Proceedings of the Pakistan Academy of Sciences:
B. Life and Environmental Sciences 53 (3): 163–178 (2016)

ISSN: 2518-4261 (print), ISSN 2518-427X (online)

Pakistan Academy of Sciences

Research Article

Environmental Issues and Concerns of Groundwater in Lahore

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Abstract: In Pakistan, about 80% population in large cities and do not have access to clean water. Demand for fresh water supply has increased many times to meet domestic and industrial requirements. Lahore is the second largest populated city of Pakistan with estimated population of 10 million, with an area of 1014 km^2. It is located on the alluvial plain of Indus Basin on an altitude ranging between 682 ft. to 698 ft. above mean sea level and is bounded by Ravi river in the North West and BRBD Canal on the east and average annual rainfall recorded is about to 675 mm. Groundwater is the only source of domestic and industrial use in the city. The un-planned excessive pumpage of groundwater as 1645 cusec has threatened aquifer depletion along with other socio-economic issues. After creation of Pakistan, the groundwater level in Lahore city was as 15-16 feet which has now reached its depth 100 feet. Under the circumstances, IRI starts a monitoring study, in this regard to get the first hand awareness of the situation and to suggest some remedial measure there at and 60 piezometers have been installed in Lahore city area and along Ravi river to monitor the time rate changes in groundwater levels and its quality. These Piezometers have been installed in batteries (3 in each) at the different depths to monitor the vertical profile and quality of groundwater. The authors have observe a great threats to groundwater in the Lahore aquifer identifying as over pumpage, industrial effluents, precipitation of air pollution, sewage and street runoff etc. Another factor of this research work is that the groundwater levels fluctuate with the river gauge which indicates that Ravi river is contributing towards aquifer recharge whereas groundwater levels in Lahore city is falling at the rate of 2.5 ft. per year. Moreover, the quality of groundwater assessment in the river reach from Ravi Syphon to Mohlanwal has been made and is found the worst near Shahdra (Lahore city).

Keywords: Groundwater, aquifer,piezometers, effluents, ravi river, artificial recharge, Lahore

1. INTRODUCTION

As it has been indicated in vision 2025 that a serious water scarcity situation may occur in Pakistan and the country may suffer badly if necessary measures are not taken from today for the management of water resources. Pakistan is the sixth largest populated country of the world with a population of more than 175 million and a population growth rate as 2.1 percent. Since last many years, rapid increase in population 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.

Groundwater is a vital and open access source and dependence on it has increased dramatically in the last six decades especially across South Asia. Together South Asia and China account for more than half of global groundwater use. Over the past three decades, South-Asia has emerged as the largest exploiter of groundwater in the world. Due to increasing shortage and inconsistencies in surface water supplies, groundwater acts as the mainstay for agriculture in India, Northern Sri Lanka, the Pakistani Punjab, Bangladesh, and the Northern China Plain. In India, groundwater provides 60 % of the total agricultural water use, accounting more

Received, January 2016; Accepted, August 2016
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than 50 % of the total irrigated area. In the North China plains, groundwater extraction accounts for 65, 70, 50 and 50 % for the total agricultural water supply for the provinces of Beijing, Hebei, Nanan and Shandog, respectively [1]. In Pakistan, groundwater contributes more than 50 % to the total crop water requirements in the Punjab province which produces 90 % of the national grain output [2]. However, the flip side of this large scale exploitation of groundwater is that the future of irrigated agriculture, which is increasingly blooming on groundwater, stands threatened due to its unsustainable use and consequent serious environmental outcomes.

Groundwater is the world's most extracted raw material with withdrawal rates in the estimated range of 982 km^3/year as per 2010 data. About 60% of groundwater withdrawn worldwide is used for agriculture; the rest is almost equally divided between the domestic and industrial sectors. In many nations, more than half of the groundwater withdrawn is for domestic water supplies and globally it provides 25% to 40% of the world's drinking water [3].

It has been estimated that about 60-70% population of Pakistan depends directly or indirectly on groundwater for its livelihood [4]. Pakistan is the 4th largest user of groundwater in the world after India, USA and China. In Pakistan irrigated agriculture contributes about 90% of food production and groundwater has become vital for irrigated agriculture in the country especially in Punjab province. Lahore, is the 2nd largest city of Pakistan and according to the 1981 census, Lahore had a population of 2.7 million which increased to 6.4 million in 1998 [5]. Now the estimated population of Lahore is more than 10 million having growth its rate as 4% per year. Issues of groundwater in the Lahore are multifarious and complex in nature. The groundwater level of Lahore after the creation of Pakistan was close to surface at the depth of 15-16 feet but as the city started expanding, it reached upto 70 feet in the period of thirty years (1959-1989) which show the decline of more than 50 ft. in water-table in Lahore city [6, 7].The un-planned pumpage of groundwater results salt-water intrusion into fresh groundwater due to which sweet groundwater resource is becoming scare in the aquifer underlying the Lahore city. The only source to recharge Lahore aquifer is Ravi river which remains nearly dry except during monsoon season. Currently, groundwater level has declined to more than 100 feet at many places. Natural recharging of groundwater aquifer is almost negligible due to construction activities and pavements of streets and roads. Untreated waste water from municipal and industrial units is being discharged into the Ravi river [8, 9]. Pollution in the Ravi river is contributing directly towards the deterioration of groundwater quality in the aquifer underlying the Lahore city [10].

In developing countries including Pakistan where environmental legislation either does not exist or is not implemented to the desired standards, the groundwater situation is alarming. The main objective of this study is to investigate the potential environmental threats to groundwater and suggest some mitigation measures for groundwater management in the urban localities like Lahore city area.

The study area consists of the Lahore City and its surroundings including a reach of Ravi river from Ravi Syphon to Mohlanwal as shown in Fig. 1. Lahore is the 2nd largest city of Pakistan and is considered to be the 24th largest city in the world. Climatic of Lahore is characterized by large seasonal variations in temperature and rainfall. Mean annual temperature is approximately 24 °C ranging from 36°C in June to 12 °C in January. The highest maximum temperature 48 ^{0}C (118 °F) was recorded on June 9, 2007 while the lowest temperature recorded in Lahore was -1 °C on 13 January 1967. The average annual rainfall recorded is close to 675mm, which can vary from 300 to 1200mm. Approximately seventy five percent of the annual total rainfall occurs in monsoon season in the months from June to September and contributes approximately 40mm to groundwater recharge in a normal year [11]. Lahore area is underlain by a significant thickness of alluvial deposits, up to 300 m in depth as investigated by WASID during the period 1961-62 [12]. The sedimentary complex has a thickness of more than 300 meters and is composed of unconsolidated alluvial sediments, consisting of sand, silt and clay in different proportions [13].

