GROUNDWATER EXTRACTION AND WASTE WATER DISPOSAL REGULATION – IS LAHORE AQUIFER AT STAKE WITH AS USUAL APPROACH?

By

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ABSTRACT

Access to clean drinking water is a survival issue for a big metropolitan city like Lahore with an ever increasing population, now exceeding 8 million, along with about 2000 industrial units. The Water and Sanitation Agency (WASA), Lahore is managing water supply from the aquifer through its 467 tubewells having 2-4.0 cusecs capacity. However, there is no artificial recharge mechanism in operation and as a result the aquifer is depleting at about 2 ft/year. After the construction of Thein Dam in 2000 upstream of Madhopur head works in India, flow of Ravi River has drastically ceased which was a major source of recharge to the aquifer. Therefore, sustainability of meeting increased water demand is very much doubtful for the times to come from quantity as well as quality perspective with this alarming depletion rate. At the same time, rapid growth in industrial establishments is having dual sustainability threat for the aquifer in terms of increasing pumping rates and underground seepage from untreated waste disposal. The paper highlights groundwater extraction and waste water disposal regulation requirements along with allied actions for planned groundwater management for long term sustainability of the resource. Imposing groundwater development and waste water treatment charges can be the only option for ensuring sustainability of this precious resource. This can cover anticipated future costs e.g. rainwater harvesting and groundwater recharge for maintaining groundwater levels and treatment of generated waste water to safe levels. Community education and participation of all the stake holders in these issues will further improve and ensure success in this regard. It is estimated that by adopting rainwater harvesting and recharge can alone stop the current declining trends in groundwater levels in the city.

Keywords: groundwater mining, governance, regulation, recharge, rainwater harvesting.

1. INTRODUCTION

Pakistan is said to have the largest contiguous irrigation system in the world, with three major dams, several barrages, numerous weirs, and a comprehensive system of main and distributary canals. Irrigated agriculture consumes 97 percent of Pakistan's allocated surface water resources of 117 million acre feet. These irrigation releases and the rainfall are major sources of groundwater recharge throughout the Indus Basin Irrigation System. The surface flows to the Ravi River started facing reductions immediately after independence in 1947 ending to nearly zero flows after the construction of Thein Dam in 2000 upstream of Madhopur head works in India. After this drastic change in Ravi River flow regime, rapid lowering in groundwater levels has been observed in river adjoining areas of Lahore city. But in contrary, groundwater extraction rates are increasing with

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passage of time due to increasing population and industrialization in and around this second largest city of Pakistan.

Groundwater is the second largest reserve of freshwater on earth. Uncontrolled abstraction of ground water in Pakistan is a real threat and has achieved an alarming situation. Fresh water aquifer depletion is taking place with increasing pace particularly in Punjab. Severe water shortages both in surface and groundwater resources of the country warrant to think over it very urgently and judiciously to avert crisis like situation in future. Water shortage in the agricultural sector will be 33 percent by 2025 (Ref : The Pakistan National Conservation Strategy)

With as usual approach of doing nothing, sustainability in water access is a survival issue for general public and the business community with billions of investments in different industries located in and around the city of Lahore.

1.1 Over exploitation of Groundwater and its Emerging Impacts

A national water quality study was carried out by the Pakistan Council of Research in Water Resources (PCRWR) in 2001. In the first phase of the program, covering 21 cities, all samples from four cities and half the samples from seventeen cities indicated bacteriological contamination. In addition, arsenic above the WHO limit of 10 parts per billion (ppb) was found in some samples collected from eight cities. The study of 11 cities of Punjab shows an excess of arsenic and fluoride concentrations in the water supply systems of six cities; Multan, Bahawalpur, Sheikhupura, Kasur, Gujranwala, and Lahore (PCRWR 2004). Subsequent studies by WASA, UET (University of Engineering and Technology Lahore) and NESPAK during 2010 also showed evidence of presence of arsenic contamination in WASA tubewells. However, the sources are yet to be established.

Steenbergen and Oliemans (1997) mentioned that with the dramatic increase in the intensity of groundwater exploitation, the policy landscape for Pakistan has changed, i.e. the main policy issues now relate to environmental sustainability and welfare. They stressed the need to avoid declining groundwater levels and deteriorating groundwater quality in fresh groundwater areas, and also to ensure equal access to this increasingly important natural resource. So, there is an urgent need to develop policies and approaches for bringing groundwater withdrawals into balance with recharge, a difficult process which requires action by the Government and informed and well organized users.

1.2 Urban Groundwater Management Efforts in India

In an effort to control and regulate the development of groundwater, India started its efforts since 1970 in the form of Model Bill. Persuasion is being made with state governments/union territories for inclusion of roof-top rainwater harvesting in building bye-laws, also nine states have already made it mandatory for special category of buildings. In two states, namely Gujarat and Maharashtra, the bill has been passed but not enacted. Action on the model bill has been initiated in 16 states/union territories. In urban areas, the Government of India has amended building bye-laws and made rainwater harvesting, as a means of artificial recharge, mandatory. So far, Tamil Nadu, Delhi, Haryana have taken action. Other states are in the process of amending the building bye-laws to make rainwater harvesting mandatory in the special class of buildings (Mehta 2006 and Romani 2006).

1.3 Need to Ensure Groundwater Sustainability in Pakistan

Surface water rights in Pakistan are already committed by and large mostly for agricultural uses. The increasing groundwater extraction in big cities like Lahore is posing increasing recharge requirements of the aquifer but do not have any direct uses/rights from the surface flows e.g. Ravi River. Unfortunately, in our society groundwater is not considered as natural resource having some limits and issues with its misuse but one of the endless blessings of Almighty Allah. At present there is no regulatory body at Federal or Provincial level which can regulate the groundwater extraction and waste disposal management at urban or agricultural levels. In reality, heavy costs are involved for holistic management of groundwater extraction and waste disposal which can be levied on its users otherwise the groundwater resources may become out of reach or unusable due to its overuse and misuse. These costs in case of groundwater management are needed for surface and groundwater projects not only for today but for ensuring sustainability in the sector in future. Taxes have always been levied for these anticipated future investments, but we are totally ignoring this part of good governance in our society. Otherwise, there are possibilities of undue cost for drinking water such as extra costs for pumping from deeper groundwater levels and/or cleaning the polluted water in the aquifer.

