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Sustainable use of groundwater for irrigated agriculture: A case study of Punjab, Pakistan

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Abstract: Irrigated agriculture in Pakistan contributes 22% to GDP, 66% to foreign exchange, over 90% to food production, employs 45% of country's labor force and ranks the country as 8th largest food producer in the world. Nature has blessed Pakistan with plenty of water resources and specially a large groundwater reservoir of more than 300 m depth. Pakistan is 4th largest user of groundwater after India, USA & China. In Punjab Province, 40 MAF of groundwater are being extracted through 1.2 million tube-wells annually. Groundwater is contributing about 45% crop-water requirements and thus has gained the vital potential in irrigated agriculture. Besides irrigation uses groundwater is the major source of drinking, industrial and commercial requirements and has boosted up the cropping intensity from 60% in 1947 to 160-170% in 2015 to meet ever increasing demand of food and fiber. A monitoring network of about 3000 piezometers has been installed to observe the groundwater potential (quantity and quality) in the Province at grid of 6x6 km. Data so observed since 2006 have been analyzed using latest tools of groundwater modeling and GIS. Under recent study some recommendations have been formulated for sustainable use of groundwater for irrigated agriculture. It has been observed that over all groundwater reservoir is depleting, quality of groundwater is deteriorating reducing the crop yields and fertile land and major source of groundwater recharge is seepage from canal network. Recharge of aquifer using flood water and rainfall harvesting are two major structural interventions for sustainable use of groundwater.

Key words: Groundwater, Punjab, Pakistan, quality, irrigated agriculture, piezometers, groundwater recharge, flood, salinity

1. BACKGROUND

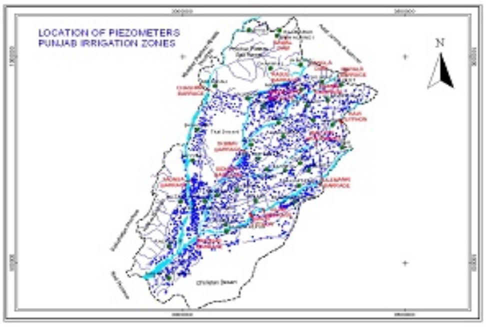
World population is expected to increase by 45% in the next thirty years. Groundwater is the world's most extracted raw material with withdrawal rates currently in the estimated range of 982 km^3/year. Out of total earth's water, 99% is unusable for human beings while only 1% is usable. Out of this usable (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's (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. The annual groundwater pumpage has increased from 4 billion m^3 in 1959 to around 60 billion m^3 in 1999-2000. About 79 % area in Punjab and 28% area in Sindh provinces has fresh groundwater suitable for agriculture Afzal (1999) and Bhutta (1999). In Punjab province about 40-50% crop water requirements are being met from groundwater through about 1.2 million tubewells installed by the farmers. 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 IBIS is the largest 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 replace the waters of 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 to 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). Pakistan is bestowed with a largest contiguous irrigation canal network, major part of which 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.

2. EXPERIMENTAL SETUP AND DATA ANALYSIS

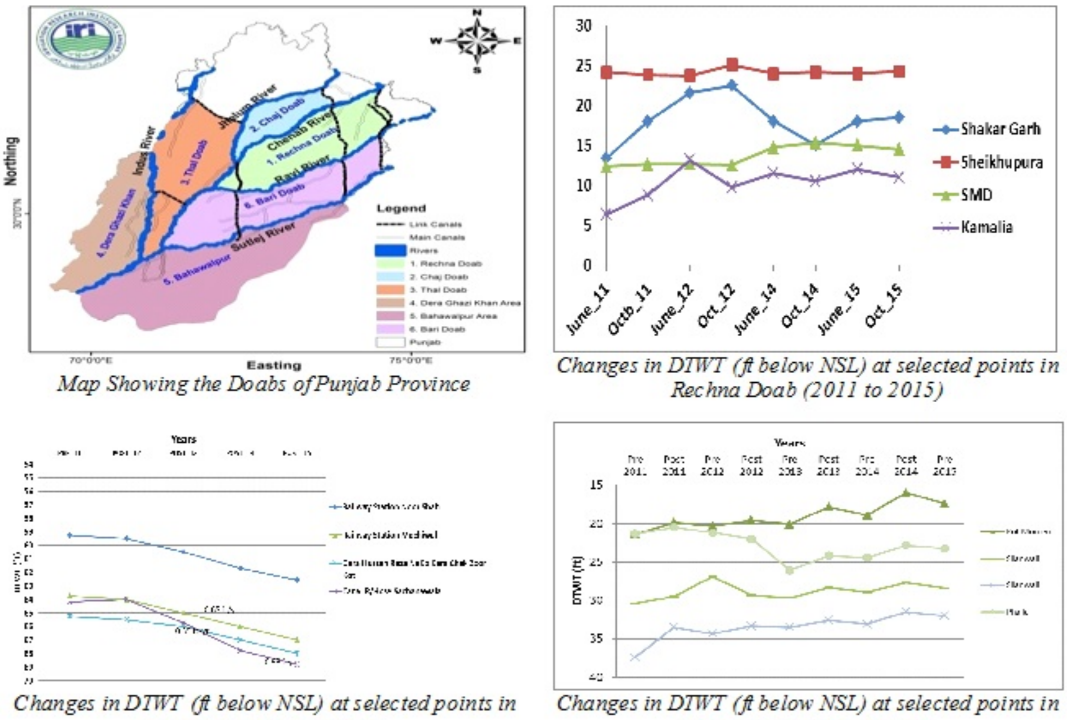
For monitoring of groundwater round about 3000 piezometers have been installed at different location scattered in whole province as depicted in Figure 1.