2. MATERIALS AND METHODS

Different experiments/Observations have been carried out in the study area to collect the required data to assess the existing scenario of groundwater as discussed below:

2.1 Installation of Piezometers

For having proper awareness of groundwater resources, it is imperative to use a mechanism of piezometers. For this purpose nineteen piezometers have been installed at different location scattered in the study area as depicted in Fig. 1. Geographical locations of all the piezometers have been determined by using Global Positioning System (GPS). To monitor the spatial and temporal impact of the pollution in groundwater through Ravi river, an experimental setup consisting of 50 piezometers has been laid along the river as shown in the Fig. 2. These piezometers have been installed on three sites along the River, viz: Ravi Syphon, Shahdra Bridge and Mohlanwal in the shape of triangular battery consisting of three piezometers at a depth of 150 ft., 100 ft. and 50 ft. on both sides of the river. First battery on the edge of river, second at a distance of 500 ft. and 1500 ft. distance from the river.

2.2 Aquifer Behavior (Water Levels)

Groundwater levels have been measured by piezometers installed in the city area and along the river biannually (pre-monsoon and post-monsoon) since 2009. The data so observed have also been analyzed to visualize the aquifer conditions in the study area.

It has been observed that as population of the Lahore city is expanding and accordingly groundwater abstraction is increasing to meet with the domestic needs of consumers with 100% reliance on groundwater. Groundwater levels from 50 piezometers installed at different locations as mentioned above were observed and found that groundwater levels are falling at most of the locations. The fall of groundwater levels at Shahdra is found greater than as compared to those at Ravi Syphon and Mohlanwal sites which indicate the excessive pumpage in the vicinity of Lahore. The groundwater level fluctuations at Shahdra have been represented graphically in Fig. 3 and Fig. 4. Due to higher rate of pumpage than that of recharge of aquifer, depth to water table is continuously increasing which results expanding of depression zone area. The natural surface level (NSL) and groundwater levels for year 2009 to 2013 (ft.amsl) have been plotted as Fig. 5 to 12. This indicates demographic pressure on aquifer near Lahore city. It has been observed that the depression zone with water level below as 38 m is also expanding continuously @ 24 km^2 per year. Depression zone has increased from 52 km^2 in 2007 to 150 km^2 in 2012 [4].

Piezometers were also installed along Ravi river at three locations, i.e., Ravi Syphon, Shahdra. 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 [10] which indicate the excessive pumpage in the city.

2.3 Groundwater Quality

Groundwater quality at downstream from Ravi Syphon to Lahore city has deteriorated. It is observed that the color of groundwater near Lahore city has been varied from colorless to yellowish and its odoris now to objectionable with turbidity ranging from 2 to 4 NTU. Heavy metals have also been found in the groundwater samples and the concentration of lead (Pb), Nickel (Ni) and number of E. coli levels exceeded the permissible limits of drinking water quality [14]. Municipal landfills are considered another sources which have a serious threat to urban environments and a great source of pollution especially groundwater [15]. 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. 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. 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 Fig. 13 to Fig 18.

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 deteriorating. This indicates that groundwater quality perpendicular to the river from Left side or right side (L_1, L_2, L_3 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 (Shahdra 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 (L_3) of Shahdra site at various depth 50 ft, 100 ft and 150 ft for the year 2012 plotted in Fig. 13 indicates that water quality of shallow groundwater (50 ft. depth) is deteriorating more as compared to 100 and 150 ft depths.

Water quality of shallow groundwater (50ft depth) along left side of the river at Location (L_3) of Shahdra site for the years 2010, 2011 and 2012 were compared as indicated in Fig. 14. The data indicates that with the passage of time water quality of shallow groundwater becomes poor. It is clear from Fig. 14 that values of EC at 50 ft depth for the year 2012 are more as compared to those of 2010. Shallow water quality data along the river from D/S of Ravi Syphon towards Mohlanwal site were also compared for the year 2011. The Fig. 15 indicates that as we go down from Ravi Syphon towards Lahore, water quality is deteriorating. The Fig. depicts that quality of shallow groundwater at Shahdra site is more poor and deteriorated and then from Shahdra to Mohlanwal it is improving due to dilution 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 Fig. 16, Fig 17 and Fig 18.

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 50 ft at R_3 and L_3 is deteriorating more with the passage of time.

3. POTENTIAL THREATS TO LAHORE AQUIFER

Being a thickly populated, hub of industrial activities and provincial capital Lahore has become a city of complex issues related to groundwater pollution. A wide range of pollutants generated by natural and human activated are contributing towards the degradation of groundwater in the area.

3.1 Population Growth

Population growth has a direct impact on depletion of groundwater resources. Abstraction of groundwater increases as population grows and over-exploitation of aquifer results in decline of groundwater levels. Temporal trends of depth to water table and population growth in Lahore are depicted in Fig. 19 and major consumer of groundwater in Lahore is WASA (Fig. 20).

3.2 Over Pumpage

Groundwater is the only source of water supply for

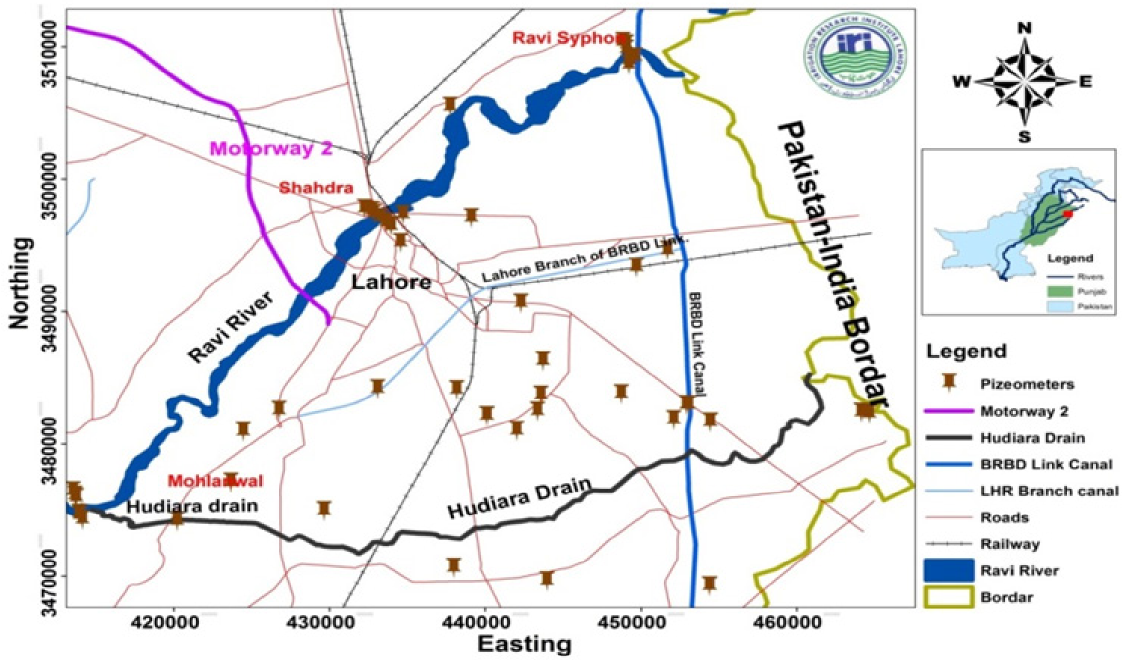

Fig. 1. Map of study area showing the Piezometers installed in the Lahore city.

