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Assessment of groundwater potential and threats for its sustainable use, case study of greater Thal Canal area from Punjab Pakistan[1]

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Abstract

Introduction: The Indus River Basin is one the largest basins in the world having an area of 1.17 million Km^2 which supplies water to a large contiguous irrigation system for about 90% of the food production in Pakistan. Due to rapid growth of population, agricultural intensification, climatic variability, industrialization, urbanization and lack of holistic regulation for groundwater development and use, the aquifer underlying the Indus Basin is under stress. This well transmissive and extensive alluvium aquifer covers an area of 16.2 Mha in Pakistan and is contributing about 40-50% towards the irrigation water requirements in addition to domestic, industrial and other commercial demands.

Materials and Methods: A study to evaluate the current potential and threats for groundwater has been carried out in Thal Doab which is partially arid and desert area and is the part of large Indus River Basin. Recently, the irrigation is being extended through construction of four new canal-systems under Greater Thal Canal (GTC) project being funded by the Asian Development Bank. At present, farmers are pumping groundwater by installation of tubewells generally run by electricity and diesel as energy source; however, trend of solar tubewells is also on the track. Results have revealed that depth to water table

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in GTC area and its surrounding area is generally less -ranging from 1.5 m to 6 m below the land surface- in the northern part and comparatively more - 9 m to 15 m- in the southern and eastern parts of the Doab.

Results: Groundwater quality in the area is fresh, marginal to saline. Shallow groundwater quality (EC value) ranges from around 300 to 3,700 uS/cm while for deeper groundwater it ranges from around 600 to 8,000 uS/cm. In the central parts of the Doab, groundwater quality is generally poor. It has been observed that the direction of groundwater flow is from North-West to South-East and major source of aquifer recharge is the Chashma-Jhelum Link Canal. Construction of GTC systems and introduction of solar tubewells will change the hydrodynamics of the aquifer and for proper development, management and to keep balance between recharge and discharge components, an appropriate aquifer mapping, regular groundwater monitoring and modeling is required in Greater Thal Canal command area. For this, a proposal has already been submitted to ADB. Recently the Punjab Government has launched the Punjab Water Policy 2018 and the Punjab Water Act 2019 which govern the groundwater regulation. The present paper encompasses the expected consequences of all these interventions.

Conclusions: Groundwater quality is also an important factor for its domestic and agriculture use. Fresh, marginal, and saline groundwater was observed in the study area. The ranges of groundwater (i) water with an EC reading of less than 1,500 uS/cm is considered as fresh, and (ii) water with an EC reading of 1,500 to 3,000 uS/cm is considered marginal as an irrigation water source, and (iii) water with an EC reading of greater than 3,000 uS/cm is considered as saline. Distribution of the shallow and deep groundwater quality in the GTC area is based on the monitoring of water from hand pumps, the piezometers and farmer's tube wells installed in the area. In the Nurpur Tehsil area, Groundwater quality ranges from fresh to saline with the EC values from 1000 µs/cm to around 7,000 µs/cm.

Keywords: Groundwater, Indus-Basin, Thal Doab, Greater-Thal-Canal, Punjab, Pakistan, Irrigation System.

1. Introduction

Groundwater is one of the important natural resources. It is a dependable source of water supply in all regions of the world (Konikow *et al.*, 2005; Moghaddam *et al.*, 2015; Chaminé *et al.*, 2013; Jain *et al.*, 2007). Approximately one-third of the world's population uses groundwater for drinking and other household purposes (Nickson *et al.*, 2005). Pakistan is the fifth largest abstractor of very precious natural groundwater resources from the Indus Basin Aquifer. Groundwater contributes about 40% of the total water resources of the country and plays an important role in the sustainability of irrigated agriculture in the Indus Basin. GTC is part of Indus Plain which is underlain by deep, well transmissive and extensive alluvium aquifer. Main source of aquifer recharge is Indus Basin Irrigation System (IBIS) and rainfall (Tank *et al.*, 2010). Thal Doab is one of the main parts of the Indus Plain Aquifer. Generally fresh water occurs near rivers, canals and in the irrigated areas.

