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IMPACT OF POLLUTION IN RAVI RIVER ON GROUNDWATER UNDERLYING THE LAHORE CITY

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By

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ABSTRACT

Lahore is the 2nd largest city of the Pakistan and huge pumpage of groundwater is being carried out to meet the domestic and industrial demands of water supply. With the increase in population and industry, extraction of groundwater is tremendously increasing and consequently groundwater reservoir is rapidly depleting and is creating a depression in the aquifer underlying the Lahore city. Ravi River, the major source of recharge, remains almost dry throughout the year except few monsoon months. This situation has seriously created a fear that in near future Lahore city can face water crisis and its citizen will suffer badly. Different drains are entering the River at various locations throwing millions of tons of effluents and the River is acting almost as a "sullage carrier" during low flow season. The polluted water of the River is leaching to the groundwater and subsequently moving towards the cone of depression in the aquifer created due to extensive pumpage of groundwater in the city area. To evaluate the impact of this pollution on underlying groundwater an experimental setup has been laid in the field especially along the River. Fifty piezometers in the shape of three batteries perpendicular to the River, one just on the edge, 2nd at a distance of 500 ft and 3rd at a distance of 1500 ft have been installed on both sides of the River at three sites viz Ravi Syphon, Shahdra bridge, and Mohlanwal. Each battery consists of three piezometers, each of 50ft, 100ft and 150ft depth below ground level. The four dimensional (along the river, across the river, vertically downward and w.r.t time) trend of groundwater levels and quality is being monitored and evaluated. Analysis of data observed so far indicates that groundwater quality is deteriorating with the passage of time especially at Shahdra Bridge (Lahore) site. Results have revealed that quality of groundwater is deteriorating, moving downstream from Ravi Syphon to Lahore and then again improves towards Molanwal. It has been further found that pollution in River Ravi is contributing in deterioration groundwater quality.

1. Introduction

Water is an essential commodity for existence of life on planet. An assured supply of water has, therefore, been the prime concern of all societies. In our own time the increasing stress on capacities of water systems has led to a growing realization that it is only through a scientific approach to their management that we can hope to sustain the quality and regular availability of this basic human requirement. The need for appropriate integrated studies in developing countries is the most important in view of an increasing population, widespread aridity and scarcity of fiscal resources and vagaries of hydro-meteorological conditions.

Groundwater, surface water and land comprise a complex interlocked system and they must be considered and managed in their totality towards making the most optimal use of this precious resource. Groundwater resources are now being increasingly tapped to meet societal

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needs on account of their possible availability in the vicinity of the consumer. However, it is important to recognize that although groundwater has ubiquitous occurrence and vast magnitude, its potential as a perennial source is subject to wide spatio-temporal variations. With the advent of remote sensing and sophisticated data processing techniques, the speed and scale of investigations of visible resources such as land and surface water have greatly improved. Since last many years, rapid increase in population and urban sprawling has resulted in over extraction of groundwater especially in the urban areas to meet with human demands due to which underground water table is depleting at alarming rates. Urban sprawl is to be the fastest growing threat to local environment and quality of life. As urban areas expand, environmental problem like losing green space, groundwater recharge area, degradation of natural ecosystem and deterioration of water resources are increased. The impact on groundwater quality from urban sprawl is attributed by the combined effect of population and land use change **(Xia ZG et al 2007)**. Groundwater is contaminated from various sources and one of major source of groundwater contamination is the surface impoundments used by municipalities and industries which discharge their wastewater to surface water bodies without proper treatment **(Jakhrani et al 2009)**. Substances which contaminate groundwater are dived into two basic categories, one which occur naturally and other substances that are produced or introduced by man's activities **(Mahmood 2006)**. The un-planned pumpage of groundwater is also causing salt-water intrusion into fresh groundwater due to which sweet groundwater resource is becoming scaree. This needs formulation of long term policy framework and comprehensive planning to guard against fast depleting ground water resources. According to the 1981 census, Lahore has population of 2.7 million which increased to 6.4 million in 1998 **(Faiza & Tabsum 2009).** Now the estimated population of Lahore is more than 10 million and it is ranked in the most populated urban areas in the World **(Wikipedia).** It has been reported that more than 480 WASA tube wells are extracting about 478.67 Million gallon of groundwater per day and is supplied through 7700 km pipelines distributed in the city **(Hussain and Sultan 2013).** This situation has resulted in tremendous depletion of groundwater levels. The only source to recharge Lahore aquifer is Ravi River, the smallest eastern river of the Indus River System (IRS) which remains nearly dry except during monsoon season. However, Ravi River along Lahore is used for the discharge of untreated domestic and industrial wastewater and effluent. There are over dozen disposal stations and surface water drains that discharge untreated wastewater into the River. It was observed that untreated wastewater is being discharged into the Ravi River **(EPD 2008, 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 the water 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).** As indicated in vision 2025 that in near future serious water scarcity situation may occur in Lahore city and it may suffer badly if necessary measures are not taken from today for the management of water resources and improvement of groundwater quality along Ravi River. A proper detailed investigation/research using groundwater flow and solute transport modeling approach in this regard is required to recommend the ways and means to replenish the groundwater reservoir to cater for the ever increasing stress on groundwater reservoir.

1.1 Need for Research

The water quality of Ravi River is being contaminated day by day due to entrance of domestic and industrial effluents due to which quality of groundwater in the underlying aquifer of the Lahore city is deteriorating. This situation demands to evaluate the pollution level/trends etc for some urgent and sustainable planning and management measures to save and replenish the aquifer for its long-term use without environmental hazards.

1.2 Objectives of the Study

To study and evaluate the impact of pollution in Ravi River on groundwater quality in the aquifer underlying the Lahore city.

2. Materials and Method

Different case studies, technical & research papers and various technical reports written by national and international agencies have been explored. Since the research was intended to estimate the impact of pollution in Ravi River on groundwater quality in the aquifer, therefore piezometers along Ravi River on its both banks have been installed to monitor the fluctuations in groundwater levels and quality which will help in estimating the relationship between water levels in the River to groundwater levels in the aquifer. Secondary data on discharge of Ravi River, population of Lahore, rainfall, groundwater abstraction, No of WASA tubewells, drains and their quality & discharge were collected from reports and websites of concerned departments.

2.1 Ravi River and Drains

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 between 1985 to 1995 was recorded as 5 MAF which was further decreased to 1.1 MAF in years 2000-2009 due to construction of hydropower projects/dams on Ravi River by India. Ravi River seems to be the main source of recharge in the North-West of Lahore. For the last two decades, Ravi River remained almost dry except in monsoon, so the recharging through River has seriously decreased.

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 has been polluted and is being polluted due to indiscriminate discharge of untreated municipal wastewater and industrial effluent into river. It was estimated that 3,304 cusecs of wastewater 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 effluent into drains which finally fall into Ravi River and the River is acting almost as a “sullage carrier”.

A survey of drains entering into the River has been carried out. Water samples from the river and drains (at point entering before the River) have been collected from different locations moving downward from Ravi Syphon to Mohlanwal, to evaluate the changes in River water quality.

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 1. 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.

Permanent bench marks were traced out, field surveying and leveling was carried out and RLs were shifted from bench marks to each piezometer to convert the depth to water table into groundwater elevations above mean sea level. River x-sections at three sites have been observed and are plotted in Figures 2, 3 and 4.

