Potable Water Saving by Reusing Greywater in the Al Ain City

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Introduction

Fresh water scarcity in arid regions is well acknowledged. Sources of urban water in the United Arab Emirates (UAE) are groundwater, desalinated water and treated wastewater. In the Emirate of Abu Dhabi (EAD), about three-quarters of the costly desalinated water supplies are used for irrigation to amenity plantations and for home gardening (Environment Agency Abu Dhabi, 2009). The per capita water consumption in EAD ranges between 170 and 200 lpcd in flats and between 270 and 1,760 lpcd in villas. The amenity (park, gardens and recreation areas) irrigation has been increasing in the region with the rapid growth of its urban development. Currently about 98% of wastewater generated from households in EAD is centrally collected through an efficient sewerage networks and then treated for reuse in the irrigation to roadside plantations and public places. In current practice, treated sewage effluent is not conveyed for domestic gardening and toilet flushing purposes. This is because of necessity of dual reticulation system that will increase the marginal cost of water supply significantly. Greywater collected from shower, ablution, washing machine, bathroom sink and other household activities (except from toilet and kitchen source) are generally less contaminated than that of municipal wastewater and can be reused for non-potable consumptions (Mourad et al., 2011; Friedler and Hadari, 2006).

The Abu Dhabi Water Resources Master Plan (Environment Agency Abu Dhabi, 2009) identified three options to ensure future water supplies (a) demand reduction (b) supply augmentation and (c) a combination of the two. Wastewater and recycled desalinated water collected by the sewer system is a valuable resource in water scarce country. Currently available modern treatment technologies are capable of treating wastewater and can meet the water quality standards. In EAD, a centralized collection and treatment of domestic and municipal wastewater is followed. Wastewater is collected through a network of 5,100 km of sewers and 500 km of rising mains. There are about 241 pumping stations to keep the system in flowing condition and a total of 32 treatment units are in operation conditions. They treat about 95% of wastewater collected by the sewer networks. The average rate of treated sewage effluent (TSE) produced per person served by the Abu Dhabi Sewerage Services Company (ADSSC) is about 130 Lpcd based on a serviced population of 1.4 million. Currently about 35% of TSE (51 Million cubic meter/year) produced in EAD is disposed of into the Gulf because of the capacity limitations of the TSE dedicated irrigation distribution systems. Domestic water consumption in EAD is about 183 million cubic meter year and the sewers collect about 181 million cubic meter/year. Therefore the efficiency of centralized wastewater collection is about 98%, which is an exceedingly efficient management system. About 50% to 80% of wastewater constitutes greywater (shower water, ablution water, washing water etc.) which is comparatively less pathogenic than black water (toilet and kitchen wastewater). Current practice of centralized wastewater collection system does not separate greywater and blackwater. It is generally considered that some demand management measures such as increase of water tariffs would primarily affect household's outdoor use of water, little of which is captured by the sewerage system. Therefore increasing tariffs will not necessarily lead to a reduction in wastewater or greywater generation rate (Environment Agency Abu Dhabi, 2009).

Approximately one fifth of residential water is used for toilet flushing and about one third is for irrigation to amenity vegetation. Though a highly efficient (98% efficiency) centralized wastewater collection sewer network and treatment plants are available in EAD, end uses of TSE requires development of an expensive distribution network (dual reticulation). This will increase the marginal cost of water supply significantly. That's why a centralized TSE reuse scheme is not economically viable. In some water scarce countries (for example, Australia), decentralized (household level) harvesting and reuse of alternative water resources such as rainwater and greywater shows an economically viable solution for water supply augmentation and capable of fulfilling a potable water savings target (Chowdhury *et al.*, 2011, 2012). For example, the South East Queensland Regional Plan (2009) in Australia set a mandatory potable water savings target of 70 kilo liter/household/year in south east Queensland by promoting alternative water resources (rainwater, stormwater, greywater etc.).

This study investigated the potential of decentralized greywater harvesting and reuse in the Al Ain city (arid region) for domestic non-potable consumptions such as home gardening and toilet flushing. The Al Ain city is the second largest city in EAD having a population of about 0.5 million. A stochastic method of water consumption and greywater generation from houses located in Al Ain is described in this paper. Characteristics of greywater are delineated. A questionnaire survey was conducted among 100 residential houses to investigate the nature of water consumptions and their willingness for reuse of greywater.

