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ORIGINAL PAPER

Sustainable harnessing of the surface water resources for Karachi: a geographic review

Muhammad Irfan[1] · Syed Jamil Hasan Kazmi[1] · Mudassar Hassan Arsalan[2]

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Abstract
Water resource management has now become the most important challenge in developing countries, especially, in an arid part of the world. In the case of Karachi city, the situation is getting worse day by day due to haphazard urban development, climate change, and an inadequate supply of fresh water. This paper reviews various published research articles and reports regarding Karachi water resources, supply, and demand. The city of over 20 million people has scarce local water resources and imports most of its required water from Indus and Hab Rivers. The city is undersupplied as its rationalized water demand is around 1250 million gallons per day (mgd), while receiving only 650 mgd. Another water source, Hab Dam, which is planned to supply 100 mgd water to the city, is highly uncertain due to intermittent drought conditions in the region. The mega city is facing a water scarcity problem very seriously because of the phenomenal growth of the population and the shortage of a water supply. Subsurface geology and surface topography are favorable to store water in dams and recharge the aquifers. However, over-extraction of water, scarcity of rainfall, sand and gravel excavation, and lack of groundwater recharge infrastructure have depleted the precious resource. There is an urgent need for a comprehensive city development master plan for future growth of the city with clear-cut priorities, policies, and implementation framework. Water sector should holistically be addressed by considering climate change, rapid urbanization, population growth, and perpetual increasing demand from all sectors including industries and agriculture. Besides the development of sustainable policies at the local government level, overall governance, administration, and management need to be improved which may implement the best practices and regulations.

Keywords Water resources · Catchment · Surface water · Flood · Climate · Runoff · Dams

Introduction

Human beings cannot survive for more than a few days without water. World water crises are increasing as the population is growing globally. Due to freshwater scarcity, it has now become a very serious challenge. Pakistan is fortunate enough having Indus River system but alike other 33 countries of the world, it has to depend on neighboring countries for water sharing (FAO 2003). It has world's biggest glaciers and receives rain from South Asian monsoon and western disturbance systems. It has a widespread canal network over an area of 796,095 km^2 on that its economy is based. However, it is also facing a big challenge of water scarcity due to uncontrolled population growth (Ihsanullah 2009). On the other side, Pakistan's water storage capacity is only for 30 days, while India has the ability to store water for 120 to 220 days. Whereas Egypt has 1000-day storage capacity only on Nile River, America has 900 days on Colorado River, Australia has 600 days, and South Africa is also capable of storing water for 500 days on Orange River (Mustafa 2012).

In order to meet the demand of water for domestic and commercial use, societies are getting huge quantities from rivers, lakes, wetlands, and underground aquifers to fulfill the need of cities, industries, and farms (Flint 2004). However, in the past few years, there has been a growing interest on watershed management. Many organizations, associations, institutes, and local government authorities are increasingly using the watershed boundaries in order to manage

✉ Muhammad Irfan
irfan.ggr@gmail.com

[1] Department of Geography, University of Karachi, Karachi 75270, Pakistan

[2] Geoinformatics and Sustainable Development Research Lab, Institute of Space and Planetary Astrophysics, University of Karachi, Karachi 75270, Pakistan

and implement water resource programs. “A watershed-based management approach is needed for drinking water, wastewater, and stormwater services to ensure integrated, sustainable management of water resources” (EPRI et al. 2010).

Across the world, urban areas are more susceptible to be hit by water crises and may impact the huge number of population and economic activities (Hellström et al. 2000). Sustainable water management has become the key to respond to the challenges associated with environmental degradation, rapidly growing urban populations, and the impacts of climate change (Brown et al. 2009). In the twenty-first century, urban population has surpassed the population living in rural areas and made the cities of the world focus on more sustainable practices (Birdsall et al. 2001). As increasing urban communities looking for to reduce the effects on under-pressure water resources, a growing challenge is to develop resilience to the effects of climate change, specifically for secure water availability for the cities (Brown et al. 2009).

This paper presents the case of Karachi as a typical megacity of South Asia which is continuously experiencing a huge influx of migrants since 1947. This paper examines the water demand and available water resources and discusses the water management challenges for one of the most populous cities in the world.

Water demand and supply for Karachi

Karachi water and sewerage board (KW&SB) is the main urban water management organization but not providing the up to the mark services to its customers (Ihsanullah 2009). Its performance is always questionable due to inequitable, intermittent, and irregular water supply, with about 60% of the city households being connected to the supply network (JICA 2008). It operates with only 12 water hydrants to distribute water in the megacity. Its supply is critically insufficient and compels consumers to get the unmet demand from other sources such as low-quality groundwater or privately supplied water through water tankers (Ahmad and Burki 2015).

The Karachi population was estimated to be about 400,000 at the time of Indo-Pak partition in 1947 (CDGK 2007). It has become around 20 million in 2015 and is expected to be around 25 million in 2020 (Anwar 2012). Ihsanullah (2009) estimated urban water demand for 2009 as 853 million gallons per day (mgd) when the population of the city was approximately 15.8 million. To fulfill that demand, city water infrastructure was capable of supplying 650 mgd but it was receiving 20 mgd less (≈ 630 mgd) from all possible sources (JICA 2008). In 2009, the deficit was 223 mgd which is still growing, and as of 2017, water demand for the city has increased up to 1250 mgd with around 50% deficit. This demand further increases when Hab Dam dries and unable to contribute 80 to 100 mgd into the system (Zia 2015).

