Title: Understanding the changes in the River Ravi Basin, after the creation of the Indus Water Treaty

By: Alina Alam

Introduction: The objective of the Master of Engineering project was to research on the water issues in Pakistan along with understanding the management and social-economical issues in Pakistan. In addition, it was to identify the best methodology to pursue resolution for these challenges. Towards the end of the project, one area emerged as potentially interesting for further research- examining the Ravi River Basin to reduce ground water reduction without affecting crop yield.

Alina Alam
Master of Engineering Project Report

Preface:

Question: What is the best way to optimize the water supply of River Ravi Basin in the Indo-Pak region and reduce the groundwater pumping after the creation of the Indus Water Treaty?

Water deficiency in Pakistan manifests itself in various ways: historical division of the land, unattended problems, increasing population size, and decreasing water resources. In order to help alleviate Pakistan's water shortage, it is important to narrow down areas where significant impact can occur within the next ten years. For example, Pakistan cannot control River Ravi's flow rate, but the nation's agricultural economy depends severely on River Ravi. Both India and Pakistan utilize the groundwater near River Ravi and this continued heavy usage is causing rapid groundwater depletion. The objective of this study is to explore both the historical origins and the current mismanagement of the water in River Ravi in order to understand problems due to water shortage in Pakistan today. Towards the end, possible studies will be discussed that can be used to further understand the situation.

Outline of the report
Section I: Historical Importance
- Canal Expansion
- Indus Water Treaty

Section II: Present Day River Ravi
- Variations in flow rate
- Groundwater pollution
- Sources of pollution
- Groundwater depletion
- Tubewells Usage

Section III: Discussion
- Future areas to study

Historical Background:

How did modern day Pakistan develop a multitude of water problems?
What are the surface water changes in River Ravi with respect to time?

Expansion of the Irrigation Network: In the middle of the 19th century, famine spread across the British colony of India, (presently known as India, Pakistan, and Bangladesh), and hence led towards the expansion of irrigation in the Indus River Basin. The irrigation system of the Indus River Basin was allegedly established as far back as 5,000 B.C.E; however, minimal water was diverted from the Indus River Basin. Most of the area surrounding the Indus River Basin has an arid or semi-arid climate that has minimal rainfall. The British India Colony diverted water from the Indus River in order to create canals and perennial canals, which ultimately created one of the most extensive irrigation systems in the world [figure 1] [Appendix 1]. The Indus River basin is composed of approximately 190,000 km^2 agriculture, of which 150,000km^2 is cropland irrigated in the Indus Plains and 40,000 km^2 in the local irrigation [Condon, 2011]. In 1859, the first Upper Bari Doab Canal (UBDC) (built extracting water from Ravi and Beas) was completed in 1861 at a length of 247 miles and provided water for one million acres of cultivated land [Arora, 2007][Tabassum,2004]. UBDC canal was solely built for agricultural purposes unlike other canals that followed its construction. The expansion of the irrigation system created many benefits and problems for the region [Malik, 2005].

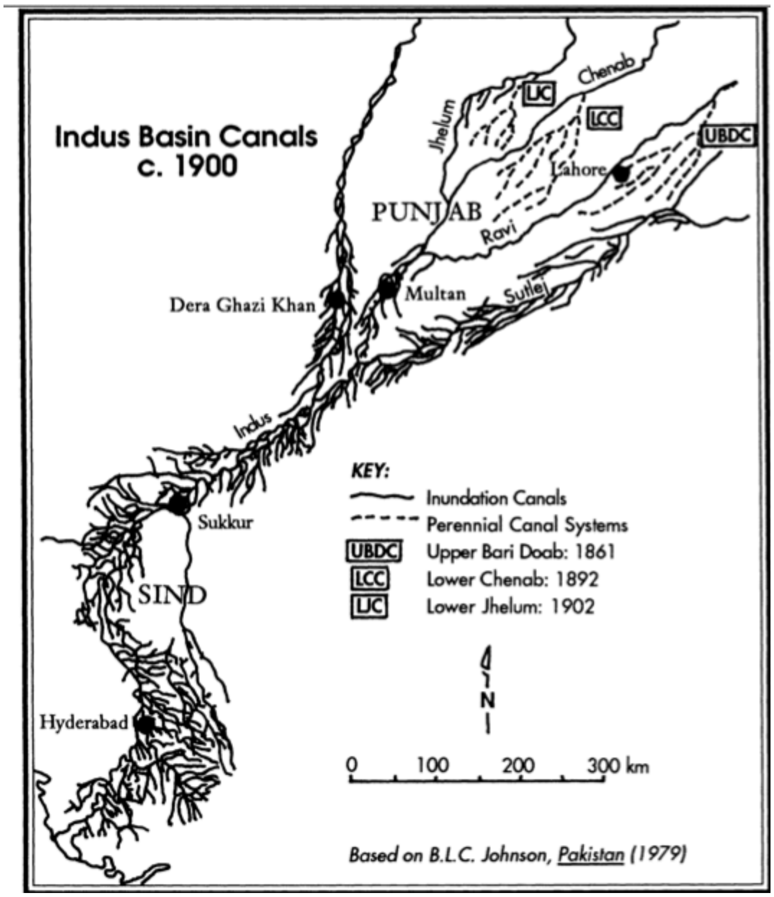

Figure 1: Map of the Indus River Basin Expansion Source: Imperial

<u>Benefit of the Expansion</u>: The population of British India grew eightfold, expanding from 165 million in 1757 to 420 million people by, due to the expansion of the irrigation system that stemmed from the Indus River Basin. The irrigation network provided food and revenue for the growing population. British India Colony expanded the irrigation network by more than a quarter in the area and the Greater Punjab (modern Punjab of India and Pakistan) became the center for population expansion. For example, the total crop acreage expansion of British India was 40% and the Greater Punjab accounted for 96% of the population expansion, which made Punjab the center of agriculture in British India [Appendix 1]. It should also be noted that some land

terminology was changed in Greater Punjab due to the massive population expansion. For instance, areas that were labeled as uncultivated became cultivated land, thus increasing more area for agriculture. This became possible because large source of water could be provided that could cultivate uncultivated land [Blyn, 1961]. However, many negative consequences occurred in the region of Punjab because of the expansion.

Social Issues: The first few canals were made in order to provide food security and prevent further famine, but in the late 19th century, canals were beginning to be built to satisfy a political ideology instead. In the 1880s, the British rulers order the construction of perennial seasonal canals, which were to provide acres of arid land in order to create new agricultural settlements. The political structure for each of the states in the India and Pakistan region functioned differently, as in Punjab the Upper Bari Doab Canal was built in order to provide bands of Sikh soldiers agricultural revenue, while in the state of Sindh, the canals were set up in order to control local Sindhi tribes [Gilmartin, 2015]. Canal areas were set-up to create communities between the local elite and their followers, so they could work together to clear the canal silt that would accumulate. The Indus River Basin was expanded for multiple reasons: creating revenue from cotton and wheat, feeding people, providing land for the Indian Army, and building population near the disputed frontier of Afghanistan [Gilmartin, 2015].

The set-up of the canals is very relevant in understanding the modern social-class complexity that takes place in India and Pakistan. The colonization created a system where only few had power and control over the agriculture, which increased class barriers for people. For example, often times poor framers might not receive the water or have the resources sustain agriculture on its land. In addition, the expansion led towards creating a desert into a farmland and problems with water became more relevant.

Expansion Problem: The engineers emphasized building efficient irrigation systems, which meant that they advocated for the use of new technologies in order to increase the local irrigation networks to serve more arid regions. Control of silt was a major concern for the engineers during the expansion[1], which accounted for a quarter of Sindh's revenue in clearing slit. The over-irrigation of the arid region started causing problems such as waterlogging and increased salinity in the region. Foremost, waterlogging in the Indus River Basin is a problem that dates back to 1857. Heavy flow of sediments had shutdown UBDC in the first year that it could irrigate land. In addition, the Canal and Drainage Act of 1873 was passed, and from 1860-1945, British India created five different organizations in order to address the issue of salinity in the Indus River Basin. Additionally, during the time that irrigation services were expanded, many engineers and scientists were not aware of the many geographic problems in the region. For example, the seepage under the canal floors was not accounted for when the irrigation system was being expanded [Arora, 2007][Tabassum, 2004][Alaf, 2009].

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[1] Sindh also had large expansion during the British Colony India, but this report mostly will discuss expansion in Punjab.

Thus it is important to realize, that the modern problems in UBDC are not a new phenomena, but a manifestation of older problems.

The river water was not effectively utilized either. For example, River Ravi already had a shortage of water, but River Jhelum had a surplus [Gilmartin, 2015]. Shortage of water indicates that the canals diverting water out of Ravi River were being extensively used[Comment 2]. As stated earlier, waterlogging and salinity issue were becoming more prevalent in the region. Figure 2 shows the rise of the groundwater level from 1860 to 1960 (in Punjab of Pakistan), where the Bari Doab region has the highest raise in groundwater level approximately 190 m above the mean sea level. These problems indicate that the irrigation system was unsustainable, yet the economy was still becoming increasingly dependent on the irrigation system. Another problem was that water was running off even less from the Indus River, decreasing from 185-km^3/ year in 1892 to 79.58 km^3/year in 1960, which significantly reduced due to the increase in canals and barrages [Kravtsova, 2009]. Furthermore, before 1950 approximately 16 percent of 1.6 million hectares of land in Pakistan was already labeled severally saline [table1]. Furthermore, before 1950, approximately 16 percent of 1.6 million hectares of land in Pakistan was already considered to have too high levels of salinity [table1]. Towards the start of 1960, 30 percent of the entire Indus Basin farmland was labeled as having too much salinity, and 30 percent accounted for soggy land that elevated from the water table [Condon]. These results indicate that major saline problems existed in Punjab, Pakistan, and the situation unfortunately only deteriorated over time [Comment 1].