Given the increasing competition for water and the high probability that there will be less of it in the future, it is important that progress be made on this issue in the form of good governance. This can be achieved through forced regulation by imposing laws and/or by regulating the surface recharge to groundwater with the intention to ensure sustainability, equity and efficiency in using this precious and limited but renewable resource.

2. CONCEPTUAL MODEL OF THE LAHORE AQUIFER

Conceptual model for an aquifer comprises establishment of a hydrogeological framework of the area of interest. The lateral and vertical extent of major stratigraphic units is defined based on the information contained within the customized borehole database. Groundwater flow directions are assigned based on interpolation of hydraulic head data contained within the customized borehole observation wells database. Available hydrological information on recharge by precipitation and other sources, evapotranspiration and groundwater extraction are linked together to get a balance between contributing inflow and outflow components.

2.1 Aquifer Boundaries of the Area

The areas upstream as well as downstream of Lahore are bounded by the Ravi River in the North West and the Sukh Beas drainage channel in the south. So the area of interest with respect to Lahore city forms the part of the Bari Doab – interfluvial lands between the Ravi in the North West and the Sutlej River to the South. The area is underlain by a significant thickness of alluvial deposits, upto 300 m in depth, proven by the investigations carried out by WASID during the period 1961-62 (WAPDA, 1980). The recharge sources are Ravi River (very occasional flows now a days) on the North West and BRBD Canal on the East. Discharging boundaries are beas drainage channel on the

South and again the Ravi River in the West. But these discharging boundaries only function in the form of surface runoff during heavy rainfalls; no groundwater discharge is possible due to excessive groundwater depletion in the area.

2.2 Hydrogeologic Conditions of the Area

During nineteen sixties, US Geological Survey initiated hydrogeological investigations in the Punjab in cooperation with Water and Power Development Authority (WAPDA) under the auspices of the US Agency for International Development (USAID). The investigations included the drilling of test bores, construction of test tubewells, carrying out pumping tests and data analysis. During this regional groundwater investigation, several comparatively deep test holes were drilled in Bari Doab to determine the thickness of the alluvium, the depth to bedrock and its nature, and the quality of water at deeper zones. Many test holes were over 600 feet deep and 33 were from 800 to over 1000 feet deep. Of the later 19 test holes were located in the north-eastern part of the Doab to explore the probable extension of the Delhi-Shahpur buried ridge, a structure on the Precambrian basement. Of these, only three test holes namely BR 1A, BR 6 and BR 7 (Figure-2) reached Precambrian basement rock at 1252, 1021 and 928 feet respectively (WAPDA, 1980).

Study of the lithologic logs of 149 test holes (600´ to 1000´ depth) and 28 test tubewells (102´ to 356´ depth) indicates that Bari Doab consists of consolidated sand, silt and silty clay, with variable amounts of Kankers. The sands are principally grey or greyish-brown, fine to medium grained and subangular to sub-rounded. Very fine sand is common, finer grained deposits generally include sandy silt, silt and silty clay with appreciable amounts of kanker and other concretionary material. Except for a few local lenses, a few feet thick, beds of hard rock, compact clay are rare in the area. Gravels of hard rock are not found within the alluvium and coarse or very coarse sands are uncommon. As is typical of such fluvial depositional environments, there is little apparent lateral continuity of the sediments. This is the only extensive data on the lithology of the deposits in Bari Doab.

2.3 Aquifer Characteristics

As reported by Bennett et al. (1967), between 1954 and 1963, aquifer tests were completed at 164 sites in the Punjab plain by Groundwater Development Organization and its successor, the Water and Soils Investigation Division (WASID). Out of these 141 tests, only three were in the vicinity of Lahore i.e. one pumping test at Kotlakhpat, the second near Kasur and the third one at Pholnager (Bhai Pheruu). The reported permeability values are 26.34, 15.80 and 34.25 m/day respectively. Maximum depth of the reported test wells was 108 meter; the results thus reflect the characteristics of upper part of the aquifer. The alluvial sediments that comprise the aquifer exhibit considerable heterogeneity both laterally and vertically. Despite this, it is broadly viewed that the aquifer behaves as a single contiguous, unconfined aquifer.

As reported by Bennett et al. (1967), the screened intervals of these test wells consisted predominantly of sand, silt and thin beds or lenses of clay. The lateral permeabilities determined in these pumping tests are thus averages for the sediments at the pumping sites exclusive of the thick deposits of clay. As such these values are undoubtedly somewhat higher than the average lateral permeability of the section as a whole. Sheikh (1971) has concluded that for Bari Doab, the specific yield varies from 22 to 35 %, the average being 26.3 %.

The alluvial complex consists principally of fine to medium sand, silt, and clay. Beds of gravel or very coarse sand are uncommon. The study of drill cuttings and electric logs has shown the absence of thick horizons of pure clay within the alluvium. Except for local clay lenses, a few feet thick, the finer parts of the alluvium consist generally of sandy, gravelly or silty clay. The lithology of the alluvium, as inferred from the study of test hole samples and electric logs show the heterogeneous character of the alluvium in vertical (depth wise) and transverse directions and random distribution of clay zones (Greenman et al., 1967). In spite of the heterogeneous composition, the aquifer is highly transmissive in which groundwater occurs under watertable conditions.