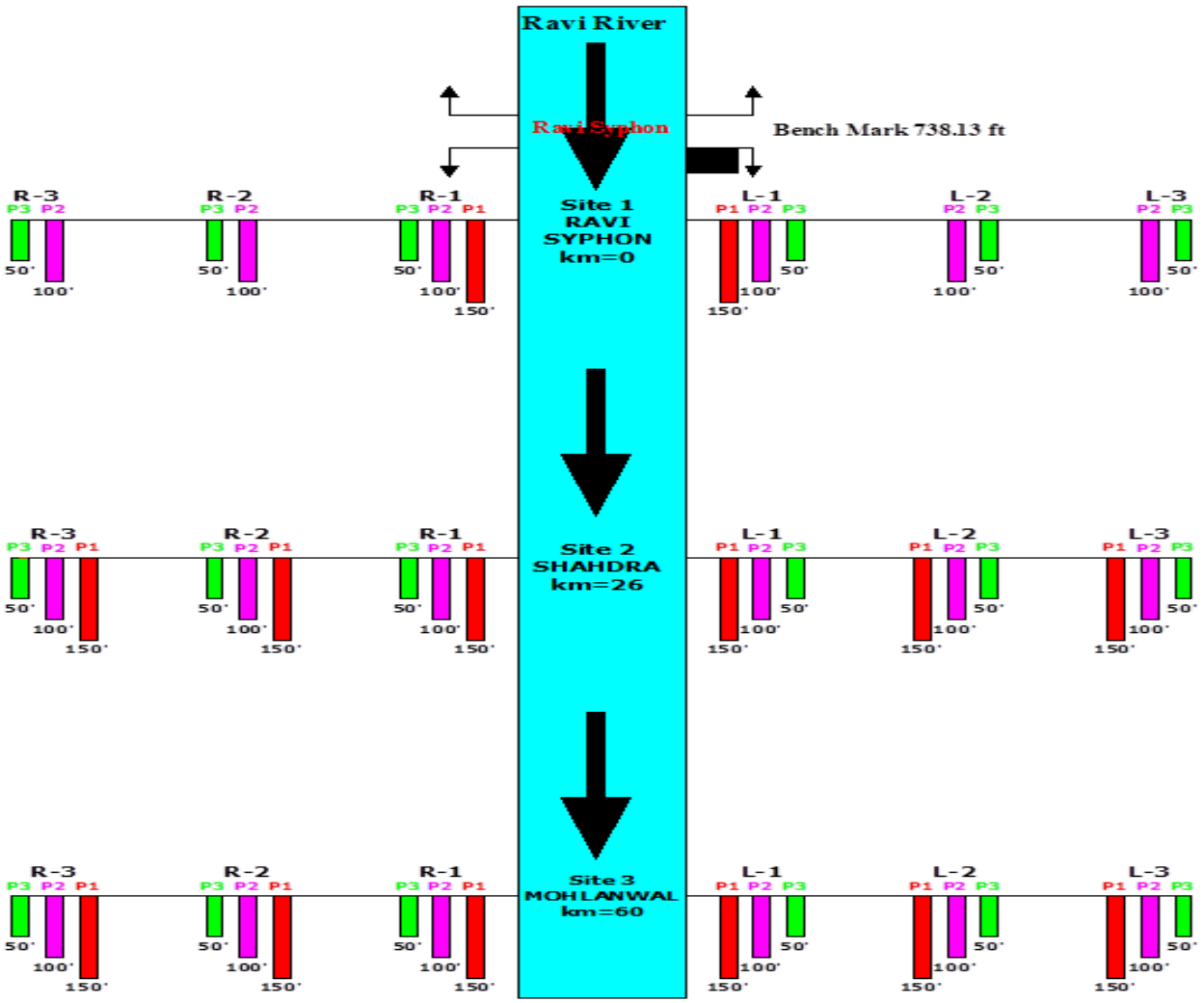


Figure-1: Schematic Diagram of Ravi River Showing Locations of Piezometers

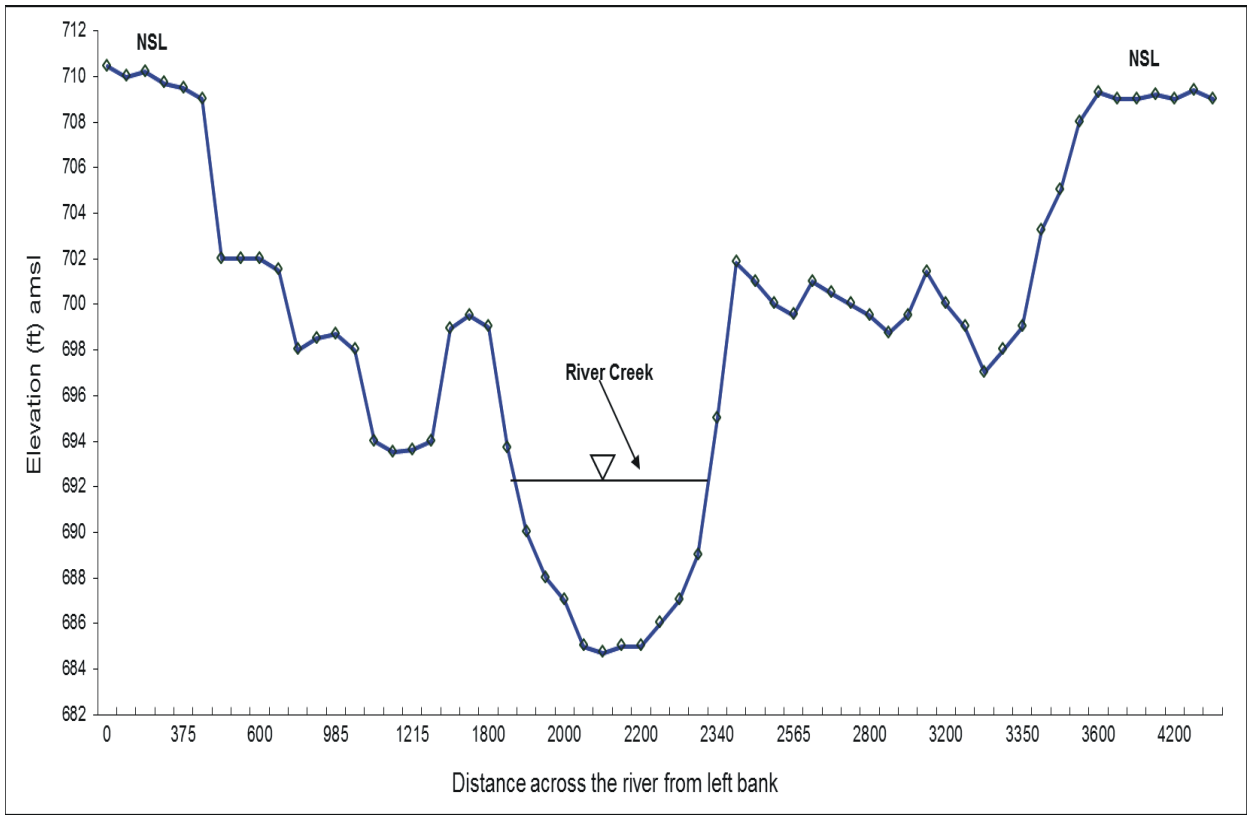


Figure-2: X-section of Ravi River downstream Ravi Syphon

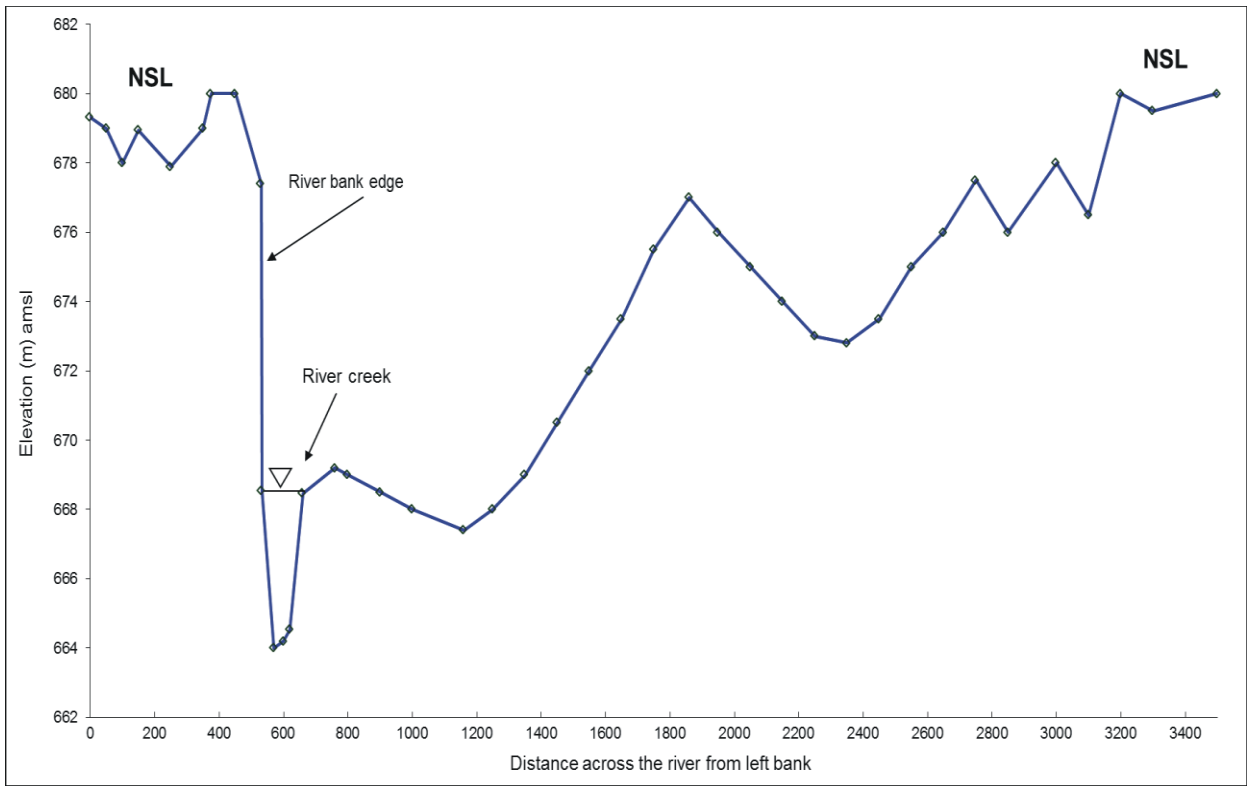


Figure-3: Cross-section of Ravi River near Mohlanwal

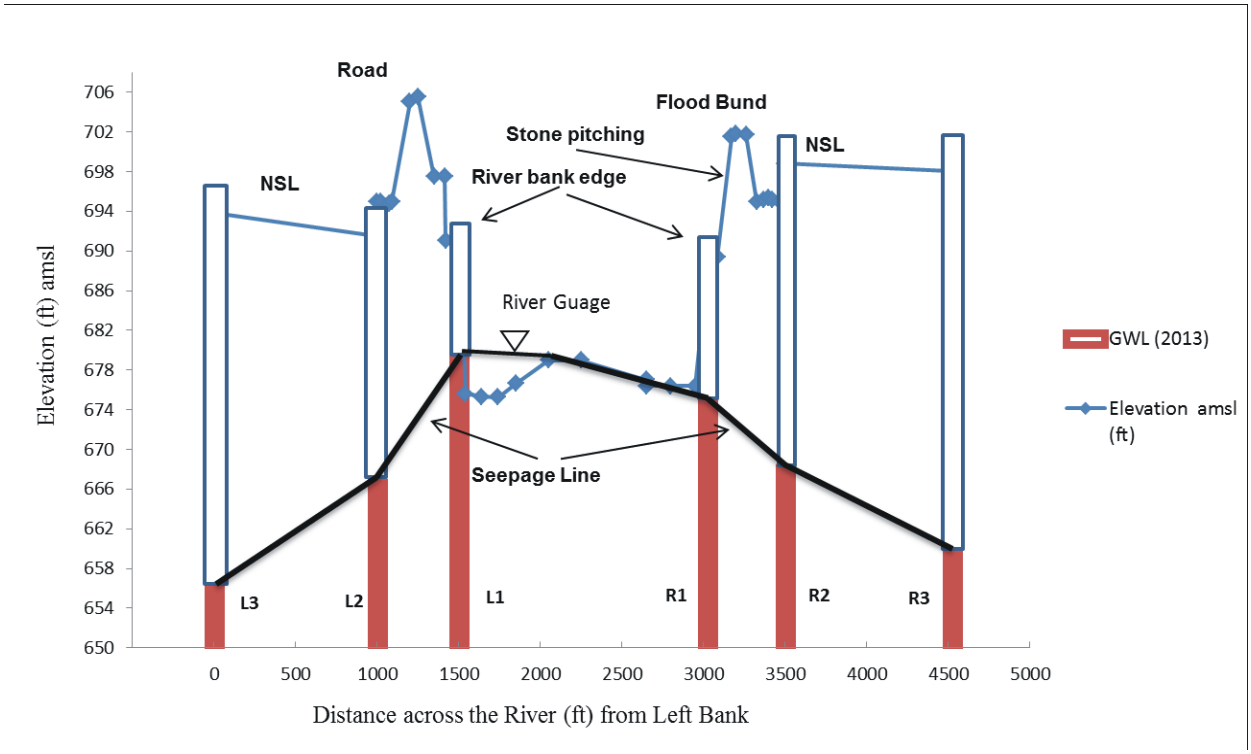


Figure-4: Relationship of Groundwater Levels with River Gauge near Shahdra Bridge