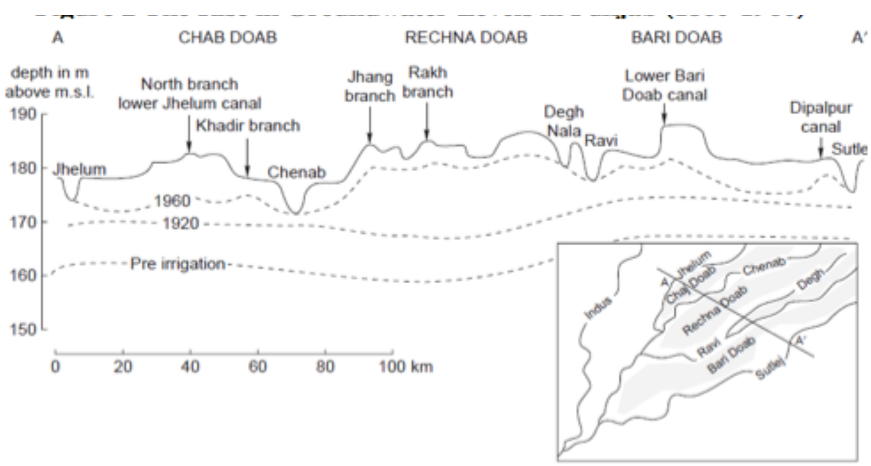


Figure 2: The Rise in Groundwater levels in Punjab (1860-1960) source: Bhutta and Smedema 2005
Retrieved from: http://watersecurityinitiative.seas.harvard.edu/sites/default/files/Indus Basin Challenges and Responses_Draft 08292012.pdf

Table 1: Status of Waterlogging and Salinity in Indus Basin Mid-20th century (Pakistan)

Source: Woodrow Wilson Scholars Asia Program

Gross Area	16 million hectares
Surface Salinity (moderately saline)	34.80%
Surface Salinity (severely saline)	16.40%

The Indus Water Treaty (IWT): The Indus Water Treaty took twelve years in making and emerged from the water dispute that occurred between India and Pakistan. Historians stated that dividing the Punjab state was the most complicated issue while creating modern day India and Pakistan. The canals of Punjab were created as uniform tubes that could provide water from Amritsar (India) to Multan (Pakistan), and consequently the Punjab region had great monetary value as well. The division of the land was problematic, as the more cultivated land went to the Punjab region in Pakistan, and the main water headworks went to India. For instance, the majority of the Indus River Basin is in Pakistan, but the main water resources belong to India. After the agreement between India and Pakistan expired in 1948, India cut off the main headwork's that delivered water to Deepalpur Canal and Upper Bari Doab Canal. These canals accounted for 90 percent of Pakistan's cultivated water area and an estimated 1.7 million acres of cultivated land was harmed [Altaf, 2009]. It is suggested that India was trying to establish riparian upper sovereign water rights, pressurize Pakistan to retain more of the Kashmir region, to demonstrate Pakistan's dependency on India, and fight against Pakistan to impose a tax on raw jute in leaving East Bengal [Wolf]. India reopened the headworks after a year, but this created a lot of fear amongst the Pakistanis. Both countries started working with the World Bank in order to negotiate deals on the water rights of the Indus River. Then after twelve years of negotiation, the Indus Water Treaty was created. The treaty gave India unrestricted usage of water for the three eastern rivers: Ravi, Beas, Sutlej, and Pakistan received unrestricted use of the Western Rivers: Jhelum, Chenab, and Indus. India had to allow flow from the eastern rivers until the 1970's so that Pakistan could build replacement canals to divert water from the western rivers to the eastern rivers [Wolf]. Since the 1960's, both countries' population and GDP have increased rapidly. The next section will discuss implications of the treaty both of these countries.

Problems within the Indus Water Treaty:

The Indus Water Treaty is considered one of the most successful treaties and was created in order to avoid future water conflicts. The treaty was not broken throughout the four wars that occurred between India and Pakistan. However, the Indus Water Treaty still lacks some key elements that could alleviate more of the water problems that exist between both nations. First, the treaty does not protect the customs of the downstream country because it offers a geo-physical divide of the river [Nollette, 2014].

Follow up questions:

- Did more irrigation activities happen downstream? Did the downstream area have more fertile land?
- What was the original intention of water practice in the upstream and downstream areas of the rivers?
- How has this traditional practice changed?

Second, the treaty does not effectively manage the entire Indus Basin. The treaty itself encourages water waste because it does not address how to allocate the surplus of water.

Follow up questions:

- How much water waste is generated in a year? Is more water being wasted in the Punjab of India or in the Punjab of Pakistan?
- What happens when there is an increase of water in the region?
- How is the increase in water supply managed in Punjab?

Also, the rules of the treaty lacks in flexibility because it does not permit any changes when droughts or floods increase [Nollette, 2014]. Thus, the adaptability towards the future might not be sustainable given the growth of the population in the region.

Follow up questions:

- How did the flood increase within the Punjab region of India and Pakistan?
- What have been the reasons for the increase in flooding?
- What is the future outlook of the flooding? What are current flood mitigation methods?
- How much damage has occurred because of the floods in the Punjab Region of India and Pakistan?

Additionally, during the time of the Indus Water Treaty, groundwater recharge was not discussed in the treaty [Nollete, 2014]. River Ravi in Pakistan provides water to many major canals and perennial canals, which Pakistan does not have control over. This means in framers in the Ravi area are lacking sufficient water supplies that lead toward the increase of tubewells and further damage the water infrastructure of Pakistan. These issues will be discussed in later sections. Given these parameters, the Master of Engineering Project will discuss issues that occurred in the Ravi River for the past fifty years.

<u>Water issues in Pakistan:</u> In year 2025, Pakistan will have its greatest water shortage of 93 billion m^3 as projected by figure three and table 2. The demand of agriculture and domestic use will increase severely based on population Currently, Pakistan has a population of 165 million people, of which at least 41 million (25 percent) are below the poverty line; 98 million rely on agriculture; 50 million do not have access to safe drinking water; and 74 million have no sanitation [Altaf, 2009].

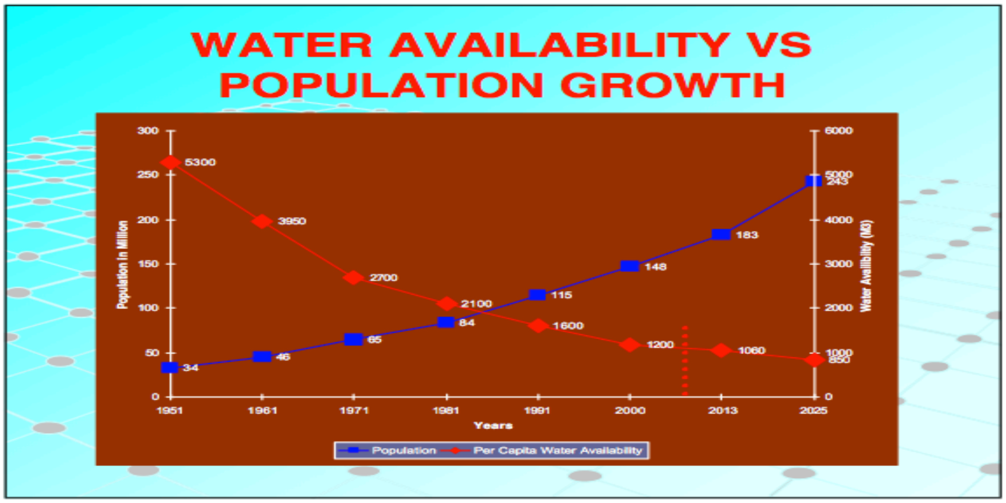


Figure 3: Water Availability vs. Population Growth in Pakistan. Source: University of Arid

Table 2: Water Availability Projected Demand of Water in Pakistan (M^3) Billion Source: University of Arid Agriculture, Rawalpindi; Reported by Dr. Khalid Mahmood Khan

Years	2013	2025
Total Availability	224	228
Population (million)	183	243
Projected Water Demand (Agriculture & Domestic)	263	321
Water Shortfall	39	93

Understanding the River Ravi Basin

In order to understand the on-going problems in Ravi Basin post Indus Water Treaty, this section will aim to answer the following questions: What are the groundwater contaminations in Ravi?

- What is future outlook of the problems?
- What are the problems in the Ravi River?
- What are the sources of pollutions?
- Why is Hudiara Drainage so unique? What will happen there?
- How is flow rate of Ravi contributing to the pollution?
- Why is India and Pakistan working together to manage the solid waste?

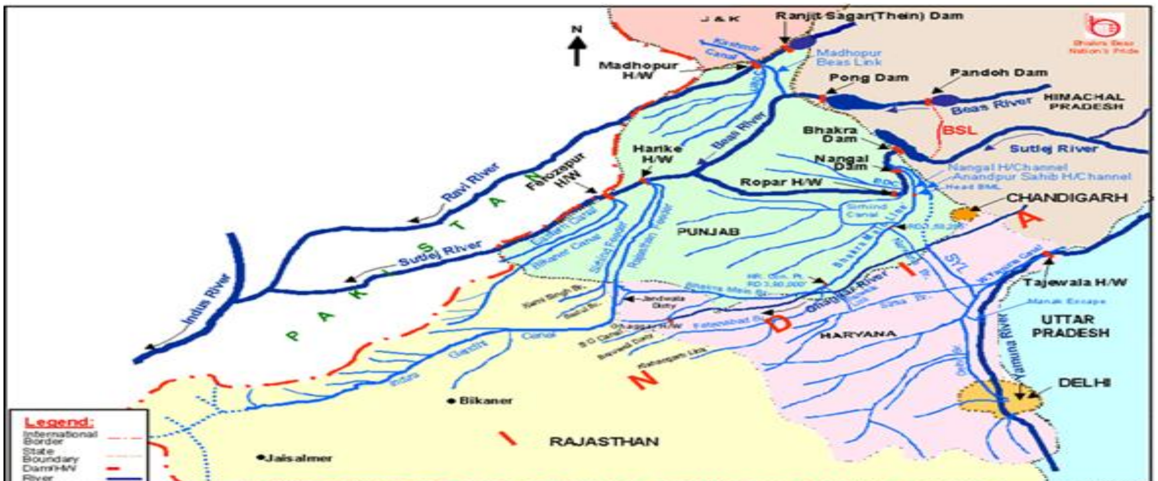


Figure 4: Map of the River Ravi from India to Pakistan

Retrieved from: http://www.bharat-rakshak.com/SRR/Volume13/sridhar.html

<u>Demographic of River Ravi:</u>

Ravi River is approximately 720 km long (450 miles). 320km (200 miles) of the river's length is within India. It originates from the Rohtang Pass in Kangra, India and enters into the Indian region of Punjab through Shahpurtown of Pathankot. Ravi forms an international boundary while passing through the Gurdaspur and Amritsar districts of Punjab. Finally, Ravi leaves the Indian Territory at the Goina/ Kakarmani village, which is roughly 80km (50 miles)(Figure 4). The main headworks of the Ravi River are in Madhopur and the total catchment area of Ravi within India is roughly 5,957 km^2 [Moza].

