DEVELOPMENT OF SUSTAINABLE STRATEGIES AND PLANS TO COMBAT THE WATER STRESS CHALLENGES IN LAHORE, PAKISTAN

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ABSTRACT: Lahore is a Mega Metropolitan City located in Punjab, Pakistan. With a population of 13 Million people, it is the second largest city in the country. It is located on the alluvial plain of the Indus basin at an altitude ranging between 682 ft to 698 ft above mean sea level. It is bounded by the Ravi River in the Northwest and Banbanwala- Ravi-Bedian-Depalpur (BRBD) Link Canal and its off-takes in the north and east. Ground-water is the only source for domestic, commercial, and industrial use in the city. The unplanned excessive pumpage of ground water is a constant threat to the Lahore aquifer, which is depleting rapidly (Ahmad, 1974; Rosemann, 2005). In 1947 the groundwater depth in Lahore city was 15 to 16 feet which has now depleted to about 150 feet that come to almost 2.50 feet per year. River Ravi has been the major source of freshwater recharging into the Lahore aquifer for millennia, but the hydrological scenario has radically changed over the last few decades (Qureshi and Sayed, 2013; Ahmad *et al*., 2002; NESPAK *et al*., 1987). The Indus Water Treaty of 1960 granted the neighboring country India exclusive rights over the three eastern rivers, including the River Ravi, as a result of which the flows into River Ravi started diminishing gradually. After the construction of Thein Dam on river Ravi in India during the year 2000, the flows in the river have drastically reduced, resulting in depleted recharge to the aquifer around the river. The factors responsible for the depletion of the Lahore aquifer have been enumerated and alternate sources to make up and sustain the water supplies to the metropolitan have been proposed.

Keywords: Indus Water Treaty, metropolitan, urbanization, recharge, groundwater depletion,

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INTRODUCTION

The human population is continually growing day by day and is about to reach a huge figure of about 9 billion people by 2040 (Abbas, 2020; Abbas, 2020a) whereas the population of Pakistan will increase to over 380 million people by 2050 (Mahsud-Dornan, 2007). Pakistan has the world's 4th largest groundwater aquifer over 1,137,819 km2 (Jalil, 2019). However, abrupt use of the groundwaterr due to excessive housing/domestic as well as industrial use has caused a serious threat of depletion of this natural reservoir (Gilani and Hamid, 1960; Kidwai, 1962; WASA, 2013; WWF, 2015). The metropolitan city of Lahore has a population of about 13,542,000 and is the largest city of Punjab which is geographically extended74°01′ to 74°39′ in the east and 31°15′ to 31°45′ in the north over the Asian plate (Muhammad and Zhonghua, 2014). It is the capital of the Punjab province in Pakistan and is intended to become one of the largest cities (42.46 million people) of the world by 2050.

However, almost all the water requirements of the city are met from the groundwater (Khan, 2018). The annual ground water withdrawal in Lahore is about 1161 Million Cubic Meters whereas the recharge to the aquifer has been estimated as 1013 Million Cubic Meters. Thus the recharge is about 15% lesser than the withdrawals (Qureshi *et al*., 2003; Basharat and Hashmi, 2010; Basharat, 2015). The resultant water table depletion has been estimated to be about 0.57 meters to 1.35 meters per year, which varies from site to site. The average rainfall in Lahore is 838.8 mm (PMD, 2015), out of which 75% of the rain falls during the monsoon season spread from June to September. As a result of the Indus water treaty of 1960, the flows in River Ravi, which was the main source of recharging of the aquifer, have reduced drastically, resulting in minimal recharging of the aquifer (Haider & Ali 2010; Haider, 2010; Baqar *et al*., 2013; Moza, 2014).

The population of the metropolitan has concurrently increased by more than 3.41% annually resulting in more and more withdrawals per year. This scenario has created a water table depression in Lahore. Fortunately, the region's aquifer is unconfined. As the water table in Lahore drops with time, the high-level water from the adjoining areas tends to creep towards this aquifer with gravity (Basharat, 2015). While this replenishment looks promising, it is a bitter fact that some of the adjacent areas close to the Lahore aquifer, such as Raiwind and Kasur, have poor-quality brackish ground-water (Kahlon *et al*. 2008; Ahmad, 1995). So there is an imminent danger that with further drop in the Lahore water table, poor quality brackish water unsuitable for domestic and industrial consumption will creep towards Lahore, which will be a perpetually permanent and non-reversible environmental hazard for the metropolitan (Shamsi and Hamid, 1960; Soomro *et al*., 2013; Shabbir and Ahmad, 2015). It is time that appropriate pre-emptive measures be taken to address this threat. Mahmood *et al*. (2011) indicated that in Lahore, rapid increase in population is leading the aquifer towards an irreversible water table depletion.