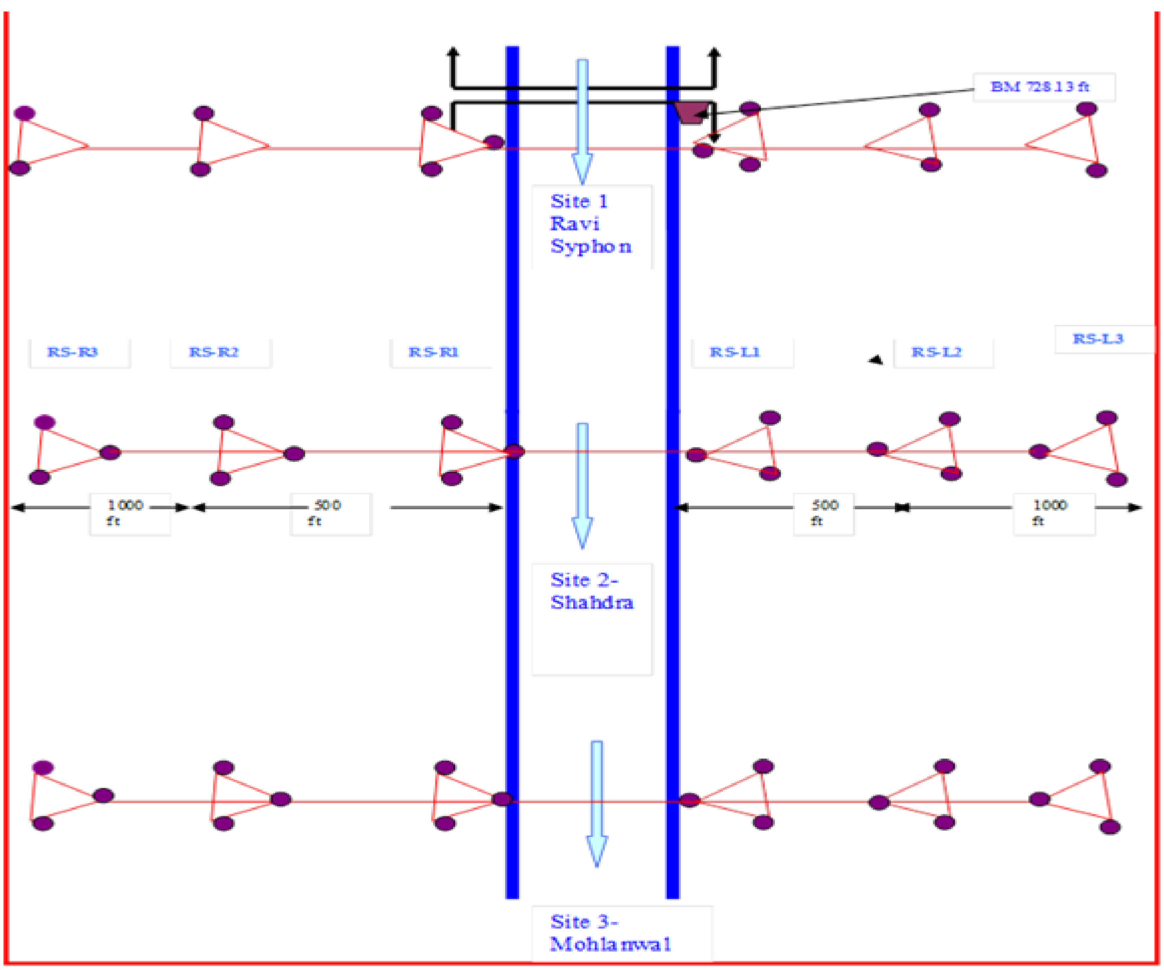

Fig. 2. Schematic diagram of Ravi river showing locations of Piezometers [21].

Table 1. Discharge and quality of wastewater in the major drains in Lahore city.

Sr. No.	Name of Drains	Discharge (Cusecs)	TDS (ppm) (May 2011)	TDS (ppm) (March 2012)
1	Mehmood Botti Drain	20.87	775	1117
2	Shad Bagh Drain	139	663	1067
3	Farrukhabad Drain	219	1088	1627
4	Bhuda Ravi Drain	41.99	1006	1100
5	Main Outfall Drain	193	627	1154
6	Gulshan-e-Ravi Drain	246.5	897	1035
7	Babu Sabu Drain	270.7	760	1135
8	Hudiara Drain	535.7	1197	1506

Table 2. List of potential sites for artificial recharge of aquifer in Lahore by rainfall harvesting.

Sr. No.	Name of site/location
1	Jallo Park, Lahore.
2	Along BRBD Canal Right Bank, near Barki Village, Lahore
3	Padhana Village, Barki Road, Lahore (Western Side of Lake).
4	Lahore International Airport Lahore, Post No. 4, Civil Aviation Authority, Southern end of Runway
5	Walton Airport, Ferozepur Road, Lahore.
6	Northern Plot of Badshahi Mosque, Lahore
7	Field Research Station, Niazbeg, Multan Road, Lahore.

Lahore city. WASA, Lahore has installed 480 tube wells of different capacities at a depth of ranging from 150 m 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 tube wells, a large number of private tube wells 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 [16]. 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 tube wells, land subsidence, land sliding, development of sinkholes, etc.

3.3 Urbanization and Commercialization

Urban sprawl is the fastest growing threat to local environment and quality of life. Lahore city is adversely affected by uncontrolled and unplanned increasing urban industrialization and commercialization. As urban areas expand, environmental problems like losing green space, decreasing 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. Urbanization trend in Lahore is depicted in Fig. 21.