Water resources for Karachi

The Indus River

The Indus River system is the backbone of water resources in Pakistan. This system and its tributaries bring on an average 154 million acre-feet (maf) annually (Ahmed et al. 2007). The Indus River is the main source of water for Karachi (JICA 2008). Currently, Karachi metropolitan area is getting water approximately 550 mgd from Indus, which is almost 85% of the total water supplied to the city (Ihsanullah 2009). This water is taken from the Kotri Barrage (located approximately 156 km away in the northeast of the city) and discharged through the Kalri-Baghar Feeder Upper in a southeast direction to Kinjhar Lake (located at 134 km away from the Karachi city in the east).

Kinjhar Lake

Kinjhar Lake is a natural water reservoir, having a catchment area of about 910 km^2 and the usable water storage capacity of about 390,000 acre-feet (acft) (JICA 2008). This lake is extended over the area of 135 km^2 at 70 m above mean sea level (Fig. 1). Kalri-Baghar Upper canal feeds the lake with the water from River Indus. However, the lake also collects runoff water from the area between the Baran Nai basin and the Malir River through Shohar Nadi and Kalu Rivers and many small water channels. The Kinjhar catchment area extends north to the Karachi-Hyderabad National Highway. It has a natural depression, and its storage capacity has been increased by about 20 km of embankments with maximum heights of 9 m. Because of excessive seepage through the southern part of this embankment, the current top water level of the lake is held at about 51.6-ft reduced level (RL), providing a maximum usable storage (down to 41-ft RL) of 125.45 ha. Raising the top water level to its original design value of 54-ft RL increases the usable storage to 157.8 ha (Kazmi et al. 2015). Kinjhar Lake serves the agricultural land of District Thatta via Kalri-Baghar Lower and Karachi via KDA and K-II canals and conduits (Ihsanullah 2009).

K-IV project: bulk water supply from Indus River

By realizing the growing demand of water in Karachi city, the KW&SB is expending water supply system with an additional 650 mgd, known as K-IV water supply project (Fig. 1), which will supply additional water from the Indus River through Kinjhar Lake by a different route of approximately 130-km length. The main components of the project include canals, two-phase pumping, three urban water storage reservoirs, and links with existing networks.

Primarily, the supply system is proposed with the capacity of 2000 mgd to Karachi in phases for meeting the future water

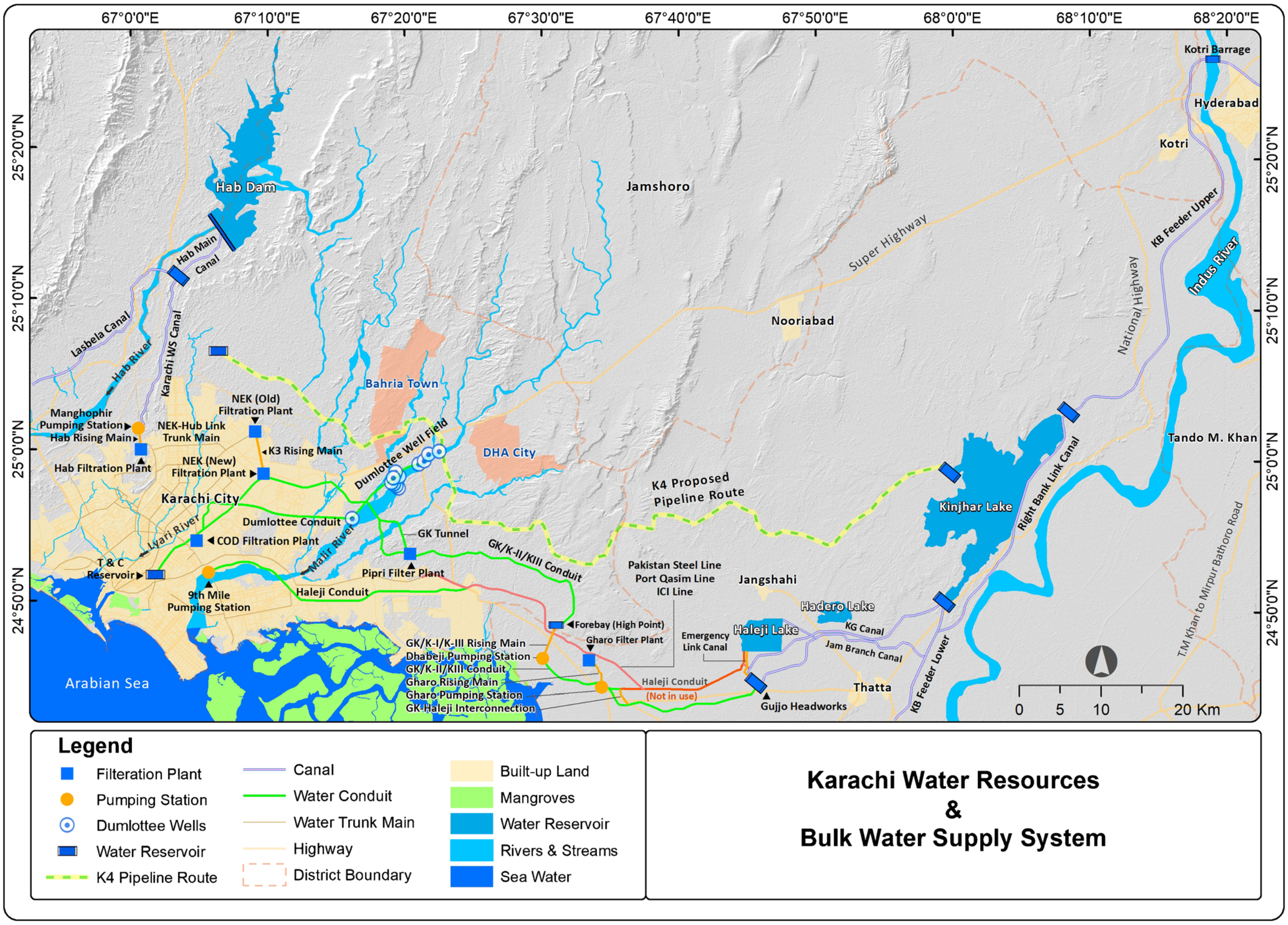

Fig. 1 Showing Karachi water resources and their distribution (modified after Ihsanullah (2009))

demand of Karachi for 50 years (Kazmi et al. 2015). Its current phase is in construction stage with the designed capacity of 650 mgd, which will cover the immediate and short-term water demand.