The conservation of a healthy and sustainable aquifer has two obvious components, i.e., reduction in withdrawals and augmenting the recharges (LDA, 2008). The rapidly increasing population of Lahore city, coupled with the diminishing natural recharges, are the enormous challenges faced by the Lahore aquifer today (Hussain *et al*., 1993). Intelligent planning based on scientific reasoning at the strategic level is essential to face these challenges (Shamsi, 1960). Appropriate administrative measures for the conservation of water (Dwive *et al*., 2017) are the first step in the right direction, and investing in alternate sources for recharging of the aquifer is the second.

It can be observed that during the year 1961-62 the total volume of inflow in the river was about 11 MAF which gradually dropped to less than 1MAF in 2001-2002 and was less than 3MAF during 2011-2012 (see figure1) In the meantime, the population of the city increased from a million to about 80 Million in 2007 as shown in Figure 2 (Sajjad, 2009). Currently it stands at more than 13 Million.

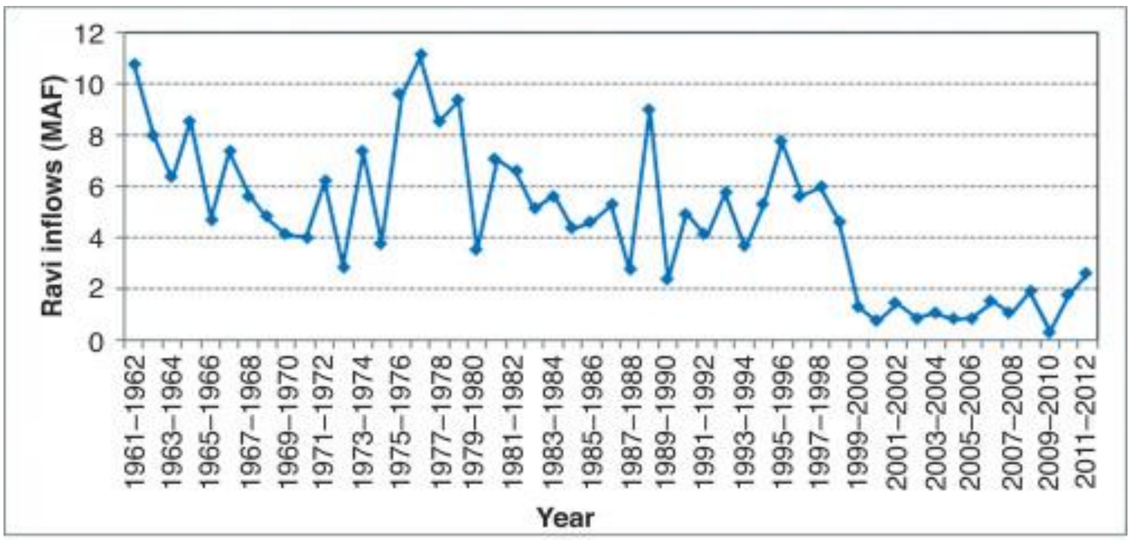

Fig. 1: The River Ravi inflows from 1961-62 to 2011-12:

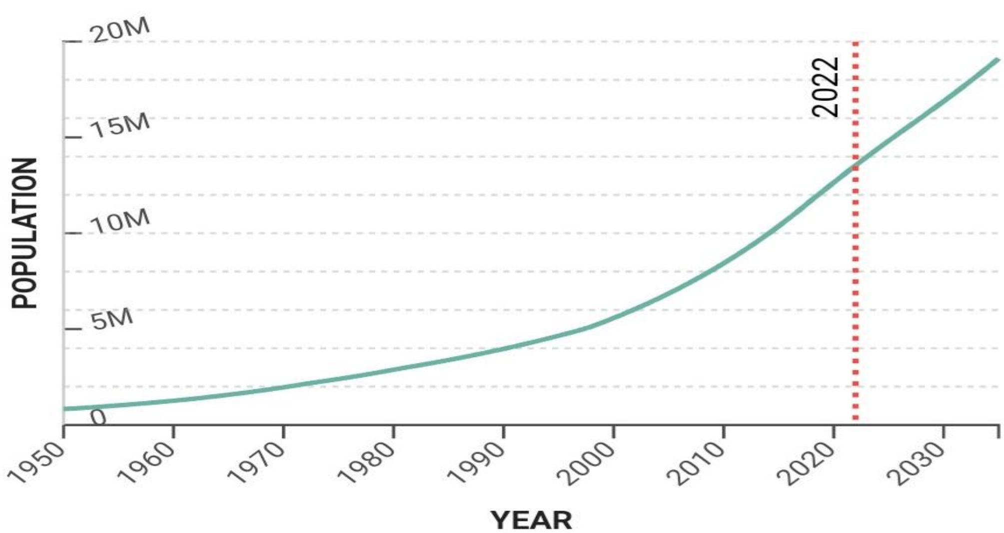

Figure 2: Population of Lahore

MATERIALS AND METHODS

The Study Area: The study area consists of the metropolitan city of Lahore and its surroundings. The location of the study area is shown in Figure 3. Lahore is located on the alluvial plains of the Indus River basin with Ravi River flowing from its north-east to south-west with the natural gradient of 1: 3000. It is located at an altitude ranging between 682 feet to 698 feet above mean sea level. The Indian border lies in its east while the district Kasur lies in its south. Lahore covers a total area of about 1014 square kilometers and is a rapidly growing metropolitan. Geographically the location falls between 31° 15' to 31° 45' North and 74° 01' and 74° 39' East. It is the 24th largest city in the world by a population that currently stands at more than 13 Millions. Alluvium under Lahore is about 1000 feet in thickness and is composed of varied layers of clay, silt and sand. Lenses of clay and silt exist within the alluvium but overall the aquifer is unconfined.

Figure 3: Location of Study Area

The subsoil strata of the area are generally sandy except for thin lenses of clay and silt in the upper layer of 50 feet thickness (Latif and Ahmad, 2009). Permeability of the strata decreases as we move away from the river and increases with depth (Hasan, *et al*, 2013). The metropolitan is administratively divided into 10 towns. The major drain in the area is known as the Cantonment drain into which a number of smaller drains fall. The Cantonment drain eventually discharges into the Ravi River downstream of Lahore City (Qureshi, 1960).

Climatic Conditions: Mean annual temperature of Lahore is approximately 24°Celsius ranging from 36°C in June to 12°C in January. The highest maximum temperature of 48°C (118°F) was recorded on 9th June, 2007 while the lowest temperature recorded in Lahore was -1° C on 13 January 1967. The average annual rainfall recorded is about 838.8 mm which can vary from 300 mm to 1200 mm. The highest rainfall of 221 mm was recorded on 13th August 2008. Approximately 75% of the total annual rainfall occurs in the monsoon season in the months from June to September and contributes about 40 mm to groundwater recharge per year on average (Hasan, *et al*, 2014).

Surface Water Regime: The study area slopes towards the south and south-west at an average gradient of 1 in 3000. The area falls in the Bari doab, the track of land in between the Ravi and Sutlej Rivers which originates from the Indian Punjab and stretches in the south west direction up to the Multan-Bahawalpur region. River Ravi has been traditionally and culturally associated as a part and parcel of the city of Lahore.

After the Indus water treaty of 1960 the annual flows into river Ravi decreased gradually from 7.0 MAF (1922- 61) to 5.52 MAF before the construction of Thein Dam, and eventually to about 1.20 MAF after the commissioning of the dam during the year 2000. A comprehensive irrigation system is present in the study area since 1879, when the Upper Bari Doab Canal

(UBDC), off- taking from Madhopur head-works on river Ravi was commissioned. After the Indus water Treaty of 1960 between India and Pakistan, India gradually stopped the flows in the three eastern rivers, i.e., the Sutlej, Beas and Ravi Rivers. In order to make up the shortages Bambanwala-Ravi-Bedian-Depalpur (BRBD) Link Canal, with the discharge of 4000 cusecs was constructed, off-taking from Marala head-works on River Chenab near Sialkot. This Canal is now providing replacement water to the command area of Upper Bari Doab Canal as well as Depalpur Canal which originally had its head at the Ferozepur head-works.The irrigation distribution system around Lahore consists of the Lahore Branch Canal (403 cusecs), Khaira distributary (141 cusecs), and Bucharkhana distributary (244 cusecs), and some minor channels which irrigate the agricultural lands in the Lahore district. The recharging boundaries of the area are the Ravi River in the north and west, BRBD Link in the East and the Beas drainage channel in the south.

