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WASTEWATER-A THREAT FOR GROUNDWATER

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By

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ABSTRACT

Globally over 30 billion tons of urban sewage is discharged into lakes and rivers and similarly more than 0.2 million gallons of sewage and at least 35,000 gallons of oil spill is released from cruise ships into the ocean each year. More than 200 million people in the world are using different forms of wastewater (treated, partially treated, and untreated) for irrigation purposes and 10% of the total world's food production is based on wastewater irrigation. As per recent survey, in Pakistan 32,500 hectares of land are directly irrigated with wastewater i.e. 26% of crops especially vegetables are being produced from wastewater. Different drains are entering into Ravi River at various locations throwing huge quantity of effluents in the river due to which it has become almost a "sullage carrier" especially during low flow season. To quantify the impact of waste water on underlying aquifer an experimental setup of 50 piezometers has been laid along the river at three locations viz Ravi Syphon, Shahdra and Mohlanwal. Groundwater quality trends are being monitored along the river, across the river, vertically downward and with respect to time for a period since 2011. Analysis of data observed so far indicates that pollution in River Ravi is contributing in deterioration of groundwater quality. It has been observed that waste water being thrown in the River has a direct impact on groundwater as shallow groundwater quality is the worst and improves as we move downward. Groundwater quality is also deteriorating with the passage of time especially at Shahdra Bridge (Lahore) site due to increase in quantity of effluents being disposed off in the River. Results have revealed that quality of groundwater is deteriorating, moving downstream from Ravi Syphon to Lahore and then again improves towards Mohlanwal. Some remedial steps has also been proposed in the paper.

Key Words: wastewater, groundwater, sustainability, Ravi River, aquifer, piezometers, Lahore, Punjab

1. INTRODUCTION

1.1 Wastewater

The World is facing a global water quality crisis. Rapid urbanization, haphazard industrial development, continuous population explosion and expanding and intensifying food production are all putting pressure on water resources and have resulted in degradation of water resources to an alarming stage. This presents a global threat to environmental and human health in addition to groundwater and surface water pollution (Hamid et al.,

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2013) with both immediate and long term consequences for efforts to reduce poverty whilst sustaining the integrity of some of our most productive ecosystems. Wastewater normally discharge of liquid and solids waste from domestic, industrial, commercial and institutions premises. It is not limited to toilet wastes, grey water (household wastewater from kitchens, bathrooms and laundries), sludge, trade wastes and gross solids **(Tatum, 2003 and WWF, 2014).**

Over 30 billion tons of urban sewage is discharged into lakes, rivers and oceans each year. Each year 1.2 trillion gallons of untreated sewage, storm water and industrial waste are dumped into U.S. waters. Cruise ships are also a major source of sea water pollution because more than 0.2 million gallons of sewage and at least 35,000 gallons of oil spill is mostly released from cruise ships into the ocean. (http://www.conserve-energy-future.com/various-water-pollution-facts.php).

More than 200 million people in the World are using different forms of wastewater (treated, partially treated, untreated) for irrigation purposes (Raschid-Sally and Jayakody, 2008). According to another estimate, 10% of the total world's food production is based on wastewater irrigation (Corcoran, 2010). A survey conducted by International Water Management Institute (IWMI) revealed that in Pakistan 32,500 hectares of land are directly irrigated with wastewater i.e. 26% of crops especially vegetables are being produced from wastewater (Baig et al., 2011).

It was also believed that cholera is caused by the bacillus Vibrio Cholera and it was transmitted by water contaminated by the vomit and fecal matter of cholera patients **(Dr John, 1849)**. Major sources of wastewater in Punjab are domestic, industrial and agriculture effluents is shown in figure 1.

