37. Water reuse and wastewater recycling: Solutions to Tehran's growing water crisis

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Introduction

Over the last century, global and rapid urbanisation and population growth have produced serious water shortages and water pollution in urban areas. Consequently, interest in wastewater reuse has grown over the past decade, particularly in arid regions, as a technology that can promote sustainable, efficient, and appropriate water use (Maksimovic and Tejada-Guibert 2001).

Tehran's water resource problems

Tehran, the capital of Iran, has a population of over 7.5 million. Population growth will place immense demands on the city's water resources within the next decade. The mean annual precipitation is only 250 millimetres, most of which falls during winter and spring. The most important freshwater resources in Tehran are the Karaj, Lar, Latian, Mamloo and Taleghan reservoirs. Water from these dams is transferred to four water treatment plants (WTP). Tehran supplements surface water with groundwater to mitigate the water shortage, and at least 250 million cubic metres (MCM) of water is discharged from wells annually in Tehran (Tajrishy and Abrishamchi 2005). Table 1 shows the maximum water capacity of each of Tehran's water resources.

Table 1: Maximum water capacity of Tehran's water resources

Water resource	Aqueduct	Well	Karaj Dam	Mamloo Dam	Latian Dam	Lar Dam	Taleghan Dam
MCM/year	96	595	330	90	180	150	150

Sources: Ministry of Energy (MoE) 2009.

Table 2 lists Tehran's population and annual water consumption from 1966 to 2006 and demonstrates that water consumption has increased more than an order of magnitude over these years.

Table 2: Population and water consumption in Tehran

Year	Water consumption (MCM/year)	Population (thousands)	Per capita water consumption (lit/day.capita)
1966	98	2720	99
1976	346	4530	209
1980	443	5454	223
1986	542	6042	246
1991	681	6475	288
1996	780	6759	316
2006	1100	7798	386

Sources: MoE 2009.

Iran's water and sewage utility (ABFA company), states that per capita water production in Tehran is currently about 378 litres per day. If water consumption continues to follow current trends, water consumption will be 1290 MCM/year in 2026 (MoE 2009). In this situation, even if all water resources were utilised to their fullest capacities, the city would still be faced with a water shortage of more than 100 MCM/year in drought years.

Water resource managers in Tehran are faced with increased water demand and waste production due to population growth and socioeconomic development, decreased availability of water per capita, large losses of urban water, and local depletion and pollution of surface and groundwater. In countries facing similar freshwater crises, such as Australia, Japan, France and Germany, water reuse and wastewater recycling are already being deployed (Chu and Chen 2004). The time has come for these options to be considered in Tehran.

Wastewater reuse potential

In semi-arid cities like Tehran, water for irrigating natural vegetation, landscaping and park areas is in short supply. Tehran has more than 7000 hectares of parks that require more than 130 MCM of water per year, and most of them use groundwater for their irrigation. Many of these parks are located close to wastewater treatment plants (WWTP), but the discharge of outflow from these plants into seepage pits and surface storm water channels wastes a potentially valuable resource. Moreover, wastewater from treatment plant effluent could also be used for groundwater recharge in the eastern part of the city, which is under development and is faced with a falling groundwater level.

Water efficiency is very low in the industrial sector of Iran, and water recycling and reuse are not sufficiently emphasised. After treatment, municipal wastewater can be reused for cooling and processing water in industry, as has become an established practice in many countries. The greatest potential for industrial water reuse in Tehran lies in supplementing or replacing the potable water demand of the Ray Petrochemical Complex with treated municipal wastewater effluent (MoE 2009). Other industries in the western part of the city (Karaj Industrial Park) could use reclaimed wastewater for landscape irrigation, direct evaporative cooling, indirect refrigeration (food processing), or for in-plant transport and washing.

There are nine public and 18 private WWTP in Tehran that can treat more than 100 MCM of wastewater per year. This capacity will increase to 250 MCM per year after the Tehran Wastewater Project is completed. There are many small canals that join the two main canals (Kan and Darband), and these small canals transfer more than 400 MCM per year; but the water quality in these canals is not suitable for many reasons, including discharge of wastewater from surrounding houses and industrial centres. The water quality can thus be improved at little cost by controlling discharge or treating runoff, and this water could then be used as another new resource that has not yet been utilised in Tehran.