Potential Threats to Lahore Aquifer: The annual groundwater withdrawal in Lahore city is about 1161 MCM whereas the recharge to the aquifer has been estimated as 1013 MCM (Basharat, 2015), which means that a net depletion in the volume of the aquifer is underway. The resultant water table depletion has been estimated to be about 0.57 to 1.35 meters per year which vary from site to site. At the time of independence in 1947, the ground water in Lahore was quite close to the surface sustaining at a depth of about 15 to 16 feet which is a convenient depth for open wells and hand pumps. As the city expanded, the demand of water also increased, and the installation of power-driven tube-wells geared up. The water table depth dropped to 70 feet in 30 years from 1959 to 1989 (Nazir and Akram, 1990; Alam, 1996). Currently the ground water has declined to about 150 feet at many points within the city. The draw-down is the lowest in elevation in the areas where the pumping is maximum owing to the high concentration of population in the area. Another factor which contributes to this unprecedented depression is the large scale of pavement s and construction activities in the city which have reduced the rain water recharging to a great extent. This deep trough under Lahore is likely to draw water from the surrounding high water table zones with gravity over a period of time. The rate of drifting of water being directly proportional to the difference in the elevations. Unfortunately, the areas around Lahore, i.e., Kasur and Raiwind in particular, possess brackish water in their aquifers (Bashie *et al*., 2012). So there is an imminent danger that with a further drop in the Lahore water-table, brackish water unsuitable for domestic and industrial consumption will slowly and surely creep towards Lahore which will be a permanent, perpetual and non-reversible environmental hazard for the metropolitan (Kanwal *et al*., 2015). The threat is frightening to say the least. It is high time that appropriate pre-emptive measures be taken to address this serious threat looming over the horizon. Figure 4 shows the depth contours of the water table in Lahore (Hasan, *et al*, 2014).

At present, there are thousands of government and private tube wells within and around the city which run around the clock. The government tube-wells owned by the Water and Sanitation Agency (WASA), extract clean potable water from a depth of 400 to 600 feet depth with the help of deep well turbine pumps (Khan, 2018). WASA operates 484 tube wells of 2 to 4 cusec capacity which run for 18 hours a day (Khan, 2018, Basharat, 2011). Only 7% of the area served by WASA is billed on a volume basis whereas the rest of the consumers are charged on flat rate.

The local government has least control over the installation and operation of private tube wells.

Management options: Maintaining a water balance between withdrawals and recharge is vital for sustainable groundwater resources in any hydrological system (Priscoli *et al*., 2009). The conspicuous figures of total withdrawals of 1161 MCM per year and recharge figure of 1013 MCM per year for Lahore vividly explain that almost 148 MCM of water is being withdrawn from the aquifer in excess of what is being recharged (Hassan and Hassan, 2016; 2013). The lower recharges have been primarily attributed to the reduced flows in the Ravi River after the Indus water Treaty of 1960 and also the decrease in rain-water recharging due to widespread pavements and other modern construction patterns in the rapidly expanding metropolis. Furthermore, the over-exploitation of groundwater has caused the depression or trough in the water table within the city area which tends to attract brackish water from the adjoining areas towards the city center. So the obvious remedy for the problem is to gradually reduce the city's dependence on groundwater by providing water from alternate sources, and also to replenish the groundwater with fresh water supplies in order to make up the water table depression.