<u>Problems of River Ravi: Variations of Flow Rate:</u>

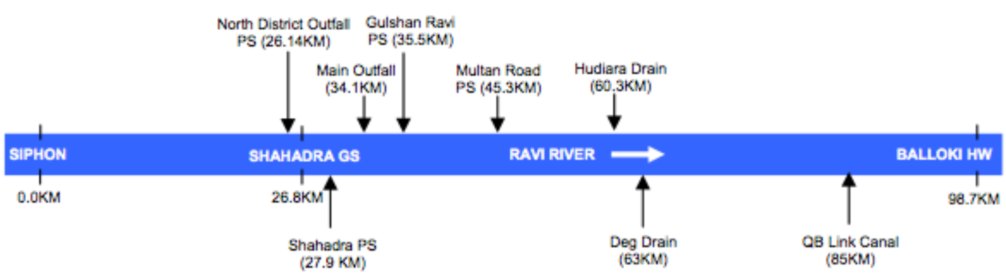


Figure 5: Flow rate study area that will be discussed in this section (Source: Haider &Ali 2010)

Figure 6 shows data for the past twenty-four years, collected at the Shahadra gauging station, which is 27 km away from the Ravi siphon(where the water enters from India to Pakistan). The data indicates that the Ravi River flow from Pakistan from 1990-2004 has varied approximately $10 m^3/s$ to $10,000 m^3/s$ [Baqar, 2013]. The highest flow rate was found to be in the year 1990, and afterwards it started to decrease. Government flow data for the Ravi River was not found after the year 2004. Thus, the University of

Punjab provided data from 1975 to 2013 from the Balloki station, which is 98 km away from the Ravi Siphon that also indicated similar variations in the flow rate. Figure 7 indicates variation in the Ravi River at Balloki Station during the kharif (April-October) and Rabi (October-March) seasons. The maximum flow rate was 15,249m^3/s and the minimum flow rate was coming at 400 m^3/s, which indicates that variations took place during the past thirty-seven years. In addition, it seems that after the 1990's, the flow rate conditions have been reasonably lower compared to previous decades. The next data set displays average ten-days flow variations between 2001 and 2003 [figure8]. This indicates that low period conditions are usual for eight months, while flood conditions occur during the monsoon season. Data from 2011 through 2014 are needed to make more accurate decisions on the low period. Generally after the Indus Water Treaty, the flow rates from the Ravi River have been described as low-flow rate conditions [Haider and Ail, 2010]. The fluctuation and the decrease of flow rate contribute to other water management problems.

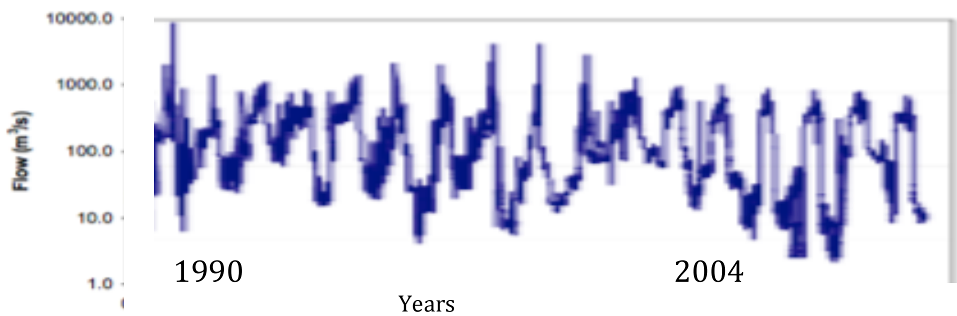


Figure 6: Daily flow variations in Ravi River at Shahadra gauging station

Source: Haider & Ali 2010

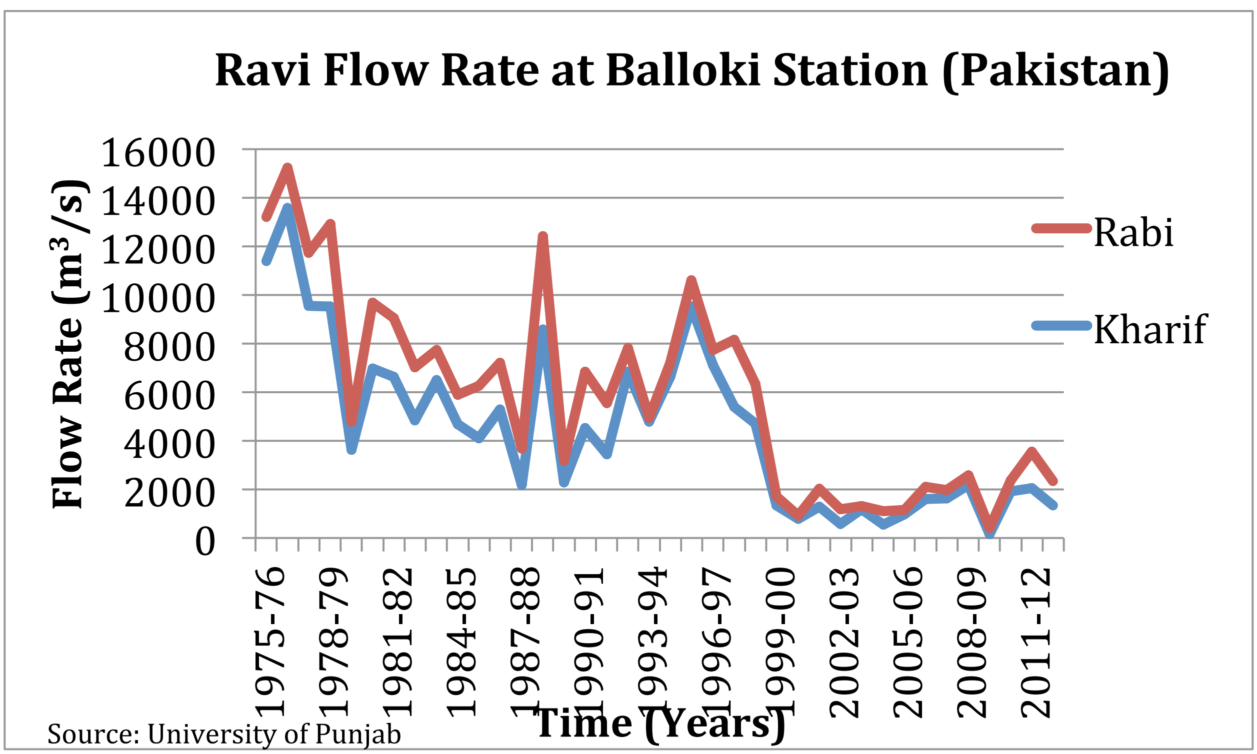


Figure 7: Flow Rates at Balloki Gauging Station

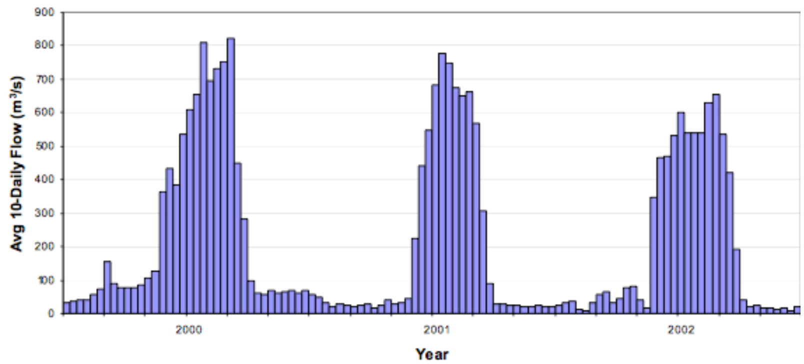


Figure 8: Average 10-day flow variations for years 2001-2003 at Shahadra gauging station

Implication on flow variations: How are variations of the flow rates contributing to the River Ravi's pollution?

High Flow Rate: Under high flow rates, water is highly turbid because of silt and clay particles that lay beneath the river. In 2004, the Punjab irrigation department indicated that the Ravi River's velocity is sufficiently high enough to keep the suspension of the suspended particles as the river flow increases from 10 m^3/s to 500 m^3/s [Haider & Ali 2010]. This statement might not be relevant after eleven years. If the particles are being suspended, transporting the water from the canal to the irrigation field will be difficult, and the deposits would damage the canal infrastructure. Historically, the area is profound with sediment issues that might get worse with changing flow rates. Thus, the canals and reservoirs residing on the River Ravi should be studied. It is important to also understand how the water fluctuations could affect the farmers or create problems for the future.

Low Flow Rate: Studies have showed that the low flow conditions have caused Ravi to be relatively anaerobic and have very high turbidities that almost behave like a sewage carrier with turbidity greater than 200 Nephelometric Turbidity Units (*NTU)*[Haider &Ali 2010]. Pakistan agricultural growth is at risk due to the variations of flow in the Ravi River. The low flow rates effect the large irrigation infrastructure because millions of farmers depend on the water. The next section of the report will discuss how changes of the flow rate are connected with the problems of groundwater contamination and groundwater depletion.

Groundwater Contamination of River Ravi Pakistan:

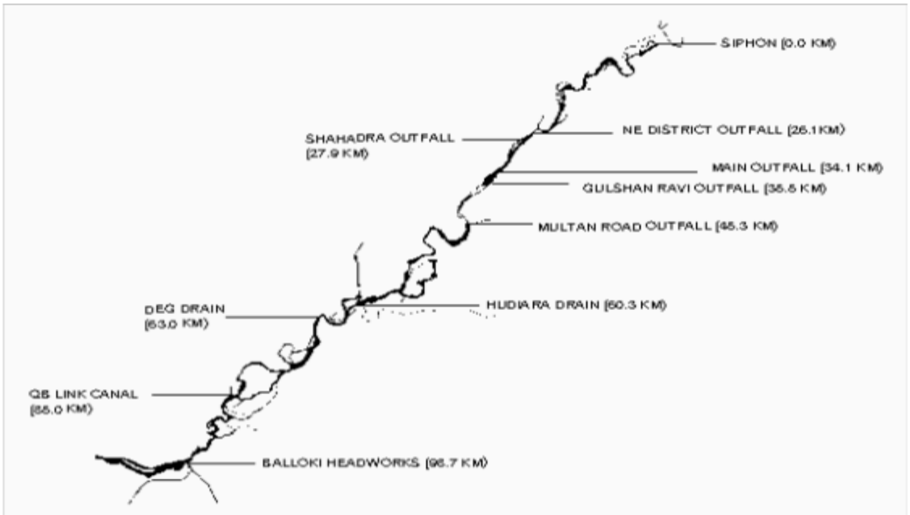


Figure 9: Study Area for Groundwater Contamination from Ravi Siphon to Balloki Headworks Source: Haider & Ali, 2010

Groundwater Contamination: Ravi is the most polluted River in Pakistan and continues to become more contaminated. As of 2010, the daily wastewater in Ravi is 3.4 millions m^3/day and the daily Biochemical Oxygen Demand (BOD) is 862,000 kg/day; it is estimated to increase 1.5 times from industrialization and urbanization by 2025 [Haider & Ali, 2010](figure 10). This will be another challenge that Pakistan will have to address in order to assure safer quality of water by 2025. As stated earlier, Pakistan will have its greatest water shortage in 2025(table 2). Table three provides Biochemical Oxygen Demand (BOD) and Total Dissolved Solids (TDS) tests that were conducted using five outfalls and two surfaces drains that discharge into Ravi. The results indicate low flow rate and high BOD and TDS content, which is harmful to the aquatic life in Ravi. Table three also shows higher wastewater coming through the NE District and Hudaira Drain, which is closer to the Indian border compared to the other districts. This data is based on 2009, which may have changed in 2015. If the pollution continues to increase, the results might get worst. Another study analyzed River Ravi's pollution from the years of 2012 to 2013 in order to get better estimates of the current state of River Ravi. Figure 11 and 11.1 indicate that the daily mean pollution rate is at high concentration rates and surpasses Pakistan's pollution rate limit. In addition, pollution rates from 2009 through 2013 did not decrease, which indicates that the pollution forecasted for 2025 is coming true. Furthermore, both studies found that the Hudaira drainage has the highest total pollution rates and discharges rates [Haider & Ali, 2010][Baqar, 2014]. Thus, it is important to understand the sources of pollution of the Hudiara Drain.