Surface storm water resources

The basin of Karachi is drained by the three major rivers, i.e., Hab, Malir, and Lyari Rivers and their tributaries. The Malir River and Lyari River contributed the most of the stormwater because they are located within the city, while the Hab River lies in western part of Karachi city which ultimately drained in the Arabian Sea, at the western border of Karachi city district.

Hab River

The Hab River is the second largest water supply source for Karachi; it serves the population of about 5 million people (Anwar 2012). However, this river partially fulfills the water supply demand of the city and Hab Industrial State (Sadaf 2014). The River shares the boundary between Sindh and Balochistan. The catchment of Hab River is located in the north of Karachi in Balochistan province of Pakistan, spreading over 8832 km^2 (Fig. 3). Its major part is out of the administrative area of the city, mountainous, long, and narrow. Average annual precipitation in the catchment area is about 194 mm, which indicates an arid climate. Therefore, a major portion of the Hab River catchment area is barren with scanty natural vegetation. Cultivation is limited to only the river plains where sweet groundwater is available for pumping. Most of the rock types consist of limestone, sandstone, conglomerates, and shale of different ages, while the soils are strongly calcareous and non-alkaline (Abulohom et al. 2001).

Malir River

Malir River is another major river of Karachi basin. It carries surface runoff and sediment load in the rainy season. This river mainly is formed by the confluence of the Khadeji River and Mol River, while Konkar, Sukhan, and Thaddo tributaries join it at the lower reaches. The catchment area of Malir River is about 2254 km^2. The Mol, Khadeji, Jarando, Langheji, Bazar, and Thaddo are the main streams which discharge surface runoff and hill-torrents water into the Malir

River. This river passes through the densely populated areas of Karachi city (WAPDA 1990; Bakhsh et al. 2011). After passing through Gizri creek estuary, it finally discharges into the Arabian Sea (Fig. 3). The average rainfall in the catchment area is about 217 mm, and maximum rainfall is in July. Whenever the area receives heavy rain due to tropical storms or monsoon, a heavy runoff discharge is recorded. In the past years, severe floods have been monitored in Malir River floodplain (Ghazal 2012).

Malir River and its tributaries have a great potential for rainwater harvesting. Rainwater harvesting through indigenous bunds is a practice in the area for the last 300 years. The agriculture in the study area is rainfed and totally dependent on seasonal rains. These bunds serve as a reservoir for one season and also charge the underground aquifers gradually. During the last 25 years, the government of Sindh has added many small check dams for the recharge of groundwater.

The Mole and Khadeji Rivers contribute the maximum runoff to the Malir River due to the large size of sub-catchment areas, land use, land cover, and soil types (Fig. 2 and Table 1). The topography of these rivers has potential to store runoff water, as they have high ridges across the river valley that may be used for small dams.

Lyari River

The Lyari River originates from the foot-hills of Kirthar Range at the point of Manghopir. Its catchment area is about 578 km^2 (Fig. 3). It has a shorter length, i.e., 180 km, and a smaller number of tributaries. Mokhi Nala, Orangi Nala, and Gujro Nala are the main tributaries which discharge surface runoff to the Lyari River. Similar to other rivers of Karachi region, it is a non-perennial water channel that flows when the rain falls in its catchment (Hassan 2004). However, it passes through the urban areas of Karachi where it carries untreated sewage and industrial waste to the Arabian Sea throughout the year (Akhtar and Dhanani 2012; Haq 1971). This river accommodates about 50 slum areas of approximately 0.8 million people along both sides, which remain vulnerable to inundation during heavy rainfall season (Mansoor and Mirza 2007).

Table 1 Sub-basin contribution to Malir River watershed

Sub-basin	Area (km^2)	Avg. runoff (1000 m^3)	Contribution (%)
Mole basin	608.1	95,038.6	32.8
Khadeji basin	548.6	82,092.7	28.3
Thaddo basin	320.2	46,092.7	15.9
Sukkan basin	194.0	26,375.8	9.1
Langheji basin	131.4	17,861.3	6.2
Jarando basin	79.5	12,254.8	4.2
Malir sub-basin	85.8	9958.5	3.4

Development of dams

Dam construction on rivers is considered a significant measure to reduce the rate of floods and store the water for its legitimate use. The Hab Dam is the third largest water storage reservoir in Pakistan. This dam was built on the Hab River between the provincial border of Sindh and Balochistan by the Water and Power Development Authority (WAPDA) in 1981 (Ahmad 2008) (Fig. 4). It is located at about 50 km to the northwest of Karachi city. It is one of the main water sources for Karachi city (JICA 2008), although it is a multi-function dam which was built on the Hab River to be used for urban, industrial, and irrigation purposes.