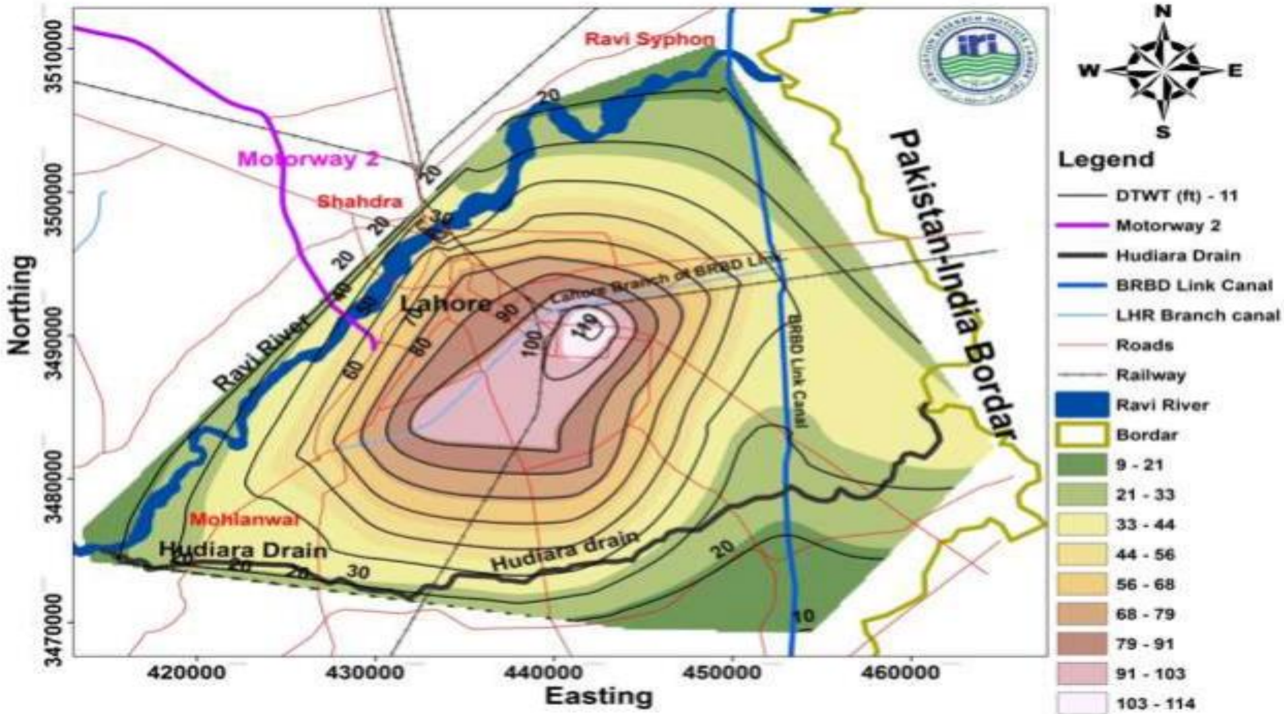

Figure 4. Lahore Water Table Depth.

Freshwater Resources: For centuries the biggest freshwater resource for the people of Lahore has been the Lahore aquifer. Water was traditionally drawn from the aquifer through the open wells. These Wells were gradually replaced by the hand pumps and eventually by power driven tube-wells. With the rapid growth in population of the city, indiscriminate installation of tube-wells also increased with time to meet the water requirements for domestic, commercial, and industrial use. At present, there are thousands of unplanned government and private tube-wells in the city drawing 1161 MCM of water per annum. While groundwater in the city is under tremendous stress and recharging from the River Ravi has also diminished progressively, the following sustainable sources are readily available in and around the city for economical exploitation:

- **The irrigation canal network**
- **River Ravi flows**
- **Rainwater harvesting**

The Irrigation canal Network: The lush green agricultural areas around the metropolitan city of Lahore are irrigated by a comprehensive network of irrigation canals. In fact the Lahore branch canal which of- takes from BRBD Link canal near Jallo village passes right through the metropolitan area (Ahmad, 1993). Freshwater from this canal can be economically tapped for domestic and industrial consumption after necessary filtration and treatment. A sketch of the irrigation network within and around Lahore is shown in figure 5.

