Water Allocation with Regard to Reclaimed Wastewater as a New Water Resource for Tehran, Iran

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Abstract

Tehran, the capital of Iran, like many megacities in the world is encountered with increasing freshwater demand and water resources limitation because of the rapid growth of population. In spite of the existence of neighboring water recourses; such as Karaj-Dam and Lar-Dam, and large usage of groundwater, the management of urban water demand is one of the biggest problems with this city. In this paper, water reuse and wastewater recycling are considered as a sustainable solution for water supply and wastewater management of Tehran. A linear programming optimization model with the object of cost minimization is used to allocate water between users and resources, concerning the water quantity and quality of each one. Ultimately the economic and environmental effects of this strategy will be presented as the conclusion of this study.

Key word: *Water resources allocation, Reclaimed wastewater, Tehran, LP Optimization*

Introduction

During the last century, rapid urbanization and population growth have resulted in many environmental problems. Among those one of the most serious are water shortage and pollution. There is an increasing interest over the past decade in wastewater reuse in many parts of the world, in particular in arid regions, to promote sustainable, efficient and appropriate water uses.

Tehran, as the capital of Iran, with a population of over 7 million, is experiencing perhaps the fastest urban development of all Asian cities. The population growth in the next decade will place immense demands on the city's water resources. The mean annual precipitation is only 250 mm and occurs mainly during the winter and spring. No rivers of any size pass through the basin, but groundwater is contained in the extensive alluvial aquifer that underlies the basin. (Figure.1)

During recent years water consumption has risen above 350 liters/person/ day. If the population continues to rise at the same rate (about 2 percent annually) as it did from 1995 to 2000, Tehran's population alone will reach about 10 million by 2015. If the high population growth of the last 25 years slows down dramatically and population migration stops, the rate of population growth may slow to 1.7 percent, which will result in a population of above 10 million by the year 2020.In the years 2010 and 2020, the volume of water consumption in Tehran is projected to reach 1,100 and 1,400 Mm3, respectively. Based on current water usage and anticipated population growth, the water shortage is expected to grow to about 100 Mm3 in the years ahead; about 400 Mm3 by year 2015, and about 600 Mm3 by year 2020.

In brief, problems that are facing water resources management in Tehran can be summarized as increase in demand and waste production due to population growth and socioeconomic development; decrease in availability of water per capita; high losses of urban water; and local depletion and pollution of surface and groundwater.

With regard to management programs in some country with crisis of fresh water because of low amounts of rainfall such as Australia, large demand from the population, such as Japan, or some environmental and economical considerations, such as Germany and France and inspection of practiced solution , water reuse and wastewater recycling as a proper and economic suggestion for these problems is evaluated; a linear programming optimization model with the object of cost minimization is used to allocate water between users and resources, concerning the water quantity and quality of each one. Ultimately, the economic and environmental effects of this strategy will be presented as the conclusion of this study.

In semiarid areas like Tehran, water is in short supply for irrigating natural vegetation, landscaping, and park areas. The city of Tehran has about 20 km2 of parks that use freshwater for their irrigation. Many of these parks are located close to satellite wastewater treatment plants from which the outflow is currently being discharged to seepage pits and surface storm water channels. In one study, it has been shown that about five parks located in Tehran (total 5,000 ha) use 30 Mm3 of freshwater that can be replaced by reclaimed wastewater from treatment plants close to them. Outflow from treatment plants can even be used for landscape impoundment and groundwater recharge in the eastern part of the city, which is under development and faces groundwater overdraft.

Water efficiency is very low in the industrial sector of the country, and there is still not enough emphasis on water recycling and reuse. Municipal wastewater after treatment can be reused for cooling and processing water in industry. This has become an established practice in many countries. The greatest potential for industrial water reuse in Tehran is to supplement or replace the potable water demand of Ray Petrochemical Complex located south of the city. Treated municipal wastewater effluent from the south wastewater treatment plant can be used for a significant fraction of the water requirements of Ray Petrochemical Complex. Other industries in the western part of the city (Karaj Industrial Park) can use reclaimed wastewater for their landscape irrigation, direct evaporative cooling, indirect refrigeration (food processing), or for in-plant transport and washing.