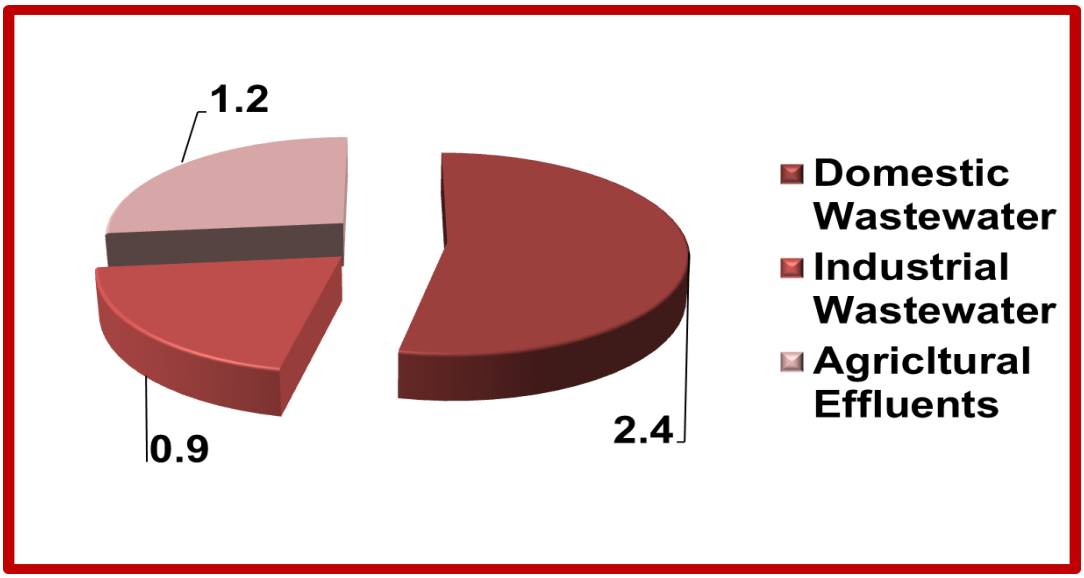


Figure 1: Wastewater in Punjab (MAF)

1.2 HISTORY OF WASTEWATER AND ITS MANAGEMENT

The sewers and its disposal is not newly concept. In ancient time during the Mesopotamian empire (3500 to 2500 BC) storm water drain system was used to carry away wastes of some homes. Similarly, a system of wastewater management was constructed in Mohenjo-Daro near the river Indus (Pakistan) at about 1500 BC. Some centuries later, River flow course was shifted due to which town was given up and covered by sand during the following decades. The new civilization with private and public houses was discovered during the years 1930s to1940s. The houses were equipped with toilets. Water used for washing and bathing as well as rain water discharged into canals through special grooves which were built with the slope. Water was eventually discharged into the river Indus. These installations demonstrate a high hygienic standard of an early culture.

Four separate drainage system was recognized by the Archaeologists at King Minos' Royal Palace at Knossos (Crete) from1700 BC. The wastewater drained through terracotta pipes which were joined with cement into stone sewers. Rainwater-fed cisterns and stone aqueducts tapped available water sources to deliver a continuous flow of water through the bathrooms and latrines which eventually discharged to the Kairatos River. A drainage system made up of terracotta pipes with bell and spigot joints sealed with cement had also used in island of Crete from 2000 BC. The system conveyed mainly storm water but also some human waste. It was found that many of such drainage systems were used in the last century (**Wolf, 1999).**

The Greeks time (300 BC to 500 AD) problem of waste was tackled in a different way. They had public latrines which drained into sewers which conveyed the sewage and storm water to a collection basin outside the city. The wastewater was taken to agricultural fields for irrigation and to fertilize crops and orchards. The sewers were periodically flushed with wastewater. The Romans during 800 BC constructed a central sewer system called Cloaca Maxima, to drain the marsh and to take surface water to the River Tiber. Sewage and wastewater from the public baths and latrines were disposed of into River Tiber through the sewers beneath the city. The Romans have knowledge of the importance of clean water and the need to dispose of wastewater away from the source of drinking water. Therefore, they built their villas in the UK on the sides of hills where springs disposed of their wastewater away from their villas.

The 19th century was period of industrial revolution and high growth of population. The early part of the nineteenth century (1820 to 1850), a great debate was started about spreading of diseases like cholera and typhus in the rapidly expanding cities and towns as the Industrial Revolution gathered pace and how to prevent these diseases. About these diseases, one group had a thought that rotting waste which abounded in streets and public places or as poisoned air led to disease. Another group derived that disease was passed by physical contact, whether from human to human, or through the consumption of infected food or water.

Melosi (2000) paid fulsome tribute to set standards for water and wastewater systems throughout Europe and North America. Sir Edwin Chadwick (1800-1890), a lawyer and journalist who developed an interest in the condition of the London slums. He proposed a hydraulic (or arterial-venous) system that would bring potable water into homes

equipped with water closets and then carry effluent out to public sewer lines to be deposited as 'liquid manures' on to neighbouring agricultural fields **(Melosi, 2000)**. He also proposed the 'backyard tubular drainage' system in which sewage was drained from the backs (where the privies, latrines and water closets were placed) of back-to-back houses rather than putting the sewer connection through the fronts of the houses as was usual (General Board of Health 1852). He claimed that it would reduce the cost of sewer runs by two thirds to four-fifths and allow the use of smaller sewers. This idea was taken up successfully 130 years later in Brazil **(Mara, 1999).**

Land application of wastewater, sludge and excreta is a widespread practice with a long tradition in many countries around the world. For centuries, farmers in China used human and animal excrements as fertilizers. **James Smith, (1842)** found that taking the excrement from his factory privies to his farm improved crop yields. He was argued that the fertilizer value (particularly the phosphate content) should be used on agricultural land **(Stanbridge, 1976).**

Chemical treatment of sewage discharges had been used in Paris in 1740 using lime as the precipitant **(Wardle, 1893).** The chemical treatment was applied to treat the sewage to remove enough of the pollutant concentration to get it to the point at which the effluent could be safely disposed. The other purpose was to enhance the settlement rate and recover more of the solids in a much smaller volume the sludge produced could provide the concentrated fertilizer. Chemical treatment had two main disadvantages: it could only remove suspended pollutants and it produced a much larger quantity of sludge, which was difficult to dispose of.

