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ORIGINAL PAPER

Sustainable urban water conservation strategy for a planned city of a developing country: a perspective from DHA City Karachi

Rabia Tabassum[1,2] • Mudassar Hassan Arsalan[2,3] • Faiza Mumtaz[1] • Nazia Imam[1]

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Abstract

Pakistan, previously a water-surplus country, is now a water-stressed country. Water is essential to achieve sustainable urban development, and the use of alternate water resources could provide essential support to urban development in the water crisis scenario. In water-scarce areas, where new water resource implementation is very difficult, water conservation practices serve efficiently and valuably. The study area, DHA City Karachi (DCK), has been visualized as Pakistan's first city which will likely serve as a role model for the future independent planned cities in the developing world. In this study, after water demand estimation for the study area, water conservation techniques have been implemented using scenario-based model approach. These techniques are water efficient fixtures (WEF) usages, dry cooling in power plant (DCP), grey water recycling (GWR), and black water recycling (BWR). The designed strategy implementation provides an overall 54% water reduction. The result shows that the best water demand reduction strategy is the deployment of WEF which is 59% of the total water reduction. Thus, the results of the study suggest that similar scenario-based urban water conservation strategies can be implemented for other regions of the world having water scarcity.

Keywords Water demands · Black water recycling · Grey water reuse · Urban water conservation · Efficient fixtures

Introduction

Water, the integral necessity of a human life, has played a crucial role in the emergence, growth, function, and physical geography of communities. In 2012, approximately 50% of the world's population lived in urban areas, and this percentage is expected to swell to 60% by 2030 (United Nations. Department of and United Nations. Department of Public 2012). As the population will increase, the municipal water demands will be increased, and eventually, it will cause the water scarcity (Loubet et al. 2014). By 2050, the world population will expect water shortage of 40% (Ward 2007); therefore, currently, water sustainable research plans have dominated the international and national agendas. Water conservation and efficiency practices provide water sustainability and have many benefits like water demand reduction, water saving, less environmental effect, and sustained water quality.

Being a developing country, Pakistan has to face many challenges like continuous increment in the population, increasing trend of migration from rural to urban areas, yearly appearance of multiple natural disaster events, and water resources scarcity (Mubushar et al. 2005). Pakistan is among the 25 most populous countries with a notable water deficit in its reservoirs (Kahlown and Majeed 2002). According to the World Bank data, Pakistan water reservoir system holds the capacity to stock water of only 30 days' usage; however, India stores water for 120 days while US reserves 900 days (Naseer 2013). Irfan et al. (2018) estimated the 50% deficit between water demand (1250 million gallon per day (MGD)) and supply (630 MGD) to Karachi metropolitan area and also explained the poor reliability of newly developed areas on the existing water resources within the region. A study, conducted by Majeed and Piracha (2011), examined the water protection,

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✉ Rabia Tabassum
rabia.tabassum@nu.edu.pk

1 Department of Science and Humanities, National University of Computer and Emerging Sciences (FAST), Karachi, Pakistan

2 Institute of Space and Planetary Astrophysics, University of Karachi, Karachi, Pakistan

3 School of Computing, Engineering and Mathematics, Western Sydney University, Parramatta South Campus, Rydalmere, NSW 2116, Australia

administration, and governance practices which are required in agriculture, municipal, and industrial divisions of the Pakistan. Siddiqui (2016) explored artificial recharge and hydroelectric production of DHA City Karachi (DCK) and recommended a hydroelectric engineering model to harness the optimum potential of the area. However, the study thoroughly explored the potential of regional and local recharge. In similar circumstances, planners always face the challenge of how to integrate all the possible means of water resource development, management, and conservation strategy for a sustainable solution. For instance, conserving scarce water through water conservation methods, such as the use of efficient fixture, grey water reuse, and wastewater recycling for the newly planned city, is an effort for sustainable water resource management. Till date, water conservation practice-based studies have not been presented for newly planned areas of Pakistan. With this background, this paper aims to develop an integrated plan for a newly planned city to deal with the challenge of water scarcity and sustainability.

This paper is organized in five sections, following this introduction; worldwide studies for water conservation has been discussed. In "Urban water conservation strategy for DHA City Karachi," a case study of DCK has been presented with water demand estimation in the context of the newly planned city. Later, some scenario-based models have been considered for water conservation. In the "Results and discussions" section, results and discussions have been presented. Lastly, conclusions have been drawn.

Worldwide studies for water conservation

Water efficient devices

The efficiency practices of the water usage are behavioural practices and engineering practices. The behavioural practices are related to water consumption habits while engineering practices are related to the installation of modified plumbing fixtures that conserve the water. Retrofit programs and low flow plumbing fixtures are considered as permanent and one-time conservation measures that can save money over the long term. These devices can conserve water up to 35 to 50% (Inman and Jeffrey 2006; Sharpe 2008). Domestically, around 17% of the water is used for shower (Sense 2013). Commonly, shower heads have 4.5 gallons per minute (gpm) flow rate, but by replacing it with low flow 2.5 gpm showerheads, a four-member family can save up to 2900 gallons of water per year (Sense 2013). The faucet aerators, devices to break the flow of water into the fine droplets to enhance the wetting effectiveness, reduce water use up to 40% (Conservation 2016). A twisted faucet can be matched with the desired task, and it has 0.5 gpm for soaping, 1 gpm for washing, and 1.5 gpm for a high rinse mode (Conservation 2016).