2.3 Sub-Surface Lithology

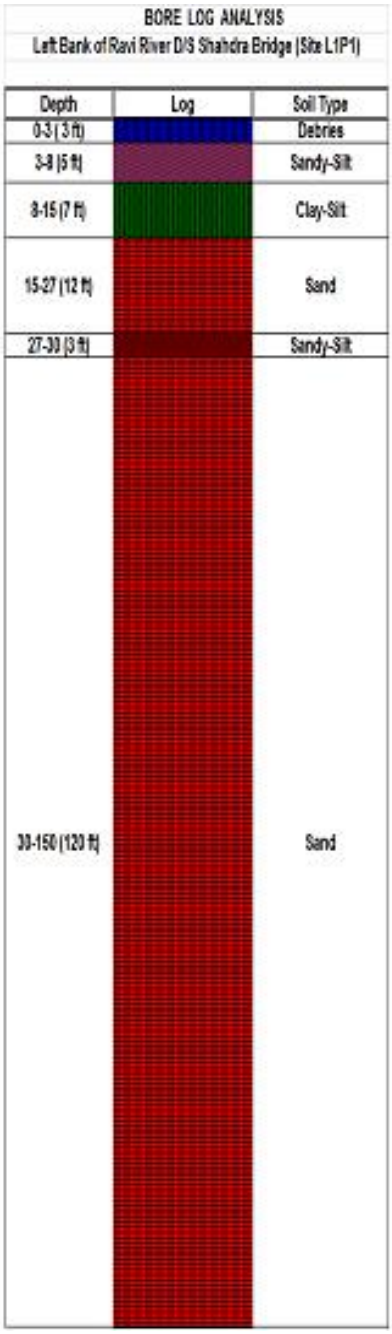
The type of strata through which water is to be recharged plays an important role as sandy formation will support the recharge process and vice versa. Analysis of soil samples was carried out to obtain the subsurface lithology and grain size distribution below the soil surface up to a depth of 150 ft.

About 216 Soil samples were collected from all the sites of 50 piezometers installed along Ravi River at different depths and locations and analyzed to determine the soil classification and permeability of sub-soil sandy strata. Aquifer permeability of sandy strata has been determined in the laboratory by constant head method. Bore-logs for 14 sites along Ravi River have been prepared after analysis of soil samples to depict subsurface lithology. Bore logs and gradation curves have been prepared which are shown in Figs 5 & 6.

BORE LOG ANALYSIS

Left Bank of Ravi River D/S Shahdra Bridge (Site L1P1)

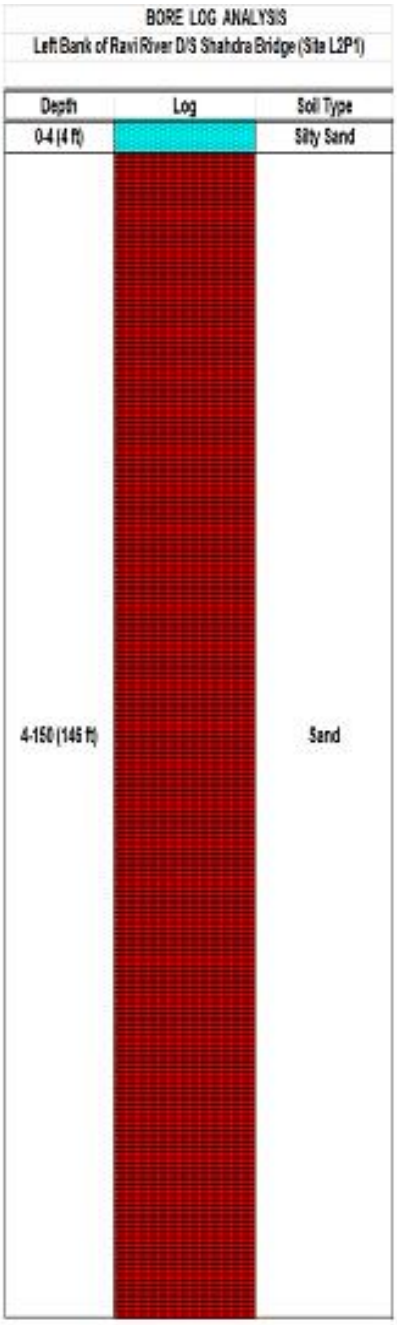
Depth	Log	Soil Type
0-3 (3 ft)		Debries
3-8 (5 ft)		Sandy-Silt
8-15 (7 ft)		Clay-Silt
15-27 (12 ft)		Sand
27-30 (3 ft)		Sandy-Silt
30-150 (120 ft)		Sand



BORE LOG ANALYSIS

Left Bank of Ravi River D/S Shahdra Bridge (Site L2P1)

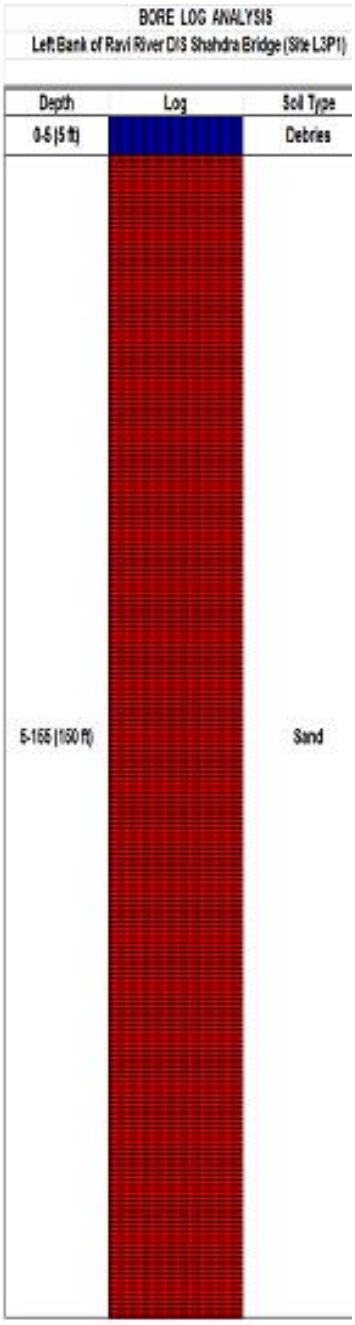
Depth	Log	Soil Type
0-4 (4 ft)		Silty Sand
4-150 (146 ft)		Sand



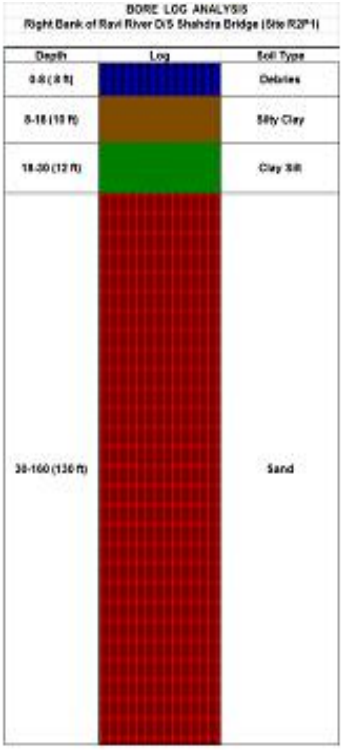
BORE LOG ANALYSIS

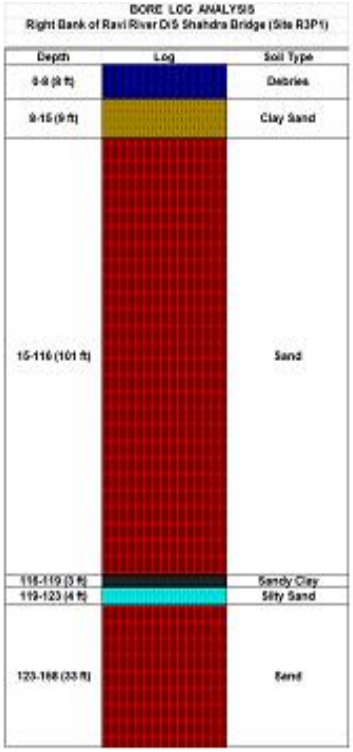
Left Bank of Ravi River D/S Shahdra Bridge (Site L3P1)

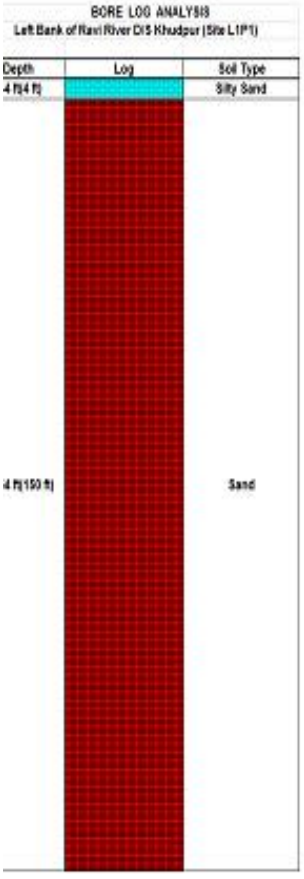
Depth	Log	Soil Type
0-5 (5 ft)		Debries
5-155 (150 ft)		Sand