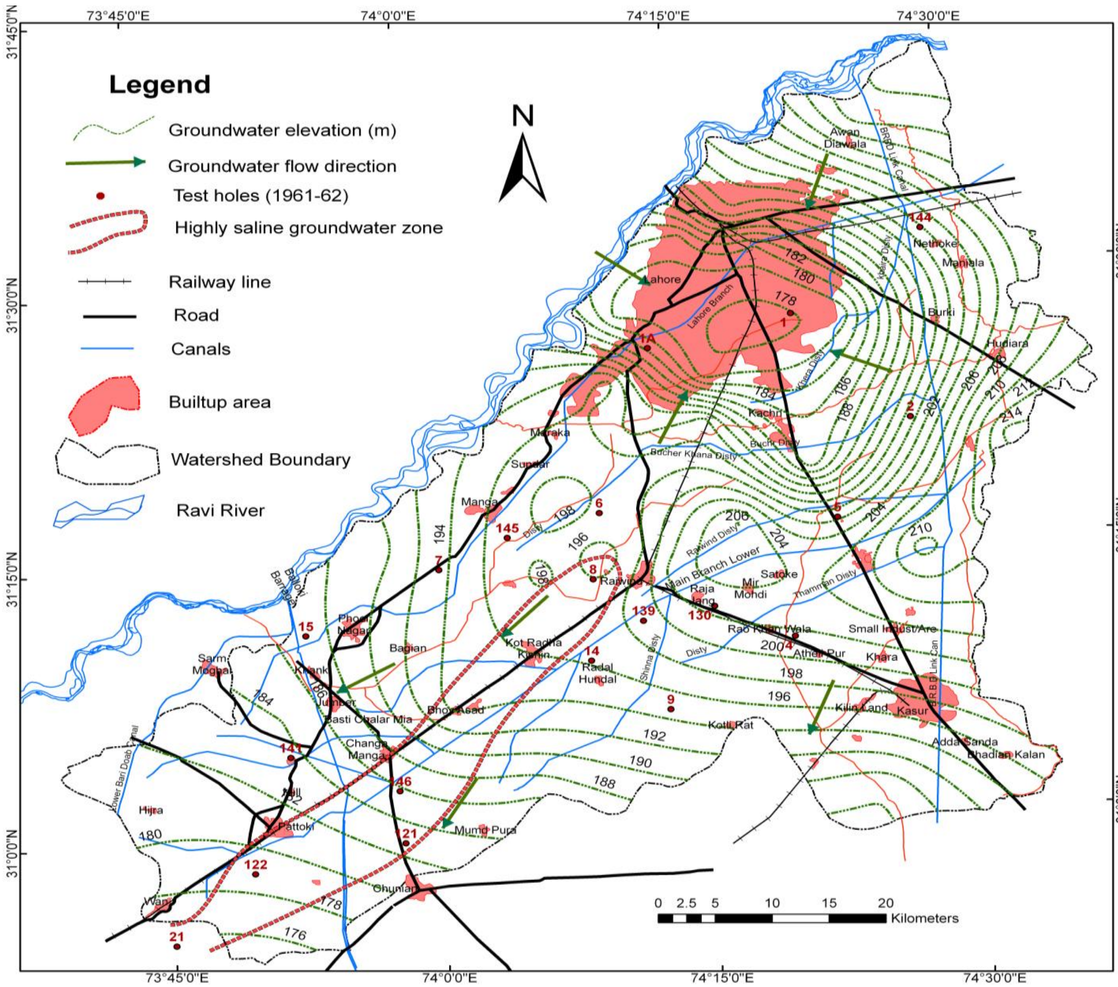

Figure-1: Groundwater Elevation Contours (m) and Flow Directions for 2009, deep test hole sites and irrigation network in the area.

2.4 Groundwater Flow Regime

Depth to groundwater is rapidly increasing in the area due to increasing use of the groundwater by the population and industries. At present the maximum observed depth to the watertable in Lahore city is 40 m and in the area of Bhubattian chowk on Raiwind road is about 12 m. The aquifer under and around the Lahore city is very deep (more than 300 m) with high transmissivity of about 2100 m^2/day (assuming 80 m thickness contributing to groundwater flow). The aquifer extends from Lahore to Piedmont area of foot hills in Jammu and Kashmir in north-eastern direction (about 100 Km). This is also the direction of rivers and groundwater flow in general, whereas in the down stream direction it extends to Arabian Sea at a distance of about 1000 Km.

2.5 Depth Wise Groundwater Quality Distribution

Groundwater water samples were also collected during 1961-62 deep test drilling by WASID while conducting deeper hydrogeologic investigation in the region. The depth wise data of groundwater quality collected at that time for the test wells falling in and around the city of Lahore watershed is given in Table-1 and some of them plotted in Figure-2. In general the groundwater lying at deeper depths is of good quality as compared to the shallow groundwater in and around the city of Lahore. Greenman et al. (1967) has concluded that the distribution of saline and fresh groundwater zones in Bari Doab is a result of past and present hydrologic, climatic, and topographic factors. Among these, the present and former positions of stream channels, representing sources of recharge, the high bluffs of the bar uplands in the upper part of the Bari Doab, and differences in the permeability within the alluvial aquifer are among the most important. The deep groundwater quality data of 1961-62 has revealed that a strip of about 10 km wide between Pattoki and Chunian starting from Raiwind and ending at about the middle of Okara and Sahiwal has the highly saline groundwater, the water samples ranged upto 10,000 ppm upto a maximum depth sampled of 200 m. As shown in Figure-2, the deep groundwater in Raiwind area is highly saline (of the order of 9000 ppm) up to depths of 110 m. In the wake of induced groundwater hydraulic gradient (due to rapidly falling watertable in Lahore) towards Lahore from Raiwind, it is likely that saline groundwater would intrude towards fresh groundwater.