1.3 Situation of Wastewater in Lahore

Punjab is the most populous and industrialized province of Pakistan. According to 1998 census, the total population of the Punjab province was 73.621 million with a population density of about 359 persons per square kilometer. It has increased upto 94 million in year 2011. The recent estimate of the population is over 99.0 million **(PDS, 2014).**

In all major cities of Punjab, domestic waste and municipal wastewater containing household effluent and human waste in addition to industrial effluents are either discharged directly to a sewer system, a natural drain or various streams, a nearby field or an internal septic tank without treatment which ultimately reach the rivers. Municipal wastes contaminate water bodies with pathogens whereas industrial wastes introduce a variety of chemicals of concern to environment and human health. In addition the biodegradable organic matter in municipal and industrial wastewaters results in the depletion of dissolved oxygen in water necessary for fish life **(EPA, 2009**).

Lahore is 2nd largest city of the Pakistan and it is ranked 42 in the most populated urban areas in the world ranking and is an important historical centre of South Asia. According to 1998 census, the total population of the district of Lahore was 6.3 million, out of which 5.2 million was urban and 1.1 million belong to rural. The recent estimate of the population is over 9.6 million as shown in figure 2. Population density is estimated about 7,000 persons per square kilometer. It is also estimated that about 82 per cent of this population lives in the urban areas and the remaining 18 per cent resides in rural areas (**PDS, 2015)**

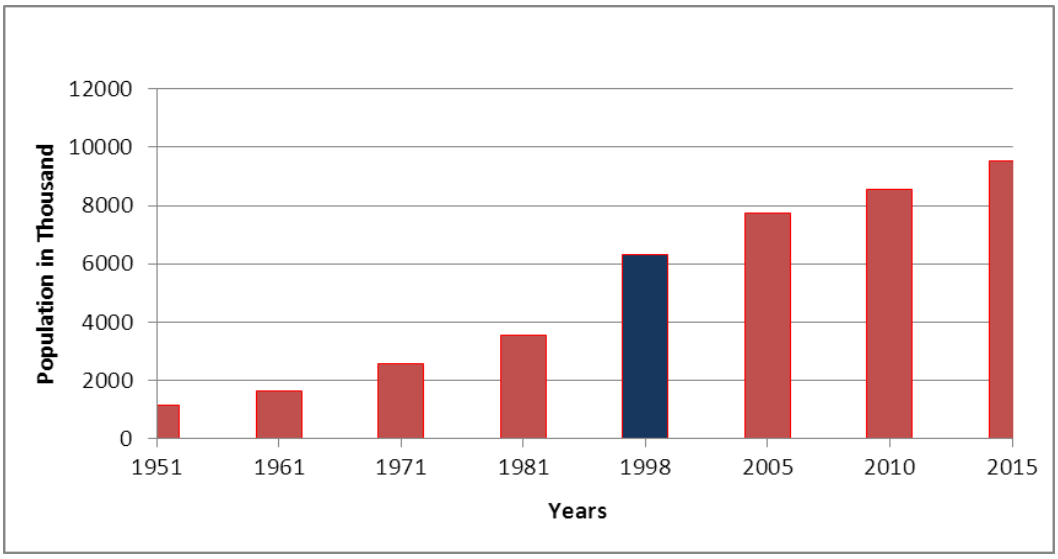


Figure 2: Population Growth in Lahore District

Pollution in surface water bodies is affecting the groundwater quality in the underlying aquifer in Lahore city **(Hassan et al, 2013)**. It was estimated that discharge of waste water of Lahore city into Ravi River was about 990 cusecs in year 2006 **(Saeed and Bahzad, 2006)** and now has increased to 3,304 cusecs through drains and various pumping stations without proper treatment **(Hussain & Sultan, 2013).** Flow in Ravi River especially during the winter is remarkably insufficient to dilute and wash off wastewater pollution **(Hassan et al, 2016).** United Nations Environmental Program (UNEP) reported that about 47% drinking water in Lahore city was contaminated due to presence of various hazardous toxic elements **(Manan, 2008).**

It may lead to a significant accumulation of heavy metals, thus influencing the food quality and safety through their ultimate entry in the food chain via plants and aquatic life (**Muchuweti et al. 2006).** Groundwater quality in the aquifer 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 mobilization of heavy metals in soil through ground water and surface water is known to have potential toxic impact on environmental quality and human health as well **(Iqbal et al, 2016)**. Moreover, the presence of heavy metals in soil and water beyond the permissible limits may render soil non- productive and may cause bio-accumulation of heavy metals in human beings **(Singh et al., 2006)**.