Table 3: Wastewater characteristics of River Ravi at different outfalls and surface drains as of 2009

Wastewater Outfalls and Drains	Flow (m3/s)	BOD5 (Kg/day)	TDS (Kg/day)
1. NE District	9.2	190,771	296,145
2. Shahadra	2	80,352	86,573
3. Main	5.7	97,511	211,274
4. Gulshan Ravi	3.9	82,892	183,643
5. Multan Road	3	60,653	133,488
6. Hudiara Drain	9.85	229,781	679,130
7. Deg Drain	5.7	120,165	N/A

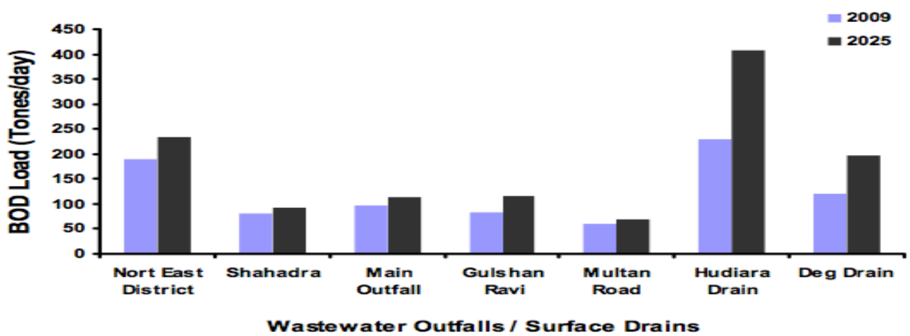


Figure 10: Estimated increase in BOD loads with from 2009 to 2025 at different outfalls and surface drains of River Ravi Source: Haider &Ali (2010)

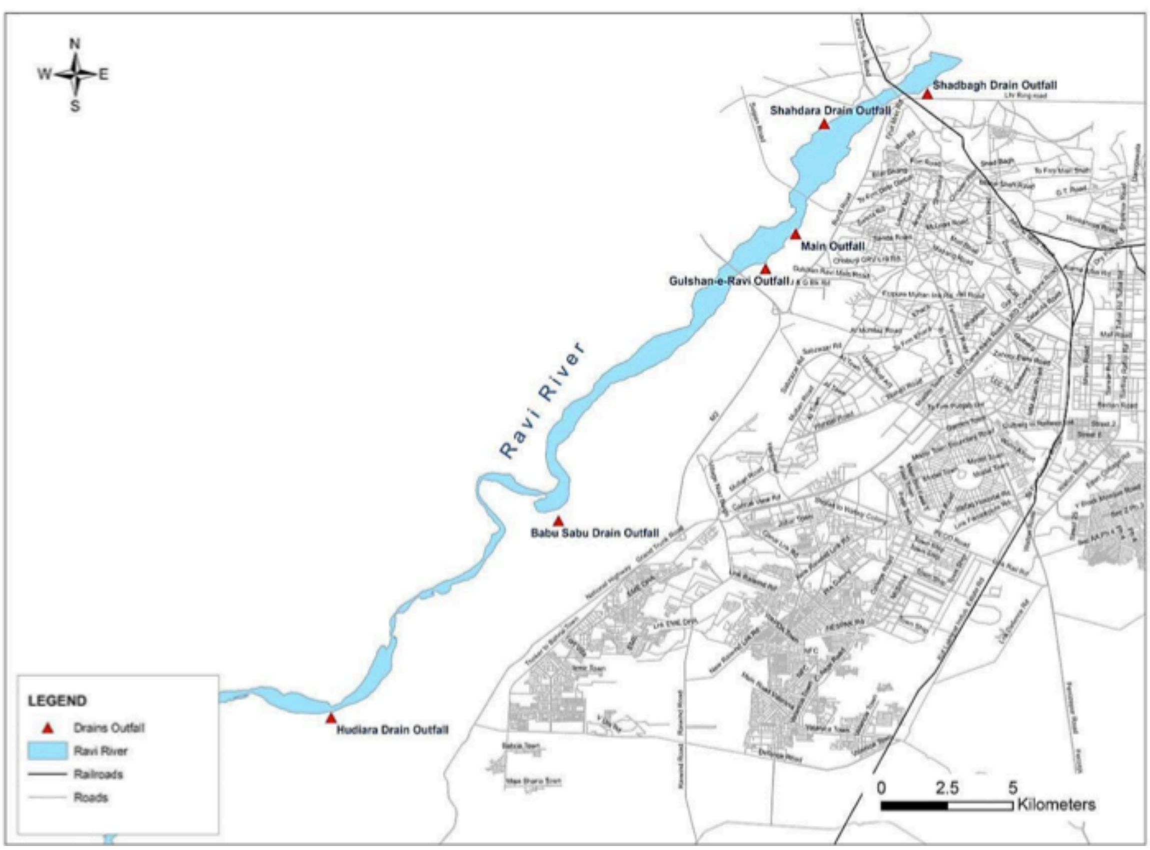


Figure 11: Schematic Diagram of the Sample Drains and outfalls Source: Baqar (2013)

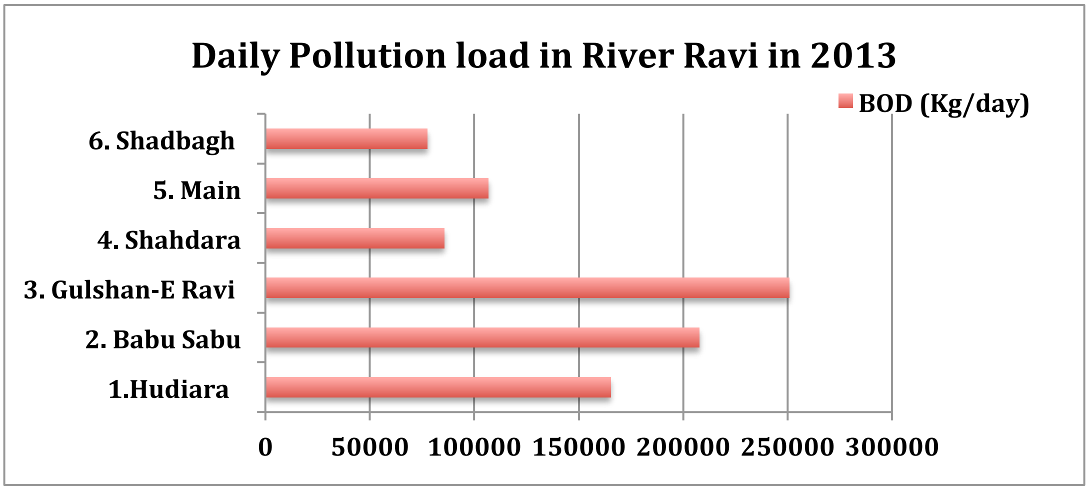


Figure 11.1: Results of daily pollution from sample areas shown in figure 3 Source: Baqar (2013)

Sources of Pollution: What are the sources of pollution?
Ravi receives pollution because of untreated sewage and the lack of wastewater treatment, which enters five drains outfalls and two natural surface drains from Lahore. Pakistan considers low flow rates to be the main source of increasing pollution for the past two decades. Pakistan claims Ravi's pollution has became worse since India built the Ranjitsagar Dam (also known as Thein Dam), which is the 2ND largest hydro-power source in India, and is placed on the River Ravi. After the Thein dams, the flows in the Ravi River have been extremely reduced. For example, in 2000, before the dam became operational, the average annual flow of Ravi was 264m^3/s, which was reduced to 206m^3/s in 2001 (IPD - Punjab, 2000-01). The TDS coming into Pakistan at River Ravi Syphon is 952 mg/l, which is identified as being of poor quality of water by the World Health Organization (WHO) (Table four). This indicates that the water entering Pakistan is already polluted and that low flow rates further pollute it. Landfills also contribute to the groundwater contamination of River Ravi in Pakistan. Figure 13 highlights the type of material that is in groundwater contaminations, which comes through landfills lactating and discharging groundwater pollution. A study was conducted that had sixteen different landfills sights in Lahore, showing that 64% of the sights do not meet Pakistan's water quality standards (PSQCA). Even though the low flow rates contribute to the level of groundwater contamination, Pakistan's solid waste management is another large factor to the pollution issue [Akhtar, 2014][Water tally].

PARAMETERS	RESULTS (mg/l)
pH	8.8
TDS	952
Ca	23
Mg	3.7
Chloride (Cl^{-1})	72
Sulphate $(SO_4)^{-2}$	183
Total hardness	21

Table 4: River Ravi Water Analysis at Syphon Point in Pakistan 2010 Source: Akthar 2014

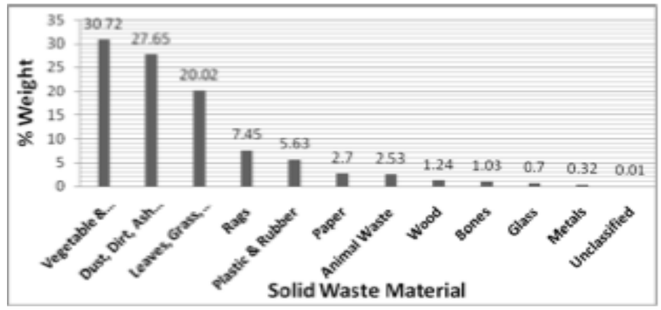


Figure 12: Composition of dumping material at landfills in Lahore Source: Aktar (2014)

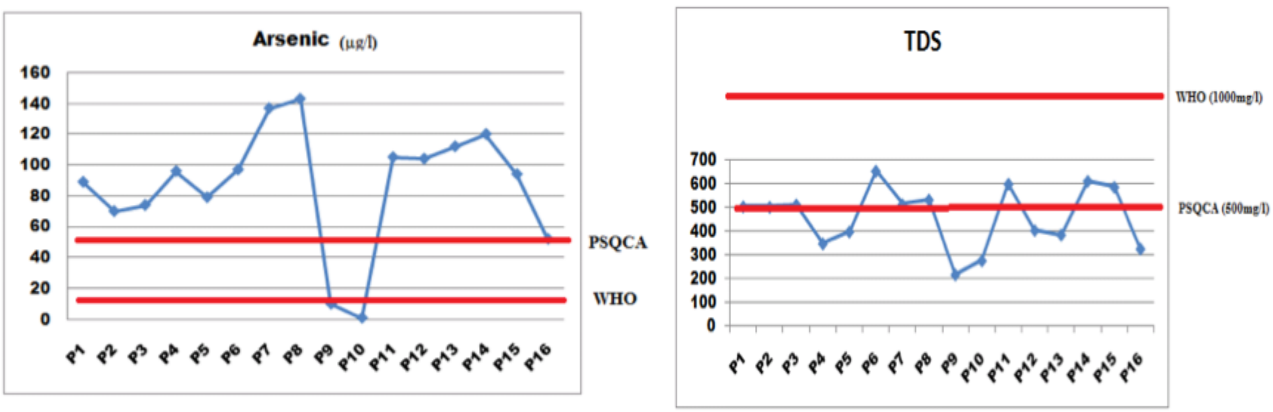


Figure13: Groundwater Arsenic and TDS content of the sixteen sites in Lahore source: Aktar (2014)

Hudaira Drain The three reports discussed earlier indicated the Hudaira Drain is the most polluted drain in Ravi. The highest content of pollutants in the Hudaira Drain are Cadmium (Cd), Iron (Fe), Cyanide (CN^-), and Copper (Cu), which exceed all the limits of the National Environmental Quality Standards (NEQS) in Pakistan [Baqar, 2013]. Pollution of the drainage is due to low flow conditions and trans-boundary issues. It is reported by the World Wildlife Fund (WWF) in 2007 that the Hudaira drain receives 12 percent of its waste from industrial sources and the rest from the inflow in India. The discharge of wastewater entering was reported to be 1,024,000 m^3/day and that is about 65% of the total flow. India's expansions of the Ferozupur Road, Raiwindi Road, and the canals have caused the wastewater discharge to go directly through the Sattokatal Drain and enter the Hudiara Drain. The Deg Drain, which is mainly near the industrial area of Pakistan, has lower biodegradability of organic matter compared to the Hudiara Drain [Haider & Ali]. This might be true depending on a number of industries and might be higher on the India side of Ravi.