Table-1: Chemical analysis of test holes drilled in the study area in 1961-64 (WAPDA, 1980)

Test Hole #	Depth (ft.)	Meq/l							Total Cat/An-ions	TDS (ppm)	Ec (µmhos/cm)	pH	SAR	RSC
		Ca	Mg	Na+K	CO_3	HCO_3	Cl	SO_4						
BR 1	124-145	1.60	2.57	11.1	-	7.24	2.04	6.05	15.33	900	1400	8.1	7.7	3.07
	248-268	1.60	2.97	9.28	-	6.60	2.00	5.25	13.85	840	1300	8.1	6.1	2.03
	315-335	1.60	1.98	11.7	0.16	6.68	2.00	6.44	15.28	900	1400	8.3	8.6	3.26
	406-413	1.12	0.67	24.3	-	8.00	3.96	14.2	26.18	1550	2380	8.1	25.0	6.21
BR 1-	112-132	2.40	1.38	9.02	0.40	6.90	1.30	4.20	12.80	750	1160	8.3	6.5	3.52

A	225-245	1.52	0.86	3.34	-	3.70	0.60	1.42	5.72	345	530	8.1	3.0	1.32
	292-312	1.28	1.10	4.16	-	3.20	0.64	2.70	6.54	390	600	8.1	3.8	0.8
BR 2	45-65	0.52	0.79	14.1	0.40	10.80	1.98	2.22	15.40	930	1420	8.3	17	9.39
	135-155	1.56	1.97	11.9	0.40	11.30	1.67	2.13	15.50	900	1410	8.3	9	8.17
	202-222	0.80	0.78	8.99	-	7.20	1.20	2.20	10.60	970	620	8.2	10	5.59
	382-402	0.93	1.24	6.03	0.20	6.60	0.40	1.00	8.20	750	490	8.3	5.8	4.63
	450-470	0.73	0.53	5.94	-	5.30	1.50	0.40	7.20	430	660	8.1	7.5	4.04
BR 5	45-65	2.00	1.18	5.07	-	2.90	4.60	0.75	8.25	510	790	7.7	4	0
	135-155	0.99	0.85	10.1	-	4.64	2.00	5.34	11.98	705	1100	7.9	10	2.8
	249-269	1.19	0.83	13.5	-	4.76	2.75	8.04	15.55	910	1420	7.9	13	2.74
BR 6	135-155	1.09	0.72	15.9	-	4.14	6.60	7.06	17.80	1040	1630	7.8	17	2.33
BR 8	67-87	1.00	2.06	54.7	3.20	21.5	32.0	1.03	57.79	3600	5500	8.5	44.0	21.7
	270-290	9.60	15.8	121	0.28	6.46	136	4.12	146.86	9000	14000	8.2	34.0	0
	337-357	6.80	2.50	112	0.60	5.80	112	2.68	121.08	7200	11000	8.3	52.0	0.2
BR 130	40-60	1.25	2.18	35.9	-	20.6	10.2	8.60	39.41	2400	3610	7.6	27.0	17.2
	108-128	1.00	3.40	34.5	-	19.8	9.70	9.38	38.96	2450	3700	7.8	23.0	15.5
	218-238	0.90	3.80	20.4	-	14.5	4.70	5.90	25.16	1530	2280	7.7	13.0	9.86
	350-370	1.02	0.40	13.2	-	9.90	2.13	2.62	14.65	880	1320.0	7.8	16.0	8.48
	968-998	0.80	0.90	18.8	-	7.70	9.62	3.20	20.52	1280	2000.0	8.1	20.0	6
	534-559	0.98	1.12	9.19	-	7.48	1.74	2.07	11.29	675	1050.0	7.9	8.9	5.38
	968-998	1.80	0.62	17.8	-	3.60	13.6	3.12	20.30	1300	1950.0	7.4	16.0	1.18
	759-789	0.65	0.24	9.19	-	5.54	1.74	2.80	10.08	600	930	7.4	14.0	4.65
BR 144	180	0.66	2.40	6.38	0.00	7.77	0.69	0.98	9.44	608	950	7.4	2	-
	740-760	0.57	1.77	6.51	0.00	5.85	0.29	2.71	8.85	576	900	7.5	5	-
	1050-1070	0.28	0.26	5.54	0.00	4.51	0.39	1.18	6.08	524	820	7.9	6	-

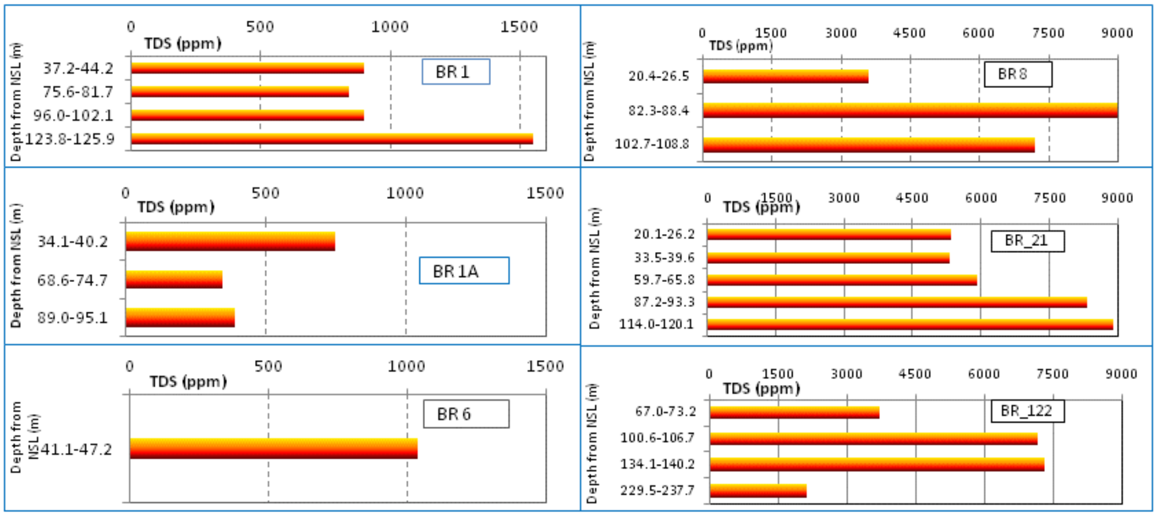

Figure-2: Deep Groundwater Quality Observed in Test Holes (Figure 1) as on 1961-62 in Lahore.