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. It was observed that depth to water table of Lahore city in 1987 was 25-65 ft and it has reached up to 35-105 ft in 2000 **(Basharat & Rizvi, 2011**). Now, the current depth to water table is ranged up to 40-140 ft. 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 is used for the discharge of untreated domestic and industrial waste water and effluent. There are over dozen disposal stations and surface water drains that discharge untreated waste water into the River. It was observed that untreated waste water 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. According to survey it was estimated that levels of impurities in drains enter into Ravi River are in excess of National Environmental Quality Standards set by the Pakistan Environment Protection Council and enforced by the Environment Protection Agency, Punjab **(EPD, 2008).**

Domestic and industrial Wastewater of Lahore is collected through 14 drains that collect the sewerage and industrial wastewater of the entire city and finally disposed off into Ravi River without proper treatment. The quantity of wastewater in these drains is subject to seasonal variation depends upon the weather conditions. According to survey conducted in 2010, it was estimated that 3,304 cusecs of wastewater is being disposed off into the Ravi River only by Lahore **(JICA, 2010).** Some industries discharge their wastewater on land or in soakage pits that results in groundwater pollution.

2. IMPACT OF WASTERWATERS ON GROUNDWATER

2.1 Ravi River

Ravi River is the smallest of five eastern rivers of the Indus River System (IRS). It enters in Pakistan at Jassar, about 120 km upstream of Lahore and joins the Chenab River near Kabirwala after flows down about 520 km. The average annual flow of the Ravi River in Pakistan territory was 7 million acre feet (MAF) during the period 1922 to 1961 but due to Indus Water Treaty of 1960 between India and Pakistan, right to use the water of this river were allocated to India. The average annual flow from 1985 to 1995 was recorded as 5-MAF which was further decreased to 1.1 MAF in years 2000-2009 flows due to construction of Thein Dam in 2000 upstream of Madhopur head works in India. Ravi River seems to be the main source of recharge in the North-West of Lahore.

After this drastic change in Ravi River flow regime for the last two decades, the recharging through River in adjoining areas of Lahore city has been seriously decreased as shown in figure 3.

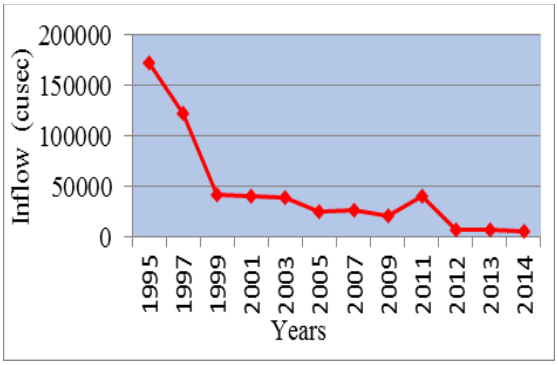


Figure 3: History of Water flow in Ravi

Water and sanitation agency (WASA), Lahore has installed 480 tubewells of different capacities at a depth of ranging from 150 to 200 m for supplying water to the citizens of Lahore which are extracting about 1170 cusec of groundwater per day for drinking purpose. In addition to WASA tubewells, a large number of private tubewells installed in housing schemes are roughly pumping 100 cusec water daily. Water is also being pumped by industries at the rate of approximately 375 cusec **(Hussain & Sultan, 2013).** In this way total extraction of groundwater in Lahore becomes 1645 cusecs. Over

exploitation of groundwater causes many serious environmental concerns like salt water intrusion, increase in pumping cost, increase in installation cost of tubewells, land subsidence, land sliding, development of sinkholes etc.

Urban population in the Lahore is increasing at an alarming rate of 4% per year which is leading towards a continuous increase in domestic sewage. This sewage coupled with street runoff is a severe threat to groundwater as a part of it ultimately leaches down to groundwater. It was estimated that discharge of waste water of Lahore city into Ravi River was about 990 cusecs in year 2006 **(Saeed and Bahzad, 2006)** and now has crossed to 3,304 cusecs through drains and various pumping stations (Figure 4) without proper treatment **(Hussain & Sultan, 2013).**

A survey of drains entering into the River has been carried out which has revealed that six (06) main drains are entering into the River which are throwing about 3304 cfs of wastewater in the River.