The Karachi urban area receives about 63.3% of the total water discharge from the dam via Karachi water supply canal with a designed discharge capacity of 210 cufs (WAPDA 2015). The water supplied to Karachi from the Hab Dam is around 100 mgd which varies due to drought season in the area. The peak or spill level of the dam is 339 ft, and the reservoir storage capacity is about 0.6 maf. It supplies water

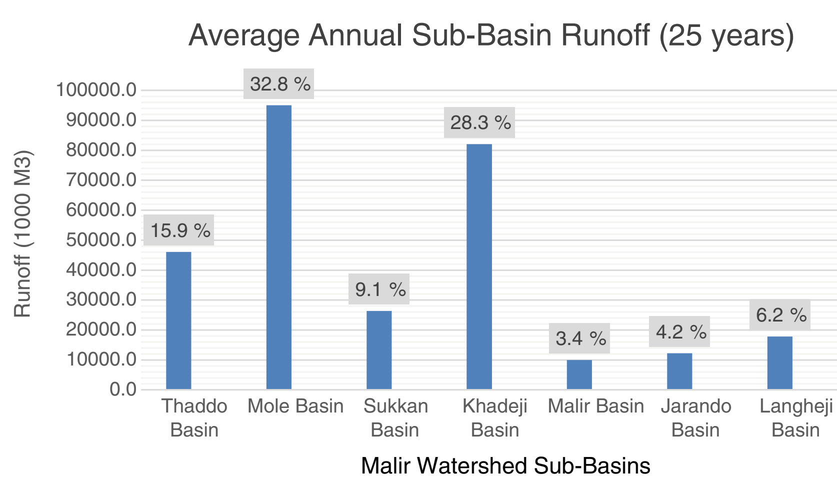

Fig. 2 Average annual sub-basin runoff

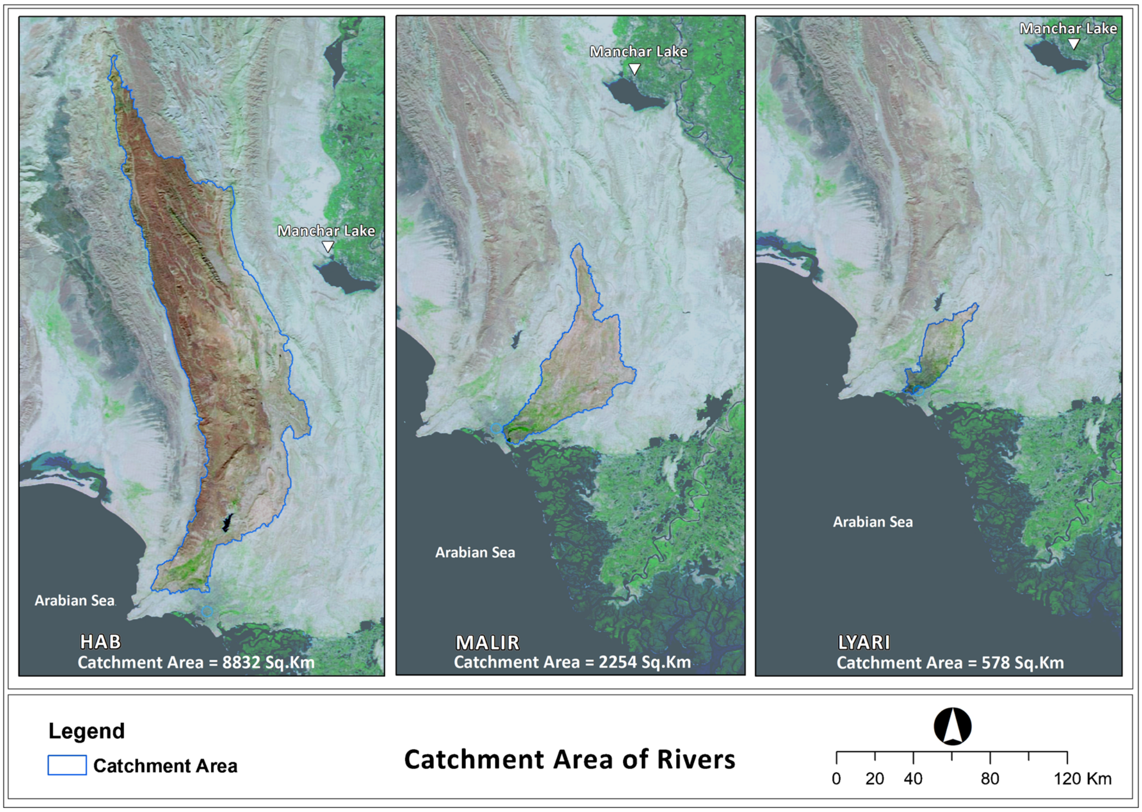

Fig. 3 Geographical locations of river (Hab, Malir, and Lyari) catchment areas

to Karachi only when the water level crosses the 300-ft mark (Hasan 2015).

Malir River and its tributaries discharge the highest amount of flood water from land area to the Arabian Sea. The feasibility reports have been prepared for multiple dams on tributaries of Malir River. In 1994, the only small dam was constructed on the Thaddo River named Thaddo Dam (Figs. 4 and 5). Two proposed dams on the Mol River and Khadeji River were also studied, which contribute a chief amount of discharge water into the Malir River but have not been considered for construction yet. Another small dam is built near Sona pass (Hawks Bay) on a seasonal hill torrent stream (Fig. 4). However, there is great potential and urgent need of small dams on the streams like Jarando, Langheji, and Watanwari for flood control and groundwater recharge (Akhtar and Dhanani 2012).

Groundwater resources

Karachi city has a unique geology, surrounded by mountains from three sides and the Arabian Sea in the south. Geologically, Karachi region is located in the southern part of the Kirthar Fold Belt (Hunting Survey Corporation 1960; Kazmi and Rana 1982). The area is underlain by Nari and Gaj Formations of Oligocene and Miocene ages, respectively (Pithawalla and Martin-Kaye, 1946). This depositional basin was formed by uplift of the surrounding area in the southern part of Kirthar Fold Belt during Himalayan Orogeny (Niamatullah and Imran 2012). Table 2 provides the potential aquifer lithology in form of layers of sandstone and fractured limestone.