3.4 Low Flow in 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 flowing 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 due to construction of hydropower projects/ dams on Ravi river by India. It results in lowering in groundwater level in Lahore and its adjoining

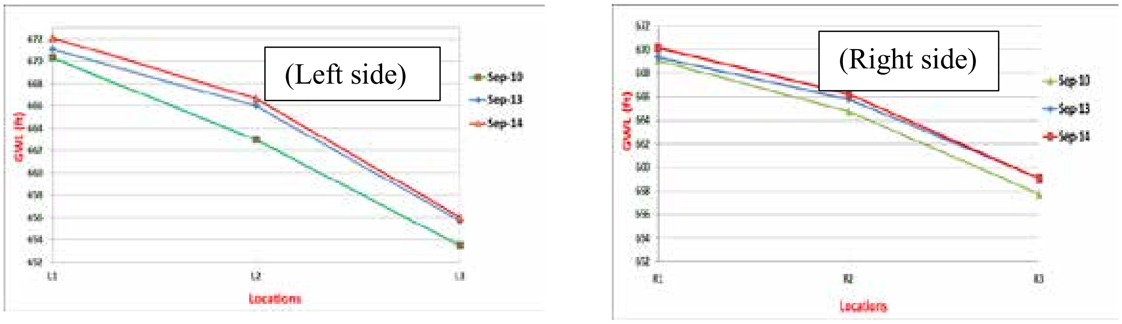

Fig. 3. Groundwater levels fluctuations at Shahdra site.

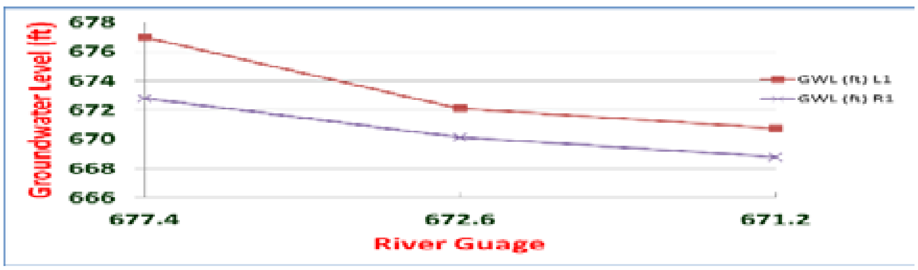

Fig. 4. Fluctuation of groundwater level with River gauge at Shahdra.

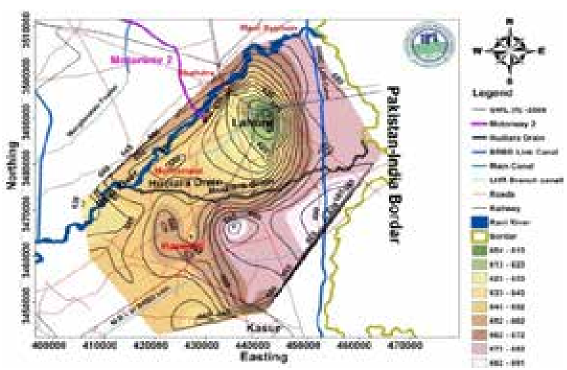

Fig. 5. Groundwater levels in the Lahore city for year (2009).

Fig. 6. Groundwater levels and depression in Lahore (2010).

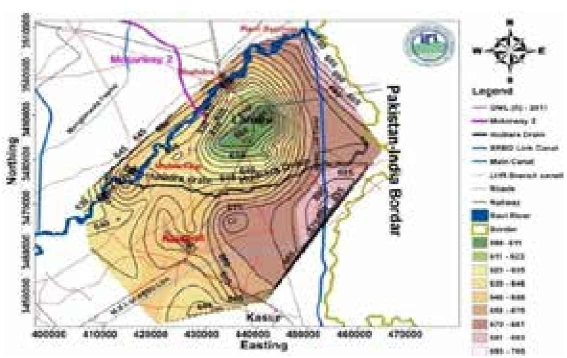

Fig. 7. Groundwater levels and depression zone area in Lahore (2011).

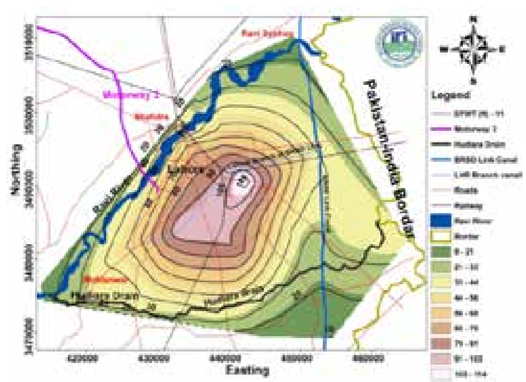

Fig. 8. Depth to water table with depressio area in Lahore (2011).

area. 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 recharge from River has seriously decreased. Under these circumstances 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” (Fig. 22).

3.5 Sewage and Street Runoff

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 [17] and now has crossed to 3,304 cusecs through drains and various pumping stations without proper treatment [16] as depicted in Fig. 23.

3.6 Surface Drainage Network

A network of surface drains in Lahore city(Fig. 24)carries wastewater from various sources and ultimately enters the Ravi river. These are earthen channels which causes the leaching of various pollutants directly to groundwater. The quality of wastewater in drains is deteriorating with the passage of time as shown in Table 2 [10].

3.7 Industrialization

As mentioned already, Lahore has become hub of industrial activities in the country. A large number of industry pertaining to textiles, chemicals, auto parts, electric appliances, machinery, food, restaurants, plastic and pvc retailers that are based in the beautiful Lahore city are polluting the environment. These Industries are 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 and using huge amount of groundwater for processing raw material and finishing the products. Instead of these industrial estates, a large numbers of in house small industrial units are working within the Lahore city which are discharging wastewater into sewerage system without treatment. Domestic and industrial effluents contain organic and inorganic pollutants, which deeply percolate through the soil depending upon the soil nature and sooner or later deteriorate the groundwater quality. Flow in Ravi river during the winter is insufficient to wash off wastewater pollution [10]. The environmental profile of Pakistan indicates that about 40% of deaths are related to waterborne diseases spread by water pollution, mainly due to the sewage and industrial wastewater contamination to drinking water distribution systems.

3.8 Dumping of Solid Waste

Typically Municipal Solid Waste (MSW) consists of household waste, commercial waste and institutional waste. Unscientific dumping of solid waste always poses serious environmental problems on groundwater. Leachate produced at landfill contains thousands of complex components and it becomes part of groundwater after infiltration. With reference to Lahore city, three sites were selected which are located at Mehmood Booti, Saggian and Baggrian for dumping of solid waste. Groundwater is suspected to be contaminated due to unscientific, unsafe, unplanned and traditional selection of these sites. At least three-quarters of the total waste generated (3800 tons/day) in Lahore is dumped at these sites without proper treatment. According to a previous study, it was found that most of groundwater samples collected from nearby these landfill sites contain pollutants and their concentration level in groundwater is higher than prescribed by Pakistan Standards and Quality Control Authority (PSQCA) and concentration of Arsenic in drinking water is higher than WHO criteria[18]. It was reported in the Daily newspaper (20 May, 2008), that according to United Nations Environmental Program (UNEP)’s data about 47% drinking water in Lahore city was contaminated due to presence of various hazardous toxic elements [19].