The water conservation is employed more exclusively in the context of water use optimization by bringing improvements in different water efficient usage. Millock and Nauges (2010) presented a study on adoption of water-efficient devices using unique survey data including 10,000 households in 10 OECD (Organization for Economic Cooperation and Development) countries. In Australia, several state governments offer rebates for a series of water efficient devices which include dual flush toilets, rainwater tank, and water efficient shower heads (Grafton et al. 2011). As the large percentage of water consumption is for flushing toilet, the department of environment protection in New York launched the old toilet replacement program which incentives to the homeowner for replacing outdated toilet (3.5 to 5 gallons per flush (gpf)) with the high efficient model (1.28 gpf) (Licata and Kenniff 2013).

Recycling and reclamation of wastewater

The proper water resource is crucial for a sustainable urban development. In the arid and semi-arid environment, a new water supply implementation poses many challenges and opposition from environmentalists due to the limits of ecological conditions (Chen 2007). Thus, wastewater recycling and reuse of reclaimed water for non-potable use could provide a guaranteed long-term water resource without developing new water supply. Wastewater from bath, sinks and, washing machines is known as grey water which outflows from homes around 60% (Madungwe and Sakuringwa 2007). Grey water, with little pathogens, has 90% less nitrogen than toilet water (black water) and does not need the same treatment process (Madungwe and Sakuringwa 2007). Zeng et al. (2007) tried to select the development pattern of urban wastewater reuse for China. Domestic gardening, golf course irrigation, aquifer recharge, and industrial applications are the suitable utilizations of grey water. Chen and Chen (2014) suggested that reuse of reclaimed water is acceptable for the industry.

The integration of the three flows (water supply, wastewater, and drainage) was presented by Makropoulos and Butler (2010) that provides a significant potential for the improvements in urban water management. In Orange County of California, USA, purifying wastewater treatment technologies are used for groundwater replenishment. Later, this treated water is utilized as potable water (Mehta 2009). In Northern Africa, Australia and some parts of USA, many studies have been done for wastewater use as substitution of freshwater and as a vital conservation strategy contributing to agricultural production maintenance (Raschi 2004). The wastewater reuse index (WRI) is introduced by Alfarra et al. (2011) for the wastewater reuse quantity measurements and for the potential to increase its utility for agricultural production

Water conservation and efficiency practices have different benefits like water demand reduction, water saving, less environmental effect, and sustained water quality. Some water conservation–related studies are illustrated in Table 1, which serve as the evidences of effective intervention for efficient use of water resources.

Table 1 shows that recycling of wastewater is exploited in most of the different studies, and it reduces a significant amount of water, approximately up to 50%. Mainly arid or semi-arid countries prefer wastewater reuse; among them, Jordan is on the top. Jordan, a subtropical, arid, and humid region, is extremely water-stressed area with just 167 m^3 per capita per year to meet the municipal water demand. Efficient fixture implementation, particularly for irrigation, conserves up to 90% of water in some countries. The majority of studies are related to water efficient devices use in Georgia. In Australia, efficient devices and reuse of rainwater and grey water are utilized as alternate water resources for rural residential development. Other countries like USA, UK, India, Texas, and China are also motivated toward the grey water recycling and efficient water use. In Japan, grey water is reused on a wide scale, and its range starts from a simple hand basin use to a complex recycling system in the offices. Water expenses are reduced in South African urban areas due to reduction in consumption of municipality freshwater supplies. Untreated urban wastewater use is undesirable and even unacceptable to many; therefore, the wastewater treatment plants are required for maximizing the benefits and reducing the risks under the prevailing social and economic conditions.

Urban water conservation strategy for DHA City Karachi

Case study

DCK is the part of Sindh desert with latitudes from 24° 57′ N to 25° 2′ N and longitudes from 67° 24′ E to 67° 32′ E. With an objective populace of 600,000, it is planned in the vicinity of Karachi Metropolis on approximately 12,000 acres, which comprises eight major land use types (see Fig. 1). It is drained by small non-perennial water tributaries of Malir River. The temperatures vary from moderate to hot, and DCK experiences the small amount of rainfall during monsoon season about 200 mm per annum. May and July are the hottest months, and temperatures often reach at 43 °C maximum. January is the coldest month of the year with a minimum temperature of 5 °C.

Materials and methods

The study aim is to establish some strategies to reduce water demand for an arid region of a developing country.

The methodology consists of different steps as shown in Fig. 2. Before applying these strategies, it is crucial to know about the water demand to understand elasticity and water saving potential. For this purpose, after the land use classification, DCK water demand is evaluated. Later, some scenario-based models are developed to conserve water.