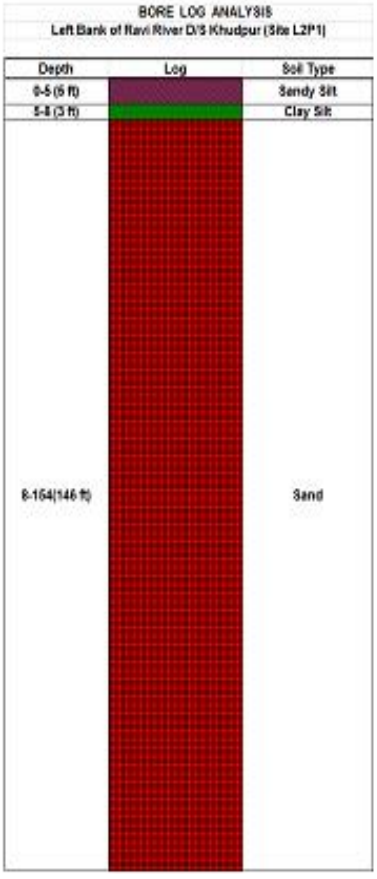


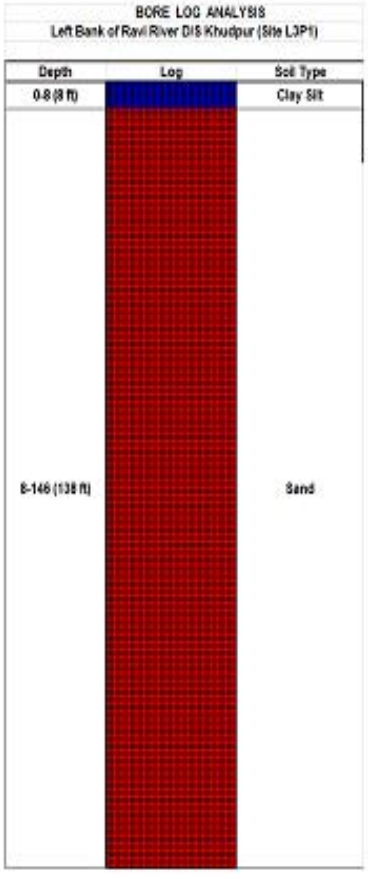

BORE LOG ANALYSIS
Depth
Log
Soil Type
Sandy Silt
Sand
Clay Silt
Sand
Silty Clay
Sand


BORE LOG ANALYSIS
Right Bank of Ravi River D/S Shahdra Bridge (Site R2P1)
Depth
Log
Soil Type
Debries
Silty Clay
Clay Silt
30-160 (130 ft)
Sand


BORE LOG ANALYSIS
Right Bank of Ravi River D/S Shahdra Bridge (Site R3P1)
Depth
Log
Soil Type
Debries
Clay Sand
15-116 (101 ft)
Sand
116-119 (3 ft)
Sandy Clay
119-123 (4 ft)
Silty Sand
123-168 (33 ft)
Sand


BORE LOG ANALYSIS
Left Bank of Ravi River D/S Khudpur (Site L1P1)
Depth
Log
Soil Type
Silty Sand
Sand


BORE LOG ANALYSIS
Left Bank of Ravi River D/S Khudpur (Site L2P1)
Depth
Log
Soil Type
0-5 (5 ft)
Sandy Silt
5-8 (3 ft)
Clay Silt
8-164(146 ft)
Sand


BORE LOG ANALYSIS
Left Bank of Ravi River D/S Khudpur (Site L3P1)
Depth
Log
Soil Type
0-8 (8 ft)
Clay Silt
8-146 (138 ft)
Sand

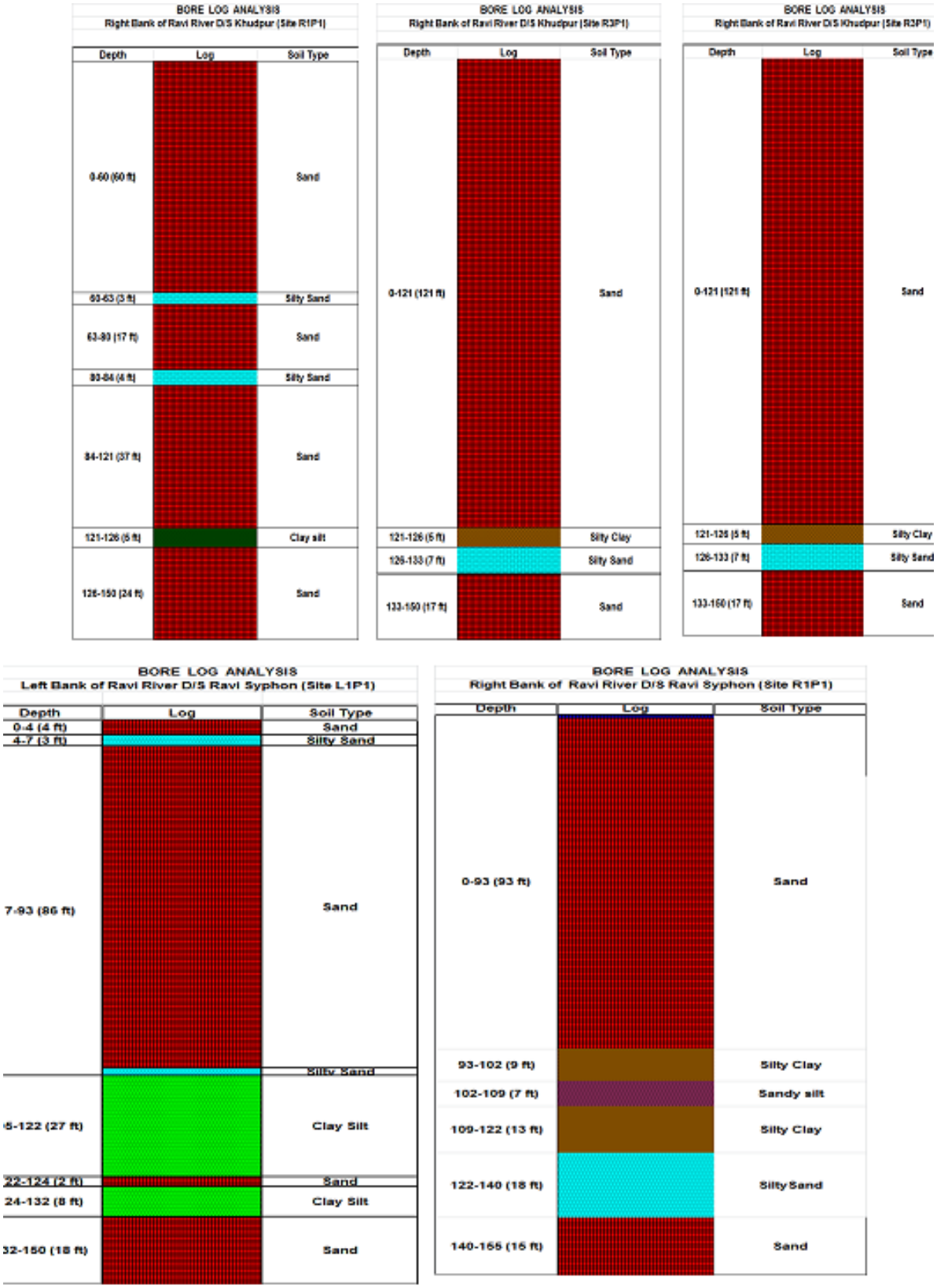
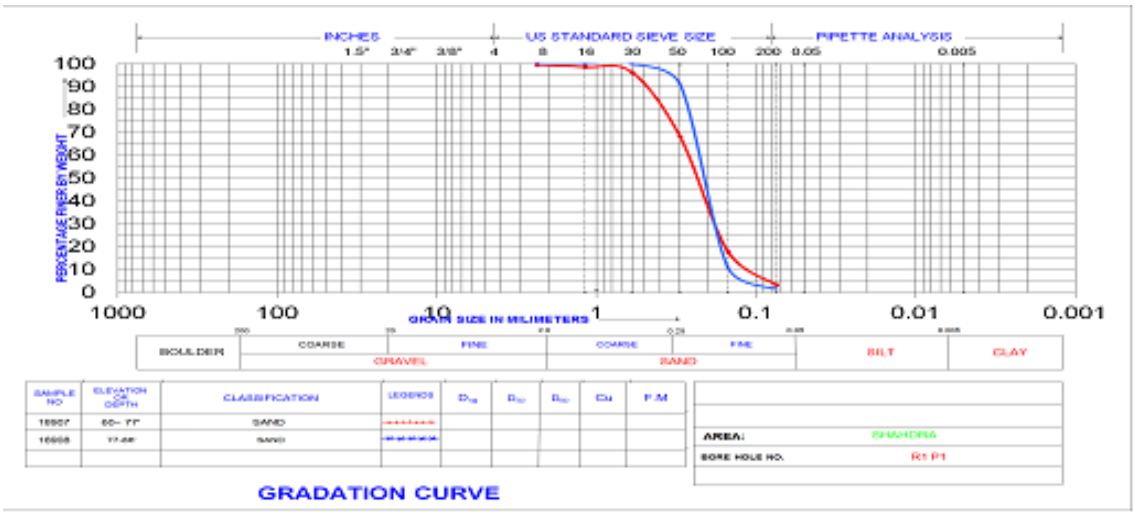
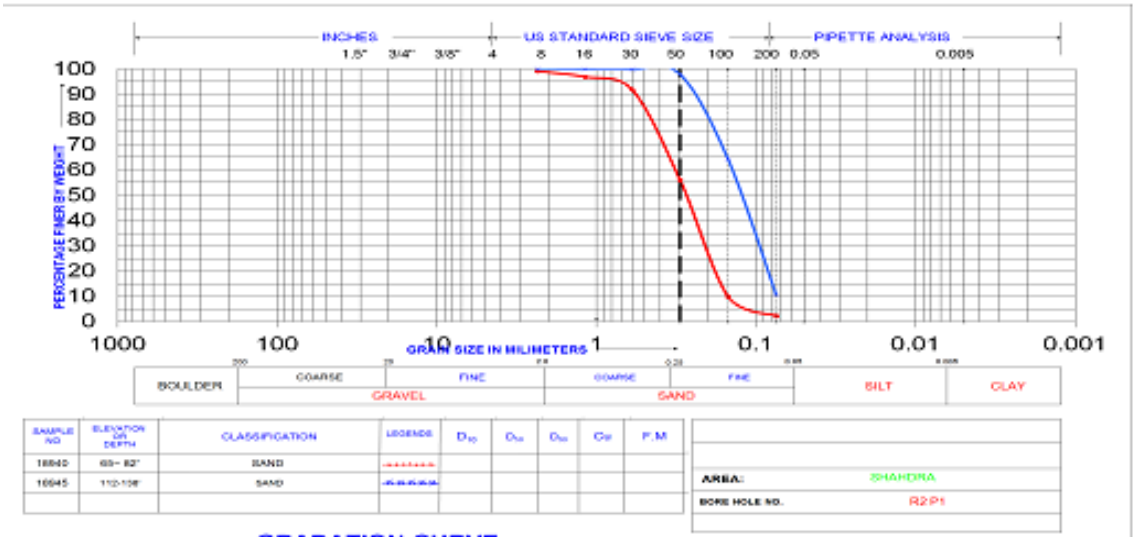