2.6 Inflow Components

2.6.1 Recharge from Ravi River

The biggest setback due to the loss of water use of one of the three eastern rivers i.e. Ravi is being faced by the Punjab Province's capital city of Lahore. Once it was the major sources of recharge to the underlying aquifer. Thein Dam across the Ravi River in India was completed in about 2000. This Dam is 160m high and is about 20 km upstream of Madhopur barrage. The live storage is reported as 1.90MAF (2.34BCM). The Dam is having significant impacts on the flood hydrology in the medium term particularly in river reach along the Lahore city, although these may be progressively reduced by long term sediment build-up in the reservoir. It is pertinent to note that the Dam is having a pronounced impact on attenuating floods and this may explain why no substantial floods have been observed at Balloki barrage since 1997. This has been particularly observed during the 2010 monsoon i.e. only a maximum discharge of 30-40 thousand cusecs was reported in the Ravi River in spite of heavy monsoon rains on regional scale. That means, future floods which can pass along the Lahore reach will be either flood from the Ravi's tributaries downstream of Thein Dam or a flood which exceeds the available capacity of the Thein reservoir. That means except the flood events from extraordinary rainy season, no regular flows of appreciable amount are expected in the reach except that of Marala Ravi (MR) link releases from Marala Barrage.

Pending an updated hydrological analysis of the Ravi (which can also draw upon the observed impacts of other Dams in the region on the downstream flood regime) it is postulated that the Dam may not have a significant effect on frequency and magnitude of floods greater than about a 50 year return period, but the occurrence of lesser floods will be reduced and these floods, arising from the Ravi's tributaries, will tend to have lesser volume and duration (ADB, 2006).

Ravi has been one of the major sources of recharge to the underlying groundwater reservoir. Construction of Thein Dam as explained above on the Ravi River at Thein for water and energy supply by India has severely reduced the recharge to groundwater in and around the city of Lahore. Average monthly flows of Ravi River for 1962-86 ranged from 1717 cfs for December to 30062 cfs during August. However, peak flows rising to more than 100,000 cfs were also observed in the period (NESPAK and Binnie & partner, 1988). This can be seen from the extra ordinary lowering groundwater levels after 2000 as observed in observation well No CL XX UB/1 (Figure 3).

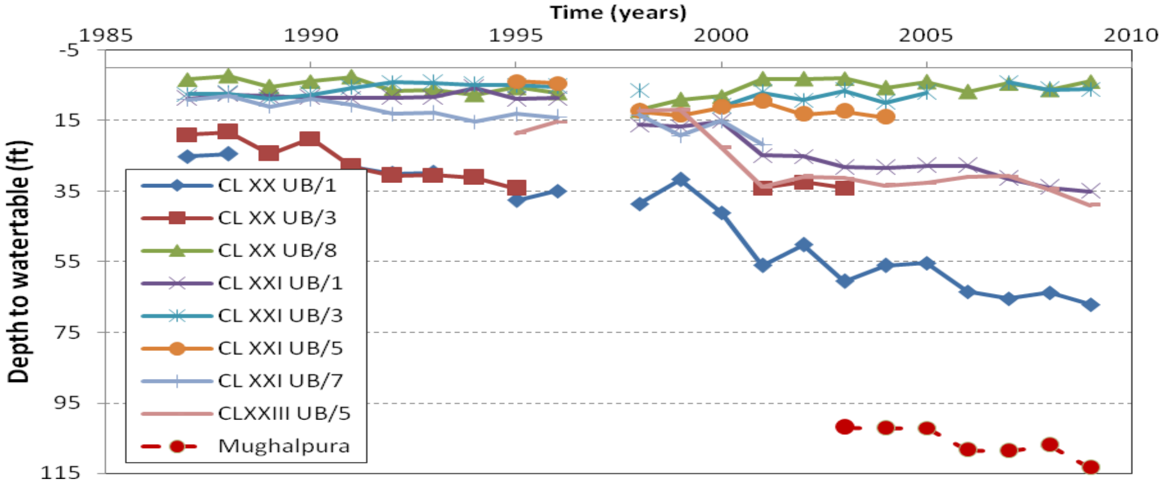

Figure-3: Hydrographs of depth to watertable in the watershed area.

2.6.2 Recharge from irrigation system

The irrigation system present in the area is operational since 1859 with the construction of the first weir-controlled perennial irrigation channel; the Upper Bari Doab Canal, off-taking from the Ravi River at Madhopur (now in India). After the partition, BRBD link canal was constructed (4000 cfs) as a result of Indus Basin Treaty (1960) which is now delivering canal water to the command area of Upper Bari Doab Canal on the Pakistan side of the border. The irrigated area as shown in Figure 1 is under the command of Lahore Branch (403 cfs), Khaira disty (141 cfs), Butcher Khana disty (244 cfs), Main Branch Lower (1591 cfs) and other smaller channels (combined capacity of 81.68 cfs) directly off-taking from BRBD Canal. The remaining discharge of BRBD is providing irrigation supplies to Depalpur Canal with a discharge capacity of 2280 cfs. The irrigation system in the area is a source of recharge to groundwater which is being pumped by the farmers for irrigation of their fields. As is depicted by depth to watertable hydrographs of observation well Nos. CLXXUB/8, CLXX1UB/3 and CLXX1UB/5 (Figure 3), there is not any depleting trend in groundwater levels in irrigated areas of the surrounding watershed.