Table 1 Different studies for efficient use of water

Study with ref(s)	Location	Environment	Strategy	Efficiency
A Review of Water Conservation Planning for the Atlanta (Gleick 2006)	Georgia, USA	Hot summer	WEF	50%
Efficient water use (Hilaire et al. 2008)	USA	Arid and semi-arid	WEF and GWR/BWR	733 to 2526 L water saving
Research of domestic water consumption (Lu 2007)	Harbin, China	Dry winter and hot summer	WEF	50%
Efficient Water Use (Gerston et al. 2002)	Texas, USA	Arid, humid	WEF	8000 to 10,000 gallons per year per family
Integrated resource planning (Fane 2007)	Australia	Tropical	GWR/BWR	Average saving of 74 million liter/annum
Wastewater reuse (Chu et al. 2004)	China	Tropical, arid, warm summers with mild winters	GWR/BWR	44.4%
Greywater reuse (Godfrey et al. 2009)	Madhya Pradesh, India	Tropical	GWR	Save Indian Rupees 30,000 per year
Grey water reuse (Allen et al. 2010; Al-Beiruti 2010)	Jordan	Subtropical arid and humid	GWR	15 to 30% (Allen et al. 2010), 30% (Al-Beiruti 2010)
Reuse of Reclaimed Water (Chen and Chen 2014)	Taiwan	humid subtropical climate	BWR	21.%

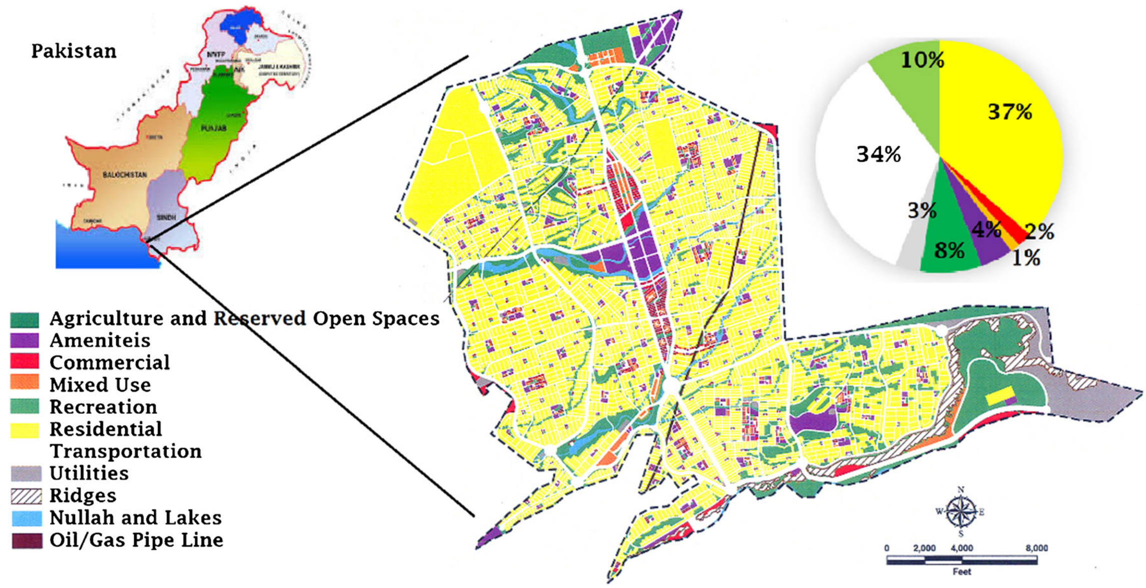

Fig. 1 Plan of DCK with land use types and % area of DCK

DCK land use classification

The master plan of DCK is consisted of detailed parcels/plots, transportation corridors, reserved spaces for natural drainage, open and green spaces etc. For water demand estimation, first DCK land use classification is applied to the parcels/plots, according to the detailed master plan categories on different levels, such as the major land uses that comprised residential, commercial, mixed (Res cum Com), amenities, recreation, utilities, transportation, agricultural, and reserved spaces. The minor/detailed land use classification was also developed for each individual major land use class according to DCK planning (as show in Fig. 3)

Water demand estimation criteria

For a newly planned city, water supply authorities are expected to supply water to their consumers with a certain degree of reliability. Non-uniform distribution of water may cause water scarcity in some area and excess in other areas which might result in the obstacle for the natural growth of the city. Therefore, a standard criterion setting is necessary to know the DCK water demand. In this regard, water coefficients such