Physiochemical and hydro-chemical parameters of groundwater of the Upper Thal Doab is analyzed to evaluate the suitability of groundwater for domestic use and irrigation purposes. These physio-chemical parameters water play a significant role in classifying and assessing water quality (Ul Hasan Shah *et al.*, 2016). The quality of water contained in alluvium varies from fresh to saline and changes from place to place. The spatial variation of ground water is dependent on availability of recharge source. Due to deficiencies of surface water supplies in the area, public and private sectors are forced to supplement their water requirement by pumping groundwater. Farmers have also installed solar tubewells in some areas to pump groundwater to meet water requirements for agriculture. However, uncontrolled and unregulated exploitation of this resource has questioned its ability to feed the rising population. The groundwater level has changed from spatial to temporal. This demands urgent action to bring a balance between recharge and discharge components for sustainable use of groundwater. Assessment of groundwater potential is a vital step to use and manage resources effectively as well as efficiently. The challenge is to work on both supply-side and demand management solutions.

2. Description of the Study Area

2-1. Location of the Study Area

The study area called Greater Thal Canal (GTC) area is located between about 30° and 32°30′ N and between about 71° and 72° E in the Punjab province which is the second largest province of Pakistan. GTC area is the eastern part of the Thal Doab bounded by River Indus on the West and Rivers Jhelum and Chenab on the East. The area falls within the boundaries of Bhakkar, Layyah, Khushab and Jhang districts. The area lies at the foot of the Salt Range and gradually slopes towards Muzaffar Garh District. Thal Doab lies in a sandy zone encompassing about 20,000 km2 having a total length of about 300 km and a width ranging from 30 km to 100 km. Thal Doab is a triangular shape area, and it is divided into two parts on the basis of physiography; Upper Thal and Lower Thal Doab. The upper Thal Doab is mainly covered with sand dunes except the areas adjoining the Indus River and northern district of Mianwali due to availability of canal irrigation. Greater Thal Canal (GTC) off-takes from Chashma Jehlum (C-J) Link Canal at RD 180+222 as shown in Fig. 1. Main length of GTC is 35 km. Total Discharge of GTC is 8,500 cusecs and its Culturable Command Area (CCA) is 1,738,800 acres (703.968 ha). The irrigation network of GTC project consists of four command systems of branch canals namely, Mankera, Chaubara, Dhingana and Noorpur and one command system of Mehmood subbranch of Dhingana branch to improve on-farm water management and agricultural production practices. The command area of each canal and its distributaries and minors are as shown in the table below (Table 1).

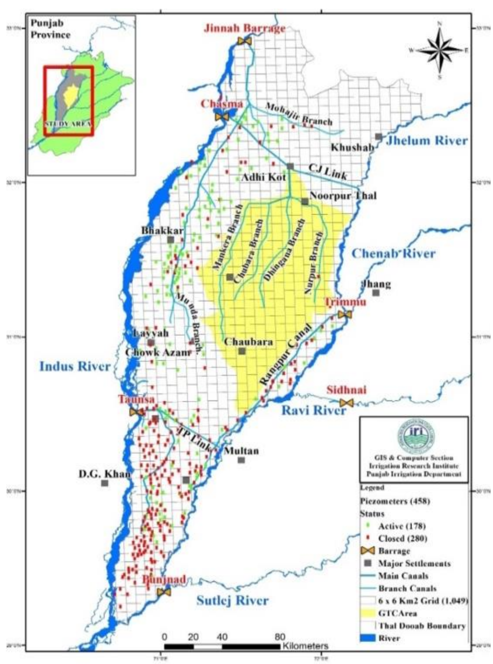

Figure 1. Map of Research Study of Greater Thal Canal area

Table 1. Canals and command area of each canal in the study area.

Canal	Capacity (cusecs)	Command Area (acres/hectares)	Outlets (no.)	Length (km)
Main Canal (MC)	8,500	1,738,800 (704,000ha)	3,533	35
Mankera BC (MBC)	1,215	257,030 (104,000ha)	526	68
Chaubara BC (CBC)	1,465	294,115 (119,000ha)	610	71
Dhingana Branch	3,880	781,080 (316,000ha)	1590	88
Mahmood Sub Br.	1,480	284,930 (115,000ha)	575	54

The GTC irrigation system is designed, re- water allocation, to provide irrigation canal flows for one (1) crop per year, during the Kharif (summer) season. About half of its land surface area is undulating due to the presence of alternative sand dunes and interdunal depressions, locally called "patties". It consists of two types of landforms; sandy river terraces (74%) and abandoned river channels (26%).[1]