The total design discharge of theLahore branch canal is 403 cusecs. The Lahore branch was designed to supply irrigation water to the agricultural areas in the Lahore district and some parts of district Kasur further in the south. With the passage of time the area of Lahore city has expanded outwards and many agricultural areas have been urbanized into residential colonies, commercial estates, and industrial towns (BAtool *et al*., 2019). With the exclusion of these lands from the irrigation command area, sufficient water is available at the canal heads to be used for alternate consumption. The surplus water from the Lahore branch and its distributaries can be conveniently diverted to the adjacent green strips and other appropriate areas for storage and further delivery to the consumers after necessary filtration and treatment (May *et al*., 2013).

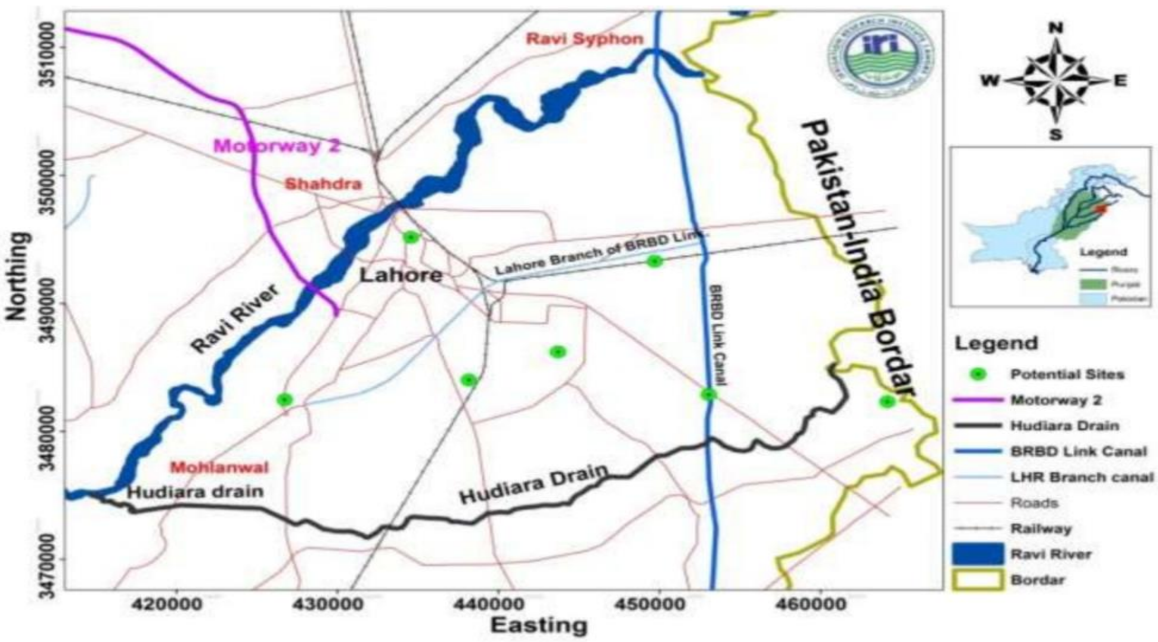

Figure 5: Surface Water Resources

River Ravi: River Ravi has been the life-line of Lahore since the earliest settlements and associated traditionally and culturally with the city in folklore. The river originates in Kangra district of Himachal Pradesh state of India. It enters Pakistan at Jassar in district Narowal and forms the international boundary uptill the Ravi Syphon in district Lahore after which it flows within the territory of Pakistan. River Ravi has been the main source of ground water recharging into the Lahore aquifer since time immemorial. In provisions of the Indus Water Treaty of 1960, the exclusive use of three eastern rivers, i.e., Ravi, Sutlej and Beas was accepted for India, whereas the right of use of the three Western rivers, i.e., Indus, Jhelum and Chenab was accepted for Pakistan. The water lost in the three eastern was agreed to be compensated from the western rivers by providing link canal of the appropriate design.

Eventually, in accordance with the Indus water treaty, India closed the waters of the eastern rivers and started constructing its own hydraulic structures on these rivers. India completed the Thein dam on river Ravi in the year 2000 after which India has established it control on River Ravi. Only surplus water is now occasionally received from India and that too at the end of the flood season.