3.9 Agricultural Runoff

Excessive and uncontrolled use of chemical fertilizers, pesticides and herbicides promotes contaminated agricultural run-off. This not only pollutes the surface drains but the water trickling

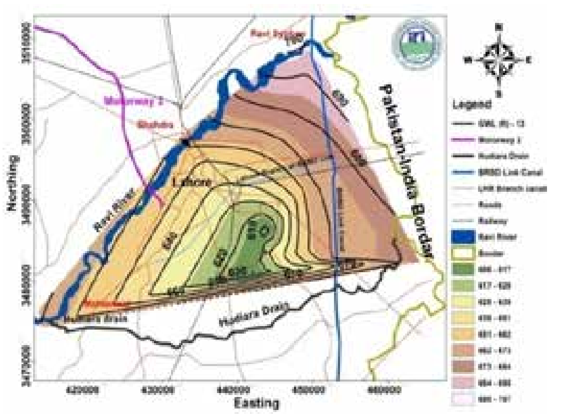

Fig. 9. Groundwater levels and depression zone area in Lahore for the year 2013.

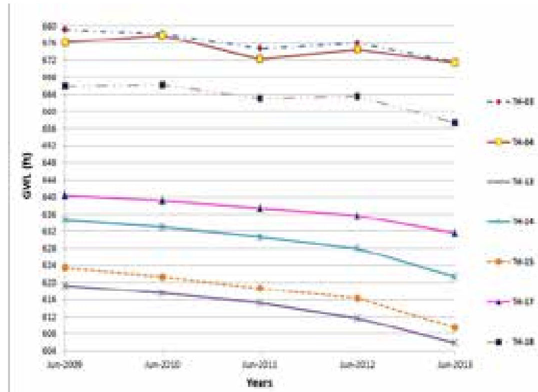

Fig. 10. Decline in groundwater level in Lahore from 2009 to 2013.

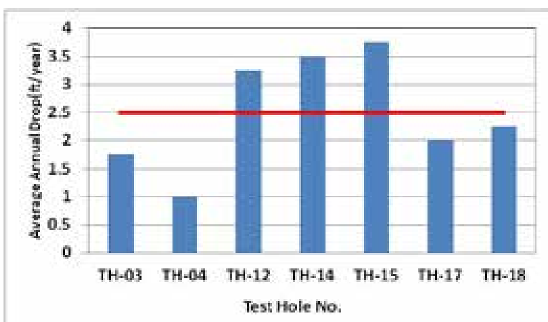

Fig. 11. Average depletion rates of groundwater in Lahore from 2009 to 2013.

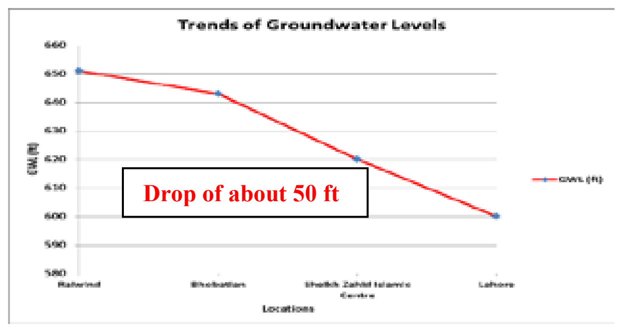

Fig. 12. Longitudinal profile of groundwater levels from Raiwind to Dharampura, Lahore for the year 2010.

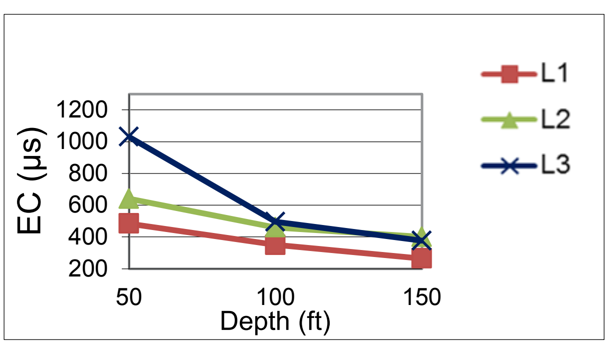

Fig. 13. EC (µs) at Shahdra site vertically downward for the year 2014.

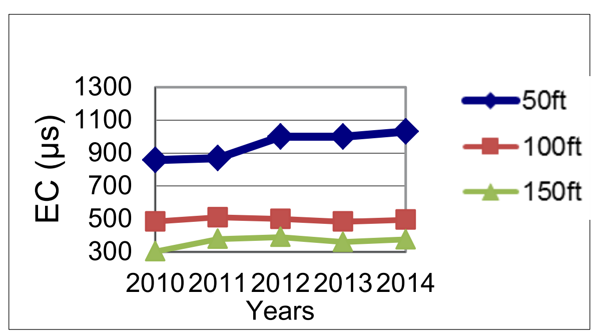

Fig. 14. EC (µS) at L3 Shahdra site w.r.t. time.

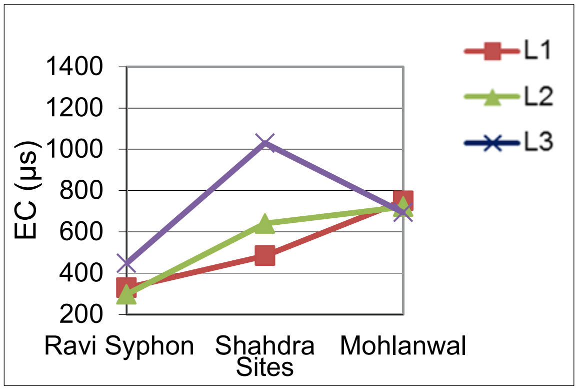

Fig. 15. EC (µs) along river from Ravi syphon to Shahdra and to Mohlanwal at a depth of 50 ft for the year 2014.

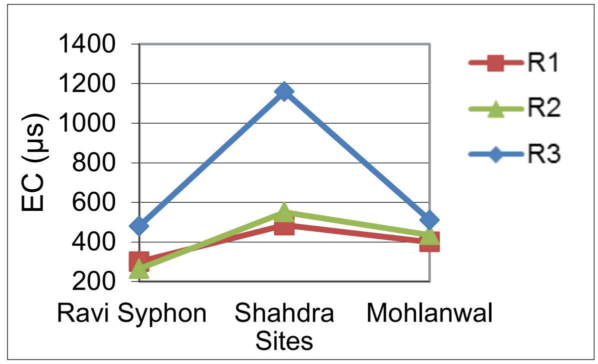

Fig. 16. EC along river from Ravi syphon to Shahdra and to Mohlanwal at a depth of 50 ft for the year 2014.