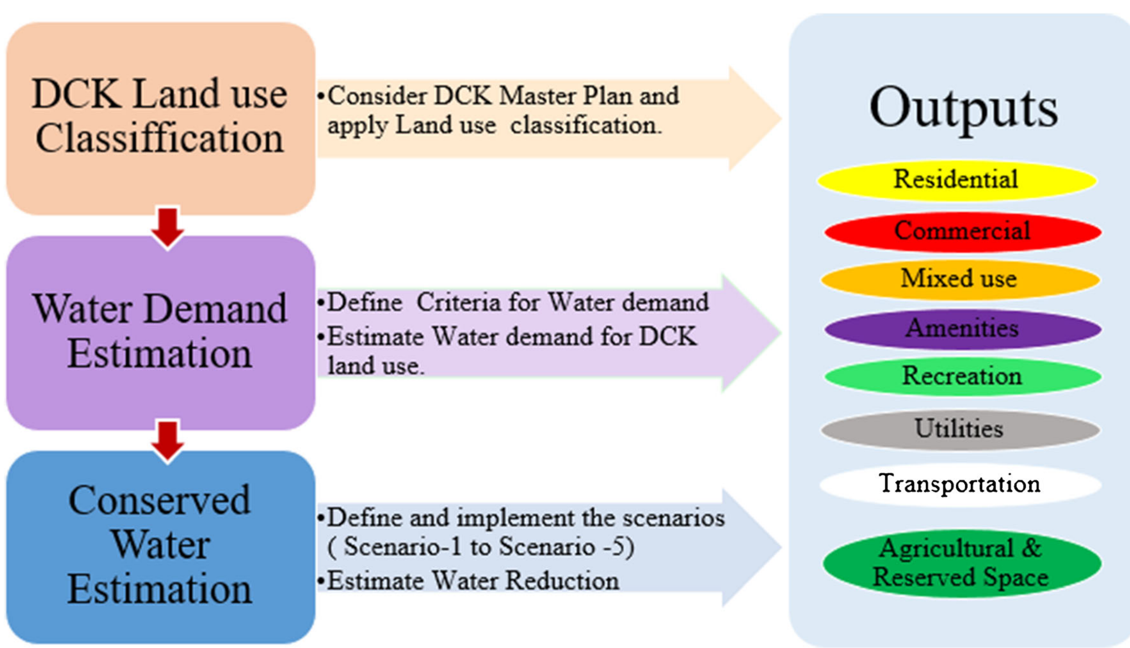

Fig. 2 Methodology work

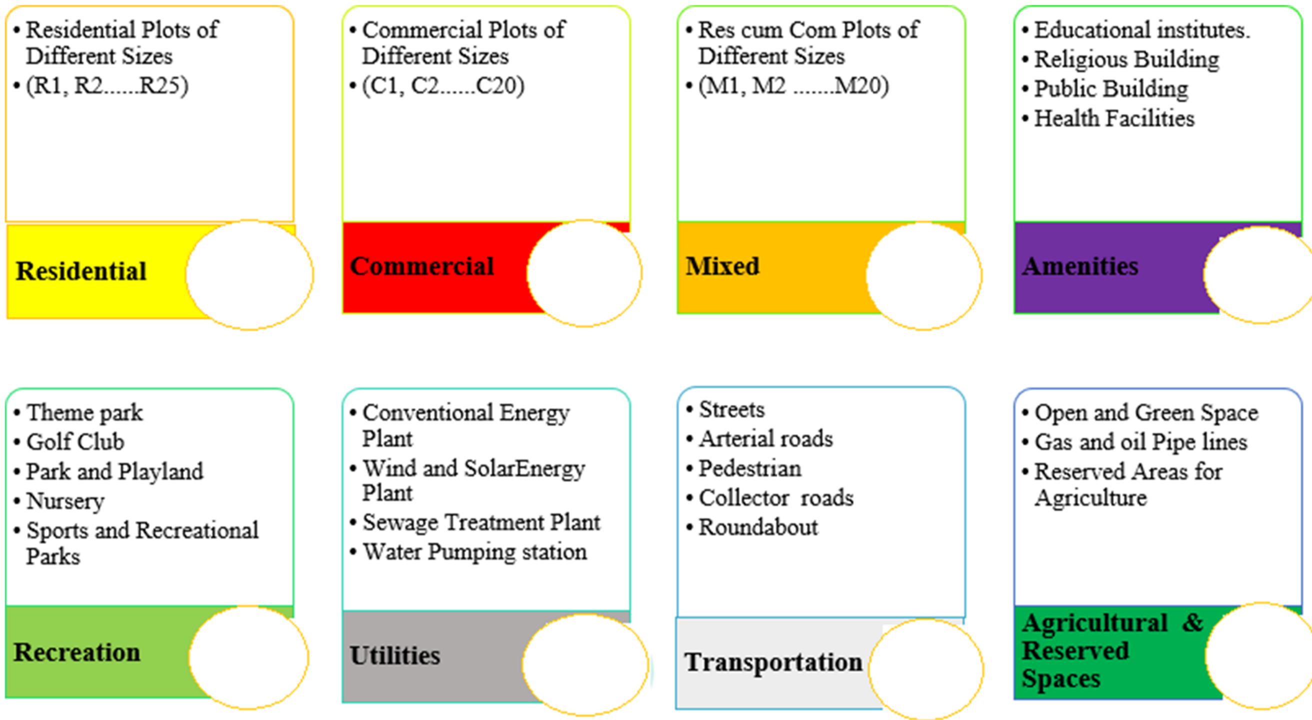

Fig. 3 Land use classifications

as gallon per capita per day (gpcd) and gallon per unit area per day (gal/ft^2) are measured according to the DCK master plan, worldwide trend of water consumption, and some separate studies. Karachi Water and Sewerage Board (KW&SB) is the main source of water supply for Karachi city. According to KW&SB water supply planning in Karachi, the average water requirement is 52gpcd (Ihsanullah 2010). Therefore, initially the average DCK domestic water requirement is assumed as 52 gpcd.

Water demand for residential and mixed land use In the DCK, almost 38% area is allocated for residential and mixed land use plots (see Fig. 1). DCK planning report mentions the expected number of persons per house varies from 6 to 12 according to the plot sizes (125 sq. yards to 2000 sq. yards) (OCL 2012). For residential and mixed land water demand estimation, the water requirement of each residential plot is calculated by multiplying the total number of persons per house with water consumption per capita (52 gpcd).