2.6.3 Recharge from rainfall

The thirty years normal (1971-2000) rainfall for Lahore is 712 mm per year, distribution round the year on monthly basis is shown in Figure-4. Whereas, the average annual rainfall for Sialkot located at about 100 Km in the North of Lahore is 962 mm. Recharge to groundwater from rainfall in irrigated agricultural areas varies from 10% to 24% of the total annual rainfall (Basharat and Tariq, 2011). Annual rainfall in Lahore is reasonable and regular enough with respect to quantity but landscape development has been set up in a way which promotes surface runoff towards sewerage and surface drainage system in the city. However, by adopting suitable building bye laws and redesigning landscape of parks, roads and other public as well as private buildings, considerable part of rainfall can be harvested and ultimately recharged to groundwater by diverting it to specifically designed open wells. Assuming that we can recharge one fourth of the annual rainfall which is 178 mm, we can add 0.89 m equivalent groundwater depth each year (assuming 20% specific yield). That means by rainwater harvesting alone, we can stop the presently observed groundwater declining trends in the city.

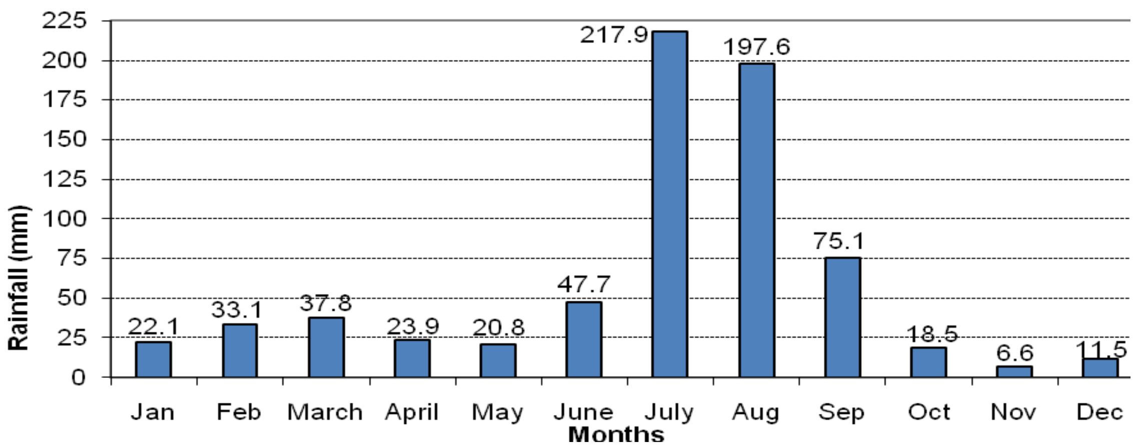

Figure-4: Thirty Years Normal Rainfall (1971-2000) for Lahore.

2.6.4 Groundwater inflow

On regional scale, the groundwater flow is occupying the same flow direction as in the canal irrigation network mostly parallel to river network i.e. in north-east to south-west direction. However due to local variations in natural surface elevations and also in discharge and recharge patterns, the depth to watertable varies considerably in the area. Particularly this is true for the area under Lahore i.e. as mentioned earlier the maximum depth to watertable has gone upto 40 m due to heavily concentrated pumping by tubewells installed by WASA, LDA for piped supply to the local population. To visualize the present groundwater flow directions, the depth to watertable data in and around the Lahore city for 2009 was converted to groundwater level elevations and contours of the same were drawn as shown in Figure-1. The map shows a big depression under the Lahore city caused by intensive pumping from and lack of recharge to the aquifer. As shown by arrows representing groundwater flow directions, the groundwater is flowing from all the sides towards urban area of Lahore city.

2.7 Outflow Components

Groundwater is the only source of water used for domestic and industrial purposes in the area and stands for almost all the outflow component from the aquifer. Access to piped Water Supply System (WSS) service through direct connections to distribution networks exceeds 75% in Lahore. Estimated abstraction by users other than the Water and Sanitation Agency (WASA) represent about 30% of the water consumed. In Lahore, unregulated abstraction has led to the lowering of the watertable by about half a meter per year during the last 30 years; WASA Lahore has commissioned a mathematical model of the aquifer to help monitor its performance and design a plan to redeploy boreholes (GoP, 2007).

Depth to watertable ranged from 25 to 65 ft (8 to 20 m) in 1987 as given in Table-2 (NESPAK and Binnie & partner, 1988). But with increasing population the aquifer is under increasing stress for supplying water to the increasing population. In general the groundwater quality is good near the Ravi River and gradually deteriorates in the South and South Western direction as depicted by deep drilling water quality samples (Figure-2).

2.7.1 Pumping by WASA

The anticipated reduction in recharge from River Ravi and the gradual lowering of water level made WASA / LDA Lahore to carry out a groundwater assessment study of the source water for the Lahore city. NESPAK and Binnie & partner (1988) conducted a study "Groundwater resources evaluation and study of aquifer under Lahore" under which a groundwater model was developed that forecasted the decline of water level in the order of 90 ft by 2010 and proposed artificial recharge. As a part of this study a groundwater model was developed and calibrated considering an area of (37 x 10) km^2 and using watertable data of 1960-1987. According to the report the installed capacity in 1987 was 195 tubewells with 583 cusecs discharge, whereas actual pumpage was 200 million gallons per day (mgpd) that means 371 cusecs were being abstracted from the aquifer. The study concluded that:

- At present artificial recharge is not required but after 2010 it will be required and recommended through injection wells.
- Location of well field would be more pragmatic near River Ravi and BRBD canal.

Another study on groundwater abstraction was conducted under Lahore Master Plan 2000, which shows that the decline in water level is between 0.63-3.4 ft / year. Historical data about abstraction, number of tubewells and depth to watertable for the Lahore city is given in Table-2.

Table-2: Groundwater development status in Lahore city (Lahore Master Plan study 2000).

Description/year	**1987**	**2000**	**Forecasted for**	Actual in
Depth to Watertable	25-65	35-105	45-155	40-135
No. of Tubewells	200	316	400	467
Total Abstraction,	320 (593)	400 (742	696 (1291)	NA
Population	3.5 millions	4.83 millions	7.4 million	7.5

Another presentation reported that WASA Lahore covers a population of (available at http://www.asb.org.pk/MD%20Lahore%20initiative.pdf) 4.8 out of 5.5 million thus serving 87 % of the population within its own network for the year 2007. The water abstraction in Lahore for (2007) has been reported as 360 mgpd (668 cfs) with 406 tubewells pumping. This does not include private schemes mostly in the periphery of the city, most of which has their own pumping systems.

