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GROUNDWATER-FOOD SECURITY NEXUS UNDER CHANGING CLIMATE-HISTORICAL PROSPECTIVE OF INDUS BASIN IRRIGATION SYSTEM IN PAKISTAN

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ABSTRACT

Irrigated agriculture plays a vital role in the economy of Pakistan by contributing about 90% of food production, 22% of GDP, employing about 45% of the overall labor force, and generating over 60% of foreign exchange. The role of water resources has become significant which underpins the food security in the country. Indus Basin Irrigation System (IBIS) is the lifeline for the economy of Pakistan and is the major pillar of food security. IBIS is one of the largest irrigation networks in the world and is confronted with multidimensional challenges out of which climate changes have attained paramount importance. The irrigation system was designed on a 67% irrigation system during the 19th century while the current cropping intensity has crossed the limits of 150-160% or even more. Continuous increase in population and consequently more food demands have shifted the pressure on the aquifer underlying the Indus Basin. India, USA & China, and Pakistan has become the 4th largest user of groundwater where about 40% of irrigated food production is dependent on groundwater. In Punjab province, about 1.2 million tubewells are extracting about 40-45 MAF of groundwater annually. Consequently, groundwater management has confronted a multitude of tiny users in Pakistan. Climatic changes have made the availability and reliability of surface water a question mark. Resultantly pressure on groundwater is increasing and water levels are dropping abruptly taking this resource beyond the bounds of rural poor farmers. The intrusion of saline water into the fresh aquifer, secondary salinity, and seawater intrusion are the major threats to groundwater quality. About 3000 piezometers have been installed to monitor groundwater behavior (levels and quality) in the Punjab province. A research study carried out in Lower Bari Doab Canal (LBDC) has indicated that by falling of water table from 40 to 70 ft. the cost of pumping per acre-feet of groundwater has increased by 125%. Similarly, it has been observed that in many urban areas groundwater is depleting at an annual alarming rate of 2.54 ft., (Lahore city) and the water table in sweet water zones in rural areas (Vehari District) has gone beyond 70-90 ft. Human activities like increasing cropping intensities, unplanned over pumpage, lack of awareness/capacity, use of chemicals in agriculture/food production, industrialization, urbanization, solid waste landfills, domestic effluents, lack of legal and regulatory framework, etc. are the major threats to sustainable use of groundwater for food security. Climatic changes are posing severe adverse impacts on the sustainable use of groundwater which is putting food security under threat. Global warming, rising sea levels, glacier melting, unprecedented rainfall, prolonged droughts, and floods are the consequences of changing climate which are affecting directly or indirectly the groundwater resources in the aquifer underlying the Indus Basin.

KEYWORDS

Groundwater, food security, climate change, aquifer, Punjab, Pakistan

1. Introduction

World population is expected to increase by 45% in the next thirty years. Groundwater is the world's most extracted raw material with withdrawal rates currently in the estimated range of 982 km^3/year. Out of total earth's water, 99 % is unusable for human beings while only 1 % is usable. Out of this usable (1%), 99% comes from groundwater while nearly 1 % world's groundwater is fresh and is accessible for consumption. Pakistan is 4th largest user of groundwater after India, USA and China. Pakistan is blessed with a plenty of water resources including a large groundwater reservoir underlying the Indus Basin. The extent of this large and highly transmissive aquifer is about 297,200 km^2 with a length of 1,900 km, but this natural resource is under serious threats and need immediate measures for its sustainable utilization. In Pakistan, over 90% drinking water and 100% industrial water comes from groundwater. Groundwater has helped in increasing cropping intensity from 60% in 1947 to 150% or even more in 2015. In Pakistan, current per capita water availability (1200 m^3/person) is low, which puts us in the category of a high water stress countries on the globe. UNESCO has predicted that by 2020 water shortage will be a serious worldwide problem. Without improved efficiencies, agricultural water consumption is expected to increase by about 20% globally by 2050 **WWAP (2012).** Groundwater quality depends on the climatic parameters, nature of the surface flow, topography, extent of seepage and irrigation with amendment practices. Groundwater in the Indus basin contributes around 35% to the total water available for agriculture and water quality of the 60 percent area is marginal to brackish **World Bank (1997)** and **Ahmad and Rashida (2001**).