2-2. Climatic Condition

Rainfall is an important parameter to delineate the groundwater potential and major hydrological sources of groundwater storage (Arulbalaji *et al.*, 2019). Climate of area falls under "arid" category. The climate is characterized by low rain, high temperature, low relative humidity, high rate of evaporation and strong summer winds (Agarwal *et al.*, 2013). The region is amongst the warmest/hottest areas of Pakistan. The absolute mean monthly temperature in the area ranges from 5°C in January to 42°C in June. In the winter, temperatures vary between 3°C, and 8°C. Two (2) gauging stations were installed at districts Mianwali and Multan where long term historic daily rainfall data is available. According to Pakistan Meteorology Department (PDM) observation, the daily average minimum temperature over the period of 30 years is 18°, whereas the daily average maximum temperature has a value of 28°C. The maximum highest temperature is 43°C. The daily minimum temperature recorded over the same period is -1.67°C in 1967, while the maximum daily temperature recorded was 54°C in 1977. Due to evaporation rates in summer (April to September) is 1250 mm while winter evaporation approximates to 500 mm (Khan, 2010) (PARC, 1996) day resulting in higher water demand for crops.

1. https://www.adb.org › files › 49372-002-eia-en "Environmental Impact Assessment - 49372-002: Greater Thal

The study area receives a limited amount of rainfall during the two rainfall seasons, i.e., monsoon and winter precipitation, with mean annual values ranging between 150-250 mm (Kazmi *et al.*,1997). Almost 56% of the precipitation occurs between the months of June and August, however there is high variability across seasons and even years. Total annual rainfall has been seen progressively decrease from the northern end of the desert to the south (Shaheen *et al.*, 2020). It also displays cyclic fluctuations where two to three years of continued decreased rainfall is followed up by several years of higher precipitation levels (Garzanti *et al.*, 2020).

2-3. Hydrogeology of the Study Area

The GTC project area is a part of Thal Doab – the interfluve between Jhelum and Indus rivers, underlain by alluvial sands and undulating landscape, i.e., sand dunes and interdunal depressions (Kazmi *et al.*,1997). Moreover, extensive areas of sand dunes are found in the central desert of Thai Doab (Greenman *et al.*,1967). The area lies at the foot of the Salt Range and gradually slopes towards Muzaffar Garh District. The groundwater reservoir of the project area consists of alluvial sediments covered by aeolian deposits. Their maximum known thickness in the area is about 1,500 feet (457 m) (Swarzenski,1968). About 90% of the thickness consists of sand formations. Silt and clay layers are thin and of a limited lateral extent and have no confining effect on groundwater movement. The groundwater reservoir is, therefore, considered to be a single contiguous water-table aquifer. It is hydraulically connected with the Lower Thal Canal system and the C.J. Link Canal. Any hydraulic connection to the Upper Thal Canal system is indeterminate.

2-4. Soil

The soil of the command area of Greater Thal Canal is sandy with undulating topography with sand dunes. The soil of the area is coarse to moderately coarse-textured and are generally free of salinity and alkalinity. The soil has a high infiltration rate and inherently low nutrient content. The soils of the surveyed area are formed either directly or indirectly from mixed calcareous alluvium. All the soils are moderately calcareous and have low organic matter content (about 0.4 percent) [18] (PARC, 1980). The soils of hollows are mainly well-drained and have an average pH value of 8.4.

3. Materials and Methods

The assessment of groundwater conditions, its use and potential, are based on the studies conducted in the Thal Doab area by public and private agencies, detailed groundwater studies conducted during the GTC Phase I from 2002 to 2005 on groundwater levels, quality and its use for agriculture. In the study area, various types of spatial and temporal data like groundwater conditions including depth to water table, groundwater quality, and also recharge and discharge parameters (rainfall, irrigation systems and tubewells) were collected. Data was managed and analysis to prepare mapping were prepared to assess the groundwater potential in the area, considering the occurrence space and supply condition. Monitoring of groundwater is one of the tools used in groundwater management to obtain the information which is required for the assessment of the groundwater system and the groundwater management issues. Historical groundwater monitoring data was also collected from the WAPDA/SMO (SCARP Monitoring Organization) and Directorate of Land Reclamation (DLR). IRI team also monitored groundwater situations from the piezometers installed in the area using water level sounder. A number of discussions with the farmer groups were carried out for the identification of problems and the pragmatic way out. Geographical Information System (GIS) tools was used for aquifer mapping to improve our understanding of the geologic framework of aquifers, their hydrologic characteristics, water levels in the aquifers and how they change over time, and the occurrence of natural and anthropogenic contaminants that affect the portability of groundwater.

4. Results and Discussions

Depth to the water table and quality of groundwater is the most important data needed for the assessment of water potential and managing groundwater resources in the area. The main parameters controlling groundwater level, quality, and its management are detailed below:

- Depth of groundwater table (GWT) – and its long-term behavior – based on systematic monitoring data.
- Groundwater Quality – and its variation in aerial and vertical extent.