The main contribution to the groundwater recharge directly by local rainfall is very small due to the low frequency of rainfall events. On the other hand, the quality of groundwater in Karachi is also not good and highly variable (Mashiatullah et al., 2002a). It is non-saline near sources of recharge, i.e., rivers and small recharge dams, but becomes saline as the depth or distance from the recharge source increases (Bhutta et al. 2002). During the last two decades, a rapid decline in the water table has been observed due to the over-utilization of groundwater and inadequate recharge of the aquifer system (Memon et al. 2011). Large-scale withdrawal of groundwater is creating differential zones, resulting in lateral and vertical movement of saline water into fresh water zones (Mashiatullah 2009). Khan and Bakhtiari (2017) strengthened the idea and concluded that groundwater aquifer near DHA and Korangi area which is 1–5 km away from the coast is found fully contaminated by seawater intrusion. On the other hand, untreated industrial effluents are released directly at various locations in the Malir and Lyari Rivers to drain the wastewater to the Arabian Sea (Memon et al. 2011). These rivers are recharging underlying aquifer with high levels of contamination (Mashiatullah et al., 2002b).

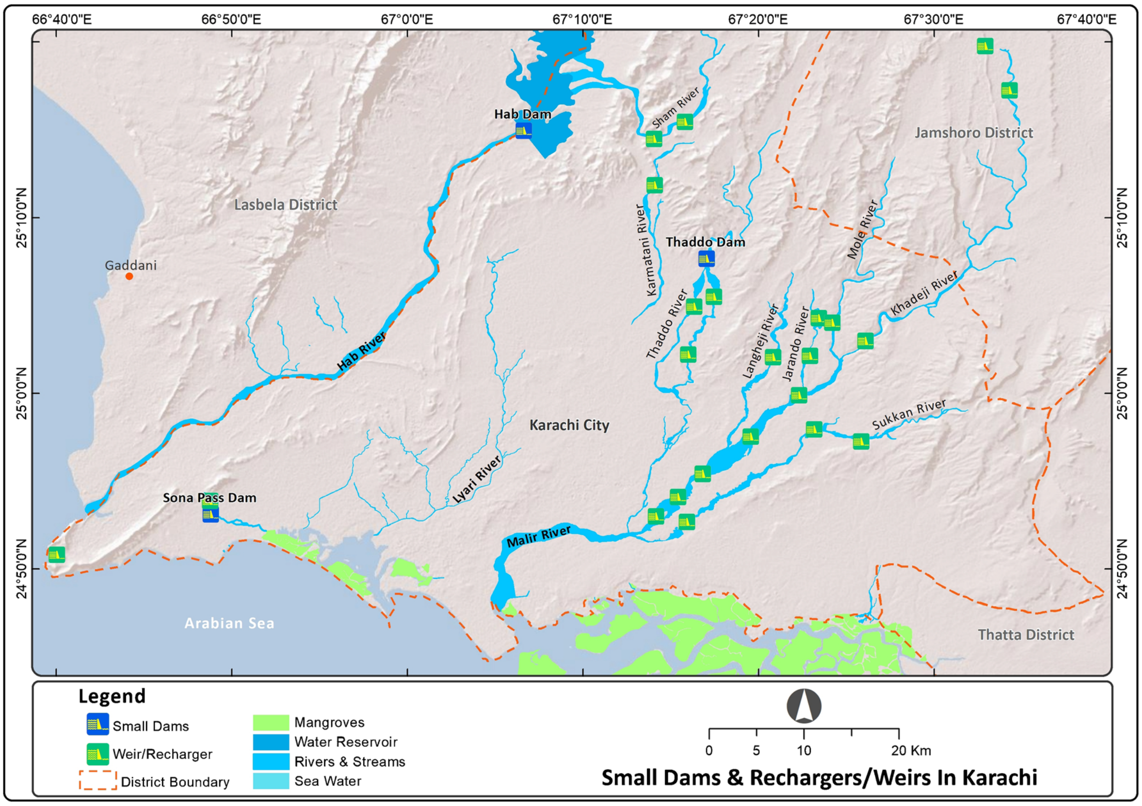

Fig. 4 Small dams and weirs/rechargers, which have been built on the rivers and on their tributaries (Karmatani Lat, Kharnai, Thaddo, Khadeji, Langheji, Sukkan, and Malir River)

Another issue which is impacting directly to the aquifer recharge in Karachi is extensive sand and gravel excavation activities in the river beds. Sand and gravel on river bed are considered as a permeable layer which infiltrates water in the strata and acts as a water-bearing medium. According to an estimation, most of the river beds have now been excavated up to the depth of 20 ft (Ghazal et al. 2013). Therefore, in absence of sufficient sand and gravel in river beds, most of the rain-waters discharge directly into the Arabian Sea without recharging the groundwater of the area (Anwar 2014). Furthermore, the underground water levels fell from 20–30 to 300–500 ft, leaving abandoned agricultural areas and subsequently poverty and unemployment in the area.

Dumlottee well water supply scheme

The Dumlottee wells were constructed in the era of the British Government after the latter half of the nineteenth century on the banks of Malir River. The wells are located in the Dumlottee area about 30 km to the northeast of the Karachi city. A number of large-diameter wells were built and provided about 8 mgd of water to Karachi city via gravity conduit (Fig. 6). For many years, this well-field has served as the main source of water for Karachi city. However, with the passage of time, a gradual decline has been observed in the water supply of this system to 4 mgd in 1985, and in 2008, it was only 1.4 mgd (JICA 2008).

Dumlottee wells were the main source of water for Karachi city before the Indo-Pak separation. Villagers utilized the water for daily domestic and cultivation purposes. With the passage of time, the water table declined due to excessive water usage with the increase in population (Pithawala and Marten-Kaye 1946; Hamid 2011). In addition, excessive sand and gravel excavation from the beds of upstream channels and low rainfall due to climate change are the other main factors (Hasan 2013).