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 1. Piezometric network in Punjab province

Groundwater levels have been measured using water level indicator from the piezometers biannually (premonsoon and postmonsoon). 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 Figures 2.



Map Showing the Doabs of Punjab Province

Changes in DTWT (ft below NSL) at selected points in Rechna Doab (2011 to 2015)

Changes in DTWT (ft below NSL) at selected points in Bari Doab (2011 to 2015)

Changes in DTWT (ft below NSL) at selected points in Chaj Doab (2011 to 2015)

Figure 2. 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 3.

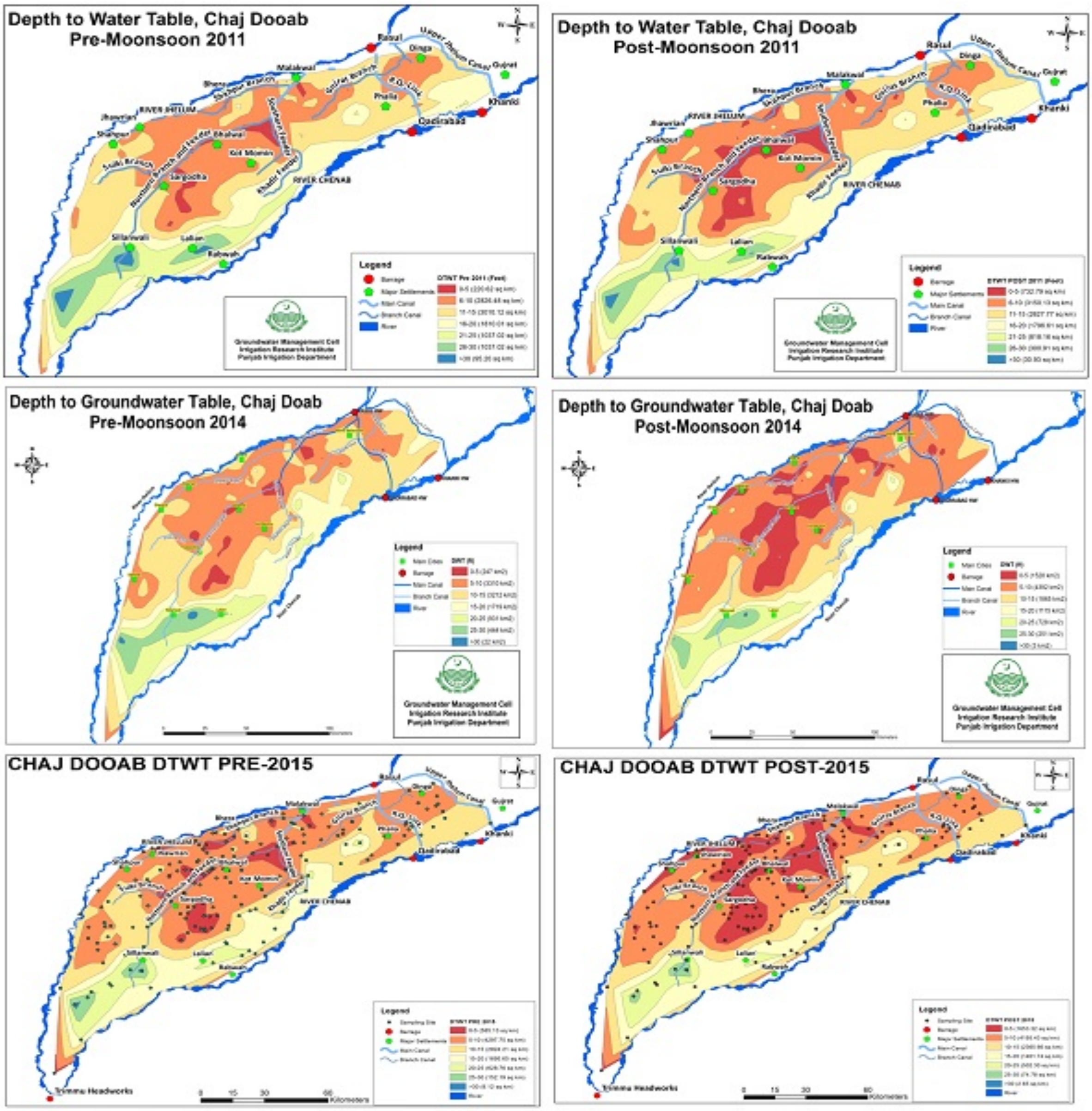


Figure 3. DTWT situation in Chaj Doab premonsoon and postmonsson (2011, 2014 and 2015)

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 4. Recharge potential in Rechna doab during October 2010 and June 2012 were found out as 15.80 and 16.381 MAF 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 70 ft the cost of pumping per acre-feet has increased 125% as showing Figure 4.

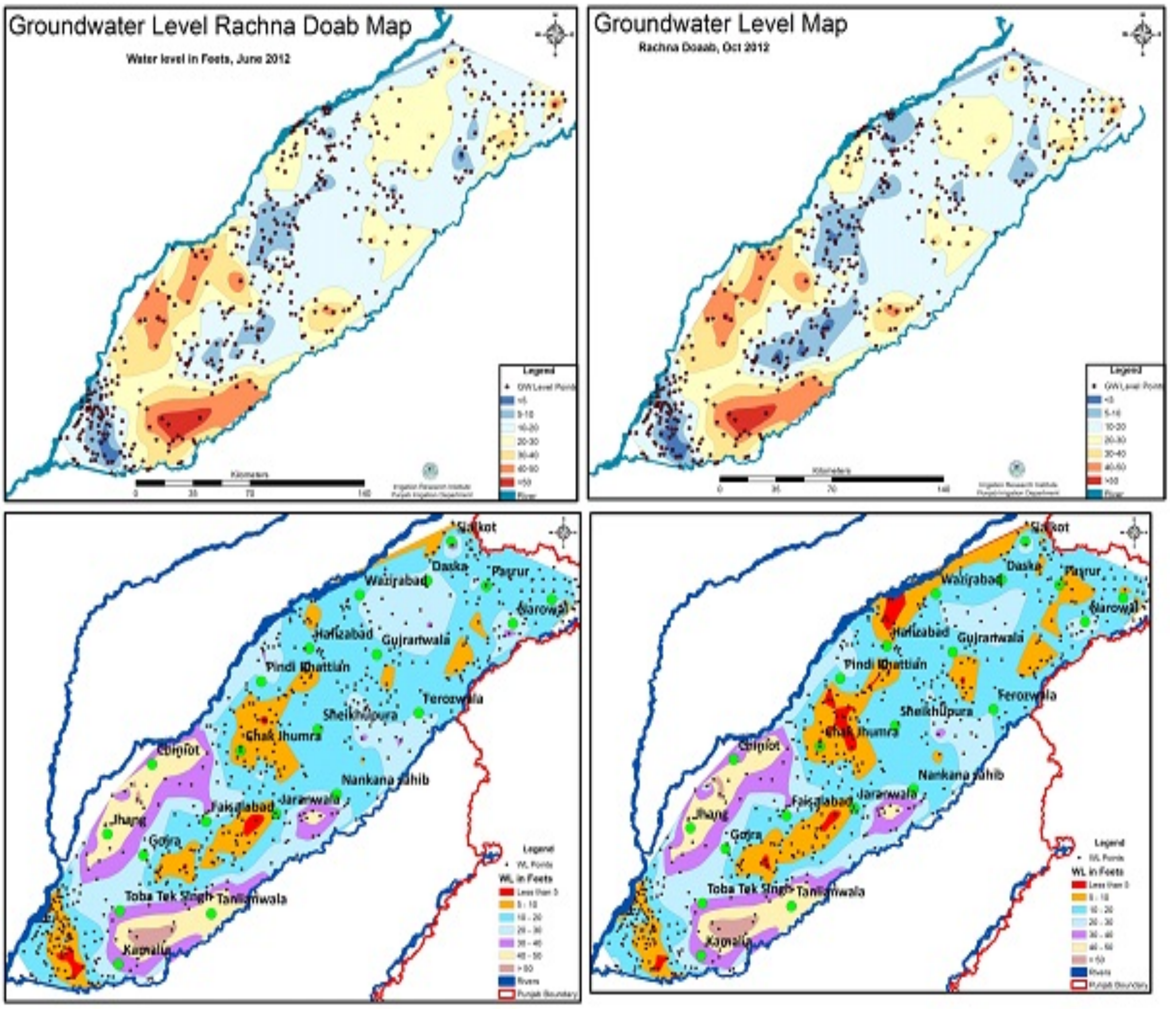


Figure 4. DTWT situation in Rechna Doab pre-monsoon and post-monsoon (2012 and 2014)