4-1. Depth to water Table

Depth to water table in the aquifer gives basic information required for groundwater studies in the area. Groundwater in the Greater Thal Canal (GTC) area is used for drinking domestic, livestock, Agriculture purposes. The current study was carried out to assess the existing groundwater conditions, ultimate groundwater potential, its use and the impact of canal water on the groundwater regime and possible decline of water table in response to groundwater withdrawal.

Data on the depth to water table was collected from WAPDA/SMO (SCARP Monitoring Organization) (SCARP=Salinity Control and Reclamation Project) from the 1960s, plus additional groundwater data collected by the GTC project's engineering design studies team from 2002 to 2004 and also from DLR from 2002 to 2004. Fourteen piezometers were installed along the left and right side of the GTC main canal to study the seepage from the canal and the water level profile on the left and right banks of the canal. Forty-one (41) additional piezometers installed in the GTC area to supplement the data on groundwater levels (Ltd, 2019). Depth to water table were monitored from these piezometers during pre and post monsoon seasonal basis to measure the water-table fluctuations. The depth to water table was around 40 feet (12.2m) in the central part of the Thal Doab in 1992 (SMO) and gradually decreased in depth moving towards the riverain areas due to the extensive pumping in the area installation of tubewells. Depth to water table in the Thal Doab was monitored especially more emphasis in the canal irrigated areas, within the Lower Thal Canal command area since 2005 to onwards by Punjab Irrigation Department. All of the monitoring points are located in the NE of Nurpur. Data of monitoring of groundwater in the Nurpur Thal area has been used to study the time-rate-change in the depth to water table profile from 2005 to 2019 as shown in Figure 2.1 given below.

Based on the data collected in the past by the Consultants under WAPDA/NESPAK, during the field checks on hand pumps and tube wells being operated in the area, a generalized picture of the depth of the water table (DTW) in the area are shown in Figure 3.1

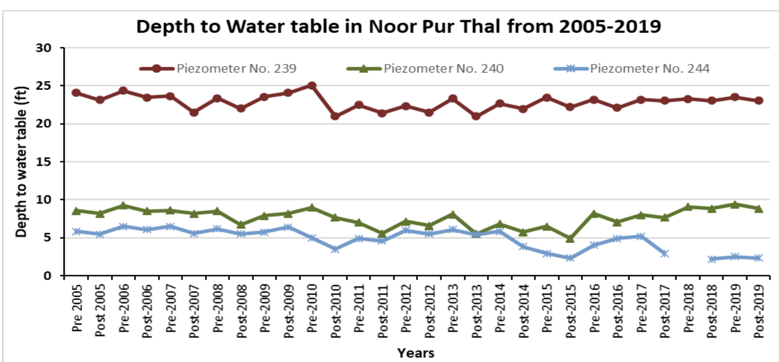

Figure 2. Depth to Water table (in feet) trend in the area of Noorpur Thal for 2005-19

The above figure indicates that the depth to water table has been more or less stable. The range of depth to water table is 5 feet to 25 feet in the area.

The water table contour maps of observed data were prepared for the post monsoon year 2014 and post monsoon year 2018 to compare the groundwater level which are shown in Figs 3 & 4. The depth to water table in GTC command area and its surrounding area is from 5 feet to 50 feet. The maps indicate that an irregular shaped depression in the water table is being created.

The IRI team (including authors) monitored depth to water table from some selected piezometers for ground-truthing and understanding the current status of groundwater in the area during 2019 as given in table 2. The study indicates depth to water table varies greatly ranging from less than 9 feet to more than 29 feet.

Table 2. Depth to water table at the selected points (piezometers) in 2019

Sr. No.	DTWT below NSL (ft)	DTWT below NSL (m)	Location	Address
1	12.96	3.95	31.34692, 71.69602	Canal Rest House Hyderabad Thal
2	16.01	4.88	31.372822, 71.55041	Adda Latif Abad near Mankera
3	18.86	5.75	32.040312, 71.800298	Along Main GTC RD 21+100
4	8.2	2.50	32.100146, 71.847982	Basic Health Centre Chan, Adhi Kot to Groat Road, Tehsil Nurpur Thal
5	29.22	8.91	31.248822, 71.910596	Civil Rest House Bharari