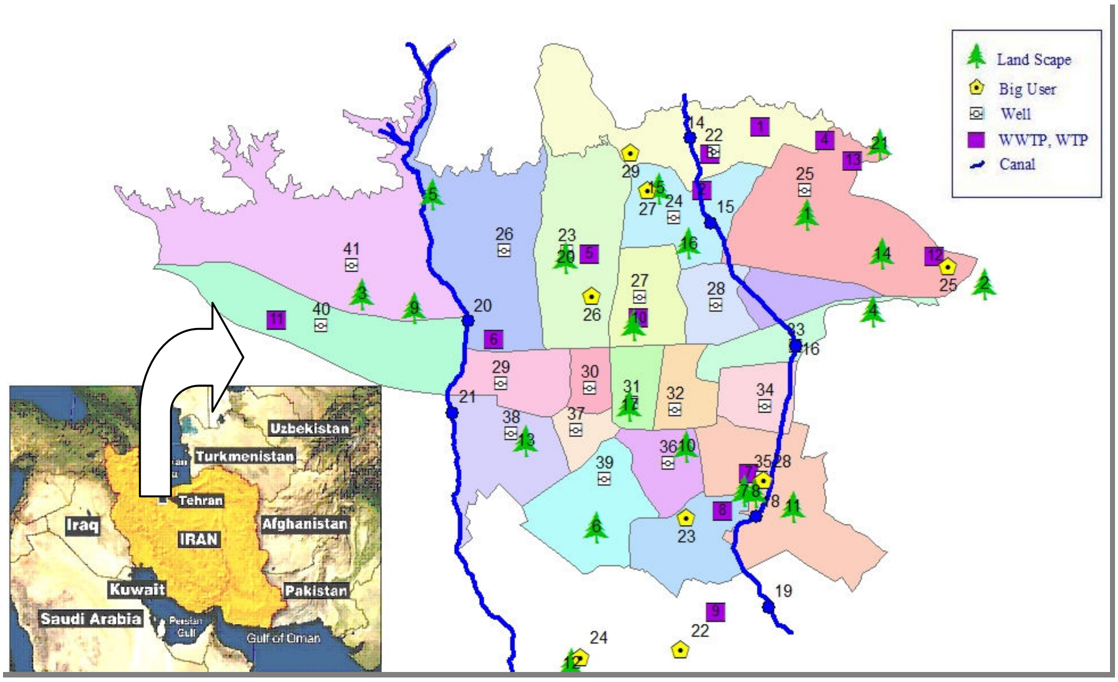

Figure 1: Water users and suppliers in Tehran

Methodology

Water reuse planning and management modeling can provide a systematic approach to assessing the potential reuse water market, and identifying and evaluating water reuse opportunities among major users in the system. Jacques and Anastasia (1996) discussed the risk analyses of wastewater reclamation and reuse. Gideon Oron (1996) presented an integrated approach for wastewater treatment and reuse that is based on engineering considerations such as treatment levels and control, water supply and demand, transportation and storage requirements, technical capabilities and social factors with cost minimization objective function for Beer-Sheva city in Israel. Keckler's material reuse model (1998) is one of the industrial ecology models demonstrating water flow design in industrial parks. Junying Chu (2003) used a linear programming optimization model to explore the potential wastewater reuse quantities, under physical and economic constraints.

ABFA Company is responsible for providing water (transfer, distribution and treatment) and sewage management (collection, transfer and treatment) in Iran. The object of this study is cost minimizing for this company. Costs that company must pay contain purchase fee, transportation and operation cost versus payment that receives from users as water rate.