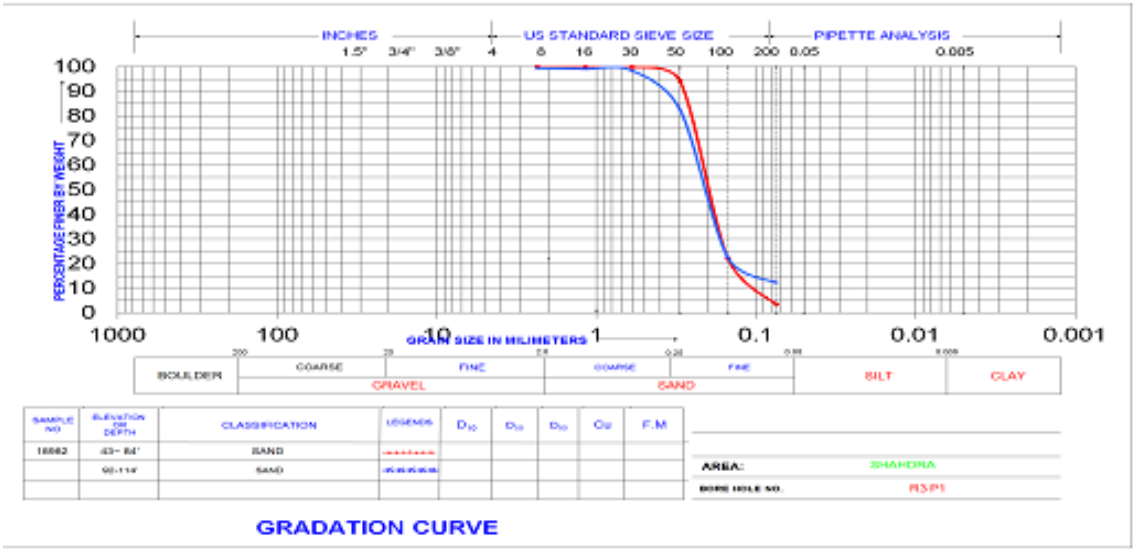
Figure-5: Exploratory Boreholes Boreloges along Ravi River



GRADATION CURVE



GRADATION CURVE



GRADATION CURVE

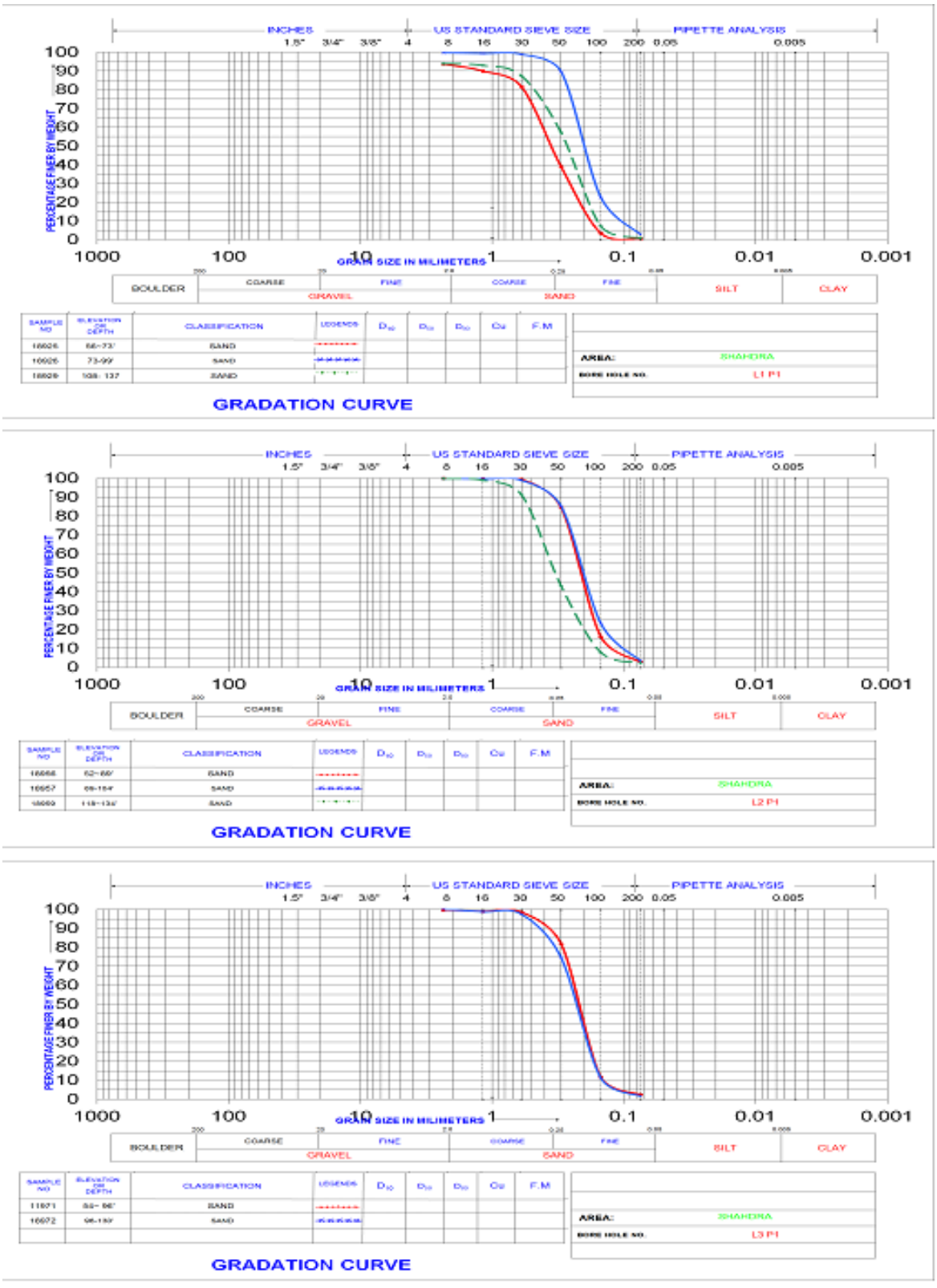


Figure 6: Gradation Curves of Soil samples at Shahdra

2.4 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 water samples from the piezometers installed along the river, away from the river and at different depth. Changes in groundwater levels and quality were monitored regularly with respect to time and locations. Calibrated water level sounder/indicator was used to observe the fluctuations in groundwater levels. 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. Geographical locations (x, y coordinates) of all the piezometers have been determined using GPS. 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.



Water Level Indicator/Sounder (Imported)



Conductivity & EC Meter (CON 11)



pH Meter (330 I)



GPS MAGELLAN TRITON 400

Figure-7

3. Results and Discussions

Major target of the study was to monitor and evaluate the impact of pollution in Ravi River on groundwater in the underlying aquifer. For this purpose a network of piezometers was installed along the River. 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)

About 56, 53 and 42 water samples from River, drains and piezometers during the years 2010, 2011, and 2012 have been collected and analyzed.

3.1 Surface Water Quality

3.1.1 Waste Water Quality (Drains)

Geographical location of different drains entering into the Ravi River has been plotted in Figure 8. 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 and also graphically represented by figure 9. More value of EC (2440 **µs)** from Farukh Abad Drain has been observed during 2012 that is adding polluted load into the River. The results represented in table 2 indicate that pollution load in drains are increasing with the passage of time and enhancing pollution in the river and groundwater.

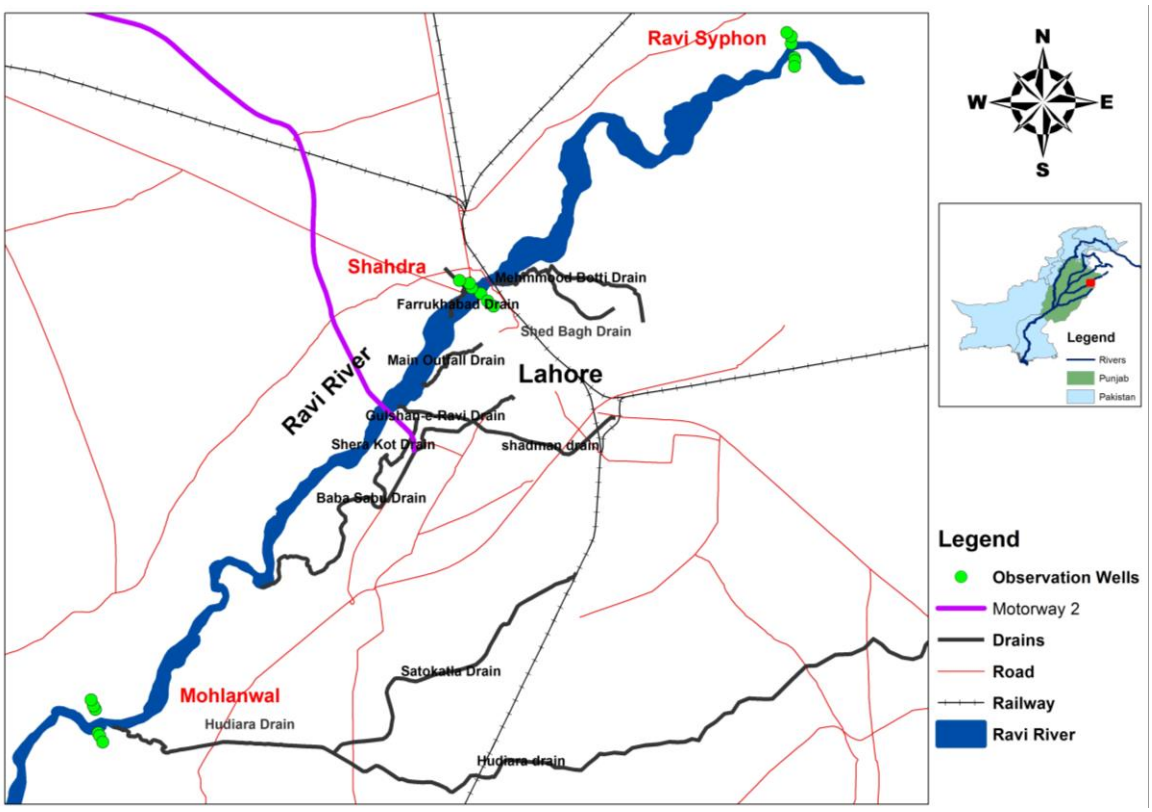


Figure-8: Layout of Drains entering the Ravi River

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
1	Mehmood Botti Drain	20.87	312	775	1117
2	Shad Bagh Drain	139	520	663	1067
3	Farrukh Abad Drain	219	1000	1088	1627
4	Bhuda Ravi Drain	41.99	690	1006	1100
5	Main outfall Drain	193	560	627	1154
6	Gulshan-e-Ravi Drain	246.5	660	897	1035
7	BabuSabu Drain	270.7	660	760	1135
8	Hudiara Drain	535.7	1020	1197	1506