Water demand for commercial land use Almost 236 acres area is designated for DCK commercial plots of various sizes in community centres and in the central business district. A survey-based study is conducted to obtain water consumption for drinking, cleaning, washroom, and other uses according to their commercial activity for Karachi (Tabassum et al. 2016). The survey results show that, for commercial land, average water demand coefficients are 2.3 gal per capita (employee) per day (gpcd) and 0.031 gal per area per day (g/ft^2/day). The water demand coefficient 0.031 g/ft^2/day is used for commercial water demand calculations.

Water demand for recreation, transportation, and agricultural and reserved land use Transportation corridors cover around 34% of DCK land with different street and road categories. Water is used for watering plants in recreation, transportation, and agricultural and reserved land uses. DCK planners have selected different types of plants according to the suitability of different land uses and derived the water demand coefficients with respect to the unit area. This selection was made by survey of plantation in Karachi. Some of the derived water coefficients for different public water use are given in Table 2. According to Table 2, water coefficient for road landscaping, agricultural, and reserved land is 0.006 gal/ft^2/day and for recreation land is 0.02 gal/ft^2/day.

Water demand for utilities land use Almost 3% of the DCK land has been selected for the utilities land use. Conventional power generation plant is the main water consumption source of utilities land. According to DCK planning, 50 mW conventional power plant is based on wet cooling requires 4.2 MGD water (OCL 2012).

Water demand for amenity land use A long list of needed amenities and special use is designed in DCK that comprises around 4% of DCK land. It consists of educational institutions, public building, religious centre, health facilities, and

Table 2 Average water demand for public water use in DCK

Land use	Average water requirement
Community hall, marriage hall, mess, club, culture, and art	0.15 gal/ft^2/day*
Hospital	250 gal per bed**
DCK clinics	0.15 gal/ft^2/day**
Restaurants	4.6 gal per capita**
University	34 gal per student per day*
Golf club, lake view park, and nursery	0.02 gal/ft^2/day*
Park, playground, and theme park	0.01 gal/ft^2/day*
Road landscaping	0.006 gal/ft^2/day*

Sources: * OCL (2012) and ** Tabassum et al. (2016)

some reserved amenities. Water demand for amenity land is determined using water coefficients given in Table 2.

Conserved water estimations

After estimation of water demand, water conservation strategies are applied on each DCK land use. The suggested water reduction methods for DCK are grey water recycling (GWR) for lawn sprinkling, use of water efficient fixtures (WEF) in residential, commercial, and public building; use of dry cooling in power plant (DCP) or recycling of water in power plant; and black water recycle (BWR) for road landscaping and agriculture. To assess the impact of suggested intervention, step by step model scenario making approach has been adopted as shown in Fig. 4.

Scenario-1 (business as usual (BaU)) indicates the water use without any intervention for demand reduction. BaU may only be assured with the assumption of uninterrupted gross water demand fulfillment. However, limited water sources will not allow BaU unless water resources are sufficiently increased to provide incremental water demand. Towards demand reduction, the first intervention is the GWR (scenario-2) and its use for landscaping and gardening within and outside of the buildings. For GWR, the overriding principle is the safe usage of recycling water. Therefore, GWR is not applied where safety could be at stake, or its consumption is not required. GWR for landscaping is suggested only for large size plots (500 sq. yards and above) because small size plots have no landscaping. Health facilities have not been incorporated into