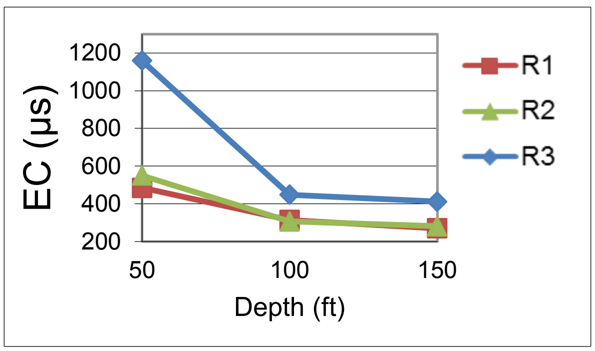

Fig. 17. EC at Shahdra site vertically downward for the year 2014.

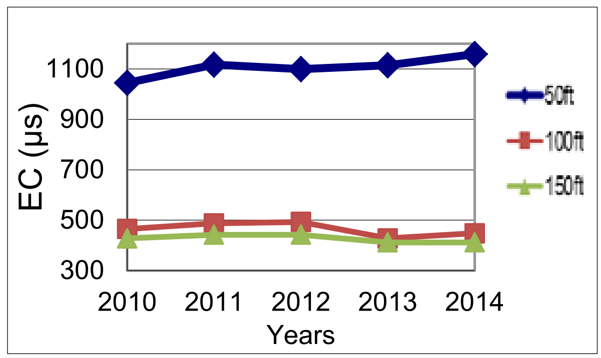

Fig. 18. EC at R3 Shahdra Site w.r.t. time.

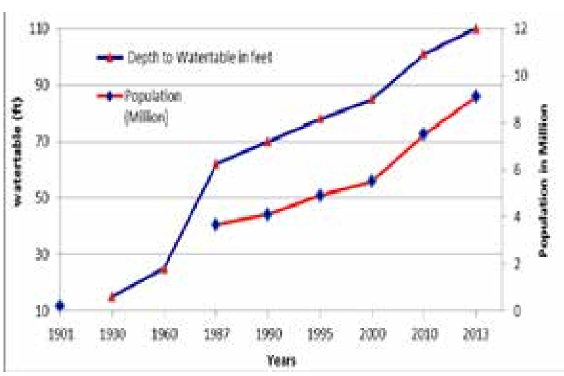

Fig. 19. Trends of population and water table depth in Lahore area.

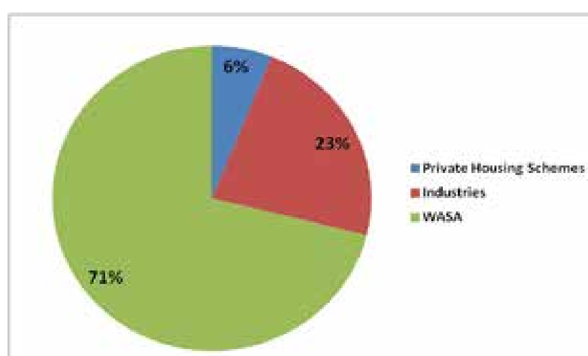

Fig. 20. Major groundwater consumers in Lahore.

down to lower layers of soil causes a severe contamination of the natural aquifer in surrounding areas of Lahore. Over abstraction of groundwater prompts recharge from the surface water drains, which themselves are severely contaminated. Different drains like Hudiara drain which collects surface runoff from agriculture fields from India and Pakistan and pollutes the groundwater in Lahore and surrounding areas.

3.10 Air pollution

Vehicular and industrial emissions comedown with rainfall in the shape of acid rain which increases the acidity of surface water body like lakes, rivers and drains due to which aquatic life is affected adversely. These toxic pollutants leach down from soil surface to groundwater. Acid rain dissolves all the useful minerals from the top soil like potassium, calcium, magnesium and leaches them down to the aquifer. Similarly aluminum is also activated by acid rain which causes the death of aquatic life and contaminates the groundwater reservoir.

In addition to the threats mentioned above, lack of proper coordination between various stakeholders and awareness among the various groundwater users are also of prime concern and contribute significantly in degradation of the groundwater resources in the city.

4 MANAGEMENT OPTIONS

Groundwater is a precious gift of nature and is playing a vital role for the existence of life at the planet. This natural resource is being used for drinking, agricultural, industrial, livestock and other uses and is continuously under threat. Groundwater reservoir is a natural system which is balanced naturally by different sources of recharge including rainfall, dams/lakes, ponds, rivers, canals, water courses and irrigated fields etc. Different inflows and outflows from the system are balanced automatically and system remains under equilibrium conditions. Human being is the major player who plays with the nature to meet with its different increasing needs of food and fiber. Human activities interrupt with the natural ecosystem and balance is disturbed which then creates various multidimensional issues in the real world, which we call environmental threats. For example, when we talk about the Lahore aquifer, we have reduced/ hindered all most all the sources of recharge of aquifer and on the same time extraction of groundwater is increasing tremendously. Such scenario leads to environment degradation of groundwater reservoir with respect to quantity and quality. Some recommended options are as under:

4.1 Artificial Recharge

To maintain the quantity sustainable, the recharge of aquifer is the only and only viable solution for replenishment of the rapidly depleting aquifer no doubt we should control pumpage as well. Recharge of aquifer can take place naturally, but if it is not possible we should intervene and should devise the artificial ways and means for recharging the aquifer.

During the year 2008-09, Irrigation Research Institute conducted preliminary survey and dug sixty exploratory boreholes in the field at various critical site in Punjab to explorer aquifer characteristic and soil stratification to identify the potential sites for artificial recharge of aquifer. Soil samples from all these sixty sites were collected and analysed for determination of hydraulic conductance and profile lithogly [20]. Irrigation Research Institute installed fifty piezometer during the year 2009-10 in the shape of triangle at different depth in the field adjoining Ravi river in its reach from Ravi syphon to Mohnalwal to check the behaviour of groundwater levels, extent of pollution and to explore the aquifer characteristic and soil stratification in the area [21].