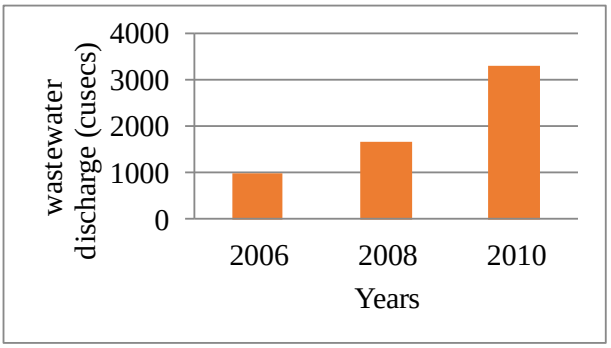


Figure 4: Effluents being thrown into the Ravi River

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).** 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)**. 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).** An important aspect of the research study is to develop a link between quality of surface water bodies (Ravi River & drains) and its impacts on groundwater quality in the underlying aquifer. Ravi River is being polluted due to indiscriminate discharge of untreated municipal waste water and industrial effluent into river. It was estimated that 3,304 cusecs of waste water of Lahore city is being discharged into Ravi River through drains and various pumping stations without proper treatment. Industries located at Kala Shah Kaku, Lahore Sheikhupura road, along Lahore band road, Quaid-e-Azam Industrial estate at Kot Lakhpat and Multan road in Lahore city discharge their effluents into drains which finally fall into Ravi River and the River is now acting almost as a “sullage carrier”.

2.2 Installation of Piezometers along Ravi River

The three approachable sites along Ravi River which are Ravi Syphon, Shahdra Bridge and Mohlanwal (near village Khudpur) were selected for installation of piezometers keeping in view the different factors including but not limited to distance from the River,

availability of bench mark, safety of the piezometers, site approach, willingness of farmers and protection of piezometers from rainfall and irrigation water etc.

Fifty piezometers along Ravi River on both sides in the shape of triangular battery of three piezometers in series (nine along left side and nine along right side of the River) at three selected locations were installed. In each battery, three piezometers were installed up to a depth of 150 ft, 100 ft and 50 ft respectively. Schematic layout of the piezometers installed along Ravi River is shown in figure 5. Three batteries of piezometers perpendicular to the River have been installed on one side of the River at three sites. First battery had been installed on the edge of river bank, 2nd battery at a distance of about 500 ft away from the river edge and 3rd battery at a distance of about 1000 to 1500 ft from the River edge. A complete network of piezometers has been installed to monitor the 4th dimensional trend of changes in groundwater levels and quality, which is along the river, away from the river, below the natural surface level (NSL), and changes with respect to time. Monitoring network along the River has been laid on permanent basis which is to be used for long-term observation of changes in groundwater levels and quality. **(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.

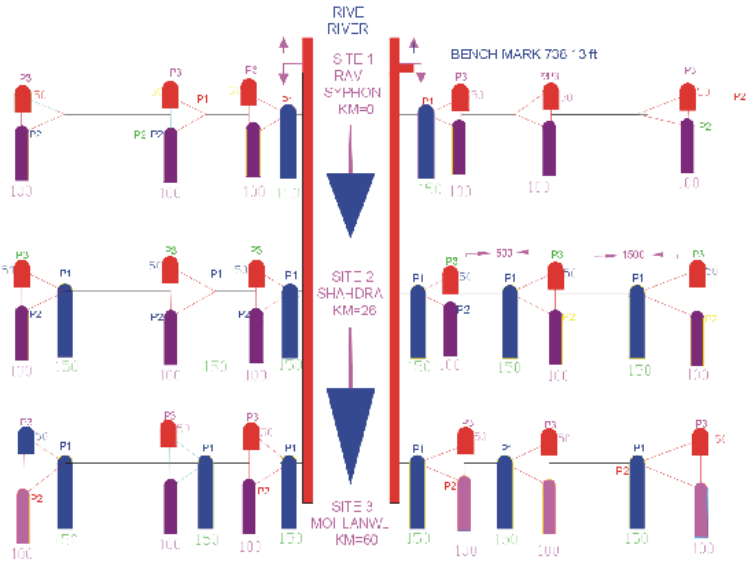


Figure 5: Schematic Diagram of Ravi River Showing Locations of Piezometers

2.3 Monitoring of Groundwater Levels and Quality

The fluctuations in groundwater levels and quality to develop the link between River flows and groundwater in the underlying aquifer was done by collecting water samples from the piezometers installed along the river, away from the river and at different depth. Groundwater quality has been analyzed in different directions like along the river, away from the river, vertically downward and with the passage of time to derive some conclusions. In addition to surface water (river and drains), groundwater samples from all 50 piezometers installed at different locations and depths along the river have been

taken through a specially designed sampler to correlate the quality of water in river with quality of groundwater. The impact of pollution in river water on the groundwater has been observed in four dimensions as mentioned already.

In this way, monitoring and evaluating the impact of pollution in Ravi River on groundwater in the underlying aquifer were observed. Samples of water from following different sources have been collected and analyzed to arrive at some conclusion.

(i) Groundwater at different depths/locations (from piezometers)
(ii) Surface water (River water)
(iii) Polluted water (drains entering the rivers)

3 SURFACE WATER QUALITY

A survey of drains entering into the River was carried out. Water samples from the river and drains (at point entering before the River) were collected from different locations to evaluate the changes in River water quality.