Methodology

In recent research, we categorised the city's primary water users (users that consume more than 300,000 cubic metres of water per year and can use reclaimed wastewater and runoff, such as parks and industries) and evaluated the quality and quantity of water they required. Then, we analysed different water resources, including WWTP effluent, groundwater (wells), runoff in canals and transferred water from dams (Karaj, Lar, Mamloo, Taleghan and Latian). After determining the possible water transfer pathways (according to the water quality that users require and the water quality of each water resource), a linear programming optimisation model, with the object of cost minimisation for the water provision and sewage management utility (ABFA Company), was used to allocate the water among users and resources. This research builds upon existing literature in water reuse planning and management modeling (Chu and Chen 2004; Ganoulis and Papalopoulou 1996; Oron 1996; Keckler 1997; Zhao and Chen 2008; Mohammadnejad and Tajrishy 1998) to model a user-supplier water resources network for the first time in a city of Iran.

In our model, urban water is used for three primary purposes: domestic uses, industrial processes and the irrigation of parks and landscapes. Domestic users require high-quality water. Because of the lack of modern treatment technology in Tehran's WWTP, the water network includes industries and parks as normal users, even though these users do not require high-quality water. The superstructure of the model is shown in Figure 1. Only the users that require more than 300,000 cubic metres per year are considered network elements in our model.

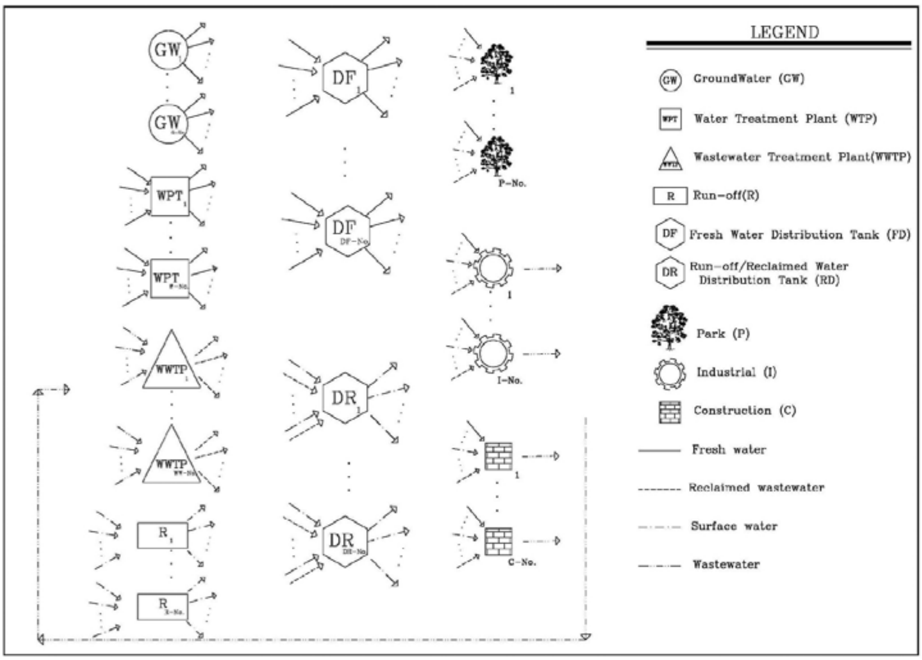

Figure 1: Superstructure of the model

Sources: Authors' research.

Water suppliers in Tehran are divided into four groups:

1. WTP effluent: There are four WTP in Tehran, which receive water from five reservoirs near the city.

2. Well (groundwater): There are 260 wells located throughout the city. In the model, these wells are divided into 20 groups according to location, and 20 virtual wells are defined as 20 supplier elements to represent each group of wells in the model (with the capacity of each virtual well being equal to the sum of the capacities of the wells in the corresponding group).
3. WWTP effluent: There are 14 large WWTP in Tehran with capacities ranging from 770 to 18300 cubic metres/day.
4. Water in canals: Two main canals crossing the city from north to south have been confined and canalised by concrete and stone. Local WWTP effluent and storm water are discharged to these canals.