- Demographics of Hudiara: The Hudiara drain is a tributary of the River Ravi, which originates at Batala, Gurudaspur District in the state of Punjab, India and flows nearly 55 km in India, entering in Pakistan near Lalloo village. It reaches the Hudiara village once flowing 7 km in from Pakistan. After flowing for nearly

63 km inside Pakistan, it joins the River Ravi and approximately 100 industries can be found next to the Hudiara drain near 55km of India's portion. The drainage is polluted before it reaches Pakistan (Shekar et al., 2008). The village of Hudiara is situated close to the Wagah border, falling in the way of a natural storm water channel called the Hudiara Drain, which originates in Batala in India's Gurdaspur District and flows for nearly 55 kilometers before entering Pakistan (Shekar et al., 2008).

India and Pakistan Project Initiative: Pollution in Hudaria Drain has raised several issues that led India and Pakistan to work together to reduce the pollution. Thirty years ago, Hudiara drain was used as a storm water drain for irrigation and domestic purposes, and to drain water into Ravi. The goal of the project was to reduce the daily pollution of Hudaira Drain and the clean up the drain by 2006. The project was funded in 2002 through the WWF and the United Nations Development Program. Also, it is important to recognize that the Hudaira Drain has become a problem that forced both India and Pakistan to collaborate together. Updates on the project are unknown, but a news article in 2014 indicates that the Hudaira Drain is being cleaned as a joint effort by India and Pakistan. News reports from 2006 and 2014, from both countries, have stated cleaning of the drain [Mustafa, 2006] [Bajwa, 2014]. On the other hand, the reports indicate that the pollution is increasing.

Groundwater Depletion of River Ravi Basin

To answer the main questions regarding optimizing water supply in the River Ravi basin, this section will look at the following:

- Why was SCARP's well needed on the Pakistani side, but not in the side of India?
- How are tubewells are contributing to water scarcity?
- How are the social and economical barriers created through the use of tubewells?
- What will happen to Pakistan's water if tubewells continue?
- How many tubewells are installed in the India side of Ravi?
- Is India facing the same problem with groundwater reduction?
- What are India's reasons for using the tubewells?

SCARP Wells: As stated earlier, water logging and salinity problems were issues from the start of the canal irrigation system. In Pakistan, this issue became very severe during the 1960's, which caused the launching of the Salinity Control and Reclamation Project (SCARP's). The objective of SCARP's well was to lower the groundwater table to create favorable crop growth conditions in the root zone and reduce the risk of soil salinization. The wells provided increased water irrigation supplies by discharging pumped groundwater into the existing public canals [Qureshi, 2010]. SCARP's wells consist of 16,000 tubewells while supplying an area of 2.6 million ha with an average distance 0.09-m^3 /s. Idea of SCARP wells directed towards innovation of privatized tubewells. Local diesel engines and subsidized electricity by the government was also offered [Qureshi, 2014]. It should be noted that Pakistan existed only for twelve years when SCARP wells were installed, and at the same time Indus Water Treaty was being signed. The new nation is already under pressure to improve the quality of water and divide the quantity of water. These were signals that Pakistan's water issues will increase. Hence, the intention of SCARP wells was to create a resolution, but it created newer problems for Pakistan. The next section will discuss the implications of tubewells in Pakistan, and its relation to groundwater depletion.

<u>Demographics of Tubewells:</u> Tubewells in Pakistan have significantly increased from 1965 to 2002. In Punjab, the density of private tubewells has increased per 1000 hectares from 3 tubewells in 1964 to 46 tubewells in 2002 this density is 9 times higher than other provinces. Figure 14 indicates that after 1990's there has been a rapid growth of tubewells in Pakistan and particularly in the Punjab region, while the increase in other provinces is significantly low (figure 14 & 15). It is reported rapid growth tubewells started in Pakistan between 1994 and 1995 from 20,000 to 48,100 [Bashart]. More information about this particular year is needed to understand the reasons for the increase. The growth might be due to the rapid increase of population in the 1990's (figure 3). An accurate number of tubewells in Pakistan is difficult to state and is estimated to be somewhere from 500,000 to one million, which will be discussed in other sections [Quershi, 2001][Basharat, 2010]. The tubewells demographics indicate that Pakistan's dependency on the resource is significant, however like everything else likewise tubewells have benefits and tradeoffs. Following sections will discuss the benefits and tradeoffs of tubewells.

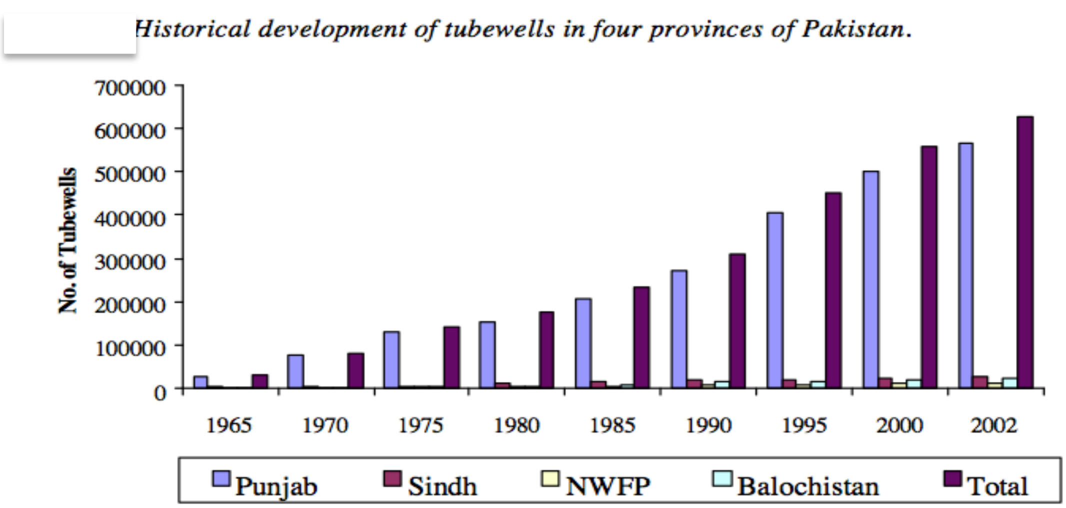
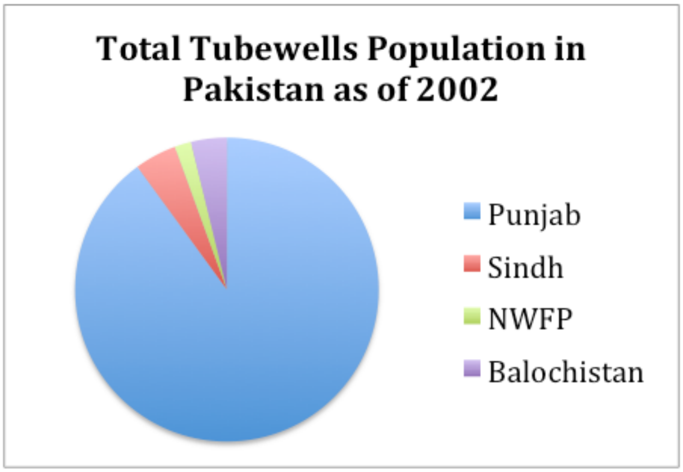


Figure 14: Historical Development of tubewells in Pakistan Source: IWMI



Province	Total Tubewells
Punjab	566446
Sindh	28079
NWFP	11077
Balochistan	24000
Total Tubewells	629602

Figure 25: Tubewell population based on Province. Source: International Water Management Institute

Benefit of Tubewells : Groundwater attraction is being done through tubewells in Pakistan because water is delepting rapidly and thirty five percent of agricultural needs are met through groundwater usage. The practice of using groundwater in rural areas secures agricultural output, which eliminates poverty. Also, groundwater usage have enlarged crop yield from 150-200 percent and cropping intensities have increased 70 to 150 percent. [Bhutta, 2007]. Another, study indicated crop intensity has increased in Pakistan 93% from the years 1912 to 2013. Furthermore, groundwater attraction through tubewells has an approximate market of Rs. 25 billion (US $400 million) and a return agricultural production of Rs.150 billion (US $2.5 billion)[Quershi, 2001]. In Pakistan, groundwater provides 50 percent of the total crop water requirements [Quershi 2014].

In addition, approximately thirty percent of farmers with tubewells sell water. This benefit is not calculated in the profitability of the tubewells. These results indicate that the groundwater usage is very critical to the food security of Pakistan and the economy of the country. If groundwater was unavailable in Pakistan, it is likely the food prices would rise or a famine would occur since it's one of the world's most populated countries. Using tubewells in Pakistan generates a large source of revenue for the country, which is critical to a developing country such as Pakistan. However, heavy usages of tubewells have led Pakistan into severe groundwater depletion, which will be discussed in the later sections. The dependency of the tubewells also suggests a problem with the countries water management because farmers are paying high prices to install tubewells. Either farmers are not getting water delivered on time or there is not enough surface water available. Thus it is necessary to understand different motives farmers might have to install tubewells and to understand such water management issues.

Installing Tubewells: The current estimate of tubewells as of 2013 is approximaltey one million in Pakistan. The cost analysis of tubewells of 2002 was implied, since the cost analysis of 2015 is unknown. Majority of the tubewells in Pakistan are either diesel or electrical with some intervention of other tubewells. Diesel operated tubewells cost Rs. 50,000($500) and create 87 percent of the total population of the tubewells[Comment 2]. The electirc tubewell cost roughly Rs. 102,000($1,000) they are not popular because electricity shortages in Pakistan. Installing tubewells can be an expensive investment for some framers in Pakistan. The cost is depends in depth size and type energy used for the tubewell(Figure 16).It cost a framer Rs. 338,000($3320) to pump water that is more than 24 meters. As stated, earlier fifty percent of people in Pakistan live below the poverty line. Thus, judging from the cost of tubewells this resource is not available to everyone. In Punjab, 77 percent of the tubewells are installed through owners own funds and roughly 10 percent through bank loans[IWMI]. This indicates that the majority of the framers in Punjab have the financial resources to invest in tubewells, which may not be true for framers that rely on agriculture for survival. Prices of tubewells have continued to increase in Pakistan compared to 2002. As of 2009, the construction cost of a deep electric tube well (>20 m) is US$ 5,000 as compared to US$ 1,000 for a shallow tube well (<6 m). Also, the present cost of pumping groundwater from a shallow tube well is US$ 4.2 per 1,000 m^3 as compared to US$ 12 per 1,000 m^3 from a deep tube well [Querishi, 2014].