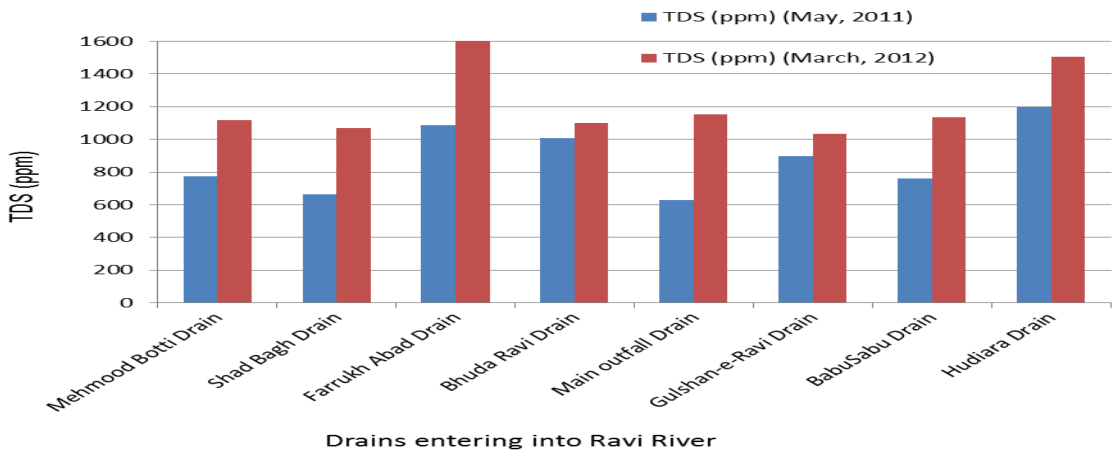


Figure-9: Wastewater Quality of Drains entering into Ravi River

3.1.2 River Water Quality

It was observed that river flow at Shahdra has decreased with the passage of time as depicted in figure10. Water quality of Ravi River at Ravi Syphon, upstream and downstream of drains was tested and results are indicated in table 3. 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 Farrukh Abad 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 wastewater. Similarly trends have been reported by **EPD 2008 and Ejaz & et al 2011.** Overall results of analysis indicate that water quality of river at Ravi Syphon is good but downstream of Shahdra quality is deteriorated due to wastewater pollution entering into the river by drains.

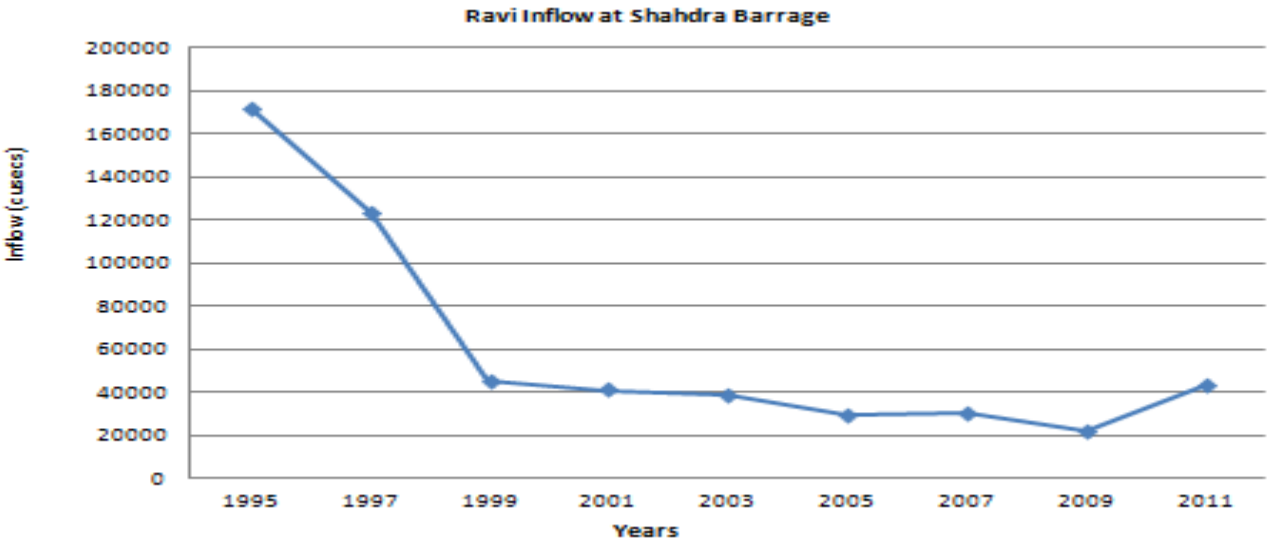


Figure-10: History of Water flow in Ravi Source: (Mehmood et al 2013)

Table-3: 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 Farrukh Abad Drain	400	490	503
4	River water D/S Farrukh Abad 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

3.2 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 11-16.

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. At Mohlanwal site, EC values of piezometer installed at 50 ft depth are more as compared to those at 100 ft and 150 ft depth on left side while lesser on right side of the river.

It is clear from data that groundwater quality at L_3P_3, R_1P_2 and R_3P_3 (Shahdara sites) is deteriorating. During 2011 and 2012 the value of EC at R_3P_3, L_3P_3 (50 ft depth) has increased rapidly. It indicates that quality of groundwater at 50 ft depth is deteriorating with the passage of time. 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.

EC values of groundwater on left side of the river at location (L3) of Shahdra site at various depth 50ft, 100ft and 150ft for the year 2012 plotted in figure 11 indicates that water quality of shallow groundwater (50ft) is deteriorating more as compared to 100 and 150ft.

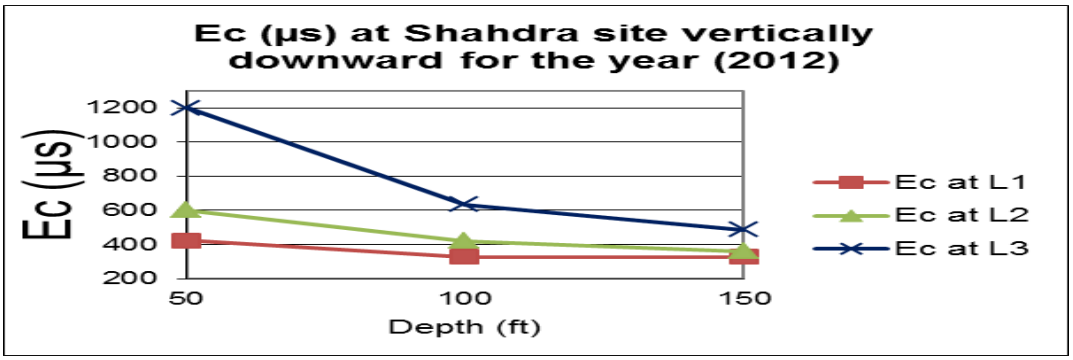


Figure-11

Water quality of shallow groundwater (50ft depth) along left side of the river at Location (L3) of Shahdra site for the years 2010, 2011 and 2012 were compared as indicated in figure 12. The data indicates that with the passage of time water quality of shallow groundwater becomes poor. It is clear from figure 12. EC values of 50ft depth for the year 2012 are more as compared to that of 2010.

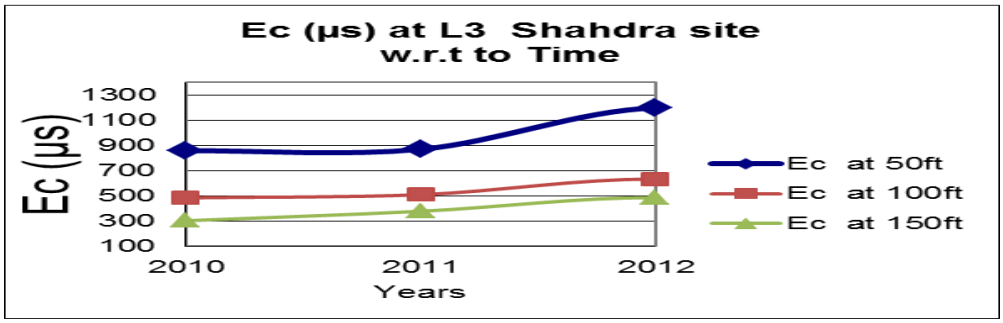


Figure-12

Shallow water quality data along the river from D/S of Ravi Syphon towards Mohlanwal site were also compared for the year 2011. The figure13 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.