"Water reuse and wastewater recycling" model performs in two procedures:

1- Feasibility: the feasibility of water transfer between two nodes is evaluated according to water quality that a user needs and the water quality that a supplier can provide. Water quality parameters are pH, TSS, BOD, Cl residual and fecal coliform.
2- Optimization: in this procedure with regard to the water allocation costs and with object of minimizing total cost in system, the optimal solution for user-supplier network is determined with a linear optimization program.

Minimizing the objective function shown in equation 1 determines the optimal set of $\mathbf{X_{i,j}}$

$$Minimize\ Z = \sum_{j}\sum_{i}\left(\left(PC_{i,j} + OC_{i,j} - Bi,j\right) \times X_{i,j} + TC_{i,j}\right) \quad (1)$$

i: each supplier
j: each user
$X_{i,j}$: the flow rate (cubic meter per year) of water from supplier i to user j
$TC_{i,j}$: Transportation Cost; contains pipe and plumbing cost
$PC_{i,j}$: Purchase Cost
$OC_{i,j}$: Operation Cost; contains pumping and treatment cost
$B_{i,j}$: Benefit from the sale of water
Each user has a demand Q_{in} (cubic meter per year) and each supplier has a specific capacity Q_{out} (cubic meter per year). The sum of water are allocated to each user must equal the Q_{in} and the sum of water comes from each supplier to users must be less than Q_{out}. These demand and supply constraints have been shown mathematically in equation 2 and 3.

$$\sum_{i} X_{i,j} = Q_{in}(j) \quad (2)$$

$$\sum_{j} X_{i,j} \leq Q_{out}(i) \quad (3)$$

Also, non-negativity constraint is shown in equation 4.

$$0 \leq X_{i,j} \qquad (4)$$

The linear program in the model was written in the general algebraic modeling system (GAMS) language using the above formulations.

The Data

As Tehran is a large city and there are many water users, we choose only 29 the top biggest users. All of them are landscape or industry; so they do not need water with very good quality and they can use wastewater treatment plant effluent.
Water suppliers in Tehran are divided into four groups:

1- Water treatment plant effluent: there are four water treatment plant (WTP) in Tehran; water is derived from three dams near city in to these WTPs.(Figure.1)

2- Well (groundwater): there are 260 wells all over the city; these wells are divided to 20 groups according to their location.(Figure.1)
3- Wastewater treatment plant effluent: there are nine big wastewater treatment plant (WWTP) in Tehran.(Figure.1)
4- Water in canal: there are two big river channels that have been confined and canalized by concrete and stone materials which cross the north to south of the city. Local wastewater treatment plant effluent and storm waters are discharged to these channels. Six points on the path of Darband-Canal and two points on the path of Kan-Canal are defined to model as supplier node. (Figure 1)

Table 1 and 2 show defined nodes to model as user-supplier network.

Table 1: Defined node as users in network

User	Code	Type	Demand (m^3/year)	Elevation (m)
pj_lavizan1	1	restricted access area (park)	26,827,500	1562
pj_ghazal	2	restricted access area (park)	22,995,000	1565
pj_chitgar	3	restricted access area (park)	22,707,563	1258
pj_khojir	4	restricted access area (park)	17,246,250	1337
pj_sorkhehesar	5	restricted access area (park)	16,291,958	1362
pj_koohsar	6	restricted access area (park)	11,497,500	1510
pj_pardisan	7	restricted access area (park)	5,748,750	1412
pj_afra	8	restricted access area (park)	3,865,076	1090
pj_sohanak	9	restricted access area (park)	3,832,500	1893
pj_tooska	10	restricted access area (park)	2,190,274	1104
p_azadegan	11	unrestricted access area (park)	1,628,813	1103
pj_khargooshdareh	12	restricted access area (park)	1,533,000	1274
p_besat	13	unrestricted access area (park)	1,025,194	1117
p_khalijefars	14	unrestricted access area (park)	996,450	1160
pj_yadbood	15	restricted access area (park)	958,125	1028
p_ghaem	16	unrestricted access area (park)	900,638	1130
p_polis	17	unrestricted access area (park)	804,825	1443
p_melat	18	unrestricted access area (park)	651,525	1568
pj_taleghani	19	restricted access area (park)	597,870	1408
p_razi	20	unrestricted access area (park)	574,875	1130
p_laleh	21	unrestricted access area (park)	519,775	1284
bu_sherkatenaft	22	industrial use	6,000,000	1031
bu_abfa	23	unrestricted access area (park)	2,000,000	1080
bu_marghademam	24	unrestricted access area (park)	600,000	1030
bu_sherkateomran	25	construction use	700,000	1525
bu_tafrihatesalem	26	unrestricted access area (recreation)	500,000	1298
bu_varzeshienghelab	27	unrestricted access area (recreation)	500,000	1564
bu_sazmaneparkha	28	unrestricted access area (park)	450,000	1108
bu_unibeheshti	29	unrestricted access area (university)	300,000	1729