Material and Methods

A field survey was made to investigate the social attitudes toward water consumption and reusing greywater in the Al Ain city. Various water consumption related parameters such as house information, family members, number of vehicles, indoor and outdoor water uses were investigated from personal interviews. The number of interviewees was estimated by using Equation (1), which estimates a population based representative sample (Ghisi and Ferreira, 2007).

$$n \geq \frac{N/\varepsilon^2}{\frac{1}{\varepsilon^2} + N} \quad (1)$$

where n is the sample size, N is the population size, and ε is the sample error (from 1% to 20%). Taking the total population of the city (approximately 0.5 million) including peri-urban areas and assuming a 10% sample error, about one hundred interviews were conducted. The respondents were chosen randomly about 50% men and 50% women. The interviews were made at homes, offices, university and in cafeterias. The questions in the interviews included house and garden area, family members, number of vehicles, social acceptance of reusing greywater for toilet flushing and gardening, and frequency of shower, face and hand washing, tooth brushing, clothes and dish washing, house cleaning, and toilet use etc. Equations (2) to (5) were used to estimate the daily water consumption. Greywater generation was estimated using the Equation (6). Similar type of method was previously applied in Mourad *et al.* (2011).

$$W_d = W_p + W_f \tag{2}$$

$$W_p = F_s Q_s + F_{tb} Q_{tb} + F_{hw} Q_{hw} + F_{fw} Q_{fw} + F_a Q_a + F_{tf} Q_{tf} \tag{3}$$

$$W_f = (F_l Q_l + F_{dw} Q_{dw} + F_c Q_c + F_p Q_p + F_v Q_v + F_g Q_g)/FM \tag{4}$$

$$Q = T F_R \tag{5}$$

$$G_w = F_s Q_s + F_{tb} Q_{tb} + F_{hw} Q_{hw} + F_{fw} Q_{fw} + F_a Q_a + (F_l Q_l + F_c Q_c)/FM \tag{6}$$

where W_d is the daily water consumption in liter per capita per day (Lpcd), W_p is the personal water consumption (Lpcd) and W_f is the water consumption within the family (Lpcd); F_s, F_{tb}, F_{hw}, F_{fw}, F_a, F_{tf}, F_l, F_{dw}, F_c, F_p, F_v and F_g are the daily frequency of using shower, tooth brush, hand wash, face wash, ablution, toilet flush, laundry, dish wash, cleaning, pet water, vehicle cleaning and irrigation to garden, respectively; Q_s, Q_{tb}, Q_{hw}, Q_{fw}, Q_a, Q_{tf}, Q_l, Q_{dw}, Q_c, Q_p, Q_v and Q_g are the water consumption, in liters, for each use of shower, tooth brush, hand wash, facewash, ablution, toilet flush, laundry, dish wash, home cleaning, pet water, vehicle cleaning and gardening, respectively; T indicates time requirements for water uses in minute and F_R indicates flow rate in Liter/minute; and FM is a number of family members.

The time requirements for one event of different personal and family water uses were estimated from a group of twelve volunteers, seven males and five females, having different age classes and marital status. The quantity for each toilet flush was estimated from the volume of toilet tank. The estimated time for each activity was multiplied by their flow rates. Average flow rates were measured using a volumetric jar and a stop watch. Finally, probability distribution of frequency of different water uses and their time requirements were performed using four distributions (normal, lognormal, gamma and logistic distributions). Using the best fitted probability distributions at 95% significance level, daily water consumption and greywater generation in residential premises were generated.

The physical, chemical and biological greywater characteristics and their treatment technologies were delineated based on a rigorous literature reviews.

Results and Discussion

Based on the questionnaire survey, it was found that more than 70% respondents in Al Ain city are willing to reuse greywater for household gardening, about 10% respondents are willing for both toilet flushing and home gardening, and about 15% respondents consider it as a harmful practice.

Frequency analysis of water uses

Statistical characteristics of different water uses per person per day (or week) are shown in Table 1. Probability distributions at 95% significance level of these variables were conducted. Number of bed rooms and vehicles were best fitted by the lognormal distribution. Numbers of people in houses were best fitted by the gamma distribution. Number of toilet flushes, hand washes, face washes, laundry (per week), dish washes and car washes (per week) were best fitted by the normal, logistic, gamma, normal, gamma and logistic distributions, respectively at the 95% significance level. All of the houses surveyed were villa type detached house and generally occupy provision for amenity plantation. Estimated average family members were found about 12 persons per house that represents cultural practices of joint family (brothers and their families live in the same house along with their grandparents) in the region. In the survey, children of age less than 3 years were not considered. The five times ablution in a day is a religious practice in the region and an average ablution frequency of 4.42 per person per day indicates that some people perform ablution outside of home (at mosque).