Pakistan is the 8th largest food producing country and economy heavily relies on agriculture sector which accounts for a quarter of its GDP and employs two-fifths of total labor force. The agriculture mainly depends on the Indus River System (IRS) for 90% of its irrigation needs, which is also a source of generation of about 30% energy of the country. Pakistan's agricultural performance is closely linked with the supply of irrigation water. This natural resource is being utilized for drinking, agricultural, industrial, livestock, commercial and other uses and is continuously under threat. The other most obvious uses of water for people are drinking, cooking, bathing, cleaning, and for some watering family food plots.. Irrigated agriculture contributes over 90% of Pakistan's food production. Agriculture sector generates over 60% of foreign exchange. It is the second largest sector, accounting for over 22% of GDP, and remains by and far the largest employer, absorbing 45% of the country's total labor force. Around 63% of country's population living in rural areas is indirectly or directly linked with this sector for their livelihood. While on the other, it is a large market for industrial products such as fertilizer, pesticides, tractors and agricultural implements. According to **Kaldor (1978)** two-sector model, agricultural and industrial sectors supply inputs to each other and provide market for their outputs but differ in a number of ways. The agricultural sector has disguised unemployment and produces consumer goods for competitive markets, while industrial sector produces investment goods which are sold in imperfectly competitive markets at mark-up prices. According to **Duranton (1998),** in order to transform from agriculture sector to industrial sector a significant increase in the agricultural sector productivity is necessary. On the demand-side, the growth in agricultural production increases agricultural income which leads to increase in the demand for industrial products; whereas on the supply side, the increase in the agricultural productivity shifts human resources from the agricultural to the industrial sector **Jorgenson (1967)**. **Chebbi (2010)** evaluated the role of agriculture in economic growth and dealings with other sectors. Johansen's multivariate approach has been used to study the co-integration with the other sectors in its country economy and he deeply analyzed how to overcome the problems of spurious regression.

Annual groundwater pumpage has increased from 4 billion m^3 in 1959 to around 60 billion m^3 in 1999-2000. About 79 % area in Punjab and 28% area in Sindh provinces have fresh groundwater suitable for agriculture **Afzal (1999) and Bhutta (1999).** In Punjab province about 40-50% crop water requirements are being met from groundwater through about 1.2 million tubewells installed by a multitude of tinny farmers in rural areas. Groundwater quality in the Punjab province is deteriorating with the passage of time and sweet water is becoming rare and out of reach of the common farmers who are dependent on groundwater for their livelihood. **(Hassan et al, 2014).**

The Indus basin Irrigation System (IBIS) is the largest contiguous integrated irrigation system in the World. Historically IBIS has been fed through run of river supplies derived from Indus and its five major tributaries.

For supplying water to Pakistan's irrigation network (the largest manmade canal system in the world) the Indus Basin Project (IBP) was designed and constructed to supplement the deficiency of water in Eastern Rivers. Any reduction in those waters will put Pakistan's agriculture, food security and economy at great risk. (**Hassan et al 2013)** during a study found that pollution in surface water bodies is affecting the groundwater quality in the underlying aquifer in Lahore city. They recommended allow/arrange minimum flow in the River at least to meet the requirements of dilution of pollutants and to treat the wastewater before throwing it into the river. Domestic and industrial effluents contain organic and inorganic pollutants, which deeply percolate to groundwater. Flow in Ravi River especially during the winter is remarkably insufficient to dilute and wash off wastewater pollution **(Hassan et al, 2016).** Major part of Pakistan's canal irrigation network lies in Punjab Province. This network was started to be constructed by British during early nineteen 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 **(Hassan and Bhutta, 1996).** This also posed severe impacts on aquifer equilibrium. From the above discussion it has been concluded that economy of Pakistan is agri-based for which water resources are required on sustainable basis to feed the ever increasing population of the country.