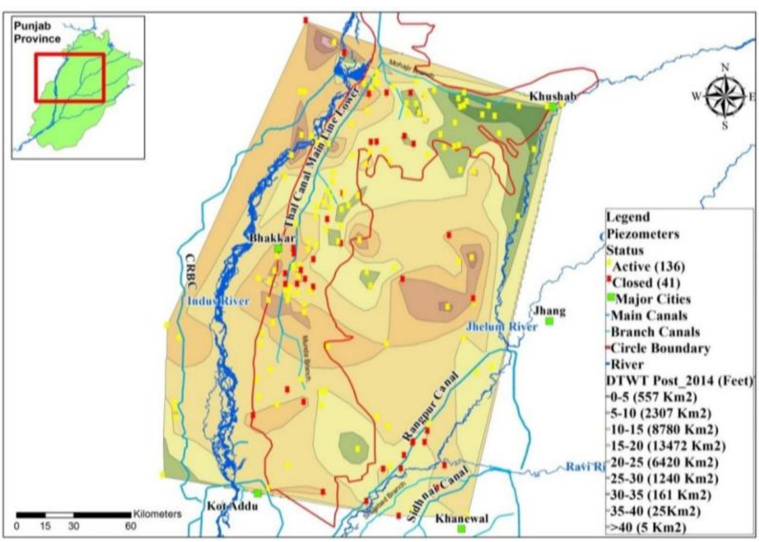

Figure 3. Depth to water table in Thal Area during Post Monsoon 2014

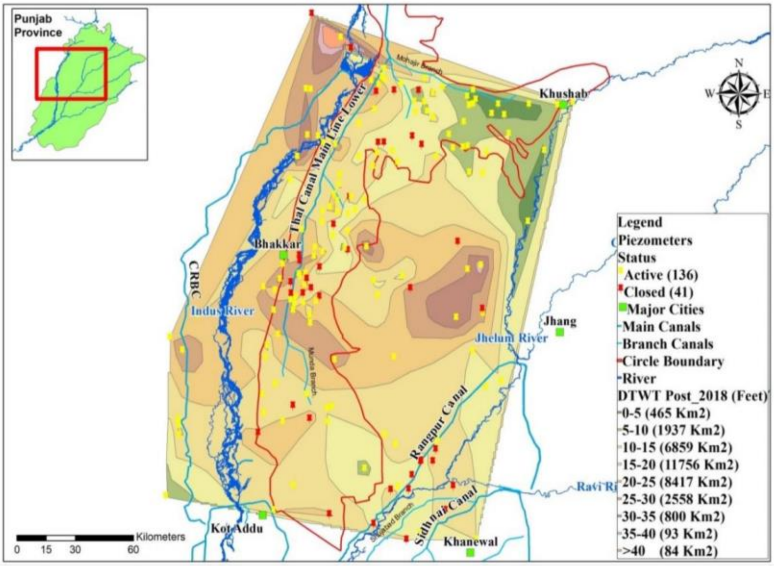

Figure 4. Depth to water table
in Thal area during Post Monsoon 2018

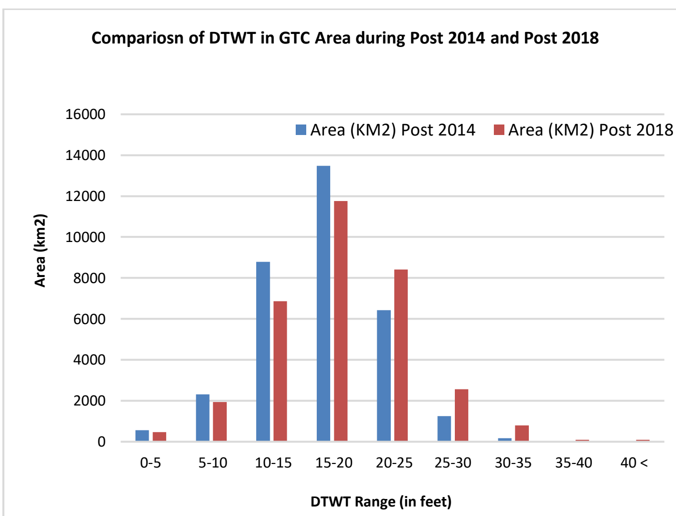

Figure 5. Groundwater Quality Status
in Thal Area Post Monsoon 2015

It has been observed that due to the increasing of farmer's tube wells to pump groundwater, depth to water table have increased. Due to pumpage, the water-logged area with less than 5 feet DTWT have decreased in the GTC command area. Similarly, the area where the groundwater table is up to 20 feet decreased and the area depth to water of 20 to 30 feet have increased because of groundwater pumpage to crop water requirement.