Table 1: Statistical characteristics of frequency of water uses at residential premises in Al Ain

Variable	Mean	St dev	Variance	CV	Minimum	Q1	Median	Q3	Maximum	Skewness	Kurtosis
Bedroom/house	6.76	2.18	4.75	32.22	2.00	5.00	6.00	8.00	12.00	0.61	0.22
Car/house	4.41	1.81	3.27	40.96	2.00	3.00	4.00	6.00	9.00	0.81	-0.01
People/house	11.60	4.62	21.35	39.82	4.00	8.00	11.00	15.00	24.00	0.41	-0.31
Shower/p/d	1.68	0.73	0.53	43.04	1.00	1.00	2.00	2.00	4.00	0.74	-0.08
Toilet flush/p/d	4.29	1.04	1.09	24.30	2.00	3.25	4.00	5.00	6.00	-0.14	-0.72
Tooth brush/p/d	2.15	0.65	0.42	29.97	1.00	2.00	2.00	3.00	4.00	0.10	-0.04
Handwash/p/d	4.71	1.52	2.32	32.37	1.00	4.00	5.00	5.00	9.00	0.47	1.19
Facewash/p/d	3.52	1.34	1.79	38.00	1.00	2.00	3.00	5.00	7.00	0.21	-1.02
Ablution/p/d	4.42	0.98	0.96	22.21	1.00	4.00	5.00	5.00	6.00	-1.50	1.48
Laundry/w	6.44	2.91	8.49	45.26	1.00	4.00	7.00	7.00	14.00	0.35	-0.10
Dishwash/d	4.03	1.29	1.65	31.85	2.00	3.00	4.00	5.00	8.00	0.85	0.84
Homeclean/d	1.24	0.65	0.43	52.76	0.00	1.00	1.00	2.00	3.00	1.00	1.08
Gardening/d	1.56	0.64	0.41	41.14	1.00	1.00	1.00	2.00	4.00	1.03	1.48
Carwash/w	2.03	1.09	1.19	53.75	1.00	1.00	2.00	3.00	5.00	1.01	0.64
Pet water/d	0.62	1.20	1.43	191.94	0.00	0.00	0.00	1.00	5.00	2.05	3.64

St dev= standard deviation, CV = coefficient of variation, Q1 = 25th percentile, Q3 = 75th percentile, per person per day = /p/d, per week = /w

Water uses time requirements

Time requirements for different water uses were estimated and their statistical characteristics are shown in Table 2. Their frequency distributions were conducted. Time requirements for toothbrush and car wash were best fitted by the logistic distribution whereas hand wash, face wash, shower, ablution and dish wash time requirements were best fitted by the gamma distribution. Time requirements for different personal water uses (shower, hand wash, ablution, for example) are generally depended on cultural practices and on water tariff structure. It is observed from Table 2 that shower time is highly variable with an average time of 9.71 minutes and a standard deviation of 4.4 minutes. This is probably because of high temperature in the region. In most of homes surveyed, there is a hose pipe connection at the garage for car washing and gardening purposes. The car wash time presented in Table 2 indicates the hose pipe running time only.

Table 2: Statistical characteristics of time requirements for different water uses

Variable (minute)	Mean	Stdev	Variance	CV	Minimum	Q1	Median	Q3	Maximum	Skewness	Kurtosis
Toothbrush	1.55	0.82	0.67	52.77	0.39	1.08	1.44	2.00	4.00	0.74	0.96
Handwash	1.09	0.86	0.73	78.81	0.12	0.29	1.02	2.00	3.00	0.68	-0.60
Facewash	0.87	0.69	0.47	79.03	0.13	0.21	1.02	1.08	2.03	0.57	-0.89
Shower	9.71	4.40	19.38	45.33	5.01	6.32	7.73	12.72	19.22	0.90	-0.44
Ablution	2.06	0.89	0.79	42.97	0.57	1.34	2.00	3.00	4.00	0.67	-0.34
Dishwash	31.67	4.20	17.65	13.27	25.00	30.00	30.00	35.00	40.00	0.60	0.20
Carwash	6.76	1.56	2.45	23.15	5.00	5.00	7.00	8.00	10.00	0.67	0.26

St dev= standard deviation, CV = coefficient of variation, Q1 = 25th percentile, Q3 = 75th percentile

Water consumption and greywater generation

Estimated water consumptions for different water uses are shown in Table 3. Using the Equation (6), estimated average greywater generation rate is found to be 195 Lpcd. This estimation is calculated by considering the average time requirements and average frequency of uses of different water uses. For personal water consumptions, it is observed that the highest consumptive uses are shower, toilet flush and ablution, accordingly. The shower consumption is much higher probably because of higher temperature in the region. Average ablution water consumption is found almost equal to toilet flush consumption – in other way it can be said that reuse of ablution water can meet the requirements for toilet flush consumption. For family water consumptions, irrigation (not estimated yet) and dish wash consumptions are generally higher than other uses.