Table 2: Define node as suppliersin in network

Supplier	Code	Type	Capacity (m^3/year)	Elevation (m)
wwtp_sahebgharanieh	1	waste water treatment plant	280,800	1678
wwtp_zargandeh	2	waste water treatment plant	3,240,000	1472
wwtp_gheitarieh	3	waste water treatment plant	1,211,760	1562
wwtp_mahalati	4	waste water treatment plant	2,786,400	1731
wwtp_ghods	5	waste water treatment plant	9,486,720	1412
wwtp_ekbatan	6	waste water treatment plant	6,480,000	1224
wwtp_shoosh	7	waste water treatment plant	4,406,400	1110
wwtp_dolatabad	8	waste water treatment plant	4,957,200	1093
wwtp_ezterari	9	waste water treatment plant	66,756,960	1037
wtp_jalalieh	10	water treatment plant	227,059,200	1263
wtp_kan	11	water treatment plant	252,288,000	1204
wtp_tehranpars	12	water treatment plant	252,288,000	1526
wtp_5	13	water treatment plant	179,755,200	1729
darband_220	14	canal	18,921,600	1620
darband_239	15	canal	47,304,000	1403
darband_132	16	canal	100,915,200	1201
darband_153	17	canal	173,448,000	1131
darband_170	18	canal	296,438,400	1094
darband_200	19	canal	362,664,000	1034
kan_555	20	canal	34,689,600	1243
kan_576	21	canal	26,805,600	1160
well_1	22	well	3,239,460	1559
well_2	23	well	16,727,891	1432
well_3	24	well	1,271,721	1448
well_4	25	well	2,370,582	1543
well_5	26	well	22,658,216	1392
well_6	27	well	8,968,079	1304
well_7	28	well	2,979,504	1268
well_9	29	well	7,230,822	1181
well_10	30	well	67,090	1154
well_11	31	well	13,425,242	1133
well_12	32	well	20,596,745	1136
well_13	33	well	1,587,080	1226
well_14	34	well	19,084,533	1161
well_15	35	well	23,494,010	1110
well_16	36	well	5,224,325	1108
well_17	37	well	2,384,618	1125
well_18	38	well	1,306,941	1130
well_19	39	well	410,801	1107
well_21	40	well	16,181,980	1209
well_22	41	well	13,444,160	1265

Results and Discussions

As was explained in the methodology section, the first step is checking the feasibility of transfer water between the two nodes according to the water quality of supplier and the required standard of water for each user. So, the model runs in two different conditions:

1- Present Condition: In this condition the water quality of all supplier defined to model as same as data reported from laboratory. So, only WTPs and Wells can supply the water demand of users; because the WWTPs are not treating their effluent to high quality standards, and some local WWTPs discharge their effluents directly to canals so the water quality of these canals is bad too. The result of present condition system is shown in table 3.

2- Improved System: In this condition it is supposed that WWTP are improved with some technical and practical solution such as adequate filtration and using ozone or UV light for disinfection. Another assumption is that water quality in the canals is improved and discharge of WWTP effluent is forbidden. So all suppliers can supply the water demand of users. The result of the improved system is presented in table 4.