4-2. Groundwater Quality

Groundwater in the GTC is being pumped by a hand pump for drinking and by farmer's tube wells; mainly for agricultural purposes. Groundwater quality, especially Electric Conductivity (EC) of a hand pump and tube wells located in the GTC area was checked and monitored by WAPDA /NESPAK to assess the aerial and vertical distribution of groundwater quality from 2001 to 2002. Groundwater quality of 113 Nos of samples collected from hand pump (shallow) and tube well (deep) were analyzed and results show that quality is varies from fresh to saline as shown in Table 3 given below:

Table 3. GWQ (EC) of Hand Pumps and Tube wells in GTC Command Area

Tehsil	Water Source	Field Check #	EC Value Range (uS/cm)			EC Range (uS/cm)	
			< 1500	1500-3000	> 3000	From	To
Athara Hazari	Hand Pumps	2	1	1		1,250	2,350
	Tube wells	5	2	3		460	2,480
Chaubara	Hand Pumps	4		2	2	1,800	3,710
	Tube wells	25	1	9	15	1,315	8,290
Mankera	Hand Pumps	16	10	6		500	2,525
	Tube wells	27	18	8	1	625	5,410
Nurpur	Hand Pumps	17	12		5	360	7,550
	Tube wells	17	10	5	2	650	4,718
	Total:	113	54	34	25		

The IRI team also checked and monitored the groundwater quality from some hand and tube wells to understand the current status of groundwater quality in the area during 2019 as shown in table 3. The EC value ranges from about 450 uS/cm to 1,000 uS/cm indicating fresh while EC value ranges from 1000 to more than 24,00 uS/cm indicating fresh to saline groundwater.

Table 4. Monitoring of Groundwater Quality

Sr. No.	GWQ		Location	Types of Pump/ Well	Depth Shallow/ Deep	Address
	EC (μs/cm)	Temp. (°C)				
1	704	30	31.372822, 71.55041	Hand Pump	Shallow	Adda Latif Abad near Mankera
2	1020	30	31.37755, 71.49276	Tube well	Deep	Kesenwala, Mankera
3	438	31.5	32.095756, 71.801608	Lal Pump	Deep	Adhi Kot, Irrigation Office
4	560	26	32.095756, 71.801608	Hand Pump	Shallow	Adhi Kot, Irrigation Office
5	2456	29.6	32.100146, 71.847982	Hand Pump	Shallow	Basic Health Centre Chan, Adhi Kot to Girot Road, Tehsil Noorpur Thal
6	1585	29.3	31.248822, 71.910596	Hand Pump	Shallow	Civil Rest House Bharari
7	1041	32	31.456115, 71.694947	Solar Tube well	Deep	Junaid Farm Chak #7 Hyderabad Ludda Road Tehsil Mankera
8	451	31.8	31.393410, 71.450525	Solar Tube well	Deep	Dr. Qasim Bhatti Farm, Chak# 3 Mankera

Groundwater quality was checked to understand the current status of groundwater in the area. Fit and unfit groundwater quality in the GTA as shown in Fig. 5. Trends of Groundwater quality in Nurpur Thal area from 2003 to 2013 has been plotted in the graph as shown in Fig. 6. which shows the time rate changes of the groundwater quality and also show the EC value from 2500 (μs/cm) to 7500 (μs/cm).