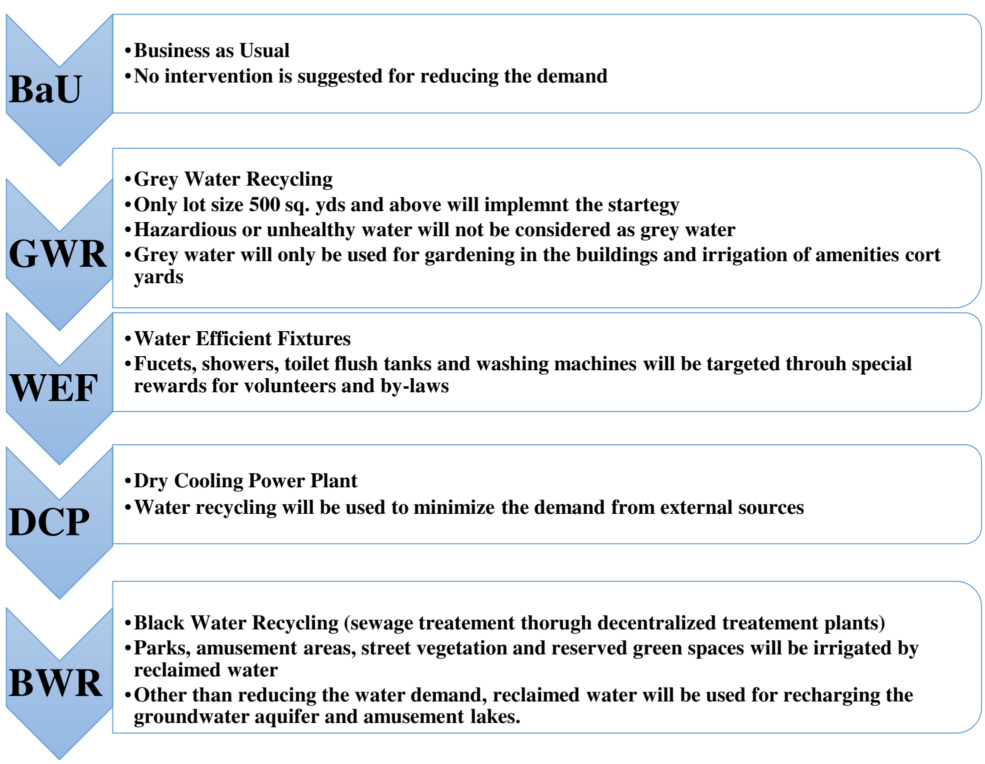

Fig. 4 Flowchart of step by step scenario making approach

the calculation of grey water because of the hazardous nature of medical waste. For estimating water reduction, the lawn sprinkling water would be excluded from total water demand (Only for residential, commercial, mixed, and amenity land uses). For making it more practical, it is assumed to construct the grey water tanks separately for storage, and to make it mandatory for all the residential, commercial, mixed and amenities plot holders having plot area of 500 square yards and above.

There are several types of WEF which are efficiently working worldwide for water saving. WaterSense is a voluntary partnership program sponsored by the U.S. Environmental Protection Agency (EPA), and it is both a label for water-efficient products and a resource for saving water. In Table 3, some WaterSense products are selected that residential, commercial, mixed, and amenity plot holders having plot area of 500 square yards and above could save up to 44% water demand. In addition to scenario-2, implementations of these devices are suggested in scenario-3(WEF). To calculate scenario-3's result, DCK water demand is estimated with the rate of 44% saving as criteria adopted in Table 3. For the execution of the scenario-3, with the separate water plumbing line connection (for GWR), WEF installation is mandatory.

The scenario-4 (DCP) suggests to use the dry cooling system in the conventional power plant at DCK. Power house usually consumes a large amount of high-quality water. Initially, a 50-mW wet cooling power plant with water requirement of 4.2 MGD is designed for DCK. The dry cooling power plant is a good choice because it consumes only 0.58 MGD. If the dry cooling system is used or water is recycled in the wet cooling system, about 4 MGD water will be saved. Thus, the scenario-4 outcome is taken by excluding wet cooling demand from the utilities water demand.

In addition to scenario-4, the BWR is implemented in scenario-5. BWR (after treatment) is used for watering plants in recreation, transportation, and agricultural and reserved land uses. Therefore, agriculture and reserved space water demand are eliminated from the DCK water demand to get the scenario-5 result.

Results and discussions

Water demand for DCK

The total average water use, when DCK will be fully developed and inhibited, is expected to reach up to 45 MGD and water demand per unit area is around 0.09 g/ft^2. The results show that as a whole DCK water demand (45 MGD) and the biggest share for residential land is about 41% (18.6 MGD) which occupies 37% of DCK land (see Fig. 5). The second highest water demand is for commercial and mixed lands about 17% (7.6 MGD) of the total DCK water demand. Transportation and recreation lands share almost the same water (about 2%). The lowest water demand 1% (0.6 MGD) indicates for the agricultural and reserved spaces. The development and full inhabitation period of the city is 25 to 30 years. The population growth rate of the city is required for forecasting the domestic water requirements. Therefore, as per DCK population planning, water demand has been evaluated over 30 years, which will be increased gradually (OCL 2012) (see Fig. 6).

Water demand optimization

The above scenario-based models have been suggested as DCK water conservation practices. The impact modeled results for all land uses with their assumptions and implementation methodology are shown in Figs. 7 and 8. The scenario-1 does not influence the water demand and can be applied if the availability of the excess amount of water is assured from any secured and permanent water source. The first intervention, GWR use for landscaping and gardening within and outside of the buildings, was done in the scenario-2 and its result shows that water demand can be minimized about 3 MGD. GWR is exploited in some of the studies (the majority are conducted in

Table 3 Water demand using water efficiency devices

Name of efficient device	Frequency of use (per person)	Daily water use without water saving device (gal/person)	Daily water saving with water saving device (gal/person)
Low-flush toilet (1.6 gpf)	5.1 flushes/day	20.4	12.2
Low-volume showerhead (2.5 gpm)	5.3 min/day	15.9	2.6
Low-volume faucet (1.5 gpm)	4 min/day	12	6
Front-loading washing machine (27 gpl)	0.37 loads/day	18.9	8.9
Water efficient dishwasher (7 gpl)	0.1 loads/day	1.1	0.4
Total		68.3	30.1