Domestic, agricultural, and industrial groundwater extraction

It has been projected that urban water demand, including industrial demand, will rise by 95% from 2001 to 2025 (Siegmann and Shezad 2006). Major cities of Pakistan are already facing problems of groundwater extraction and lowering of the water table (Ahmad et al. 2003). In case of Karachi, groundwater usage is being increased considerably due to the acute shortage of water supply from KW&SB. In 1960–1980, the depth of water wells along the banks of Malir River was about 20 to 25 ft, but now, it has increased to 40 to 60 ft (Khattak and Khattak 2013). The water table will further drop in the future because of excessive groundwater usage using boreholes and wells.

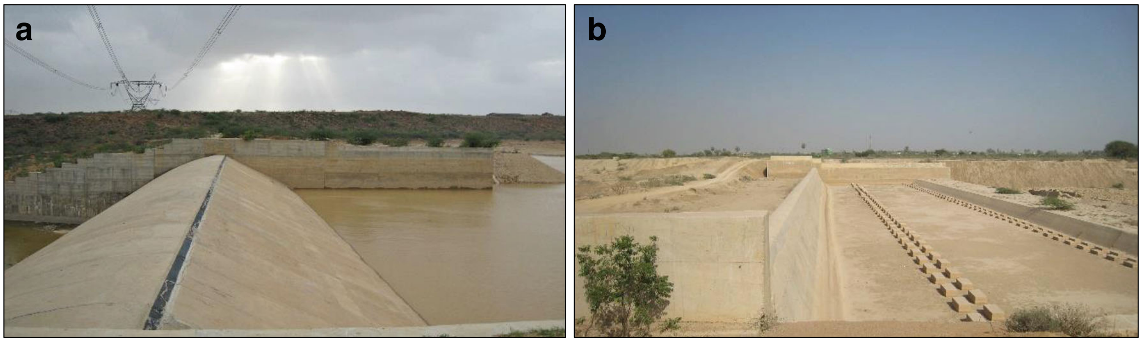

Fig. 5 **a**, **b** A view of small dam (Thaddo Dam) and weir/recharger (on Malir River)

The city required 1250 mgd of water for its domestic, commercial, and some industrial use. Ihsanullah (2009) provided the distribution of 650 mgd supplied water to the city at around 55 to 60% for domestic, 5% for commercial, and 5% for industrial, and 35% is lost in leakages. Major industrial units and agriculture farmers in Karachi arrange their water sources on their own, e.g., Pakistan Steel Mill and ICI industries bring water from Kinjhar separately via their own water system (Kazmi et al. 2015), while many industrial units and agricultural farmers heavily depend on local groundwater sources (Ghazal 2012). Some water-selling companies extract, process, and sell groundwater at a very high commercial cost in bottles.

Generally, the groundwater quality in Karachi varies but in some areas, chemical parameters are significantly higher compared to the recommended limits of WHO (WHO 1994; Khattak and Khattak 2013). Karachi receives a low amount of precipitation about 250 mm per year and sewage in downstream is the main source of groundwater recharge (Panhwer 2011). Due to declined water level, scarcity of rain, quality of groundwater, and high cost of desalination, Japan International Cooperation Agency (JICA) (2008) concluded that there is no feasible prospect to develop groundwater resources for combating increasing water demand of the city.

Discussion

Urbanization

Uncontrolled population growth and poor city administration have made urban sprawl a big challenge. Due to the growth of infrastructure and buildings, the absorption capacity of soil has been reduced while the surface runoff amount has increased. In most of the city, the stormwater drains and sewerage have same water outlets. The domestic sewage and polluted water from industries are being discharged into the natural water channels. Due to poor implementation of land use plans and building control bylaws, most of the natural drainage channels and low-lying areas which were left as open lands in the city have been converted into settled land and slum areas (Anwar 2012). Urban development and encroachments alongside the river beds have increased the risk of flooding in Karachi city.

Karachi, one of the largest cities in the world, does not have any master plan which can direct the development of the city. Many attempts have been made in the past and the most recent one was the Karachi Strategic Development Plan-2007 (CDGK 2007). However, KSDP-2007 is only considered as a city evaluation and proposal document

Table 2 Geological formation and lithology of Karachi and surrounding areas

Age		Formation[1]	Formation (new literature)[2]	Lithology
Period	Epoch			
Quaternary	Pleistocene-Pliocene	Recent	Recent	Sandstone, shale, and conglomerate
Tertiary	Miocene	GAJ	Mole	Limestone and shale
				Rectal limestone
			Mundro	Shale and limestone
	Oligocene	NARI	Orangi	Sandstone and shale
				Rectal limestone
				Siltstone and shale
			Pir Mangho	Limestone, shale, and sandstone
			Hab	Sandstone, shale, and limestone

Modified after Niamatullah and Imran (2012) and Pithawalla and Martin-Kaye (1946)

Fig. 6 a–c A view of Dumlottee well (inner and outer view)

without any legal worth. As a result, the whole city is being developed and administered on an ad hoc basis. Mushroom growth with the increasing burden of slums is on the rise. Water supply is always a part of a comprehensive city master plan, which is totally missing. City District Government Karachi (CDGK) (2007) and JICA (2008) evaluated the alarming situation of water for the city 10 years ago. Although K-IV started after those assessments but "What is after K-IV?." K-IV project is proposed for 50 years; however, in more than a decade, it has just started for meeting the current water requirement of domestic users which is estimated as 1250 mgd. In next 5 years when the project will commence the supply, the demand will be increased quite proportionately. There is no further plan known to the stakeholders or shared with the public for future challenges.