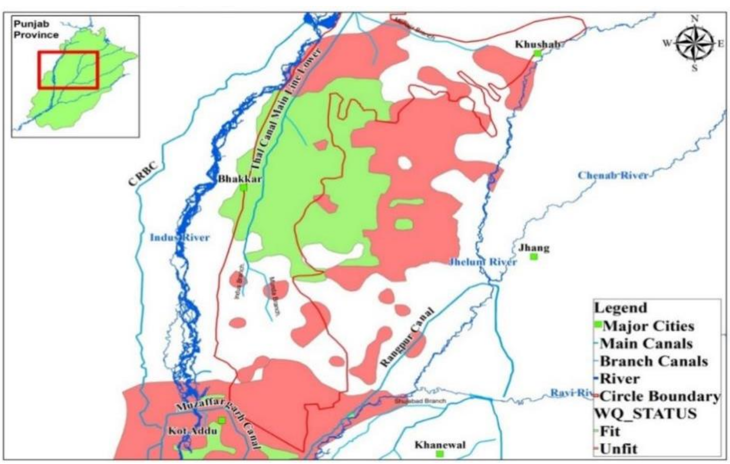

Figure 6. Groundwater Quality Status in Thal Area Post Monsoon 2015

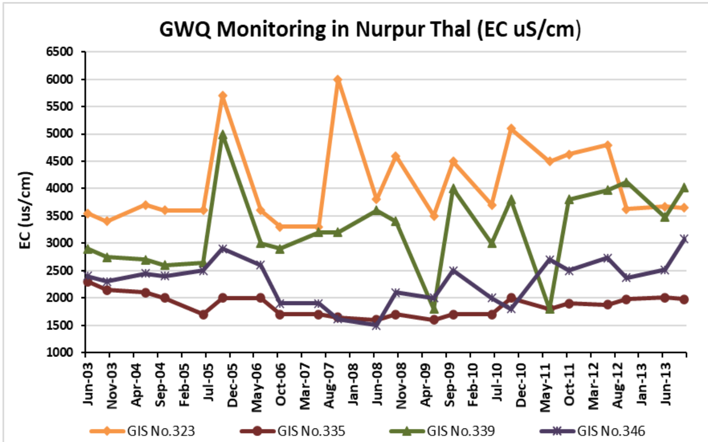

Figure 7. GWQ Monitoring in Nurpur Thal area

High values of EC in areas were observed from 1500 µs/cm to 7500 µs/cm.

4-3. Growth of Tube wells and Use of Groundwater

The assessment of the existing GW and the growth of the number of the farmers tube wells in the command area of GTC has been made on the basis of current data and historical collected in the study area. There were 7,737 tube wells for might be 450,000 Acres (considering 50 to 60 acres being provided irrigation water from each tube well within tehsils of Nurpur (2,309 Nos.), Mankera (2,054 Nos), Chaubara (1,782 Nos) and Athara Hazari (1,592 Nos) of GTC area in 2005. Of these around 80% tube wells are located in the command areas of the above three (3) canals of the current GTC. Pumping equipment, discharge and operation factor of the tube under the existing conditions has been carried out. The discharge of the tube wells ranges from 1.0 cusec to 1.5 cusecs with the general depth of the tube wells is from 120 feet to 160 feet. Under the existing conditions the pumping cost may range from Rs.300 to around Rs.600 per hour which demands judicious groundwater use. Data regarding the number of farmers tube wells in the Nurpur, Mankera, Chaubara and Athara Hazari was collected by the Agriculture Department (PAD) through periodic surveys. Huge numbers of Solar tube wells are also being installed in the GTC command area Fig. 7.

Due to development of Irrigation System including Main Canal (MC), Mankera Branch Canal (MBC) and Chaubara Branch Canal (CBC) in GTC, the number of tube wells have been drastically increased. Farmers adopted conjunctive use of groundwater and canal water for irrigated agriculture

Figure 8. Solar Tube well in the GTC command area System

Farmers in the area also rely on groundwater for irrigation. Intensive and increasing pumping will cause the lowering of water tables in some areas, increases the pumping costs and results in saltwater intrusion into aquifers.

5. Conclusions

In the aquifers, groundwater flows from higher to lower elevation. Based on the existing data from the piezometers located at different positions, the groundwater level profiles have been developed. Groundwater parameters, such as depth of water table and water quality have been observed to evaluate the groundwater potential of the study area. Depth to water table is an important factor for aquifer development and management. Shallow water table conditions lead to water logging, whereas deep groundwater tables create difficulty for the farmers for installing tubewells and pumping, Capital and operation costs increase as the water table goes deeper and deeper. There is evidence of waterlogging near the canals and in low lying areas. Depth of water table (DTW) in Nurpur tehsil is generally shallow in the area near Adhi Kot and is deep in the eastern part towards Athara Hazari Area; up to more than 30 feet (9.15 m). DTW in Mankera Tehsil area ranges from around 15 feet (4.6 m) to more than 40 feet (12.2 m) in the greater part of the Tehsil; particularly towards the eastern part. DTW in Chaubara Tehsil also is relatively shallow, 10 to 20 feet, (3m to 6 m) and increases towards the eastern part up to more than 40 feet (12.2 m) below Natural surface level (NSL). It indicates that adequate groundwater potential is available which can be tapped by scientific planning, management and planning. No of solar tubewells in increasing due to very high diesel and electricity costs in Pakistan. Solar based pumpage will encourage the trend of lavish use of this natural resource and water table may go down increasing the overall cost of groundwater extraction.