Impact of groundwater table depth on installation cost of private tubewells in Pakistan.

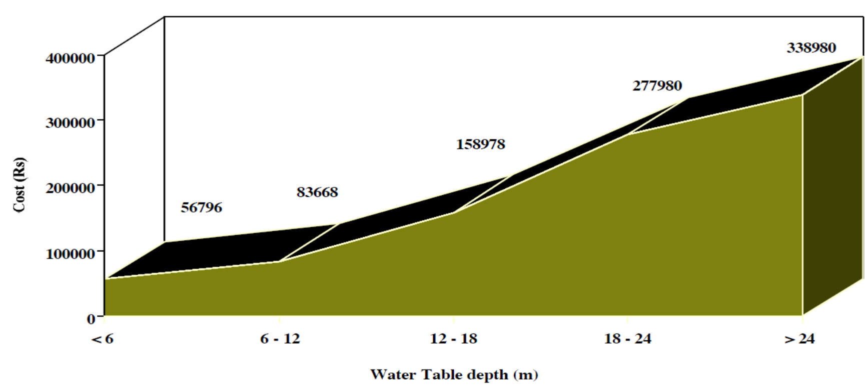


Figure16: Installation cost of Private tubewells in Pakistan as of 2002source[IWMI]

<u>Complications with Tubewells</u>:
In Pakistan, there is no law or regulations on the tubewells purchase or the usage, which means anyone with funding for a tubewell, can have infinite access to groundwater resources. This has led to many challenges with groundwater depletion and social-economic barriers in Pakistan. Before the introduction of the canal system in Pakistan, the depth of groundwater was generally 20 to 30 meters below the natural surface level and sources of recharge were river, floods, and rainfall. It is assumed the groundwater elevation levels were stable for the most part with few seasonal fluctuations [Bhutta, 2007]. The expansion of the irrigation system have caused social and water challenges. From the start of the irrigation system in 20th century, the groundwater table started rising until it reached ground surface in 1960's(figure 2). The SCARP wells were introduced as salinity controlled wells in the 1960's and from

the idea of SCARP wells framers in Pakistan started using tubewells. Since 1960's, tubewells had a rapid growth in Pakistan because canal water delivery time was not sufficient or predictable enough for the farmers. Through the usage of tubewells, farmers have unlimited access to the water, which led towards groundwater depletion in Pakistan. From the years 1965 to 2002, the annual ground water abstraction has increased from 10 to 68 Billion Cubic Meter (BCM). In Pakistan 70 percent of the ground water is being pumped for irrigation usage. The Government of Pakistan conducted surveys from the years of: 1953-1954, 1977-1979, and 2001-2003; the data showed seventeen Million Hectares (MHA) of the land surveyed, salt-free land has increased from fifty six percent to seventy three percent. In addition, waterlogged area in general decreased, but these trends were mostly found in Punjab not in the Sindh region due to better management of the water system. However, Punjab might have the highest rate of groundwater depletion in Pakistan, since it has the largest number of tubewells [Bhutta, 2007]. For instance, the average water source distance for a tubewell is estimated to be 1,000 Meters (M) in Punjab, 400M in Sindhi, and 94 Meters KPK. The most common recharge aquifer for the tubewells are canals followed by rivers, ponds, and streams. The canals that are diverting water from River Ravi whose groundwaters recharge access belong to India. This indicates that the groundwater being abstract in tubewells near the River Ravi Basin of Pakistan is not getting recharged. Groundwater pumping causes water logging and secondary salinization problems, since salt accumulated from the topsoil when water from shallow depth evaporates [Bhutta, 2007]. The present mean annual canal diversion is found to be 128 BCM, which major parts of the diversion seep down from the rivers, canals, watercourses, and fields recharging the groundwater. Table five indicates that no further significant groundwater recharge can be done since total annual groundwater recharge is equal to, or less than, discharge. The estimation rates were not done taken evapotranspiration from the groundwater and that was done the water balance becomes negative. Since 1998, groundwater table has been falling in almost all the canals commands, which indicates that current net groundwater abstraction is higher than recharge. It is estimated that 60 percent of farmers in Punjab use groundwater for addition source to enhance canal water supplies. Most importantly, Punjab supplies 90 percent of the total agricultural production of Pakistan; major food shortages can occur if water scarcity issues continue to increase. Furthermore, there is a water distribution problem from the tubewells because approximately 92% have unlined channels with a tubewell depth of 600-900M; 6% are lined channels with a tubwell depth of 180-500M, and only 2 percent are piped channel with a tubewell depth of 300M[Quershi, 2001][Basharat, 2010]. Even though, tubewells are being used as groundwater abstraction water is still leaking through them through the unlined channels.

Table 5: Groundwater recharge of the Indus River Basin source: Atakhar 2010

T

Location		At head	Infiltration		Recharge to aquifer	
		(BCM)	%	(BCM)	%	(BCM)
1.	Canals Diversions					
	Canals	128	15	19	75	14
	Distributary / Minor	109	8	9	75	7
	Watercourse	100	30	30	60	18
	Fields	70	30	21	90	19
	Crops	49				
	Sub-Total			79		58
2.	Rainfall: Average rainfall of 0.195 m over area of 17.4 M ha.					
	Rainfall recharge	34	50	17	50	8

<u>Groundwater Depletion in Ravi:</u> In Pakistan, thirty five percent of agricultural rely on groundwater usage. In rural communities, groundwater is used as a way of eliminating poverty, since it secures agricultural output [Bhutta, 2007]. Post 1960's tubewells in Pakistan have grown because farmers are not being provided water from canal and some of the major canals of Pakistan reside on Ravi's water. There is no legislation on installation and usage of tubewells, which is why there is not an accurate number on tubewells in Pakistan. It is estimated that between 500,000 to one million tubewells in Pakistan are resulting in rapid groundwater depletion. The original intention of the SCARP tubewells was to reduce the salinity problems that were occurring in the area; instead it led to more social and regional problems in the area. Punjab has the highest tubewell population and the largest extraction of water, which implies rapid groundwater depletion in the region. It has to be assumed tubewell population to be the highest in the River Ravi Basin, since Punjab has the highest tubewell population and three major canals use Ravi's water. For example, in a case study on Lower Bari Doab Canal (LBDC) (canal built diverting water River Ravi) found groundwater rate to depletion rate to be 31.4 cm/yr. due to increase in demand and shortage of irrigation water supplies. Due to the shortage, the farmers in the Shergarh Area of LBDC installed wells and started pumping groundwater in more saline areas. In another study, indicated groundwater table depths in LBDC are increasing (>15 m). However, farmers at tail end of the canal have no choice except to drill deeper wells because water delivery is insufficient. Drilling deeper for water led towards increase in installation and operational costs [Basharat, 2010]. If the framers have to continue to draw deeper for groundwater, prices for tubewells will increase that will create future barriers for the poor farmers. In addition, the food prices will arise. Thus, it is important to understand how canals water availability and the groundwater pumping issues are interlinked.

<u>Upper Bari Doab Region:</u>
Upper Bari Doab is located in Lahore (capital of Punjab, Pakistan) and has significance in India as well. The Upper Bari Doab Canal in India cultivates a command area of 543 thousand hectares of land and gross command area of 834.06 thousand hectares. There is still an ultimate irrigation potential of 354 hectares [India Water Resource

Information System]. Figure seventeen shows the original Upper Bari Doab set-up during British Colony India, but as stated earlier, this was set-up to be cultivated together dividing the sections may have caused unseen problems. Agricultural changes and water demand should be studied to understand if problems in Bari Doab occurred. Figure eighteen displays the usage of Upper Bari Doab Canal in India, which indicates how the Bari Doab is an important source in India as well as Pakistan.

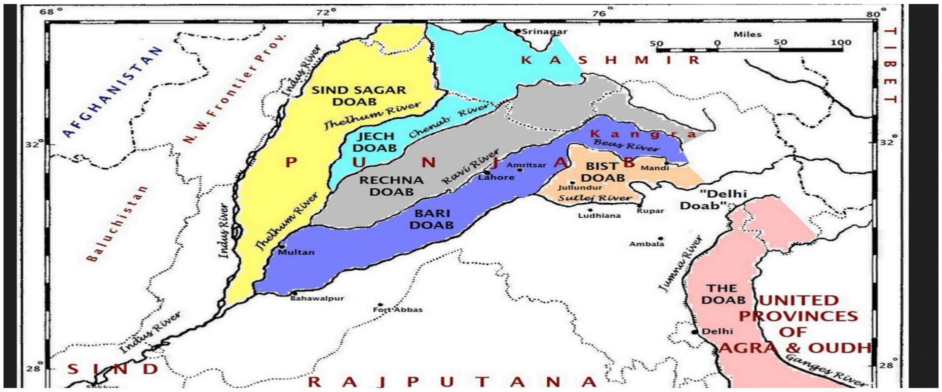


Figure 17: Map of Doab before partition of India and Pakistan Retrieved from: http://en.wikipedia.org/wiki/File:Punjabdoabs1.jpg#/media/File:Punjabdoabs1.jpg

"Source: "Partition of the Punjab and of Bengal," by O. H. G. Spate, The Geographical Journal, 110(4-6):201-218, November 1947.