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 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 depleting rate is 1-2 ft/year and over exploitation in certain areas is causing intermixing of fresh and saline water leading to overall 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 to infrastructural development groundwater in under tremendous pressure. For example in Lahore city (provincial capital) groundwater has fallen even more than 100 ft below the natural surface and average annual rate of groundwater depletion is 2.54 ft. Direct energy intensity has risen 80% (from 1 to 1.8 MJ per kg of crop produced) in Punjab between 1995-2010. Use of groundwater in irrigated agriculture consumes 30 times more energy as compared to surface water. It has been observed 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.

4. RECOMMENDATIONS

Management of groundwater can be accomplished by adopting suitable measures both on demand as well as on supply side. Some mitigation measures 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 major management options.
- Rain water harvesting and groundwater recharge particularly in south Punjab.
- Aquifer recharge using flood water by flood plain management and building retention reservoirs along rivers.
- Sewerage, agricultural and industrial effluents must be treated and recycled it will avoid groundwater pollution as well.
- Legislation for regulating the groundwater abstraction and IWRM are required.
- 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.

REFERENCES

Afzal, M. 1999. Water for agriculture. Paper for water Vision Pakistan.

Ahmad, S., Rashida, M. 2001. Indus basin irrigation system water budget and associated problems. J. Engineering and Applied Sciences., 20(1): 69-75.

Bhutta, M. N. 1999. Vision on water for food and agriculture: Pakistan's perspective. Regional South Asia Meeting on Water for Food and Agriculture Development. New Delhi.

Chebbi, E. H. 2010. Agriculture and economic growth in Tunisia. China Agricultural Economic Review, 2(1): 63-78.

Duranton, G. 1998. Agricultural Productivity, Trade, and Industrialization. Oxford Economic Papers, 50: 220-236.

Hassan, G. Z., Bhutta, M. N. 1996. A Water Balance Model to Estimate Groundwater Recharge in Rechna Doab Pakistan. Irrigation and Drainage Systems, 10(4): 297-317.

Hassan, G. Z., Shabir, G., Hassan, F. R., Akhtar, S. 2013. Impact of Pollution in Ravi River on Groundwater underlying the Lahore City. 72nd Annual Session of Pakistan Engineering Congress, Lahore, Pakistan, 749: 355-380.

Hassan, G. Z., Hassan, F. R., Akhtar, S. 2014. Environment Threats to Groundwater in Lahore Area., Pakistan Engineering Congress, Lahore Pakistan., World Environment Day: 68-97.

Hassan, G. Z., Hassan, F. R., Akhtar, S. 2016. Environmental Issues and concerns of Groundwater in Lahore. Proceedings of the Pakistan Academy of Sciences., Life and Environmental Science 53(3): 163-178.

IRI (Irrigation Research Institute) 2009. Research Studies on Artificial Recharges of Aquifer in Punjab. Government of the Punjab, Irrigation Department, Irrigation Research Institute: Research Report No IRR-Phy/552.

IRI 2012. Groundwater Investigation for Sustainable Water Supply to FDA City Housing Scheme, Faisalabad. Government of the Punjab, Irrigation Department, Irrigation Research Institute, Lahore, Pakistan: Research Report No IRR-Phy/577.

IRI 2013. Research Studies on Artificial Recharges of Aquifer in Punjab. Government of the Punjab, Irrigation Department, Irrigation Research Institute, Lahore, Pakista: Research Report No IRR-Phy/579.

IRI 2015. Groundwater Behavior in Rechna Doab, Punjab, Pakistan. Groundwater Management Cell, Irrigation Department, Irrigation Research Institute, Lahore, Pakistan: Research Report No IRR-GWMC/101.

IRI 2016. Challenges and Opportunities for Sustainable use of Groundwater in Chaj Doab, Punjab, Pakistan. Groundwater Management Cell, Irrigation Department, Irrigation Research Institute, Lahore, Pakistan: Research Report No IRR-GWMC/102.

Jorgenson, D. 1967. Surplus Agricultural Labor and Development of a Dual Economy. Oxford Economic Papers 19(3): 288-312.

Kaldor, N. 1978. Further Essays on Economic Theory. In: M. Baskin (ed.) Economics and Human Welfare., Essay in Honor of Tibor Scitovsky, Academic Press, New York.

World Bank. 1997. Staff Appraisal Report. Pakistan National Drainage Program. Rural Development Sector Management Unit, South Asia Region.

WWAP (United Nations World Water Assessment Program). 2012. Managing Water under Uncertainty and Risk. The United Nations World Water Development Report 4 UNESCO, Paris http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/