3.1 Waste Water Quality (Drains)

Geographical location of different drains entering into the Ravi River has been plotted in figure 6. Water samples from these drains were collected and analyzed. Effluents of these drains are deteriorating the quality of groundwater along the River. The water quality determined from the drain samples are shown in table 1. More value of EC (2440 µs) from Farrukhabad Drain has been observed during 2012 that is adding polluted load into the River.

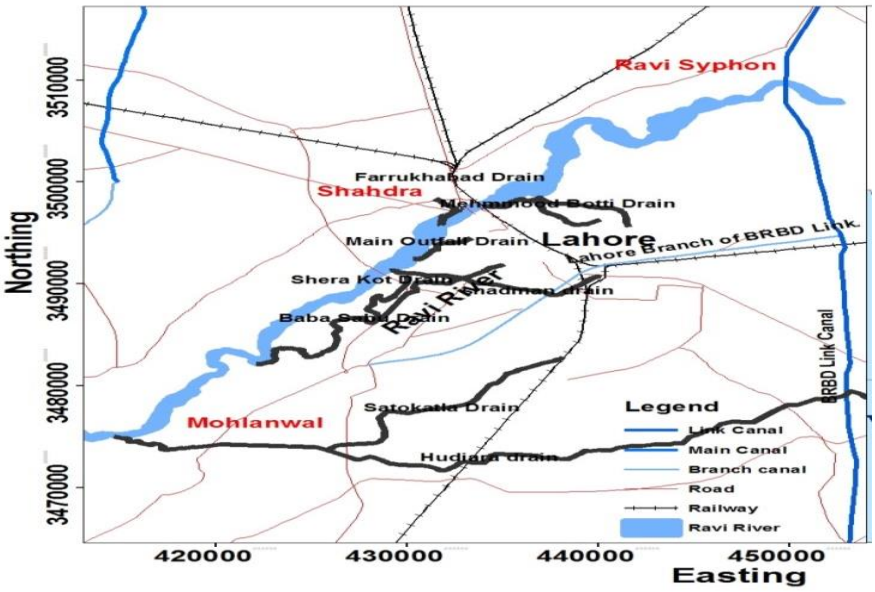


Figure 6: Layout of Drains entering the Ravi River

Ravi River has been polluted and is being polluted due to indiscriminate discharge of untreated municipal waste water and industrial effluent through drainage networks into it as shown in figure 7.



Figure 7: Entrance of drainage effluents in the Ravi River

Low flows in Ravi River have resulted in lowering in groundwater level in Lahore and its adjoining area. On one side recharge to the aquifer has decreased tremendously and on the other side the ecosystem in the river has suffered badly and river has become a "sludge carrier". **(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 and recommended to maintain minimum flow in the River for dilution of wastewater into the river.

Table 1: Result of Pollution Load entering the Ravi River

Sr. No.	Name of Drains	Discharge (Cusecs) EPD (2008)	TDS (mg/l) (2008) By EPD	TDS (ppm) (May, 2011) By IRI	TDS (ppm) (March,2012) By IRI	TDS (ppm) (March,2012) By IRI
1	Mehmood Botti Drain	20.87	312	775	1117	850
2	Farrukhabad Drain	219	1000	1088	1627	1145
3	Main outfall Drain	193	560	627	1154	1050
4	Gulshan-e-Ravi Drain	246.5	660	897	1035	925
5	Babu Sabu Drain	270.7	660	760	1135	800
6	Hudiara Drain	535.7	1020	1197	1506	1230

Source: (Hassan et al, 2013)

3.2 River Water Quality

Water quality of Ravi River at Ravi Syphon, Shahdra Bridge, upstream and downstream of drains was tested and results are indicated in table 2. The results show that values of TDS in River water at the locations just downstream of the entering points of drains are

greater than that of upstream value which indicates that drains are participating in the deterioration of the river. TDS value indicates the concentration of dissolved solids in the water. The value of TDS of river at upstream and downstream of Farrukhabad drain was higher as compared to others points. The results of analysis indicate that dissolved solids in Ravi River are increasing from upstream to downstream of Lahore city (downstream Ravi Syphon to Mohlanwal) due to indiscriminate discharge of waste water. Overall results of analysis indicate that water quality of river at Ravi Syphon is good but downstream of Shahdra, quality is deteriorating due to waste water pollution entering into the river by drains.

Table 2: Water quality of Ravi River at Different Sites

Sr. No.	Sampling Site of River	TDS (ppm)		
		EPD, (2008)	May, 2011	March, 2012
1	River water at Ravi Syphon	160	159	165
2	River water at Shahdra Bridge	200	229	371
3	River water U/S Farrukhabad Drain	400	490	503
4	River water D/S Farrukhabad Drain	180	597	614
5	River water U/S Babu Sabu Drain	330	358	397
6	River water U/S Entrance of Hudiara Drain	470	508	540
7	River water D/S Entrance of Hudiara Drain	500	546	580

Source: (Hassan et al, 2013)

3.3 Groundwater Quality (Piezometers)

Groundwater water samples from piezometers installed at three sites of Ravi Syphon, Shahdra and Mohlanwal at different depths were collected and tested. Electrical Conductivity (EC) of groundwater at all sites has been graphically plotted as shown figures 8-12.