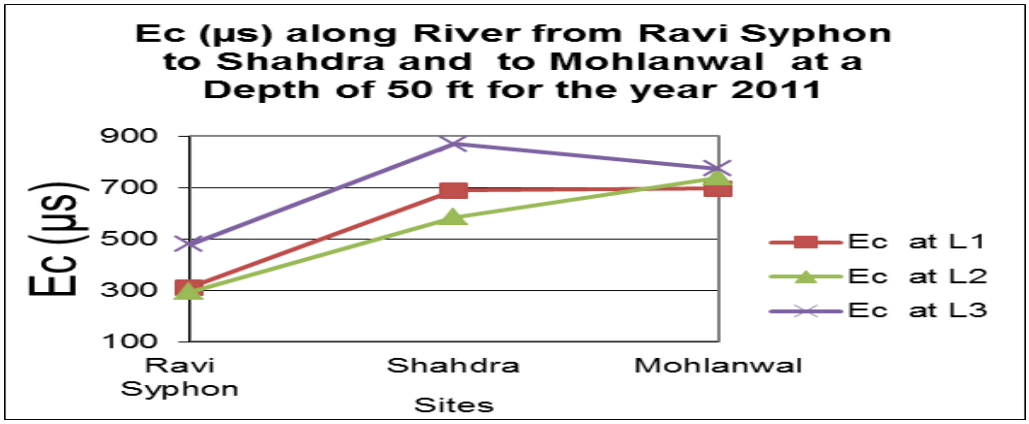


Figure-13

Similar trend occurs along right side of the River from D/S Ravi Syphon to Mohlanwal as shown in figures 14, 15 and 16.

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.

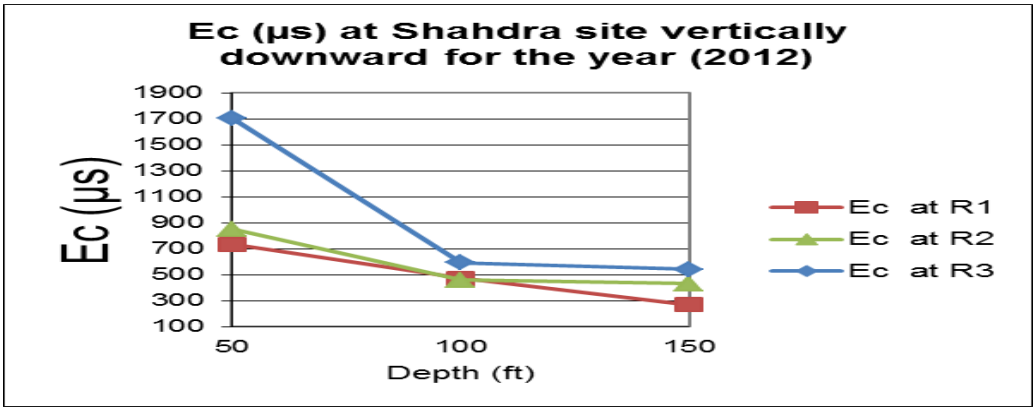


Figure-14

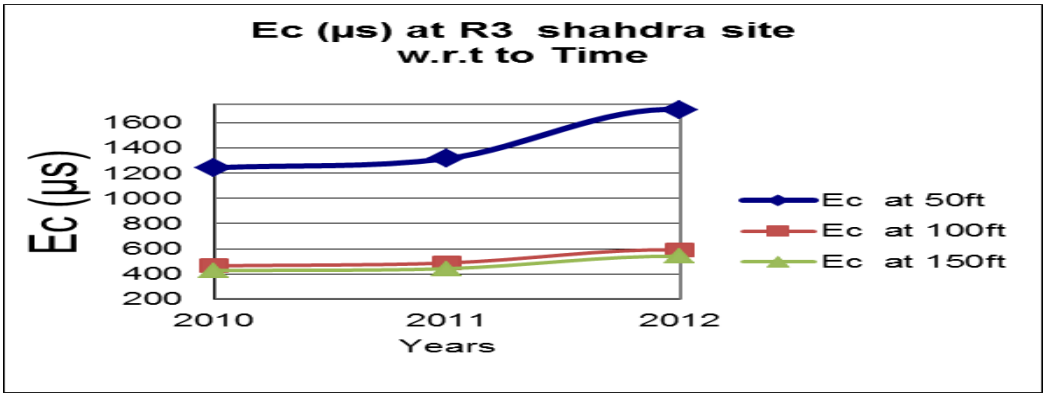


Figure-15

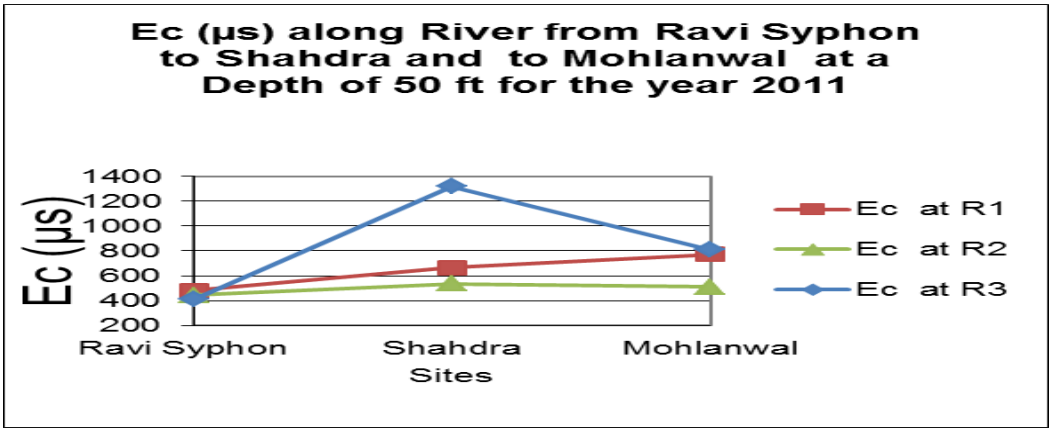


Figure-16

3.3 Groundwater Levels

Groundwater levels from 50 piezometers installed along Ravi River at three locations i.e. Ravi Syphon, Shahdra and Mohlanwal were observed. Water levels either from left or right side of river at Ravi Syphon, Shahdra and Mohlanwal are falling at most of the locations with the passage of time. The depth to water table observed in piezometers is more at Shahdra as compared to those at Ravi Syphon and Mohlanwal sites which indicate the excessive pumpage from Lahore aquifer. The groundwater level fluctuations at Shahdra sites have been represented graphically in figure 17, 18 and 19.

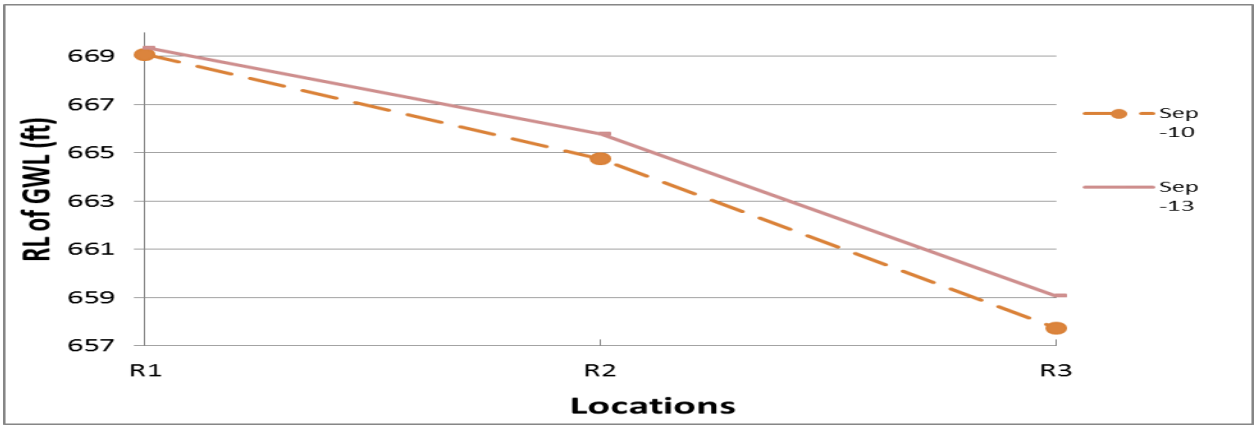


Figure-17: Groundwater Levels Fluctuations at Shahdra Site (Right Side)

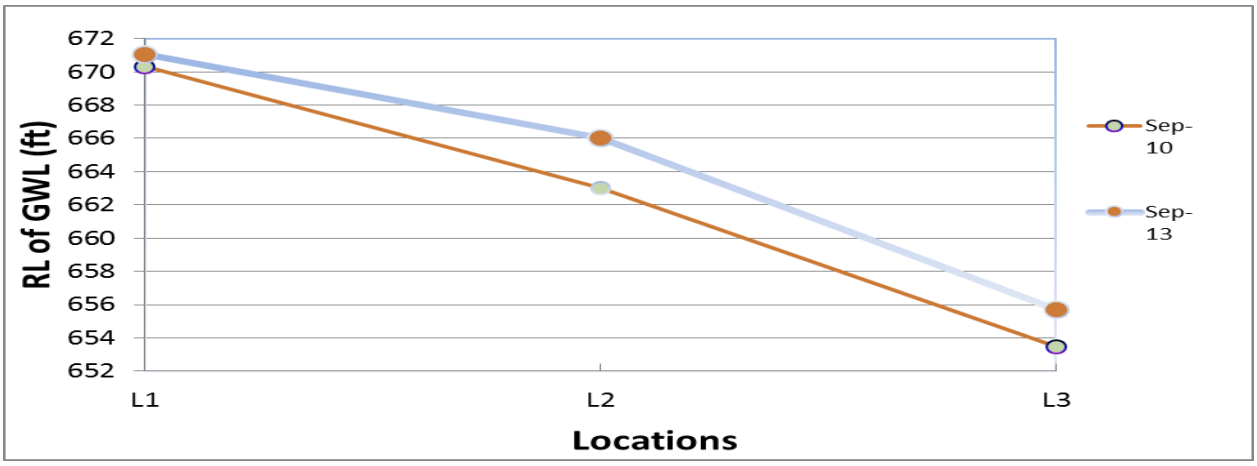


Figure-18: Groundwater Levels Fluctuations at Shahdra Site (Left Side)