Table 5 shows the result of two systems. In the present condition all of the water is supplied from freshwater and groundwater, but in the improved proposed system most of the amount of the water is supplied from WWTPs effluent and the water in the canal. In other words, more than 3.14 Mm^3 freshwater and more than 150 Mm^3groundwater are saved in a year. This amount of water can be used as drinking water and other usage with high water quality need. In addition to the environmental benefits, such as reducing pollution loads to receiving streams, adjusting increasing water demand and preventing groundwater level drop off; the economic benefit is remarkable. The reduction cost from 27.2 billion tomans (equals 27.2 million USD) to 18.86 billion tomans (equals 18.86 million USD) in a year excuses the cost for upgrading WWTPs.

Table 3: Water allocation in the present condition system (m^3/year)

	pj_ lavizan1	pj_ ghazal	pj_ chitgar	pj_ khojir	pj_ sorkhehesar	pj_ koohsar	pj_ pardisan	pj_ afra
well_2	10979141						5748750	
well_4	1777542							
well_5	14070817	1974326				6613073		
well_11								3865076
well_12		2342201		14453675				
well_14				2792575	16291958			
well_15		18678473						
well_21			16181980					
well_22			6525583			4884427		
	pj_ sohanak	pj_ tooska	p_ azadegan	pj_ khargoosh dareh	p_ besat	p_ khalijefars	pj_ yadbood	p_ ghaem
wtp_ Tehran pars							958125	
well_1	3239460							
well_4	593040							
well_15		2190274	1628813			996450		
well_16					1025194			
well_18								900638
well_22				1533000				
	p_ polis	p_ melat	pj_ taleghani	p_ razi	p_ laleh	bu_ sherkate naft	bu_ abfa	bu_ sazmane parkha
wtp_ jalalieh	804825							450000
well_3		651525	597870					
well_6					519775			
well_11				574875				
well_12						3800869		
well_16						2199131	2000000	
	bu_ marghade emam	bu_ sherkate omran	bu_ tafrihate salem	bu_ varzeshi enghelab	bu_ unibeheshti			
wtp_ jalalieh	600000							
wtp_ Tehran pars		700000		477674	300000			
well_3				22326				
well_6			500000					

Table 4: water allocation in developed system (m^3/year)

	pj_lavizan1	pj_ghazal	pj_chitgar	pj_khojir	pj_sorkhehesar	pj_koohsar	pj_pardisan
wwtp_ghods							5748750
wwtp_shoosh							
darband_239	26827500						
darband_132		22995000		17246250	16291958		
darband_170							
kan_555			22707563				
kan_576						11497500	
	pj_afra	pj_ sohanak	pj_ tooska	p_ azadegan	pj_ khargooshdareh	p_ besat	p_ khalijefars
wwtp_shoosh			2190274			1025194	
darband_220		3832500					
darband_170	3865076			1628813			996450
kan_555					1533000		
kan_576							
	pj_yadbood	p_ghaem	p_polis	p_melat	pj_taleghani	p_razi	p_laleh
wwtp_ zargandeh				651525			
wwtp_mahalati			804825				
wwtp_ghods							519775
wwtp_ezterari	958125						
darband_239					597870		
kan_576		900638				574875	
	bu_ sherkatenaft	bu_abfa	bu_ marghademam	bu_ sherkateomran	bu_ tafrihatesalem	bu_ varzeshi enghelab	bu_ sazmaneparkha
wwtp_zargandeh						500000	
wwtp_ghods					500000		
wwtp_dolatabad		2000000					
wwtp_ezterari	6000000		600000				
wtp_kan				700000			
wtp_tehranpars							450000

Table 5: comparison between two systems

	Freshwater (m^3/year)	Groundwater (m^3/year)	WWTPs effluent (m^3/year)	Canal (m^3/year)	Total Cost (toman/year)
Real System	4,290,624	150,152,837	0	0	27,213,038,639
Developed System	1,150,000	0	21,498,468	131,794,993	18,858,408,235

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