The lost water of Ravi River is now being replenished by the operation of Marala Ravi Link Canal during the kharif season and only small quantities of seepage water and leakages down-stream Madhopur head-works are received at Ravi Syphon / Shahdara bridge during the Rabi season. These lean flows can be usefully harnessed for seepage purposes by compounding the water in the form of a shallow reservoir or lake upstream the Ravi railway bridge, or preferably upstream the Mahmood Booti drain for environmental reasons (Ayesha , 2011). This will be a perennial lake refreshed by the continuous low flows even during the Rabi season. As the natural slope of land in this area is about one in three thousand, therefore a lake of about Two Thousand and Four Hundred feet in length can be created with the heading of just eight feet of water which will ensure continuous seepage of fresh water into the aquifer. While expensive concrete structures can be an option, the low cost Rubber dams, suitable for low head compounding can be an economical option. These easily transportable water filled dams are made of durable rubber fiber and have a reasonably long life. A view of a rubber dam is shown in Figure 6.

Rain-water harvesting: Rain water harvesting is an arrangement in which the rain water is efficiently collected and stored in a natural or specifically designed facility for further utilization. These facilities may include small tanks or vessels; or larger facilities like depressions, deep pits or even the ground water aquifer using infiltration mechanism.

Figure 6: A Typical Rubber Dam

Rain water harvesting in urban areas not only preserves precious water but at the same time it's a means to avoid urban flooding, overflowing of drains & nullahs and choking of sewerage systems (Qayyum, 2019; Postel *et al*., 1996). Rain water in its purest form is free of minerals, pollutants and pathogens and can safely be used for ground water recharging by adopting suitable measures (Farooqi *et al*, 2006). Like other urban areas, rain-water can be efficiently harvested in Lahore to supplement the other water resources. Field investigations have been carried out in Lahore to identify the potential sites for artificial recharging of ground-water by rain-water harvesting (Hussain, *et al*., 2019). The recharging sites have been selected after detailed physical, topographical, and geological surveys (Hasan, *et al*, 2014). These are the areas where rainwater is collected naturally (Hussain *et al*., 2019), especially in depressions. Irrigation Research Institute of the Irrigation Department Punjab has identified 07 sites in Lahore for artificial rain-water recharging. Basic calculations of Roof-top Rainwater Harvesting (not counting the wastages) are given below for a small house with a concrete roof of an area of 50 sq meters.

Area =50 sq meter

Average annual rainfall in Lahore =838.8mm =0.838meters

Available water per year =50*0.838= 41.9 cubic meters =41900 liters

Management Options/ Conclusions

1. The population of Lahore Metropolis is increasing at a current growth rate of more than 3% and the boundaries of the city are expanding rapidly. Hence a requirement for more and more water. The major reason for this expansion is the migration of population from rural areas to the city in search of jobs, quality education and better lifestyle. Creating jobs based on local agriculture and natural resources, and providing modern day facilities in the rural areas has to be planned at the strategic level to slow down the present pace of migrations.
2. Wastage of water in the urban area has to be curtailed strongly by appropriate legislation in coordination with the stakeholders. This includes the removal of the flat rate policy by WASA under which only 7% area served by WASA is billed on a volume basis whereas the rest pays a fixed bill on flat rates. This encourages wastage.
3. The authorities have continuously failed in checking the unplanned installation of tube walls in the area. Therefore, the sale and use of ground-water exploration and extraction equipment and pumping machinery have to be regularized in order to monitor the installation of tube wells.
4. Installation of new tube wells within and around the metro areas should be documented.
5. There are hundreds of registered and unregistered housing societies within and around the Metropolis. Their registration should be tied up to the provision of ground water recharging, and the provision of low-level parks and open spaces.
6. Vehicle service stations should be regularized. These stations should be encouraged to use water saving equipment including appropriately designed nozzles to save water. There should be provisions of carriage of the used water to nearby parks for irrigation purposes.

7. Building bye-laws should be amended to encourage roof-top rain harvesting.
8. A small low level weir of appropriate self-flushing design upstream of the Mehmood Booti drain may be constructed in the river Ravi to compound fresh river water to supplement year round seepage and recharging of clean fresh water into the aquifer.
9. Sufficient quantities of fresh surface water is available within and around the Lahore city running in the extensive irrigation canal network. These channels currently possess surplus water which can be used not only for direct water supply to consumers after necessary treatment but also for recharging of the aquifer through established mechanisms. The canal water is free of harmful Arsenic and can be supplied to purpose-built reservoirs and artificial lakes not only for seepage and fresh-water recharging but also for recreational purposes.

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