Groundwater is the world's most extracted raw material with withdrawal rates currently in the estimated range of 982 km3/year. About 60% of groundwater withdrawn worldwide is used for agriculture; the rest is almost equally divided between the domestic and industrial sectors. In many nations, more than half of the groundwater withdrawn is for domestic water supplies and globally it provides 25% to 40% of the world's drinking water. About 38% of irrigated lands in the world are equipped for irrigation with groundwater. Out of total earth's water, 99 % is unusable for human beings while only 1 % is usable. Out of this usable (1%), 99% comes from groundwater while nearly 1 % world's groundwater is fresh and is accessible for consumption. In Pakistan, current per capita water availability (1200 m3/person) is low, which puts us in the category of a high water stress countries on the globe. Pakistan is blessed with a plenty of water resources including a large groundwater reservoir underlying the Indus Basin. The extent of this large and highly transmissive aquifer is about 297,200 km2 with a length of 1,900 km, but these natural resources is under serious threats and need immediate measures for its sustainable utilization. Globally, total freshwater withdrawals are believed to have increased by about 1% per year between 1987 and 2000, based on data obtained from FAO AQUASTAT.UNESCO has predicted that by 2020 water shortage will be a serious worldwide problem. Without improved efficiencies, agricultural water consumption is expected to increase by about 20% globally by 2050 **WWAP (2012)**. Global distribution of water resources is shown in Figure 1.

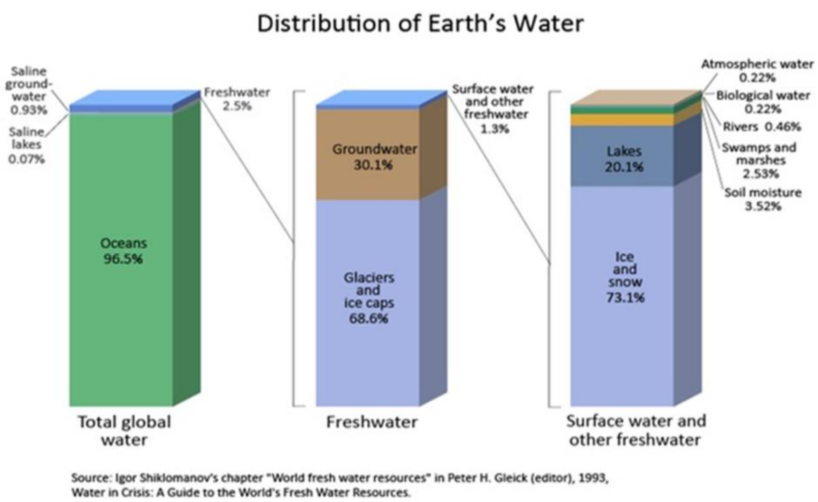


Figure 1: Water Distribution in the world

Global estimates show that approximately 4430 km^3 of fresh water resources are abstracted annually, of which 70% are used in agriculture, 25% in industry and 5% in household **(Kinzelbach et al., 2003**) as depicted in Figure 2.