The results analysis of groundwater from piezometers installed at Ravi Syphon site indicate that groundwater quality downstream Ravi Syphon on both sides of the River at all depths (50 ft, 100 ft and 150 ft) is good and is not deteriorated. This indicates that groundwater quality perpendicular to the river from Left side or right side (L_1, L_2, L3 or R_1, R_2, R_3) is good and can be used as bench mark for comparison of groundwater quality while moving downward. The data analysis at Shahdra site reveals that EC values at 50 ft depth are more while the value at 150 ft depth is lesser on both sides of the River. Groundwater quality at 50 ft depth at R_3P_3 and L_3P_3 is deteriorating. Overall results of analysis of groundwater samples along Ravi River indicate that the quality of water is deteriorating, moving downstream from Ravi Syphon to Lahore.

Water quality of shallow groundwater (50ft depth) along left side of the river at Location (L3) of Shahdra site for the years 2010 to 2016 were compared as indicated in figure 8. The data indicates that with the passage of time water quality of shallow groundwater becomes poor. It is clear from figure 8. EC values of 50ft depth for the year 2016 are more as compared to that of 2010.

Shallow water quality data along the river from D/S of Ravi Syphon towards Mohlanwal site were also compared for the year 2016. The figure 9 indicates that as we go down from Ravi Syphon towards Lahore, water quality is deteriorating. The figure depicts that shallow water at Shahdra site is more poor and deteriorated and then from Shahdra to Mohlanwal it is improving due to dilation effect. By comparing three sites Ravi Syphon, Shahdra and Mohlanwal, water quality is becoming deteriorated/ poor at Shahdra site along the river.

Similar trend occurs along right side of the River from D/S Ravi Syphon to Mohlanwal as shown in in figure 10.

Overall result of analysis indicates that groundwater quality is deteriorating more at Shahdra (as compared to that of Ravi Syphon and Mohlanwal) due to entrance of effluents through different drains into the river. The data at Shahdra site along both sides of the river indicates that quality of shallow water at depth of 50ft at R3 and L3 is deteriorating more with the passage of time.

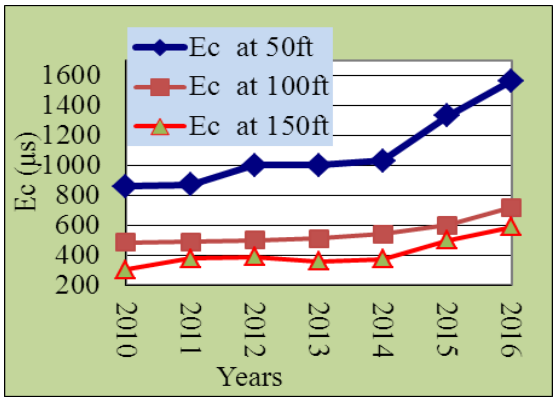


Figure 8: Ec (µs) at L3 Shahdra site w.r.t to Time

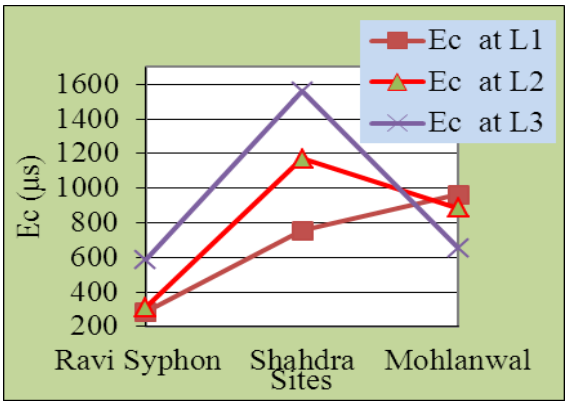


Figure 9: Ec (µs) along River from Ravi Syphon to Shahdra and to Mohlanwal at a Depth of 50 ft. for the year 2016