Table 3: Estimated water consumption for different water uses

Personal water uses	Average time required (minute)	Flow rate (L/minute)	Consumption of water per use, Q (Liter)	Frequency of use, F (per person day)	Average water consumption (Lpcd)
Shower	9.71	5.75	56	1.68	94
Toothbrush	1.55	4	6	2.15	13
Hand wash	1.09	4	4	4.71	19
Face wash	0.87	4	3	3.52	11
Ablution	2.06	4	8	4.42	35
Toilet flush	-	-	9	4.29	39
Family water uses	**Average time required (minute)**	**Flow rate (L/minute)**	**Consumption of water per use, Q (Liter)**	**Frequency of use, F (per family per day)**	****Average water consumption (Lpcd)**
Laundry	-	-	255	0.92 (6.44 per week)	20
Dish wash	31.67	4	127	4.03	44
Carwash	6.76	13.5	91	0.29 (2.03 per week)	2
Home clean	-	-	24	1.24	3
Irrigation	*	*	*	1.56	*
Pet water	*	*	*	0.62	*

**Not calculated yet **Divided by average family size of 11.6*

Characteristics of greywater

Typical characteristics of household greywater are shown in Table 4. Greywater contains about 3.8 x 104 cfu/100 mL of fecal coliforms and about 1.6 x 10 cfu/100 mL of heterotrophic plate count bacteria (Gilboa and Friedler, 2008). The COD values were found 258 to 354 mg/l (Li et al., 2003). Greywater with BOD_5 to COD ratio of 0.45 ± 0.13 exhibits good aerobic biological treatment. Greywater with COD: N: P ratio of 100: 20: l and 350: 5: 1 exhibits necessity of aerobic and anaerobic treatment, respectively (Metcalf, 2003). Surfactants in excess of 30 mg/l exhibits bad effect on irrigated soil causing of chlorosis problem (Shafran et al., 2006). Previous studies showed that about 70% of greywater COD are biodegradable under anaerobic condition whereas anionic surfactants showed a poor anaerobic degradability of 35±13%.

Table 4: Characteristics of house hold greywater (Li et al., 2003; Elmitwalli and Otterpohl, 2007; Fittschen and Niemczynowicz, 1997; Palmquist and Hanaeus, 2005; Hernandez et al., 2007; Shafran et al., 2005; Al-Jayyousi, 2002; Dallas et al., 2004; Gilboa and Friedler, 2008)

Source	Sampling	COD	BOD_5	Total N	NH_4^+-N	Ortho P	Total P	Anionic surfactants
111 houses, Germany	4 months	258-354	-	9.7-16.6	-	-	5.2-9.6	-
111 houses, Germany	9 months, n = 6	640	-	27.2	4.2	8	9.8	-

37 houses, Sweden	2 months, n = 8	361	-	18.1	-	-	3.9	-
47 houses, Sweden	2 months, n = 4	588	-	9.7	-	-	7.5	-
150 houses, Netherlands	2 weeks, n = 104	425	215	17.2	7.2	2.3	5.7	-
32 houses, Netherlands	4 months, n = 10	1583	-	47.8	16.4	2.3	9.9	-
House 1, Israel	1 year, n = 96	474	195	-	-	-	-	17
House 2, Israel	1 year, n = 96	200	62	-	-	-	-	3
6 Houses, Israel	5 weeks, n = 5	-	133	19	-	-	31	34
4 houses, Costa Rica	1 year, n = 11	-	167	-	-	6.28	-	-
13 families, Jordan	n = 6	1351	873	17	-	-	-	76
1 family, USA	n = 10	-	-	0.5-6.2	0.12-2.49	1.9-16.9	-	-

Conclusions

With rapid population growth and in a changing climate regime, urban water supply scheme in many cities of the world are under stress. The situation is more severe in arid regions where there are no reliable surface water resources. In UAE, urban water demand is increasing day by day due to adoption of amenity plantations and desert greening policies. To tackle this problem, water authorities are adopting several measures including water demand management and promoting alternative water sources. The treated sewage effluent is successfully used in UAE for roadside and public place plantation. However this cannot be conveyed for home gardening and toilet flushing because of requirement of expensive dual reticulation system.

Domestic water consumption in Al Ain is very high, which is because of cultural practices, high temperature in the region and for subsidized water tariff structure to consumers. Based on survey to around 100 villa type houses, it was found that on average about 195 Lpcd of greywater is generated. It was also observed that the ablution water consumption is almost equal to toilet flush water requirements. Therefore there is potential for greywater reuse in Al Ain. From the questionnaire survey it was found that about 70% of respondents agreed that greywater can be reused for gardening purposes and about 10% agreed to reuse greywater for toilet flush purposes. Because of high variability of different water uses (frequency and time of uses) –a probabilistic model considering probability distribution of different variables in Equations (2) to (6) is recommended rather than considering average generation rate.

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