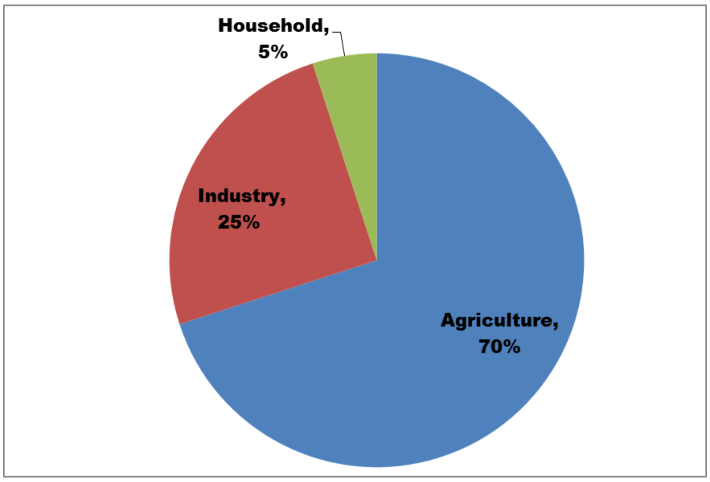


Figure 2: Major Global Groundwater Consumers

An assured supply of water has, therefore, been the prime concern of all societies. In our own time the increasing stress on capacities of water systems has led to a growing realization that it is only through a scientific approach to their management that we can hope to sustain the quality and regular availability of this basic human requirement. The need for appropriate integrated studies in developing countries is the most important in view of an increasing population, widespread aridity and scarcity of fiscal resources and vagaries of hydro-meteorological conditions. Groundwater, surface water and land comprise a complex interlocked system and they must be considered and managed in their totality towards making the most optimal use of this precious resource. Groundwater resources are now being increasingly tapped to meet societal needs on account of their possible availability in the vicinity of the consumer. However, it is important to recognize that although groundwater has ubiquitous occurrence and vast magnitude, its potential as a perennial source is subject to wide spatio-temporal variations. With the advent of remote sensing and sophisticated data processing techniques, the speed and scale of investigations of visible resources such as land and surface water have greatly improved. Since last many years, rapid increase in population and urban sprawling has resulted in over extraction of groundwater especially in the urban areas to meet with human demands due to which underground water table is depleting at alarming rates. Urban sprawl is to be the fastest growing threat to local environment and quality of life. As urban areas expand, environmental problems like losing green space, groundwater recharge area, and degradation of natural ecosystem and deterioration of water resources are increased. The impact on groundwater quality from urban sprawl is attributed by the combined effect of population and land use change. Substances which contaminate groundwater are dived into two basic categories, one which occur naturally and other substances that are produced or introduced by man's activities **(Mahmood 2013)**. The un-planned pumpage of groundwater is also causing salt-water intrusion into fresh groundwater due to which sweet groundwater resource is becoming scare. This needs formulation of long term policy framework and comprehensive planning to guard against fast depleting ground water resources. Pressure of aquifer is increasing with the rapid increase in population, industrialization and urbanization. For example according to the 1981 census, Lahore has population of 2.7 million which increased to 6.4 million in1998 **(Faiza & Tabsum 2009).** It has been reported that more than 480 WASA tube wells are extracting about 478.67 Million gallon of groundwater per day and is supplied through 7700 km pipelines distributed in the city **(Hussain and Sultan 2013).** This situation has resulted in tremendous depletion of groundwater levels. The only source to recharge Lahore aquifer is Ravi River, the smallest eastern river of the Indus River System (IRS) which remains nearly dry except during monsoon season. However, Ravi River along Lahore has become a sullage carrier due to disposal of untreated domestic and industrial wastewater and effluents. There are over dozen disposal stations and surface water drains that discharge untreated waste water into the River. It was observed that untreated wastewater is being discharged into the Ravi River **(EPD 2008 and Ejaz et al 2011)** and it is causing deterioration of groundwater quality along the river which may impact the overall quality of aquifer due to salt intrusion. Ultimately these effluents either leach down to aquifer or are used for irrigation in the downstream areas which cause severe health concern.

Over exploitation of groundwater poses serious consequences on our infrastructural network in addition to other socio environmental concerns. Land subsidence is the lowering of the land-surface elevation from changes that take place underground. Common causes of land subsidence from human activity are excess pumping water, oil, and gas from underground reservoirs; dissolution of limestone aquifers (sinkholes), collapse of underground mines; drainage of organic soils; and initial wetting of dry soils (hydrocompaction). In areas where climate change results in less precipitation and reduced surface-water supplies, communities will pump more ground water. Also, increased demands on ground-water supplies cause more land subsidence in areas already subsiding and new subsidence in areas where subsidence has not yet occurred. In the future, however, increasing population may result in subsidence problems in metropolitan areas where damage from subsidence will be great. Land subsidence causes many problems including: (1) changes in elevation and slope of streams, canals, and drains; (2) damage to bridges, roads, railroads, storm drains, sanitary sewers, canals, and levees; (3) damage to private and public buildings; and (4) failure of well casings from forces generated by compaction of fine-grained materials in aquifer systems. As such, over exploitation of groundwater reservoir is a serious hazard for economy of a country. Human activities like increasing urbanization, use of chemicals in agriculture/food production, industrialization, acidic rains due to air pollution, domestic waste, solid waste landfills, increasing cropping intensities, unplanned over pumpage etc are the major threats to groundwater which are deteriorating its quality and quantity at very alarming rates. At the same time water availability in Pakistan is become sever and sever with the passage of time while water demand is increasing tremendously. This situation has put the country among the water scare countries. Per capita water availability and its reduction trends are shown in Figure 3.