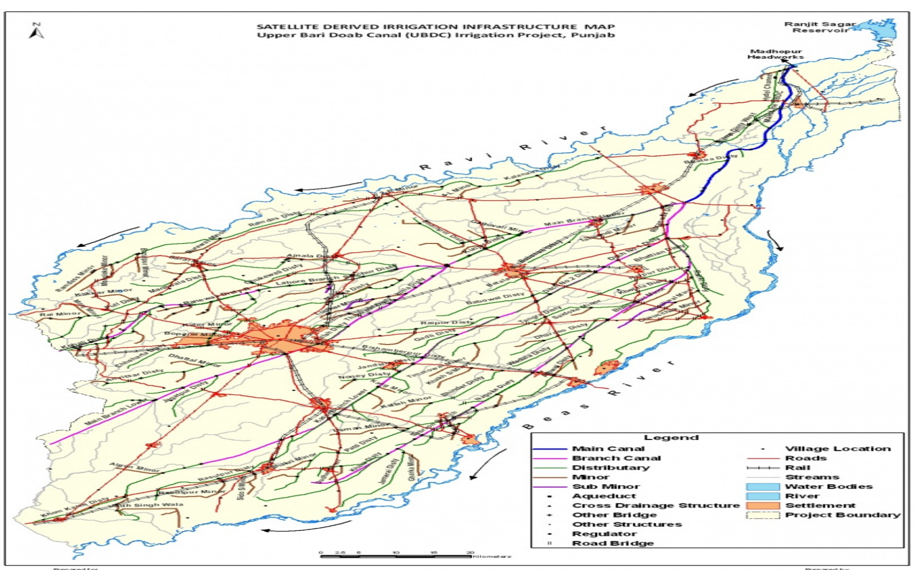


Figure 18: Upper Bari Doab Canal in India

Retrieved from: http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Upper_Bari_Doab_Canal_%28U.B.D.C.%29_System_JI03042

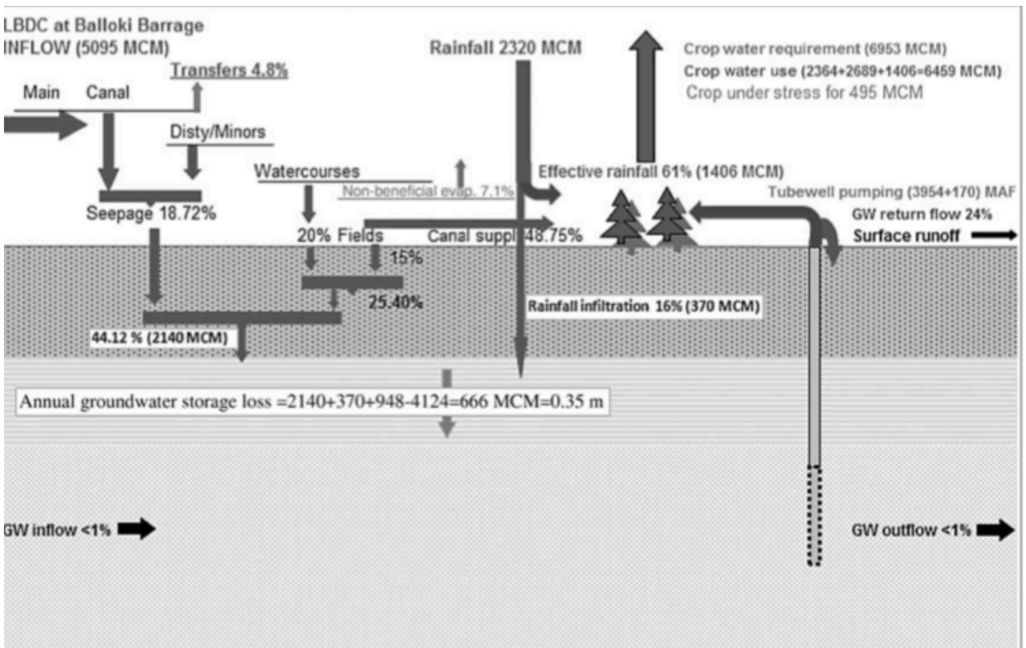
<u>Canal Damage:</u>

Indus Basin Irrigation system (IBIS) is based on a gravity run system, thus the operation of the canals is based on continuous water supply not on actual crop water requirements. The canals cannot allocate water more than there design capacity, which is 2mm/day. This is problematic since the demand for agricultural supply has increased significantly, but the design for change is unavailable [Quershi, 2014]. In addition, climate variations contribute to water supply's in the canals, which does not address the water demand. For instance, some province might need more water compare to others. According to Pakistan' s meteorological Department (PMD) precipitation ranges from 100mm in parts of Lower Indus Plain to 1,000mm near Upper Indus Plain and also the lake evaporation increases from 1,270mm at Peshawar to 2,800mm at Thatta. This implies that some canals may have better groundwater recharge compared to other canals based on their geographic locations. Furthermore, the mean annual rainfalls in upper parts of Punjab where both the Bari Doabs are located do not have high quantity of rainfalls [Basharat, 2014]. This is problematic considering that these Bari Doab canals were the first one to be constructed for irrigation purposes. If the problems in Bari Doab canals are occurring, this indicates that food security is at risk considering the region to be a breadbasket for more than a hundred and fifty years.

Four immense issues identify for the Indus Basin Irrigation System are water and supply demand, surface and groundwater, irrigation and drainage, as well as water and land-related infrastructure. Punjab, Pakistan covers 75% percent of the Indus Basin Irrigation System (IBIS), where rapid groundwater depletion is being observed in the canal commands lying in central and lower parts of the Bari Doab. Also, Pakistan has been classified in categories of water-stressed and water scarce based on per capita water availability (1,000m^3/capita*year). Cropping intensity is the highest in Mailsi, Pakpattan, LBDC and Sidhnai canals all of these are close to the Indian border and covers central and lower parts of Bari Doab [Basharat, 2014].

Water shortage is explained from case study in 2012 done in LBDC (figure 19). The delivery of annual average water in LBDC from time period of 2001-2009 was 4,849 million cubic meters (MCM), but the annual crop command was 6,953 MCM. The need for extra 2,104 MCM for crop consumptive requirement was met as 2,364 MCM was provided from canal supply, 2,689 MCM from groundwater (68% as consumptive use out of 3,954 MCM groundwater pumping) and 1,406 MCM as effective rainfall from annual average rainfall, which are about 472 mm at the head end and 212 mm at the tail end of the command. There was still a net shortage of 495 MCM of irrigation water is being faced by the farmers in addition to groundwater mining of the aquifer [Basharat, 2014]. From this data, importance of groundwater and usage of tubewells can be seen in the LBDC area. Also, the data shows shortcomings of link canals, since they can only provide limited supply of water because canals on the other side divert water. If depletion rates are occurring, groundwater may be unreachable in the upcoming years, which can reduce major agricultural production for Pakistan. The water management and delivery of water should be studied to improve the situation. As mentioned earlier, groundwater pumping can be costly, which indicates poor farmers are suffering from the shortage of water in LBDC. In addition, social-economical issue is created where farmers with funding can harvest their crops vs. farmers without funding for tubewells. Tubewells are a tradeoff for the Pakistani

Government. For instance, if they create regulations on limiting the practice of tubewells they will create food insecurity; on the other hand, they will eliminated the leading cause of groundwater depletion and secure water for the future. Before any rules and regulations can be implemented, the region should apply methodologies of optimizing water and adopting sustainable farming. The entire basin should be studied to understand how agricultural in India and Pakistan is being done because both nations might be facing the same negative consequences.



1. Crop water requirement, surface water and groundwater balance in LBDC command (Basharat, 2012).

Figure 19: Graph of Crop water requirement in the LBDC Source: Water policy

Basharat(2012) studied also conducted the total recharge it was estimated to be 3,458 MCM, whereas the groundwater pumping for agriculture and domestic purposes was 4,124 MCM. This shown net loss in groundwater storage of 666 MCM was occurring for the aquifer under LBDC command, which is equivalent to 36 cm per year drop in aquifer levels (assuming 0.25 as specific yield) over the gross command area of 0.8 million hectares. In the Bari Doab the average groundwater depletion is 2.32 BCM from time period of June 2002-June 2012 with a gross command area of 2.91 Mha (figure20). The groundwater reservoir depletion was found calculating soil volumes and the area above the water table. In addition, figure 20 shows depth to water table (DTW) and area cultivated, which indicates increase in cultivated area. If more area is being cultivated than more agricultural revenue is being generated, however the water table is increasing that is alarming because water depletion is occurring. Now more farmers are relying on groundwater for irrigation, but the water is declining rapidly [Qureshi, 2014]. The cultivation is increasing in this area because this is historically where agricultural investment was made. These finding on the Bari Doab region present Pakistan's leading problem in groundwater depletion and reliance on agriculture.

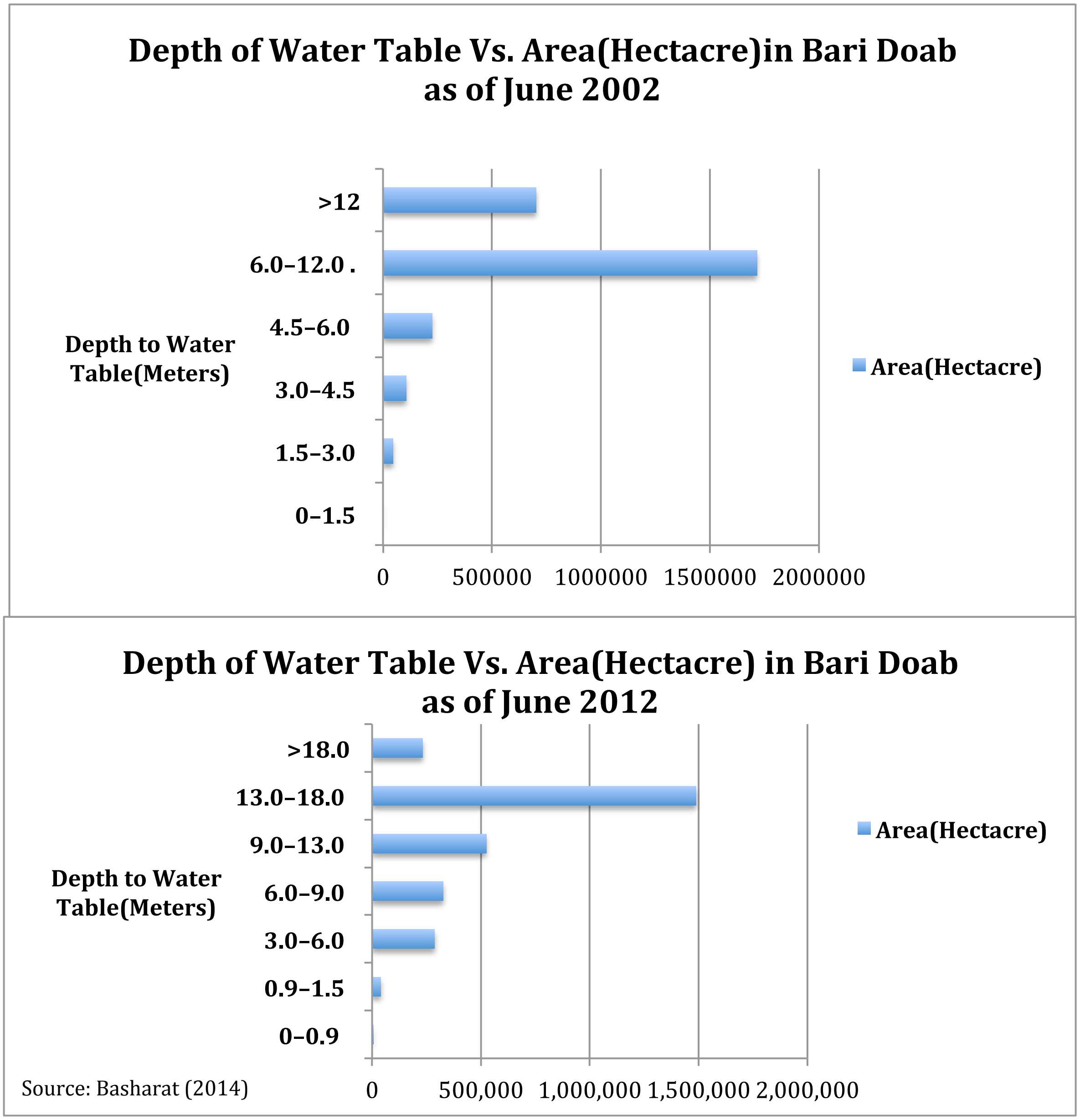
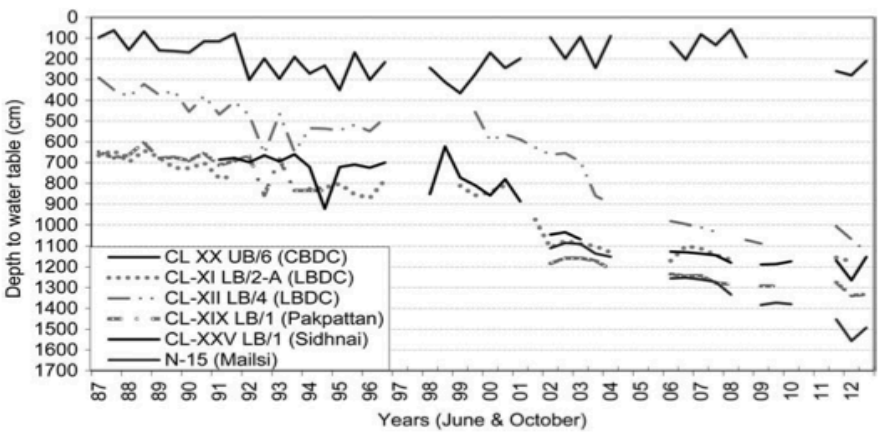