Climate change

Climate change has been a serious debate for the past years. The world is getting warmer and intense weather conditions have increased in the past few years (Anwar 2012). Future changes in the magnitude of climate (increase in surface temperature and in rainfall events) projected by the most global climate models would cause a severe impact on water resources, agriculture, forestry, fisheries, coastal lands (sea level rise), and human settlements. In Pakistan, there is a consistent rising trend in mean surface temperature from the beginning of the twentieth century, i.e., 0.6–1.0 °C, in arid coastal areas. Pakistan is one of the countries where the condition is highly vulnerable in climate change perspective because a major part of its economy is heavily based on climate-sensitive sectors like agriculture and forestry (Farooqi et al. 2005).

Effects observed from climate change include intense heat events which are predicted to become more extreme, more frequent, and long-lasting over the most regions (Habitat 2011). Karachi has recently faced a severe heat wave in June 2015 (Fig. 7), when the temperature went as high as 45 °C (Haider and Anis 2015). It caused more than 1200 deaths in Karachi. The heat wave is one of the symptoms of global climate change, aggravating in the result of deforestation, expansion of asphalt highways, and rapid urbanization (Wasif 2015). This urbanization has put the Karachi urban at increased risk in the form of urban heat island effect and air pollution, due to increasing vehicle usage.

The scale of these effects will be higher due to the change in climate. In extreme heat events like a recently faced heat wave, a great pressure is exerted on water supply sources. Karachi is already a water-stressed city and needs to develop and manage its water resources. As a result of projected climate change, more extreme and frequent heat wave events may occur in the future (Chaudhry et al. 2015).

According to Anwar (2012), "A new paradigm in water resources management has to be envisioned by working with a basket of options for improved service provision and institutional reforms." Karachi is a city where rainfall is highly unpredictable (Fig. 8). Farooqi et al. (2005) stated that there is a "need to develop and implement incremental adaptation strategies and policies to exploit no regret measures and stressing the importance of considering climate change in planning, designing and implementing development activities."

Flooding

The city faces the threat of floods after a rainstorm or torrential rain in the rivers' catchment. There are densely populated slum settlements and some industrial units along the banks of rivers. As the catchment of the Malir River is located in Karachi city, Mol River and Khadeji River join it in upper reaches and carry their runoff water in Malir River. Similarly, the Gujro Nala and Orangi Nala drain-out their runoff water to Lyari River. Finally, both rivers drain water into the sea (Bakhsh et al. 2011). Whenever there is a coincident to occur between heavy rainfall and high-tide periods, then rivers fail to discharge their water into the sea due to sea level rise. In 1977, historic worst flooding was an example of this phenomenon. Intense flooding occurred in Karachi city in 1944, 1961, 1967, 1970, 1977, 1994, and 2007 (Fig. 9).

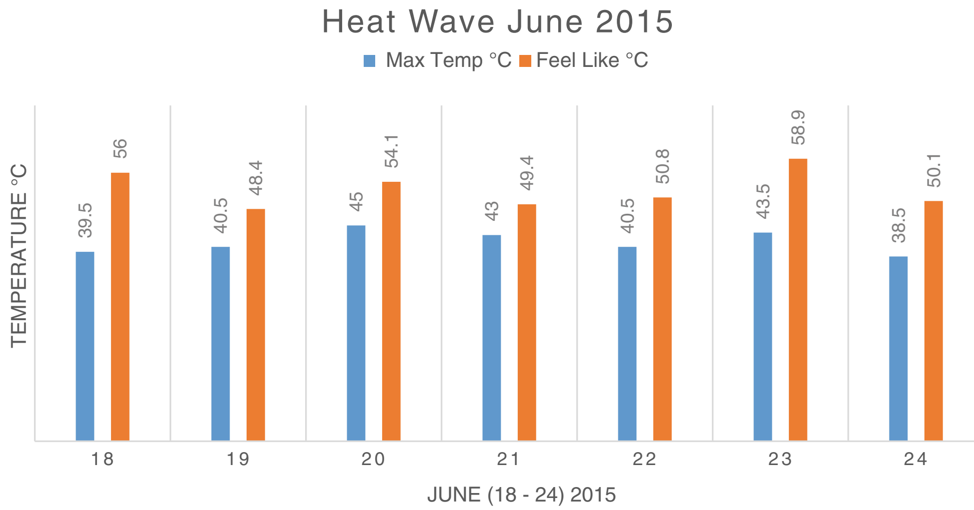

Fig. 7 Graph showing extreme heat wave event in June 18–24, 2015

According to WAPDA (1990), the 1944 flooding occurred due to intensive discharge in the Malir River. The probability of flooding has become higher since then because of encroachments and major blockages in and around the plains of drainage basins. In 1977, the high flood occurred due to the encroached river banks and illegal settlements on the river bed of Malir River. There are many densely populated slums which have been developed such as Azam Basti, Kashmir Colony, Rehman Colony, Liaquat Ashraf Colony, Manzoor Colony, a portion of Mahmoodabad, and some parts of DHA. As a result, the width of the river has been reduced, for instance near Qayumabad, the original width of the floodplain was 5000 ft which have now become only 550 ft (Akhtar and Dhanani 2012).

There is a dire need to prepare a flood management plan to secure precious lives and property in the city. All encroachments should be removed from the watercourses and floodplain should remain open to drain flood water. Water should be stored in upstream reservoirs and small dams which could directly be used for cultivation or recharge the groundwater.

In a rainy season, Malir River flows with a huge amount of water and millions of gallons of water wastes into the sea. If the government authorities become serious about this matter and construct a dam or a reservoir on this river, it will benefit the whole of Karachi a great deal.