Results and discussion

Currently, the two main canals and the effluent of wastewater treatment plants in Tehran are not of suitable quality for irrigation and industrial processes, so the model is run under three different sets of conditions:

1. Present Condition: In this case, the water quality of all suppliers in the model is the same as current data reported from laboratory tests. Only WTPs and wells can supply any users' water demands. The WWTPs do not treat their effluent streams to sufficiently high quality for user's purposes, and the quality of the water in the canals is not sufficient for reuse because local WWTPs and factories discharge their effluents directly to the canals.
2. Improved System: In this case, it is assumed that simple actions, such as reduction of WWTP loads, disinfection, filtration and protecting the canals against pollution have been taken and that the water quality of canals and WWTP effluent has sufficiently improved for use in irrigating parks with restricted access and in some industrial processes. Under these conditions, WTPs and wells can supply the water demand of any user, while WWTPs and canals can supply the water demands of users with limited access.
3. Ideal System: This case incorporates technical improvements to WWTPs such as adequate filtration and using ozone or ultraviolet (UV) light for disinfection. Water quality in the canals is also improved, and WWTPs and industries are forbidden to discharge effluent to the canals. In this case, all suppliers provide water of sufficient quality to supply the water demands of all users in the network.

Table 3 shows an economic and environmental comparison of the three cases. The major finding is that developing WWTPs, improving the quality of WWTP effluent, and controlling the runoff into canals would result in reduced freshwater and groundwater usage. Increasing the use of WWTP effluent will reduce soil and groundwater pollution in the south of the city because the transfer of sewage is prevented. As fresh water and groundwater usage decreases, the growing requirements for sanitary water will be met through other means, and the falling groundwater level will stabilise. Clearly, Tehran could compensate for water shortages in drought years whilst preserving its aquifers.

Naturally, the total cost of water transmission and distribution in the Ideal System is greater than in the Improved System because treating wastewater to a high-quality level costs more than treating it to moderate quality. The total cost of water transmission and distribution in the Present Condition is, however, higher than in either of the other two cases because of the high energy costs associated with pumping water from wells and transferring water from dams. The cost savings that would result should encourage the authorities to improve WWTP technology and control runoff quality.

Table 3: Comparison between Present System and two new systems

	Present Condition	Improved System	Ideal System
Freshwater usage (MCM/year)	51.7	7.7	0
Groundwater usage (MCM/year)	115.8	23.4	0
WWTPs effluent usage (MCM/year)	0	21.5	37.8
Channel usage (MCM/year)	0	115	129.7
Transportation cost (10^6 \$/year)	1.4	1.3	1.5
Purchase cost (10^6 \$/year)	1.3	0.2	0
Operation cost (10^6 \$/year)	41.8	28.3	33.5
Benefit (10^6 \$/year)	13.9	10.8	11.1
Total cost (10^6 \$/year)	30.6	19.0	23.9

Sources: Authors' research.

In order to test the conclusions, we also conducted a sensitivity analysis of model parameters. A number of observations emerge:

- If the costs of wastewater and runoff treatment increase, the resulting water allocation in the network changes. Until the cost of wastewater treatment is higher than that of runoff treatment, runoff usage is preferred to use of WWTP effluent (because the other costs of these two resources are nearly identical) and the latter is therefore the best solution as far as reducing total cost and adjusting usage of water resources.

- Reducing the income from selling WWTP effluent and runoff produce a reduction in the overall benefit to ABFA and, as a result, it becomes economical for ABFA to distribute fresh water and groundwater instead of WWTP effluent and runoff.
- If the price ABFA must pay to the MoE to buy water from dams and wells increases (e.g., due to new policies that reduce subsidies), then supplying water from WWTP effluent and runoff becomes more economical than using fresh water and groundwater.

Conclusions

Like many megacities in the world, Tehran is faced with increasing freshwater demand and limited water resources because of rapid population growth. Our model's results demonstrate that positive economic impacts result when users that do not require high-quality water, such as parks, industrial plants and construction projects, utilise WWTP effluent and treated runoff rather than fresh water and groundwater.

Although improving WWTPs and controlling runoff quality require large initial investments, over time, they are likely become more economical than the present system. This result is dependent, however, on the cost of treating wastewater and runoff and the purchase cost of fresh water and groundwater, with the latter result being a direct function of policy settings.

Tehran may have a pressing need for solutions to its water crisis, but there are solutions available. Our research demonstrates that water reuse and wastewater recycling are not only physically feasible but also economically attractive options. In future the complexity of urban water issues will increase, continuing to push the traditional boundaries of water and sewage management into the areas of integrated solutions within the water sector. The most plausible option is to integrate water supply, wastewater and stormwater to satisfy outdoor water use demands of sprawling megacities in the developing world.

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