Source: https://www.epa.gov/watersense/watersense-products

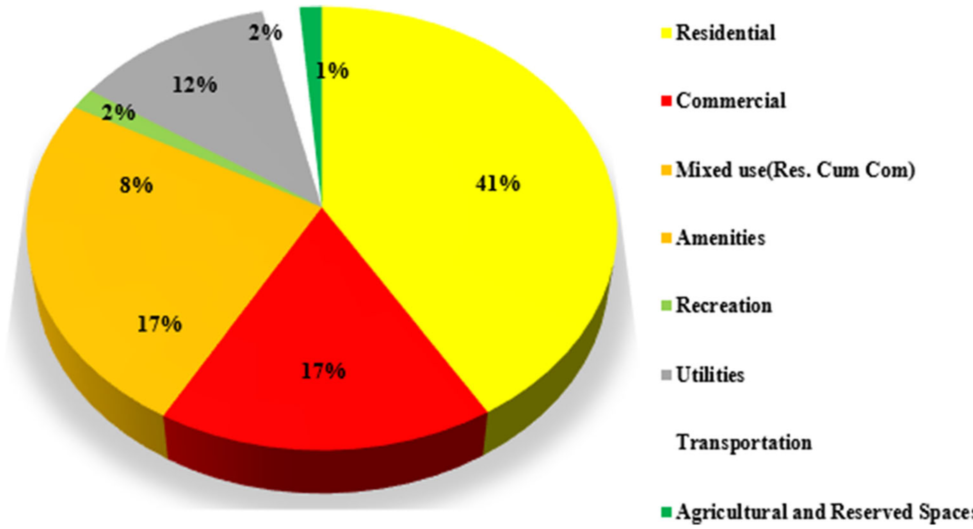

Fig. 5 Water demand (MGD) for DCK land uses

Jordan) and able to reduce a significant amount of water, approximately 10 to 30%. This study result predicts 7% reduction in water demand for GWR which is comparatively less if worldwide studies are considered. The reason for the less reduction is the GWR's usage only in landscaping and gardening of DCK.

Worldwide studies for water conservation indicate that the majority of studies are related to water efficient devices use and can conserve water up to 90% especially for irrigation. According to Inman and Jeffrey (2006) and Sharpe (2008), retrofit programs and low flow plumbing fixtures are considered as permanent and one-time conservation measures that can save money over a long term and save water up to 35 to 50% (Inman and Jeffrey 2006; Sharpe 2008). In this study, the scenario-3 (WEF) outcome points out the substantial amount of water reduction about 39% (18 MGD) in residential, commercial, and mixed lands water demand and considerably a satisfied result.

The DCP is a worthy choice because it consumes only 0.58 MGD. Total utilities water demand is approximately 5.4 MGD including 4.2 MGD wet cooling power plant water demand and 1.3 MGD other water use. If the dry cooling system is used or water is recycled in the wet cooling system, this will allow about 4 MGD (9% of total DCK water demand) water saving. Thus scenario-4 implementation reduces only the utilities water demand and further lowers the water requirement up to 49% (22 MGD).

Untreated urban wastewater use is undesirable and even unacceptable to our community; therefore, the wastewater treatment plants are required for maximizing benefits and reducing risks under the prevailing social and economic conditions. Reclaimed wastewater is planned to be utilized as conjunctive use for irrigation and groundwater recharge. It will not only reduce the water demand for landscaping and agriculture but also produce ground water recharge after treatment in sewage treatment plants (STPs). Table 4 shows the estimated projected sewage volume according to DCK land uses.

In addition to scenario-4, if the BWR (scenario-5) is used for landscaping and agriculture, it can fulfill the requirement of the agricultural space and transportation water demand and save water approximately 5% (2 MGD). As the total amount of the projected sewage volume is about 30 MGD, whereas the DCK