A variety of methods have been developed and applied to artificially recharge groundwater reservoirs in various parts of the world. Selection of the feasible methods is important and can be challenging. The methods may be generally classified as: i) the direct surface recharging techniques; ii) indirect recharge techniques; and iii) combination of surface and subsurface methods including subsurface drainage (collector wells), basins with pits, shafts, and wells, etc. Possible options for artificial recharge in Lahore area are:

(i) Rainfall harvesting at potential sites;

(ii) Lahore Branch Canal;

(iii) BRBD canal;

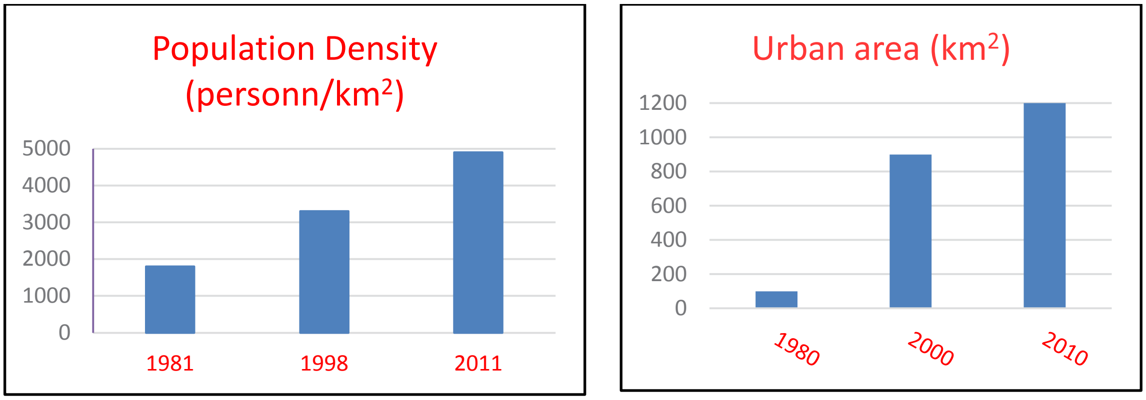

Fig. 21. Urbanization in Lahore.

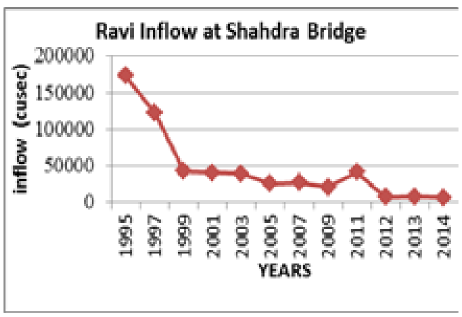

Fig. 22. History of water flow in Ravi river.

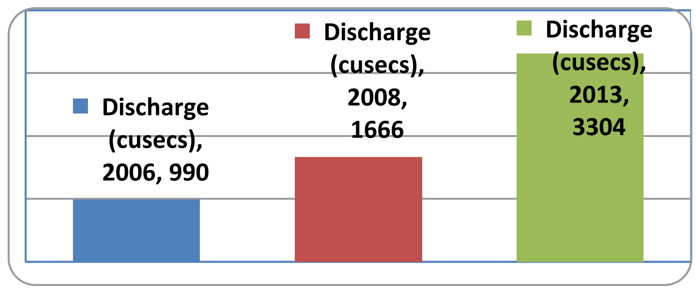

Fig. 23. Effluents being thrown into the Ravi river.

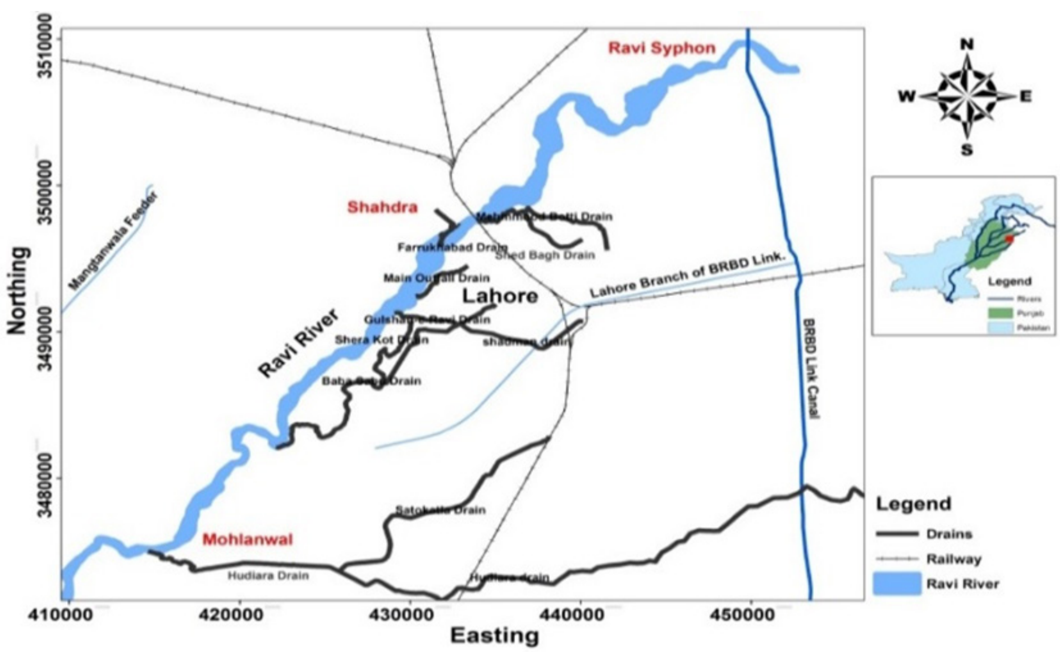

Fig. 24. Location of major drains in Lahore area entering into Ravi river.

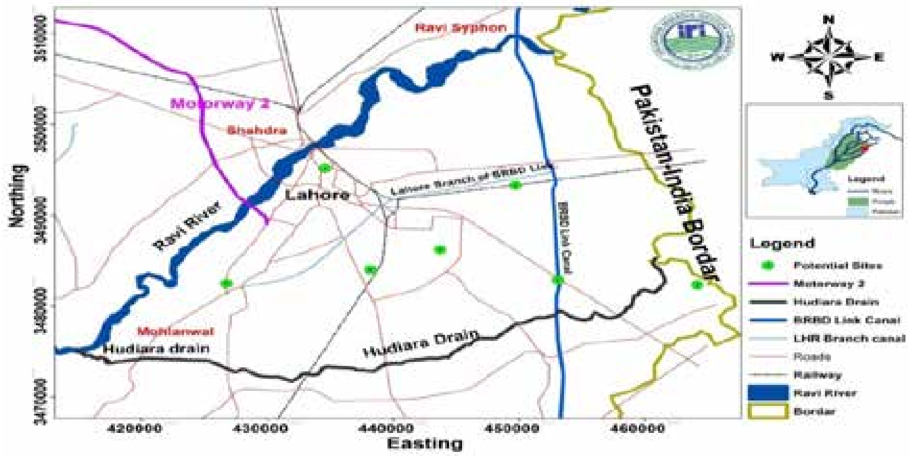

Fig. 25. Potential sites for artificial recharge in Lahore.