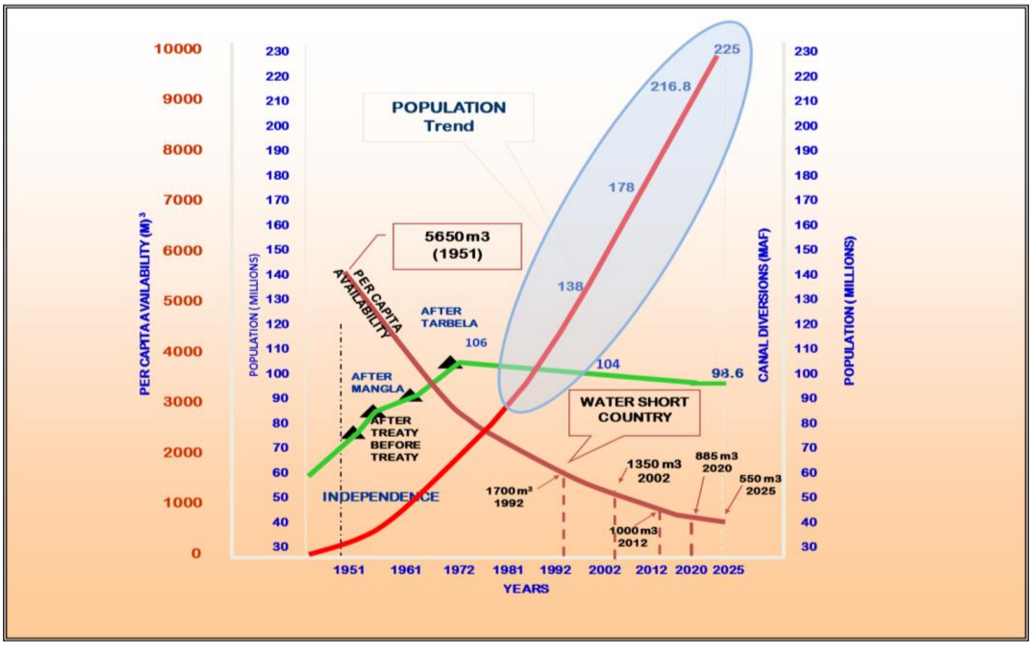
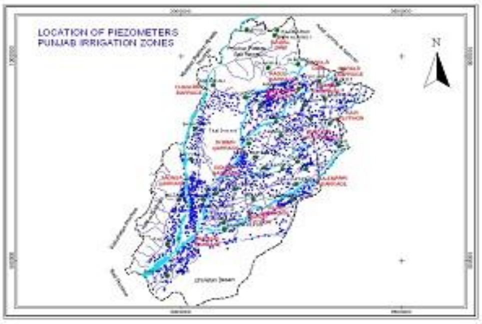


Figure 3: Water Availability in Pakistan

2. Experimental Setup and Data Analysis

Keeping in the significance of groundwater in the national GDP and ever increasing pumpage of g groundwater, the Punjab Irrigation Department is monitoring the groundwater in the province. For monitoring of groundwater round about 3000 piezometers have been installed at different location scattered in canal commanded areas in the whole province as depicted in Figure 4.



Sr. No.	GW Monitoring Units	Total No of Piezometers	Area (km²)
1.	Bahawalpur	607	23100
2.	DG Khan	464	12138
3.	Faisalabad	559	15626
4.	Lahore	320	18195
5.	Multan	587	22735
6.	Sargodha	421	10814
7.	Thal	248	13929
	Total	3206	116537

Figure 4: Piezometer for groundwater monitoring in Punjab Province

Groundwater levels have been measured using water level indicator from the piezometers biannually (pre-monsoon and post-monsoon). The observed data have been analyzed to visualize the aquifer behavior in the study area**. (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 water 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)**. Map Showing the Doabs of Punjab Province and depth to watertable data at selected points in different Doabs over the period of 2011-15 have been plotted to depict the fluctuations of groundwater levels which have been shown in Figure 5.