2.7.2 Pumping by private housing societies.

A large number of private housing societies are well established and their growth is also remarkable. All these societies have installed their own pump stations with capacities of the order of two cusecs each. Based on the one month data (November 2010) of groundwater pumping by Wapda Employees Cooperative Housing Society, the per capita consumption in the area comes out to be 315 litres per person per day. The pumping rate for phase-I of the society is 6 cusecs and the ratio of sewerage disposal to groundwater pumping is 0.53. Very roughly it is estimated that all the societies may be pumping groundwater @ 100 cusecs.

2.7.3 Pumping by individual house-holds with shallow pumps

Assuming 20% of Lahore's population i.e. 16,00,000 out of total population of 80,00,000 is without piped water supply, and using 200 litres per person per day as water consumption, the total groundwater use rate by this population comes out to be (16,00,000*200*3.2808^3/1000/84600) 131 cusecs.

2.7.4 Pumping by industries

About 2000 industries are located in and around the city of Lahore. It is observed that 1 to 4 pumps (capacity ranging from 0.5 to 2 cusecs) have been installed by most of the industrial units, depending upon scale and type of processing involved in the industry. Assuming average capacity of these pumps be 0.75 cusecs and utilization factor of 25%, the groundwater pumping by these industrial units can be of the order of (2000*0.75*0.25=375 cfs) of the order of 375 cusecs.

So the total pumping from the aquifer comes out to be (700+100+131+375) 1306 say 1300 cusecs.

2.7.5 Evapotranspiration and groundwater outflow from the area

The study area under Lahore city is 90 % covered and groundwater is very much deep, so outflow through evapotranspiration is negligible. Similarly, regional groundwater out flow is an important component of groundwater budget of an area. However, from

Figure-1, it is evident that groundwater mining of the area is taking place and no regional groundwater out-flow from the area is possible due to reversed hydraulic gradient towards city center.

3 SOURCE WATER CONCERNS

The groundwater management in urban areas is mainly tackled by WASA of Lahore Development Authority and in rural areas by WAPDA and Irrigation Department jointly with respect to planning and development. But at present there is not any long term plan in action which can assure long term sustainability of the resource for this mega city. It is still a big question that to what extent the aquifer under Lahore is capable of sustaining the future increased demands in the long run without greatly overstressing the groundwater reservoir particularly with respect to groundwater quality. For the purpose of long term sustainability, providing surface water as a source of recharge, provision of which is already there in the form of Ravi River bed, has never been given serious thought. Such opinions are often being heard from various corners but any sound project in this regard is not yet ready. Raw sewage in all the cities is either used for irrigation purposes or discharged into fresh water bodies through a net work of drains, which ultimately fall into the rivers. Water from these water bodies and rivers is again used for irrigation purposes. The river waters contaminated by untreated municipal and industrial discharges are also used for drinking and recreational purposes. All this has serious environmental concerns and impacts on the ecosystem and human health significantly. In Punjab, none of the cities has a proper waste water treatment (WWT) system, except in Faisalabad that has a limited capacity of treating only 20 percent of the total wastewater generated in the city (GoP, 2007). There are some individual wastewater treatment plants in some of the industries (e.g. the one installed in Coca Cola Bottles Pakistan Limited Lahore plant), mostly the exporting industries. These plants are installed under the international environmental governance by the buyer's.

3.1 Groundwater Mining

The only source of water supply to the inhabitants of mega city of Lahore for domestic as well as industrial purposes is ground water which is of the order of 1300 cusecs as estimated above. Although, the aquifer under Lahore is a part of the huge groundwater reservoir underlying the Indus Plain, extensive groundwater withdrawal has formed a trough in groundwater levels which is gradually expanding. The watertable, which was about 5 m deep in 1960, has declined now to more than 40 m in central part of the city due to over abstraction of groundwater by public and private tubewells and reduction of recharge. Lahore aquifer is under stress, regulation and monitoring of quality and quantity of groundwater pumped and disposed off is the need of the day for assuring sustainability of this precious resources. Hydrographs of selected observation wells in and around Lahore city (Figure 3) show groundwater mining of the order of 2 ft per year.

3.2 Untreated waste disposal

Although the Lahore city has well established sewerage system, but eventually all this sewerage outflow is discharged to the unlined surface drains within the city which ultimately discharge to the nearby points of Ravi River. As already mentioned above many of the industries particularly the small one and municipal waste is being discharged into the surface drains in and around the Lahore city. So this untreated water along with all its pollution, join the watertable by deep percolation. The Ravi River reach from Lahore to Balloki Barrage is one of the most polluted rivers of Pakistan receiving untreated domestic, industrial and agricultural waste water not only from Lahore but also from bordering country India, through the Hudiara Drain.

3.3 Hudiara Drain

Hudiara Drain (shown in Figure 1), which is a natural storm water channel, originates from Batala in Gurdaspur District, India, and enters into Pakistan at village Laloo. After flowing for nearly 55 km inside Pakistan, it joins the River Ravi. It flows round the year carrying untreated sewage and chemical waste water of 104 industries. There are around 100 industries located adjacent to the Hudiara drain on the 55-kilometre Indian side, so it is already quite toxic when it enters Pakistan. Until about 30 years ago, the Hudiara used to be a storm water drain used for irrigation and domestic purposes, draining into the Ravi, and adding to the river's aquatic health. But this is no longer the case. All along its route in India and Pakistan, wastewater, sewage, and industrial pollutants are discharged into the drain without any proper prior treatment except very few industries working under international regulations for waste water disposal. As a result, organic wastes and toxic chemicals have badly affected aquatic life both in this drain and in the River Ravi.