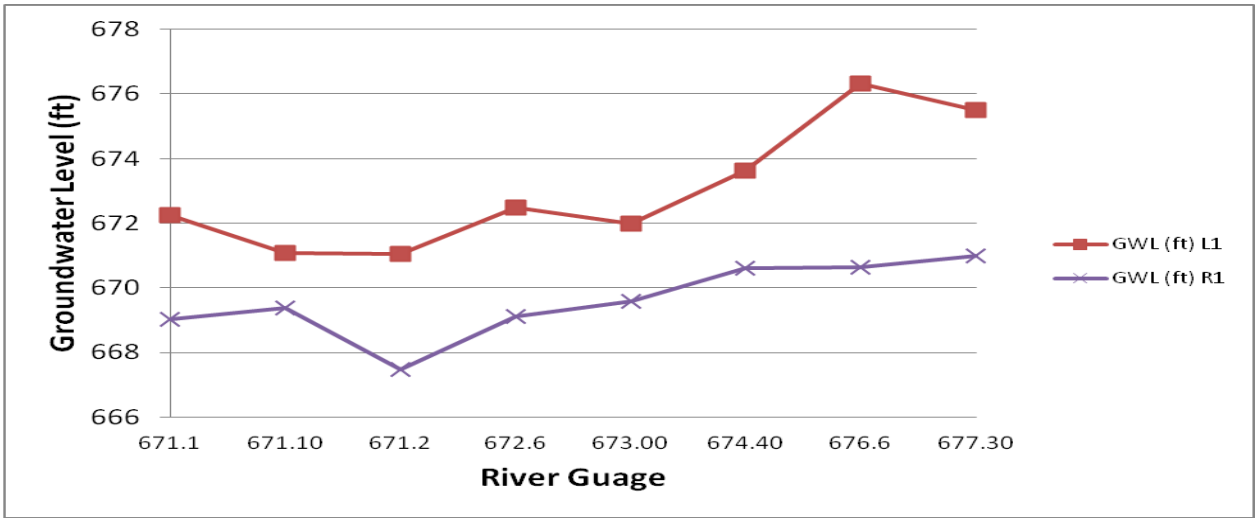


Figure-19: Fluctuation of Groundwater Level with River Gauge at Shahdra

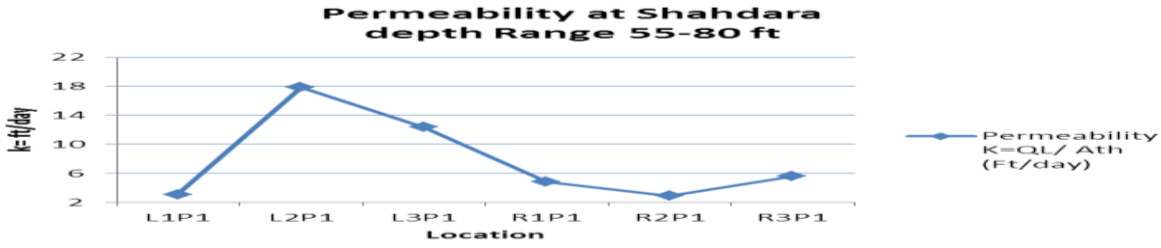
3.4 Permeability

Soil samples from three experimental sites i.e. Ravi Syphon, Shahdra and Mohlanwal along Ravi River were collected at variable depths for determination of hydraulic conductivity of the subsoil strata up to depth of 150 ft. Total 33 samples were collected from different locations (left and right sides) and different depths and were analyzed in lab by constant head method. The results show that values of permeability on left side of Ravi River downstream Ravi Syphon are in the range of 1.2 to 39ft/day while on right side are in the range of 6 to 28 ft/day and more value of permeability (39.064 ft/day) has been observed along left side (L_1) at a depth of 141-150 ft at downstream Ravi Syphon. The values of permeability at Shahdra are in the range of 3 to 30 ft/day on left side while 3 to – 19 ft/day from right side of the river and more value of permeability (29.57 ft/day) has been observed at left side(L_1) at a depth of 108 – 137 ft/day. The values of permeability at Mohlanwal are in the range of 0.8 to 10 ft/day at left side while 0.7 to 21 ft/day from right side of the river and more value of permeability of 20.718 ft/day at a depth of 100-109 ft has been observed at R_3 site. The results indicate that range of values of permeability are as shown in table 3:-

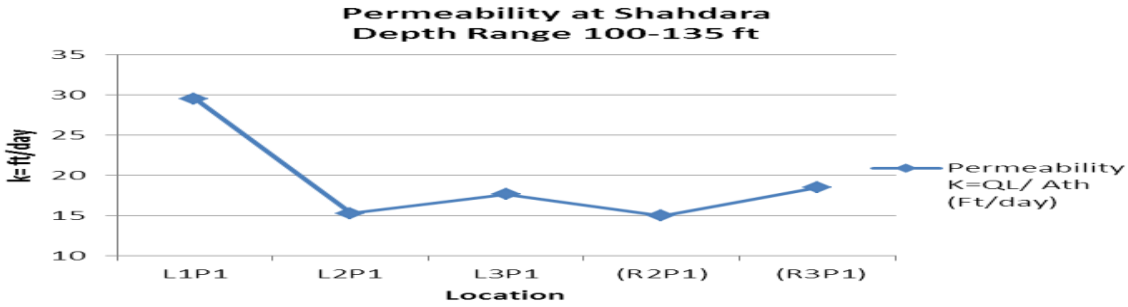
Table-3: Results of permeability

Sr. No	Location	Range of Permeability	Average value of Permeability (ft/day)
1	Ravi Syphon	1.2 – 39	20.1
2	Shahdra	3 – 30	16.5
3	Mohlanwal	0.7 – 21	10.85

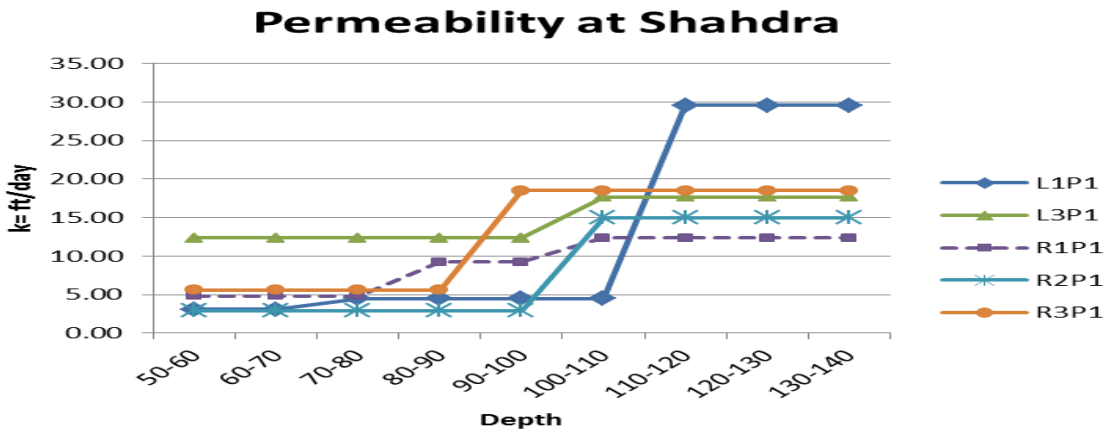
Overall results of analysis indicate that more value of permeability of 39.064 ft/day at a depth of 141-150 ft (L_1 side) of Ravi River downstream Ravi Syphon can be predicted out of three located sites (Ravi Syphon, Shahdra and Mohlanwal). The permeability at Shahdra sites is also graphically represented in figure 20, 21 and 22.



Figures-20: Permeability at Shahdra sites



Figures-21: Permeability at Shahdra sites



Figures-22: Permeability at Shahdra sites

4. Conclusions

On the basis of data collected and analyzed so far following conclusions have been drawn:

1. River inflow is decreasing with the passage of time due to which process of wastewater dilution is being affected and pollution load in the River is increasing.
2. Municipal and industrial effluent is being discharged indiscriminately without any treatment which is contributing pollution in the River.
3. Ravi River is contributing towards recharging the aquifer as groundwater levels fluctuate with the River Gauge.
4. Groundwater water levels in the aquifer are falling mainly due to excessive pumpage and less recharge.
5. Groundwater quality deteriorates moving downward from Ravi Syphon to Mohlanwal and is the worst near Shahdra.
6. Pollution entering the Ravi River is ultimately affecting adversely the quality of underlying groundwater.
7. Groundwater quality improves with the depth below natural surface.
8. Sub-soil strata at most of the sites is generally sandy except thin lens of clay/silt in the upper layer of 50 ft. However, near Ravi Syphon, thick silty/clay layers have been found below the depth of about 100 ft.
9. Permeability values increase generally with the depth below the ground surface and decreases as we move away from the River.
10. Quality of drain water entering the River is deteriorating with the passage of time and consequently similar trends have been observed in River water quality.
11. Slope of groundwater seepage line at Shahdra on left side of River is steeper as compared to right side due to excessive pumpage of groundwater.

5. Recommendations

It is an ongoing study and still further investigations are required to be carried out to derive useful conclusions.

1. Development and calibration of a groundwater numerical model (Flow and solute transport) to understand the dynamics of surface and groundwater linked together specially to quantify the impact of River water on groundwater.
2. On the basis of groundwater modeling to study the factors which are responsible for the worse groundwater quality and declines in level and to recommend the ways and means to replenish the groundwater reservoir to cater for the ever increasing stress on groundwater .
3. Rainfall harvesting through rainfall-runoff modeling to estimate the water volume and to explore/experiment different artificial recharge options.
4. Further detailed/close monitoring the groundwater levels and quality in the installed to quantify different parameters more precisely.
5. Treatment of industrial and municipal effluents before throwing into the River

6. To allow/arrange minimum flow in the River to meet the requirements of dilution of pollutants.
7. Construction of a lake/ponds at upstream of Lahore to recharge the aquifer. This can be accomplished after detailed investigation.

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Annexure A

Pictures of field activities



Confluence Point of Mehmood Booti & Shad Bagh Drains



Discharge of Wastewater in Ravi River



Entrance Point of Gulshan-e-Ravi Drain into Ravi River



Development of Piezometers



Piezometers installed at Left Bank of Ravi River at Shahdra Bridge



A view of installed piezometer along with inserting of PVC pipes into other borehole along left bank of Ravi River downstream Ravi Syphon



Measurement of Nature Surface Levels (NSL)



Measuring of Groundwater Level



Taking Groundwater sample from Piezometer



Testing of Groundwater Quality at site



Analysis of Soil Samples in Lab



Analysis of Soil Samples in Lab