(iv) Ravi river by diverting more water in it;

(v) By constructing a ponds/lake between Ravi river and BRBD canal; and

(vi) Recharge wells at suitable sites.

4.2 Rainfall Harvesting

Rainfall is a natural source which can be harvested and diverted/injected to groundwater reservoir. It helps a lot to maintain groundwater potential and at the same time can we can avoid the street flooding and overflowing of drains/nalahs and choking of sewerage systems. Rainfall water, after some time, is comparatively of good quality and can safely be used for recharge purpose by adopting a suitable design mechanism.

Field surveys and sub-surface investigations have been carried out by IRI to identify potential sites for artificial recharge through rainfall harvesting. A list of such sites is given in Table 4 and is shown in Fig. 25.

These sites have been identified after physical and topographical surveys where a reasonable volume of rainfall is collected naturally in depressions and can be recharged. After physical surveys, sub-surface lithology and soil characteristics have been determined to ascertain whether the sub-surface strata support recharge or otherwise. It has been found that all these locations are hydrological, geo-hydraulically and geo-chemically feasible for recharging the aquifer.

4.3 Redressing the Surface Pollutants

The 2nd largest issue of groundwater is its continuously deteriorating quality which is of more concern as it deals directly with human health. Sources of groundwater pollution are normally manmade intervention on earth surface and in certain cases the salts in bed rocks. Most of the pollutants effluents like industrial, agricultural, municipal etc. are in liquid forms which leach down to groundwater. Some other are in solid form like solid waste heaps through which pollutant leach down to subsurface soil and then to groundwater. Some pollutants are in gaseous form like vehicular and industrial emissions, which return back to soil surface via acidic rains and percolate down to groundwater through unsaturated zone. Broadly speaking these are the surface pollutants.

As a first effort, their production at source should be reduced or minimized through scientific research and public awareness campaigns. For example, farmers must be educated to use less toxic and in limited/required quantity fertilizers, pesticides, weedicides, etc. Similarly, industrialists should be provided with scientific solution to recycle or treat the effluents at source instead of throwing it into nearby water body or injecting directly to groundwater which off-course is not less than a crime. In the same way, sever steps are required to be taken for control/mitigation of gaseous emissions. Regarding solid waste management we can go for use of geo-synthetic materials at landfill sites to avoid leaching of pollutants. Solid waste can also be used to obtain energy. Regarding municipal effluents we should take care to avoid mixing of rainfall with such pollutants and should capture and harvest the rainfall separately and store it in surface or subsurface storages. Treatment plants should be adopted to make the industrial, municipal, and agricultural waste waters useable for some purposes like industries, irrigation etc. keeping in view the cost and need options into considerations. Control on over-pumping can be helpful to avoid mixing of saline-fresh water in the aquifer

5. CONCLUSIONS

i. Potential identified threats to groundwater reservoir in Lahore are uncontrolled and un-planned over-pumping, untreated effluents, lack of recharge of aquifer, lack of coordination between various stakeholders, etc.

ii. Groundwater levels in the city area are falling at an average rate of 2.5 ft. per year and even more than 3 ft. per year at certain locations due to excessive pumpage and less recharge.

iii. Groundwater in some locations in the city area has fallen more than 100 ft. below the natural surface level.

iv. Ravi river has become a source of pollution for groundwater reservoir underlying the Lahore city (due to low flows and throwing of effluents in it).

v. Groundwater quality in the aquifer is deteriorating with the passage of time and sweet water is becoming rare and out of reach and improves with the depth below natural surface.

vi. Groundwater quality deteriorates moving downward from Ravi Syphon to Mohlanwal and is the worst near Shahdra along the Ravi river.

vii. Ravi river can contribute towards recharging the aquifer as groundwater levels fluctuate with the river gauge.

viii. Quality of effluents in drains entering the River is deteriorating with the passage of time.

ix. Slope of hydraulic gradient line has been observed from Raiwind/Kasur to Lahore and steeper slope has been observed as the line approaches Lahore.

x. There is lack of awareness and communication/ coordination among different Government Departments/ agencies and the various stakeholders/consumers

6. RECOMMENDATIONS

6.1 General

i. Establishment of National Groundwater Management Board, Provincial Boards/Cells as Groundwater is contributing more than 50% for irrigation and almost more than 90% for drinking purposes in Punjab.

ii. Formulation of long-term policy framework and comprehensive master planning to guard against fast depleting groundwater resources.

iii. Enforcement of Canal & Drainage Act 1873 and Punjab Environmental Protection Act 1997 (Amended 2012) and compliance of NEQS and other relevant rules and regulations.

iv. Formulation of Special Regulations/legal frame work for sustainable use of groundwater in rural and urban areas.

6.2 Specific for Lahore

i. A working group consisting of inter-departmental experts and the members of civil society/NGOs to sit together to bridge the gap of coordination/communications.

ii. To strengthen the monitoring network for groundwater levels and quality (vertical and temporal).

iii. Detailed groundwater investigations through modeling approach (future prediction of flow and solute transport under various stresses) to study the factors which are responsible for the worse groundwater quality and declines in levels.

iv. Installation of treatment/recycling plants for sewerage and industrial effluents as well as for solid waste in the city at appropriate locations.

v. Pumping tube wells should be installed after assessment of aquifer potential and should be scattered uniformly and possibly near a recharge source.

vi. Water saving campaign through public awareness and giving subsidy on water saving instead of water supply.

vii. Artificial recharge / Rainfall harvesting through rainfall-runoff modeling at identified potential sites and to explore more feasible sites in parks, playgrounds and other natural depressions.

viii. Regular monitoring and lining of surface drains in city area.

ix. To maintain minimum flow in Ravi river for dilution of pollutants and enable it to act as source of recharge.

x. Construction of lake/ponds in the east-west of Lahore to recharge the aquifer after detailed investigations.

xi. Explore possibility of Lahore Brach Canal and BRBD canal as recharge sources.

xii. Concept of earthen green belts/dividers along the roads should be adopted from where rainfall water can leach down naturally or some injection wells can be installed as deemed appropriate.

7. ACKNOWLEDGEMENTS

The work of this paper has been carried out by Physics Directorate of Irrigation Research Institute (IRI) under a Provincial Government funded project on artificial recharge. Cooperation extended by different provincial, federal institutions/departments is acknowledged. The team of scientist who has been working day and night to collect the data and analyze the same is a collective effort and wisdom without which this work would have not been completed.

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