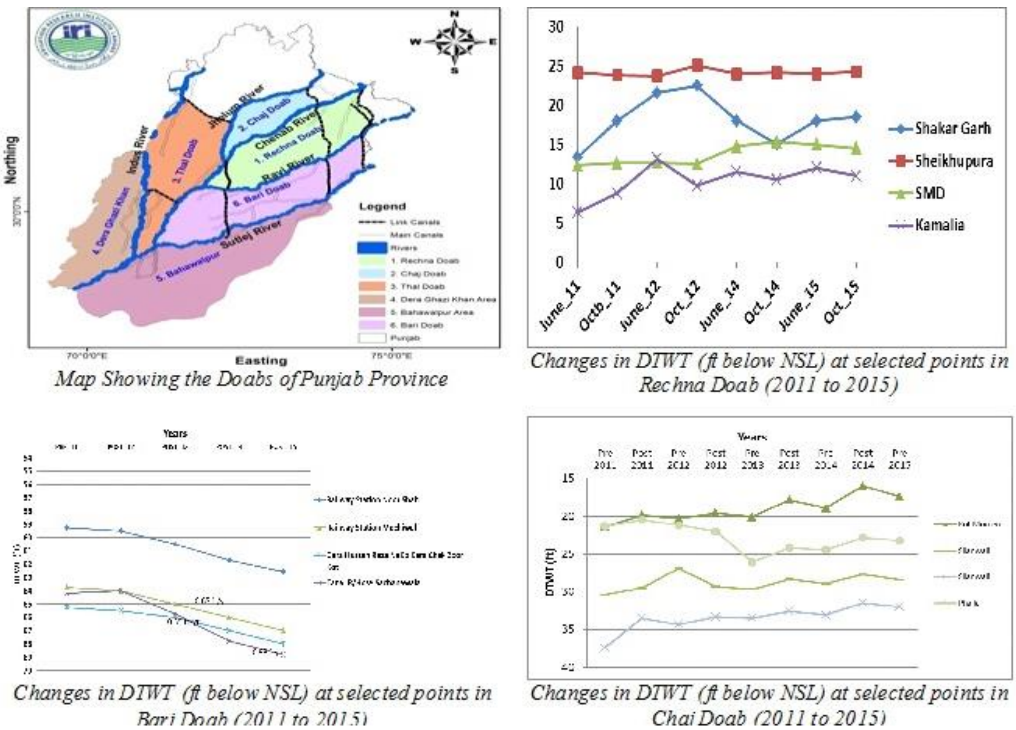


Figure 5: DTWT at selected points in different Doabs over the period of 2011-15

In Chaj Doab (bounded by Chenab River on the south-east and Jhelum River on the north-west) groundwater deeper than 20 feet showed nearly constant rise of 1.7 to 2.2 feet per year. During years 2011-2015, water levels in the Chaj Doab rose from 0.3 to 2.6 ft per year with average 0.9 ft. Groundwater level is in rising trend. Flood water contributes significantly towards recharging the aquifer average rise in Chaj doab during flood 2014 is 0.77 ft/season. Total recharge of GW during flood season 2014 in Chaj Doab is 1.20 MAF. Recharge potential in Chaj doab during October 2010 and June 2012 were found out as 4.32 and 4.675 MAF respectively **IRI (2016).** The area under depth to watertable more than 30 feet was 95 Km^2 in pre-monsoon 2011 which decreased to 30 Km^2 in post-monsoon 2011 and it further decreased to 2.65 Km^2 in post-monsoon 2015 in Chaj Doab area as shown in Figure 6.