Groundwater quality is also an important factor for its domestic and agriculture use. Fresh, marginal, and saline groundwater was observed in the study area. The ranges of groundwater (i) water with an EC reading of less than 1,500 uS/cm is considered as fresh, and (ii) water with an EC reading of 1,500 to 3,000 uS/cm is considered marginal as an irrigation water source, and (iii) water with an EC reading of greater than 3,000 uS/cm is considered as saline. Distribution of the shallow and deep groundwater quality in the GTC area is based on the monitoring of water from hand pumps, the piezometers and farmer's tube wells installed in the area.

In the Nurpur Tehsil area, Groundwater quality ranges from fresh to saline with EC values from 1000 µs/cm to around 7,000 µs/cm. In the larger parts of tehsil Nurpur, shallow groundwater quality (GWQ) is fresh and is being exploited through hand pumps for domestic use. Deep GWQ is fresh in Nurpur Tehsil, except in some poor GWQ zones in the eastern part of the tehsil.

In the area of Tehsil Mankera, EC value ranges from about 1,000 to more than 4,000 uS/cm indicating fresh to saline groundwater. GWQ is fresh in the northern part and some southern parts of Mankera Tehsil, the groundwater quality is marginal with EC values exceeding 1,500 uS/cm.

The groundwater quality is marginal to saline in Chaubara Tehsil with EC value ranging: from around 1,800 to 3,700 uS/cm. Groundwater quality of deep water is generally marginal to saline in the area with EC readings range from 1,300 uS/cm to more than 8,000 uS/cm.

According to data analysis, it has observed that areas lying in the central part of the Thal Doab and away from the rivers on both sides of the Thal Doab were identified as a saline groundwater zone as the flushing effect of the rivers on either side of the Doab has little impact. Whereas nears and along the rivers and the canal irrigation system has improved the groundwater quality gradually from fresh to moderate groundwater zone due to seepage losses acting as groundwater recharge (in fact inefficient irrigation practices – as low as 40% efficiency). Time rate changes of groundwater level and quality in the GTC also occurred during pre and post monsoon. The quality improved slightly in October due to rainfall recharge and a reduction in pumping by the farmers.

6. Recommendations

A careful assessment of the groundwater aquifer system is essential using groundwater modelling and decision support tools for its sustainable management. Potential groundwater recharge mapping can assist water resource managers to make better management plans. For proper groundwater management, appropriate aquifer mapping, groundwater monitoring and modelling is required in the Greater Thal Canal command area. More piezometers need to be installed for the effective and purposeful monitoring of groundwater levels and quality. For aquifer mapping and development of groundwater modelling, geophysical data, hydrological data, agriculture data, aquifer parameters etc. need to be collected and updated regularly. If we can monitor effectively, we can manage precisely.

Remote Sensing and GIS are tools used for aquifer mapping to improve our understanding of the geologic framework of aquifers, their hydrologic characteristics, water levels in the aquifers and how they change over time, and the occurrence of natural and anthropogenic contaminants that affect the portability of ground water. Use of innovative tools like loggers, data recorders, drones for monitoring, Mobile-Apps, models, sensors can support sustainable management and use of groundwater.

Groundwater modelling is a scientific tool wherein combinations of geologic, geophysical, hydrologic etc. are applied to characterize the quantity, quality and sustainability of ground water in aquifers. Management of groundwater in Greater Thal Canal at sub basin level is direly needed to capture the surplus surface water of rainfall/flood etc. The model will help to understand the overall groundwater situation in the project area and to describe the better groundwater conditions for different hydrological and water management specific scenarios. It will also be used for predicting future groundwater conditions in the model area and to determine spatial and temporal changes in groundwater levels caused by the implementation of different water resources management strategies.

For proper groundwater management, appropriate aquifer mapping by Remote Sensing and GIS tools, groundwater monitoring through data loggers and Groundwater modeling by GW vista 7 to determine spatial and temporal changes in groundwater levels should be implemented in Greater Thal Canal command area. More piezometers will be installed for the monitoring of water levels. Geophysical and hydrogeological study should be conducted in the area for groundwater potential assessment and sustainability of ground water in aquifers. In depleted zones artificial recharge of aquifers, especially the managed aquifer recharge (MAR) projects in the areas where groundwater is depleted are recommended.

Adoption of water conservation practices, introduction of micro-irrigation technologies, and using groundwater to grow high-value crops can assist in boosting groundwater economy. Educational programs should be initiated to create awareness among farmers for judicious /efficient use of groundwater to increase water productivity and adopting water conservation practices to minimize groundwater extraction.

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8. Author Contributions

All authors contributed to the study conception and design. Filed survey, data collection and analysis were performed by the IRI team. The first draft of the research paper was written by the IRI team. All authors read and approved the final manuscript.

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