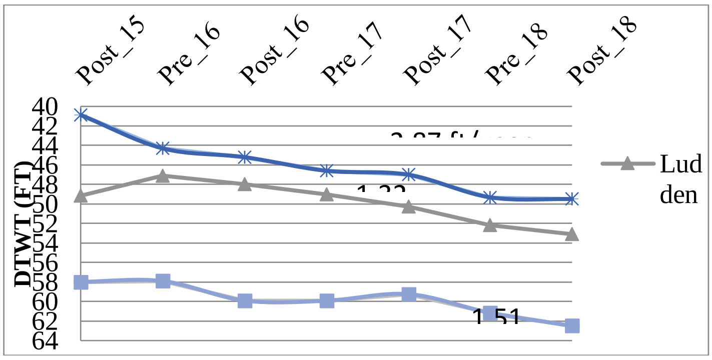

Figure 7,b: Hydrographs of selected piezometers in district Vehari, Punjab, Pakistan

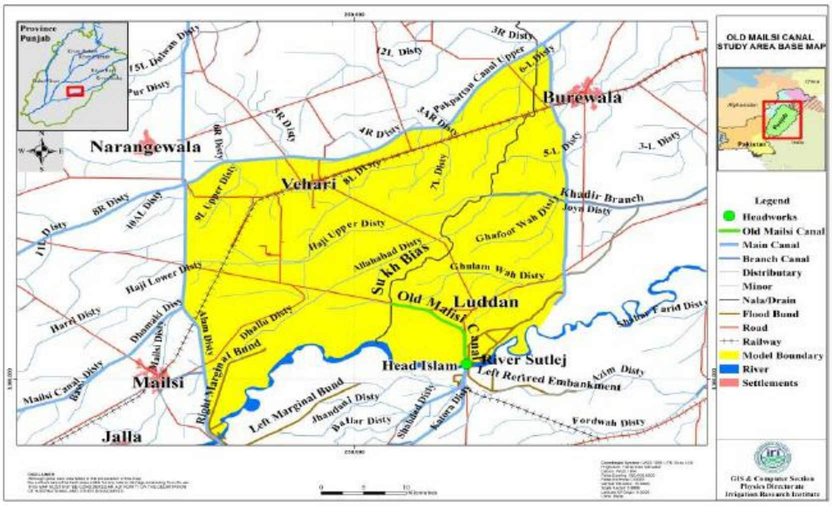

Figure 8: Area identified for artificial recharge of groundwater district Vehari, Punjab Pakistan

6. WAYFORWARD

From various studies and on the basis of data collected and analyzed so far it has been concluded that over exploitation of groundwater in certain areas is causing intermixing of fresh and saline water leading to overall degradation of groundwater quality. Groundwater in

Bari doab is under the worst conditions where water table has gone below 50-60 ft in certain areas and cost of pumpage has increased more than 100 times. Due to less discharge and increased pumpage aquifer in the old Mailsi Canal and surrounding areas is under tremendous pressure. Management of groundwater can be accomplished by adopting suitable measures both on demand as well as on supply side. To redress the over mining of groundwater, artificial recharge can be a suitable intervention coupled with other management options like rain water harvesting, flood plain management, legislation for regulating the groundwater abstraction and uses, study the conjunctive use of surface and groundwater, awareness raising and capacity building of stakeholders about groundwater management, strengthening the groundwater institutional setup, adopting the drought-tolerant and low delta crops where water is scarce or unreliable, increase the efficiency of surface water application etc.

Bed of old Mailsi canal is a suitable location for experimentation and replication of managed aquifer recharge where groundwater levels are falling annually at the rate of 1.3 to 3 ft with and average value of 2.1 ft. Water table is mostly below 50 feet from the land surface, cost of pumpage has increased. It would be appropriate to go for construction of recharge wells in the bed of canal. After experimentation on the recharge, the methods/technique developed can be up-scaled for other similar locations in the province. Regular monitoring of groundwater levels and quality in the study area needs to be continued. It is further suggested that groundwater and GIS models and other latest scientific tools must be applied to investigate the study properly.

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