Farmers living near the drain frequently use its water for irrigation. Preliminary investigations have revealed that this water has high concentrations of metals. Long-term irrigation from Hudiara Drain may have resulted in the accumulation of higher concentrations of metals in the surface soil. Hudiara drain which carries about 5 cusecs of discharge (estimated value with float method, no measured data is available). Heavy metal such as Pb, Cu, Ni and Zn have been detected in Hudiara drain (DLR, 2007). So the presence of these heavy metal and other salts are posing a major threat to the quality of underlying groundwater.

Although x-section of the Hudiara drain varies drastically along the length, the wetted perimeter of the drain on an average is about 55 feet at its crossing with Raiwind road. Punjab Private Sector Groundwater Development Project (1998) adopted 2 to 4 cusecs as seepage loss rate per million square feet of wetted perimeter of the canals having discharges from 20 cusecs to 500 cusecs. The total wetted perimeter of 1 Km reach of Hudiara Drain comes out to be 0.18 million square feet, using 2 cusecs per million square feet as the seepage rate from Hudiara Drain, the total seepage per Km of the drain is calculated as 0.36 cusecs. This shows the possible extent of seepage which possibly joins the shallow groundwater with its pollutants.

Agricultural lands along the length of drain are being irrigated with the polluted water of Hudiara Drain. Farmers have setup their pumping sets along both the banks of the drain to irrigate their lands. This water is probably polluting the upper shallow aquifer and the underlying deep fresh groundwater may also be vulnerable to pollution from this leakage to deeper depths. So these two facts though still not accurately measured, show the vulnerability of the groundwater being polluted. Similarly, there may be other sources of undocumented pollution such as open spreading of industrial and sewerage wastes in the watershed area particularly in the vicinity of small villages, small scale industries which are not connected to any surface drainage system.

3.4 Water Legislation and Governance

Groundwater in Pakistan is under increasing threat from over-exploitation, pollution and lack of proper management to match the demand and supply patterns of this natural resource base. Pakistan, still being a developing country and equipped with weakened water research, development and management institutions, is considerably lagging behind in converting the existing knowledge base into state-of-the-art management policy. At present, no governance regime has been developed to control over-exploitation and ensure sustainability in use of the resources which is common property of all. Groundwater is now being over-exploited in Lahore city and though not established but there is probability that its quality is deteriorating due to lateral movement of brackish water to the sweet water aquifers and from deep percolation of waste water through surface spreading and seepage from sewerage and surface drainage system.

The particular single cause for increased use of groundwater is the increasing urban and rural population which is causing substantial pressure on surface and groundwater resources. Main features of the existing status regarding water use in Lahore are as follows:-

- The Lahore city does not have any rainwater or surface water recharge mechanism or entitlement to any river supplies.

- No regulation exists with respect to installation of groundwater pumps and the volume extracted there from by any individual, community or industry;

- Absence of any groundwater model of the aquifer system currently in running position indicates negligence of concerned government departments regarding the up to date health of the aquifer. In this regard it is appreciated that the prediction made based on the groundwater model developed during an M.Sc. thesis has proved to be true. It was predicted that in the years 2000, 2010 and 2020, the depth to watertable is predicted to be 29.8, 41.8 and 57.0 m respectively in the most affected area (Alam, 1994). The prediction made by this model for 2010 is proved to be true in the form of present depth to watertable in the city centre.

3.5 Stakeholders and their Engagement

There are a number of stakeholders working within Pakistan and specifically, the Lahore city and its surroundings. Each of the stakeholders has potential to impact the aquifer and in turn get affected in the form of reduced and costly pumping in future at varying levels and through varied means.

4 CONCLUSIONS AND RECOMMENDATIONS

Maintaining the water balance of withdrawals and recharge is vital for managing human impact on groundwater resources. There is a little evidence that the government agencies particularly the WASA of Lahore Development Authority have re-engineered their capacity and funding to deal with this great challenge. Furthermore, there is no mechanism for allocating groundwater nor regulating its use. Any landowner can install a tubewell and begin pumping groundwater to the extent of his satisfaction. It is urgent that groundwater management, ensuring utilization of safe yield and quality protection, be done through intensive monitoring and enforcement of regulated control over the Lahore aquifers.

Various options for Lahore aquifer management should be designed to achieve the following objectives:-

- Groundwater mining balance can be reduced or even made zero by supply and demand side management. Cost-effective rainwater harvesting and groundwater recharge schemes can help to stabilize groundwater levels.

- Through appropriate adoption of regulation policy and strategic actions such as building recharge structures in Ravi bed for groundwater recharge during wet years, the current worrying situation can be reversed to preserve and improve the groundwater quality and to ensure its availability on equitable and sustainable basis.

The above goals can be achieved by adopting following steps by making the community to treat water as an economic good and achieving control of groundwater abstraction and waste disposal;

- Each and every use of existing groundwater above 0.20 cusecs should be registered with all the allied information regarding his borehole and quantum of pumping;

- Each new user should be required to get a permit before installation of pumping equipment

- Building bye laws should be amended and enforced for private as well as public buildings for achieving maximum possible rainwater harvesting and recharge to groundwater.

- Monitoring of waste disposal at key points should be done to act as guiding tool for finding point sources of major pollution in the surface drains.

- At present about half of the WASA area and most of the housing societies are providing water to it residents at flat rates which is also one of the major reason for wasting the precious groundwater resources, the policy should be forced to change to metered water connections for reducing stress on the underground reservoir.

- Every user of groundwater should be charged with certain amount of groundwater development and management surcharge. The amount so collected should be reserved and used for future development projects in the Lahore city for improved management of the resources, so that sustainability can be assured for generations to come.

- Quantity and quality of waste water disposed off by government as well as private entrepreneurs should be monitored regularly. All these polluters should be given the option either to treat it at source before its disposal in to the drain or otherwise pay extra charges for untreated load by the government installed treatment plant at appropriate location.

- It is recommended that all sewerage being disposed into the Ravi River should be conveyed in to a lined channel built along side the edge of the river bed. This can help reducing the pollution loads to the aquifer.

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