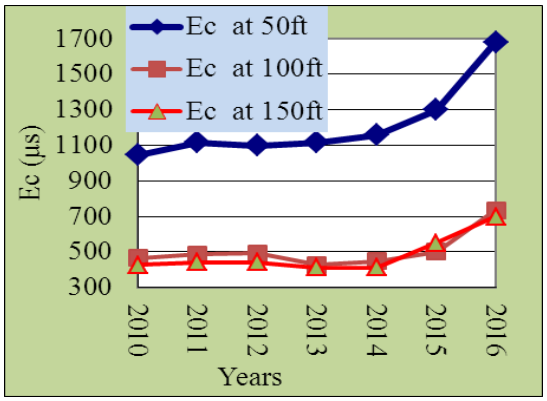


Figure 10: Ec (µs) at R3 shahdra site w.r.t to Time

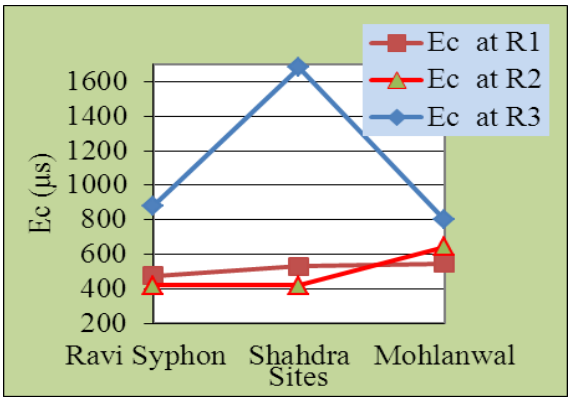


Figure 11: Ec (µs) along River from Ravi Syphon to Shahdra and to Mohlanwal at a Depth of 50 ft. for the year 2016

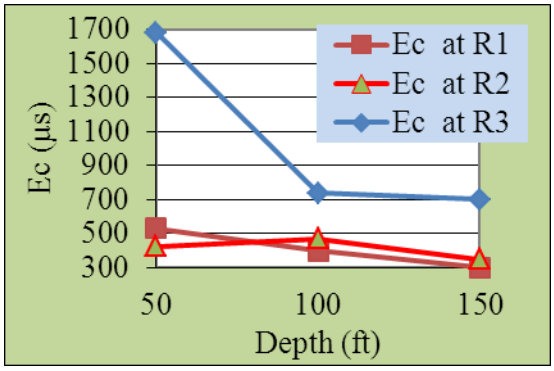


Figure 12: Ec (µs) at Shahdra site vertically downward for the year (2016)

4. CONCLUSIONS

1. Sewage of Lahore city is being discharge into Ravi River without treatment which has polluted the river water quality and consequently the groundwater.
2. Industries located at Kala Shah Kaku, Lahore Sheikhupura road, along Lahore band road, Quaid-e-Azam Industrial estate at Kot Lakhpat and Multan road in Lahore city discharge their effluents into drains which finally fall into Ravi River and the River is now acting almost as a "sullage carrier".
3. About 3,304 cusecs of wastewater from Lahore is being disposed through drainage network into the Ravi River**.**
4. Flow in Ravi River especially during the winter is remarkably insufficient to dilute and wash the wastewater pollution.
5. Groundwater quality at Ravi Syphon upstream of Lahore city is good but quality is deteriorated at downstream of Shahdra bridge due to discharge of wastewater into Ravi River by drains.
6. Pollution in River Ravi is contributing in deterioration of groundwater in the underlying aquifer.
7. Pollution in Ravi River has spatial and temporal impacts (horizontal and vertical directions with passage of time) on the groundwater quality.
8. Groundwater quality is deteriorating more at Shahdra (as compared to that at Ravi Syphon and Mohlanwal) due to entrance of effluents through different drains into the river.
9. Groundwater quality has deteriorated at Shahdra in shallow groundwater (upper aquifer) and it is better in deep aquifer.
10. Surface water bodies especially drain are playing a vital role in contamination of groundwater.
11. Waste water being thrown in the River has a direct impact on groundwater as shallow groundwater quality is the worst and improves as we move downward.

5. RECOMMENDATIONS/WAYFORWARD

- Discharge and quality of urban sewage and industrial effluent should be monitored regularly and may be classified on quantitatively and qualitatively basis.
- Sewage may be properly treated according to NEQS through biological or other treatment before throwing into river.
- The industrial effluents may be properly treated according to NEQS through engineering solutions before throwing into drains or river so that treated water can be reused for agriculture, horticulture or other suitable purposes.
- Industrial units and housing societies may be directed to install in-house wastewater treatment plants to implement the 3-R principle.
- Environmental flow in the Ravi River should be maintained at least for dilution and washing off the wastewater pollution load.
- Rainwater harvesting with in the city and at up stream of Ravi River may be carried out for aquifer recharge.
- Building bye-laws should be amended for rainwater harvesting mandatory, as a means of artificial recharge, in private as well as public buildings.
- Some relatively clean wastewater can be reused without treatment for meeting the agriculture requirement or simple treatment by chlorination.
- Reuse of industrial effluents imposes less pressure on groundwater pumpage.
- Quality of Surface and groundwater monitoring should be conducted on regular basis.
- To develop an integrated Water Resources Management Policy and Regulatory framework for groundwater Management.
- Awareness raising campaign regarding value of Ravi River, pollution in Ravi, and its impact on groundwater may be promoted among the stakeholders
- Training and capacity building and mutual coordination among the stakeholders in mandatory.

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