Water for agriculture and rural Karachi

Livelihoods of rural settlements in Karachi are highly dependent on groundwater as the economic activities of most of the villages are associated with agriculture. Once, this agriculture was a major market gardening economic activity for Karachi to provide local fruits and vegetables. Malir basin was a significant producer of fruits (guava, mango, mulberry, papaya, and bananas) and vegetables (brinjal, tomatoes, spinach, pumpkin, okra, etc.) (Ghazal 2012). It has now shown an immense decline in production of these fruits and vegetables due to the scarcity of water, thus gradually losing its prime signature. Variability and unreliability of rainfall have created an immense shortage of water. Declining soil moisture and depleting groundwater reserves are turning the cultivated areas into a barren uncultivable land. This condition is alarming as it is compelling the natives to switch their

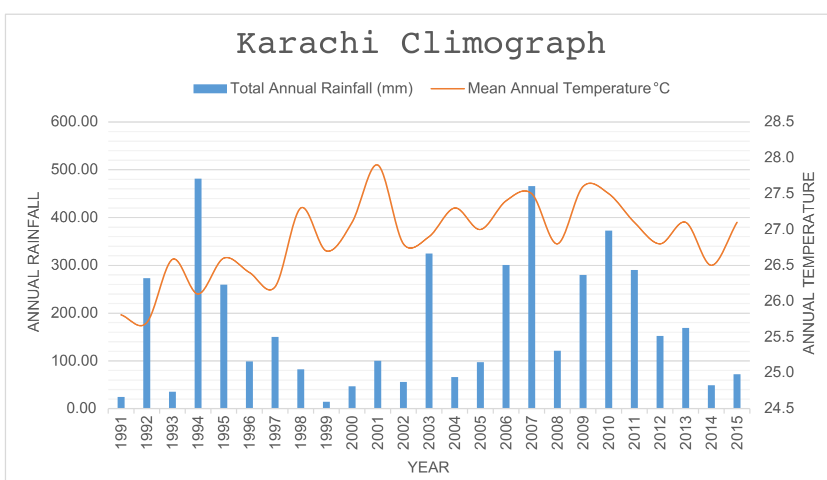

Fig. 8 Climograph showing mean annual temperature and total annual rainfall. Source: Pakistan Meteorological Department (PMD)

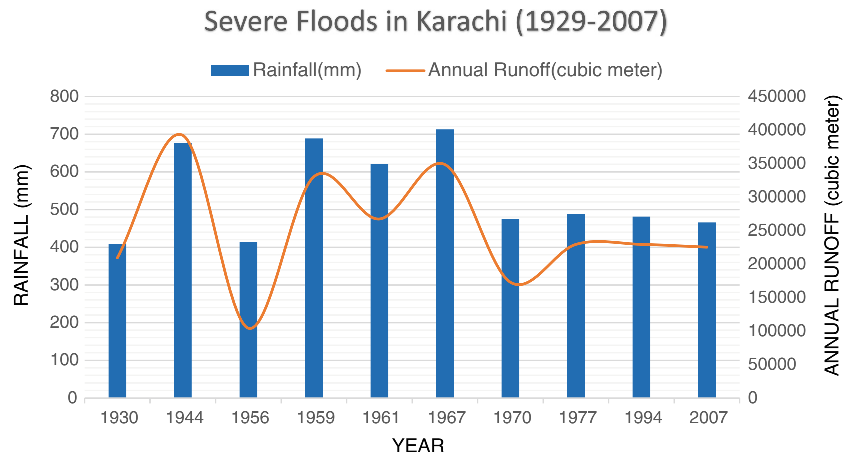

Fig. 9 Severe floods in the history of Karachi city. Source: Akhtar and Dhanani 2012

attention to other professions, such as sand and gravel excavation, inland fishing, transport, or migrating to the city center to work as laborer to earn money.

The groundwater table is already dropping, and aquifers are endangered due to human activities such as large-scale sand excavation from dry river beds and rare activities for groundwater recharge. According to the roadmap study of Karachi city climate change, there are no capacities for flood water storage (Anwar 2012) which can be used for agriculture and rural Karachi.

Conclusion and recommendations

Karachi, a city of over 20 million population, has many growing challenges. Being a part of the arid climatic region, water scarcity in the area is considered as one of the biggest problems, while rainfall pattern is highly erratic. Most of the time torrential rainfall occurs with urban flooding in monsoon season.

It has been revealed from this study that the city has three seasonal rivers draining through and in close proximity, i.e., Malir River, Lyari River, and Hab River. Karachi is getting benefits of Hab River in form of water supply for domestic use from Hab Dam. Malir River needs proper management as it has sufficient amount of stormwater which can be harvested for direct use in cultivation and groundwater recharge. Construction of small dams can be a better solution on upstream specifically on Mol and Khadeji Rivers which have ideal topography to store water and control flooding in downstream urban areas. Proper cleaning and removal of encroachments from the banks and river beds should also be part of flood management plan for both Malir and Lyari Rivers. It has been found that Karachi has a great potential for the development of check dams, and rainwater harvesting could be a very effective option in the future as an alternate water source.

Subsurface geology is favorable to store groundwater in aquifers. However, over-extraction of water, scarcity of rainfall, sand and gravel excavation, and lack of groundwater recharge infrastructure have depleted the precious resource. As a result, rural communities in the vicinity of Karachi are at high risk of water shortage and increasing salinity. Agriculture activities are shrinking, and people are searching for alternatives for their sustenance.

There is a dire need for a city development master plan for future growth of the city with clear-cut priorities, policies, and implementation framework. Water sector should holistically be addressed by considering climate change, rapid urbanization, population growth, and perpetual increasing demand from all sectors including industries and agriculture. Besides the development of sustainable policies at the local government level, overall governance, administration, and management need to be improved which may implement the best practices and regulations. New development in the periphery of the city must be in line of the available water resources; otherwise, the supply of water will be a serious challenge for the upcoming residents of the city.

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