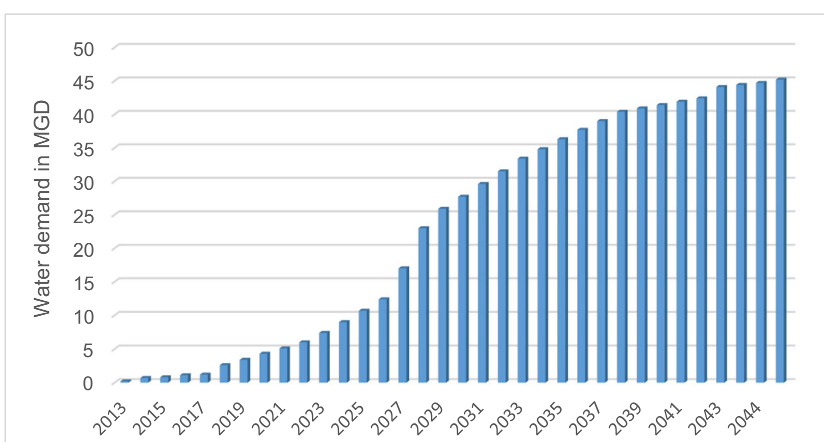

Fig. 6 Water demand of DCK on yearly bases

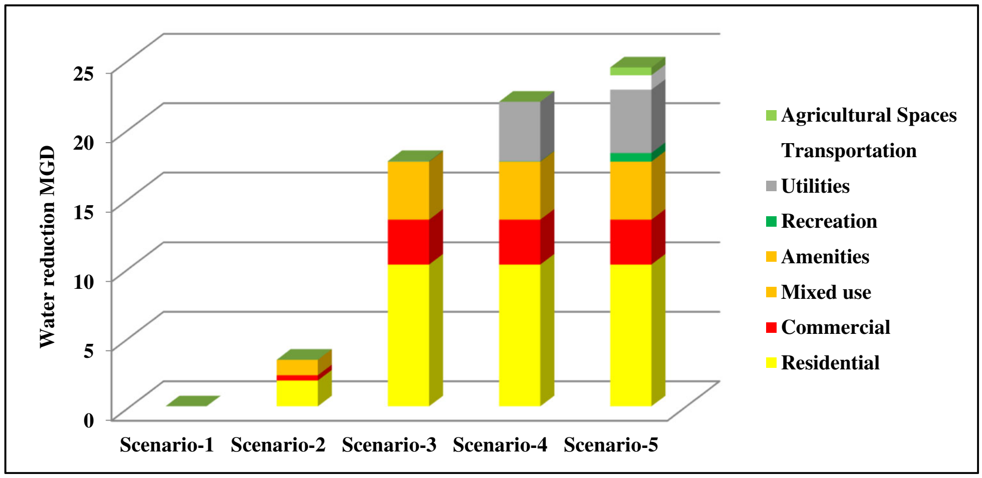

Fig. 7 Results of model scenarios

water demand for agricultural space and transportation is only few MGD. The remaining water is planned to recharge the ground water through the designed reservoir and lakes.

The distribution of water demand reduction in different land use types is shown in Fig. 8. The scenario-4 (DCP) and scenario-5 (BWR) do not have an effect on the residential, commercial, and mixed land water demands.

The combined model result is capable of about 54% (24 MGD) reduction in total DCK water demand (45 MGD). All scenarios' results indicate that the most significant intervention is the WEF (scenario-3) deployment which has 59% of overall saved water (24 MGD) as shown in Fig. 8. GWR and BWR share 24%, whereas DCP shares 17% of the net water saving.

Conclusions

Karachi, a city of 20 million inhabitants with 50% demand and supply gap, is unable to provide a secure and sustainable water to planned satellite towns such as DCK. There are many historical reasons which have accumulated at the point where the urban sustainability of the city is challenged. Irfan et al. (2018) indicated that city has a range of urban issues to deal with the growing challenges including high urban growth rate, lack of effective administration, absence of city master plan, increasing burden of climate change, and scarcity of water resources are a few out of the list. Recently, WorldBank (2018) released a report on Karachi addressing the similar issue in numbers and circumstantial economic analysis. The secure and reliable water supply is a question for the city to maintain the continuity and sustainability. In this situation, the addition of local resources with all means of conservation is highly recommended. In the long run, the conservation strategies have highly positive impacts on energy, greenhouse gas emissions, and health (Sokolow et al. 2016).

This case study provides a review of the best urban water conservation practices all over the world and presents scenario-based models for a newly planned city in a water scarce region. Multiple step-wise scenarios are considered, such as WEF, GWR, DCP, and BWR. The most efficient water reduction strategy is the adoption of WEF that has a substantial impact on the water demand for residential, mixed,

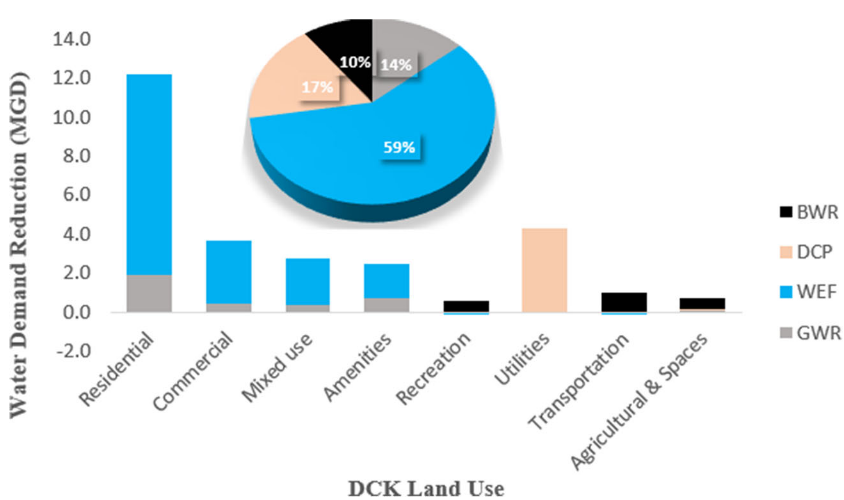

Fig. 8 Share of water demand reduction in various land uses

Table 4 Projected sewage volume of fully developed DCK

S. no.	Land use types	Projected sewage (MGD)
1	Residential	14.84
2	Commercial	6.05
3	Mixed (Res Cum Com)	5.92
4	Amenities	2.99
	Total	29.80

Source: OCL (2013)

commercial, and amenities lands and conserves about 18 MGD water. GWR and BWR positively satisfy the water demand for landscaping and irrigation and also acceptable in society. The 45 MGD water demand for 0.6 million populations on 12,000 acres of land can be minimized by 54%. It is a great achievement in struggling to find out the water scarcity solution.

The study is limited to present BWR implementation only for irrigation of Parks, amusement areas, street vegetation, and reserved green spaces. But other than reducing the water demand, BWR can be used for recharging the groundwater aquifer and amusement lakes. The reclaimed wastewater reuse could be planned as conjunctive use to recharge the groundwater for further water saving. Rainwater harvesting (RWH), another method for water conservation, could also be considered to extend this study. But DCK is a part of Karachi which experiences the small amount of rainfall during monsoon season (about 200 mm per annum), and it is insufficient for the reuse of rainwater. The same best practices and scenario-based strategies can be suggested for other parts of the city and elsewhere in the world with similar environment and resource constraints.

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