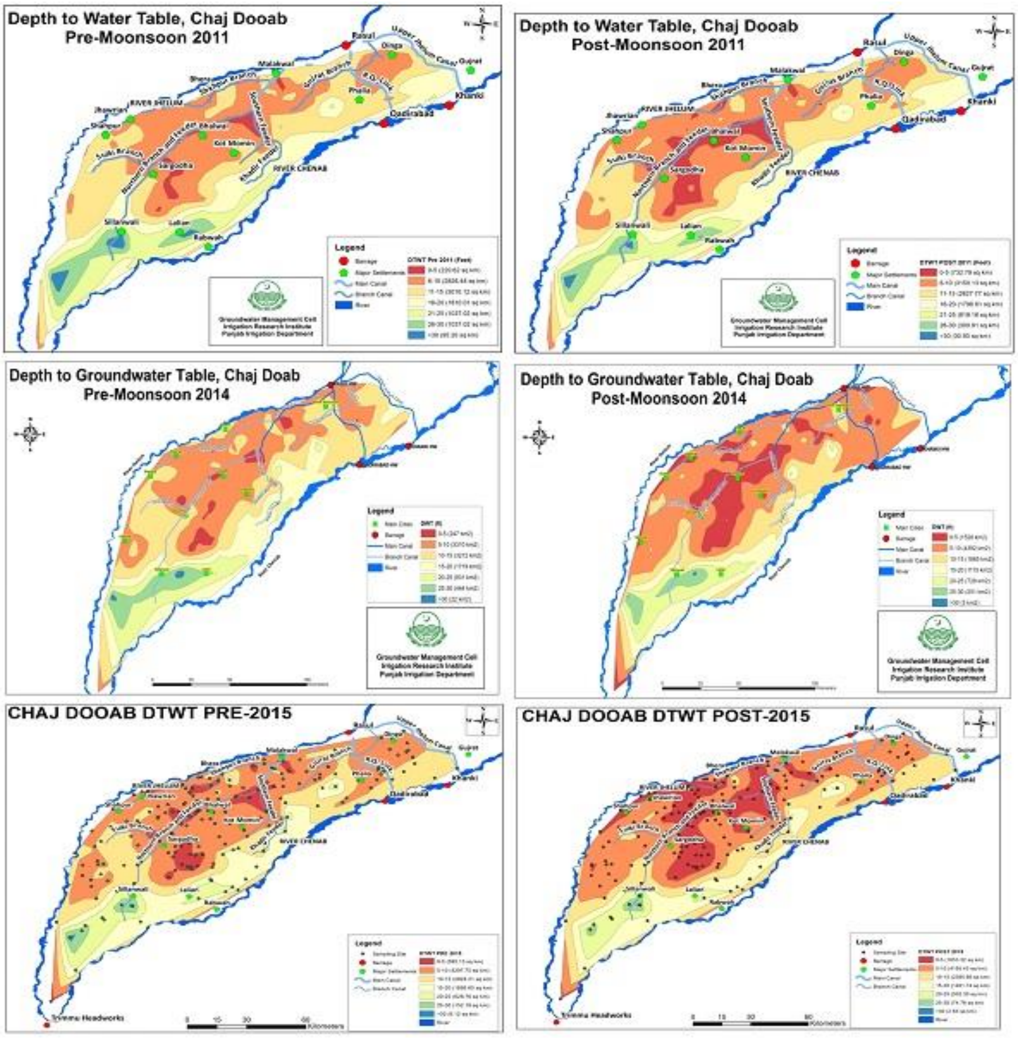


Figure 6: DTWT situation in Chaj Doab premonsoon and postmonsson (2011, 2014 and 2015)

Groundwater levels are falling at an average rate of 1-2 ft/year in some areas of Rechna Doab (bounded by two rivers, on the south and east by the Ravi River while on the North and West by the Chenab River) is showing in figure 7. Recharge potential in Rechna doab during October 2010 and June 2012 were 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 is 1.90 MAF **IRI (2015).** Research study carried out in Lower Bari Doab Canal (LBDC) has indicated that by increase of depth to water table from 40 ft. to 70ft the cost of pumping per acre-feet has increased 125% as showing figure 7.