Figure 20: Depth of water table over area with soil volume found in Bari Doab using four depleting canals Mailsi, Pakpattan, LBDC, and Sidhnai

Bari Doab area is closer to Indian border and were created using water from Rivers Ravi and Beas. Groundwater depletion is connected to Pakistan's many interlinked problems such as excessive pumping of the tubewells led to mining of the aquifer, variation in canal supplies and increasing irrigation demand towards the south are jointly affecting the underground recharge, demands on groundwater pumping and, ultimately the depth to the groundwater. Figure 21, shows water decline in LBDC, Mailsi, Sidhnai, and Pakpattan Bari Doab canals to be 16 to 36 cm/year from the years of 1987 to 2009, while the depletion rate were found to be 15 to 55 cm/year for the years of 2002-2009. It is reported by Punjab Private Sector Groundwater Development

Project that these areas are at the tail reach of the canal system and groundwater may become out of the reach. Only CBDC canal is not declining in groundwater table because of the area receives heavy rainfall. Also, mobilization of deeper saline water is taking place as result of pumping by the framers because saline groundwater is lying below the upper layer of irrigation-leaked fresh water [Basharat, 2014][Bhutta, 2007].



CBDC=Central Bari Doab Canal
LBDC=Lower Bari Doab Canal

Figure 21: Depth of water table hydrographs for Bari Doab canals source: [water policy]

<u>Groundwater Depletion in India:</u> The Punjab of India has an area of 50, 362 km^2 with an area of 85% agriculture and with cropping intensity of 184%. Like Pakistan, Punjab region of India is estimated to have 1 million tubewells with similar growth trend over decades. Thus, exploiting groundwater sources are not an unusual phenomenon in India. Approximately, 78% (39,000 km^2) of Punjab State shows decline in water levels. In Pakistan, farmers near the Bari Doab exploit groundwater because surface water is limited. Hence, someone might except less groundwater depletion of River Ravi in Indian side because of the unrestricted access, however Amritsar is found to have depth of water more than 20 meters [Gupta, India]. These results indicated similar activities are partaking on both sides of the border. If both sides are exploiting the Ravi River Basin, discharge rate might be higher than recharge rate. Negative consequences are seen in both nations, but no joint studies have been done on the basin. If the groundwater runs out, food security and aquatic life are at risk. In addition, there will be increase in pollution and demand for water.

<u>Discussion:</u>   Water problems of River Ravi are not a new phenomenon, but are a set of historical problems that keep accumulating. For instance, British invent the canals, which led towards increase in groundwater level and salinity; that required the installation of the SCARP wells. The installation of SCARP wells innovated installation of privatized tubewells. At the same time, the Indus River was being divided through the Indus Water Treaty, which limited the surface water. Post Indus Water Treaty, Pakistan largest source of revenue is still in agriculture and resides within the Punjab Province, but that is becoming a major concern.

Punjab of Pakistan faces major issues in groundwater pollution and depletion, particularly in the River Ravi Basin. Historically, the Ravi River was the first river to have the canal expansion and harvest rapid agricultural growth. If considering Punjab as the breadbasket of Pakistan, River Ravi area should be considered the capital of the breadbasket. Any solutions that is recommend in Pakistan should be first applied in the areas of Bari Doab Canals, where region high groundwater depletion rates are occurring and canal agricultural has been present for more than 100 years.

The best way to optimize the water supply of River Ravi is to study the entire Ravi River Basin from India through Pakistan because groundwater depletion is occurring in both countries through the usage of tubewells. For instance, both sides are tapping into the aquifer and will eventually reach the minimum point. Even if Pakistan reduces the usage of tubewells in Ravi, India will still be using the tubewells, which will causes groundwater depletion. Also, the Ravi River Basin is in the cities of Amritsar and Lahore both historical and populated cities. If the groundwater runs out, millions of people dependent on agricultural growth and livelihood will be at risk. The interconnection of River Ravi Basin problems can been seen in Hudiara Drain, where joint initiatives are needed to resolve the problem and shows issue of trans-boundary. Furthermore, the health of aquatic life in the river basin will become degraded if the pollution continues. The next, sections will discuss some possible solutions that can be implemented.

<u>Sample Solution</u>: The main concern of Ravi River is groundwater depletion and dependency on tubewells. India can create more reservoirs on the Ravi River Basin, which will provide framers with water to reduce the usage of tubewells. At the same time, the increase in reservoirs will continue recharging the groundwater before it reaches in Pakistan. Through this resolution, the Indus Water Treaty will not be broken and the Ravi River Basin will be restored. To implement this, it will require study of basin in both nations and working with research institutions of Punjab in both nations.

<u>Sample Solution 2</u>: Currently, both nations use warabandi system to provide water to the farmers, which also contributes to water losses. The system was designed in the 19th century and it was based on few farmers. Now, farmers have expanded and more area is cultivated than before. For instance, high tubewell density was found at tail ends of the canals where farmers receive the water towards the end. This may be case for all tail end farmers because they face high conveyance losses. In Pakistan, transportation and insufficient timing of water played a role in implementing tubewells. Reasons for installing tubewells in India need to be researched. However, both nations can work together to implement a system of modifying the warabandi system that can reduce the usage of tubewells without affecting the agriculture. This will provide reduction conveyance loss in the River Ravi Basin and secure groundwater depletion. To implement this system, warabandi system in River Ravi region needs to be studied, agriculture production, farming methods, and channels of tubewell.

Comments:

1. Why did problem of salinity only occur in Punjab side of Pakistan and not India? Are there any geological differences?
2. Agricultural data of 2013-2014 of Pakistan is needed to get more precise tubewell demographics.

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Appendix [1]

Indus Irrigation System: The Indus River is one of the largest Rivers in the world. Indus River water comes from Lake Mansarvor, which at altitude of 6770 m above sea level on the Plateau of Tibet. The Indus River basin is divided into 27 tributaries 13 are hilly and 14 are plains [7]. The largest tributary Indus receives are from Panjnad (five) confluence of rivers: Jhelum, Chenab, Ravi, Bias, and Sutlej. These tributaries are estimated to be 700 miles long (1,126 km). Indus estimated length is between 2900-3200 km^2 approximately 2,000 miles long and the area on Indus is estimated to be between 888 thousand km^2 to 1165 thousand km^2. Density of Indus River Basin is estimated to be 0.15km/100 km^2[5]. Pakistan contents 52. 38% percent of the Indus Basin and India contents 33.51% of the Indus Basin [Figure 1]. The annual discharge rate is about 207 BCM [7]. Indus Basin has the largest delta and seventh largest mangrove system. It is very important to discuss the Indus river basin when understanding the current water problems in India and Pakistan [5].

Indus*

Total area: 1,138,800 km²

Countries	Area of Basin in Country km²	%
Pakistan	597,700	52.48
India	381,600	33.51
China	76,200	6.69
Afghanistan	72,100	6.33
Chinese control, claimed by India	9,600	0.84
Indian control, claimed by China	1,600	0.14
Nepal	10	0.00

Figure 1: Size of the Indus River Basin
Source:
http://www.transboundarywaters.orst.edu/publications/atlas/atlas_pdf/4_Treaties_asia.pdf

Indus River Basin from (1850-1947) [Expansion of the Indus Irrigation System]: In late 19th century famine came across the British India Colony known as the modern India and Pakistan. The Indus river basin was used to expand the irrigation system and create canals. This expansion created one of the most extensive irrigation systems in the world. It provided sources of food and stability for the local people. In 1849, British conquered the Kingdom of Lahore and started the expansion canals and created perennial canals. Three main reasons for this expansion are stated. First, the famine of 1837-1838 was fresh in the mind of people. People were concern about the food security issues. The British needed to create a resettlement of the dissolved armies of the indigenous rulers who were replaces by colonial administrative. This was considered to be part of the colonization scheme. Lastly, the irrigation system offered a great potential for creating revenue [2][5]. The entre Punjab region dependent on irrigation system and agriculture was the most important source of income. The Northern India canals were set based on a rain-fed system based on the monsoon rainfall (barani). However, in the West Punjab (Pakistan & India) barani system was insufficient because very few rainfalls occurred in the area. The canals in the west Punjab region were designed to extract water from the 5 main tributaries of Indus known as the Panjab: Jhelum, Chenab, Ravi, Bias, and Sutlej. The term doab is used to extract the water from these five extensive rivers. It was noted that the canals would get water by gravity flow from the doab. However this system was not sufficient in the winter, solution was found to throw a barrier or weir across the river to raise the water levels. The work on the perennial canals started. In 1859, the first Upper Bari Doab Canal (UBDC) was completed by 1861 it started irrigation. The 247 miles long UBDC irrigated 1 million acres of land. In 1886, Sindhani Canal was completed and these first few canals were solely on bases for food security and prevention of a famine. From 1850-1901, all Punjab's rivers except Beas River were used under extensive irrigation system. After World War I, 4 new barrages and number of link canals were introduced[1][2][3]. The British rule from 1885-1947 Punjab irrigated area increased from 3 to 14 millions acres. This made Punjab the center of agriculture in British India Colony. Today, the irrigation system accounts for 90 percent of water to agricultural lands and the total length of the network from is the Indus basin is 58,000km[4]. The Indus basin mainly composed of agriculture, approximately 190,000 km^2 of cropland irrigated in the Indus Plains, 150,00 km^2 by the Indus basin irrigation system and 40,000 km^2 in the local irrigation [6]. From 1860s until 1960s the basin expanded from massive construction of 16 barrages, 12 inter river link canals, 44-canals system, and more than 107,000 water courses. The Sukkur barrage made in 1932 was one of the largest barrage during that time. It created 7 link canals and cultivated 3.16 millions acre of land.

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