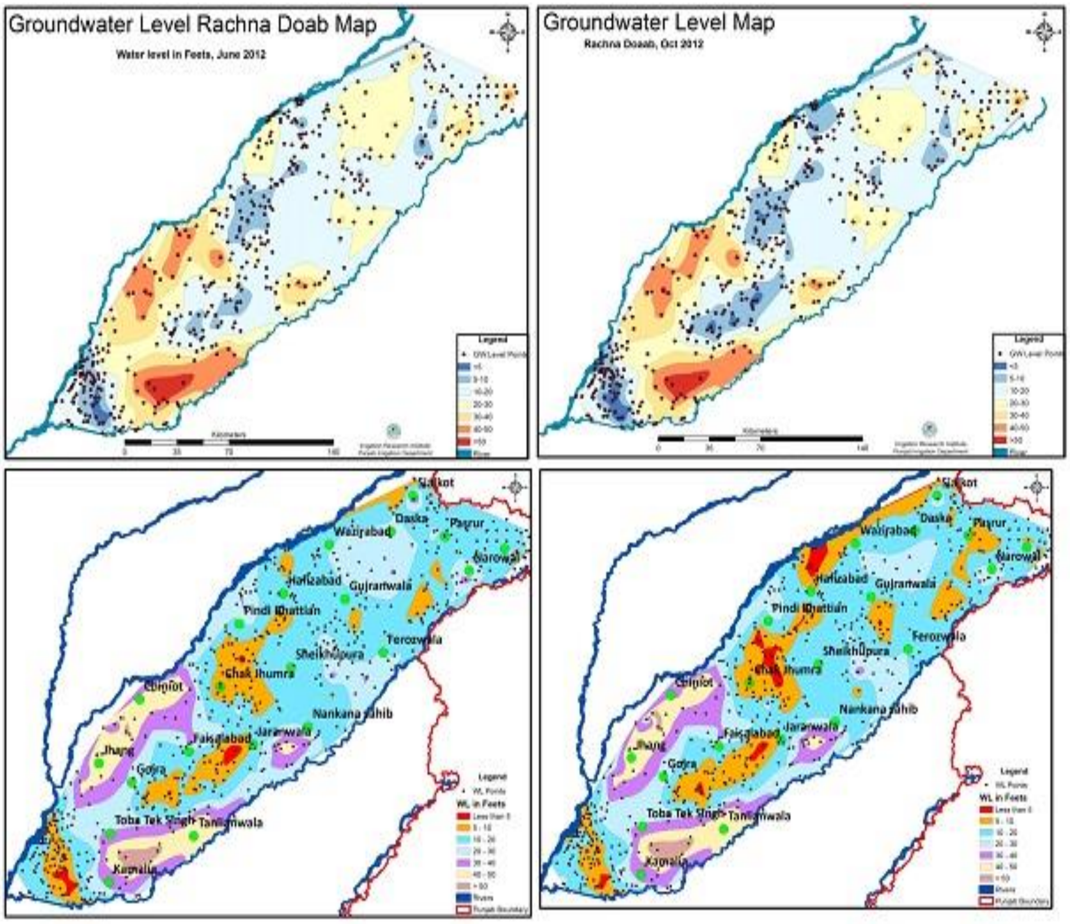


Figure 7: DTWT situation in Rechna Doab pre-monsoon and post-monsoon (2012 and 2014)

3. Conclusions

From the analysis of data collected it has been observed that unplanned excessive pumpage, lack of awareness and capacity of stakeholders, lack of regulatory framework and spatial/temporal uncertainty in surface water availability due to climatic changes (droughts and floods) are the major challenges for groundwater management in Punjab. In Chaj Doab the watertable are showing rising trends with an average rate of 0.9 ft/year and quality is deteriorating with the passage of time. In the Rechna Doab area it is been observed the average groundwater depletion rate is 1-2ft/year and over exploitation in certain areas is causing intermixing of fresh and saline water leading to overall deterioration 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. In urban areas due to increase in population and reduction in recharge due to infrastructural development, groundwater in under tremendous pressure. For instance in Lahore city (provincial capital) groundwater has fallen even more than 100 ft below the natural surface and average annual rate of groundwater depletion is 2.54 ft. In irrigated agriculture scenario, direct energy intensity has risen 80% (from 1 to 1.8 MJ per kg of crop produced) in Punjab province during the period from 1995 to 2010. Use of groundwater in irrigated agriculture consumes 30 times more energy as compared to surface water. It has been found that flood water plays a significant role in recharging the aquifer. For example, during flood 2014, 2.57 ft rise in water table has been observed in Rechna doab in Punjab province of Pakistan.

4. Recommendations

Management of groundwater can be accomplished by adopting suitable measures both on demand as well as on supply sides. Some options for groundwater management are:-

- Creating additional surface storages, improving canal operations for timely deliveries, improving application and delivery efficiencies to reduce the pressure on groundwater, increasing the water productivity are the best management options.
- Rainwater harvesting for on-farm use and groundwater recharge particularly in south Punjab is recommended.
- Aquifer recharge using flood water by flood plain management and building retention reservoirs along rivers.
- Domestic, agricultural and industrial effluents must be treated, recycled and used. It will avoid groundwater pollution as well.
- Legislation for regulating the groundwater abstraction and IWRM are direly needed for development, utilization and protection of groundwater resources.
- Awareness raising and capacity building of stakeholders about groundwater management must be ensured
- The capacity of groundwater institutions be developed to perform key functions of planning, research and providing information/technical support at regional level as well as local level.
- Adopting the drought-tolerant and low delta crops where water is scarce or unreliable
- Subsidy on SMART energy and water use and defining groundwater entitlements.

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