Jordan Journal of Civil Engineering, Volume **2**, No. **4**, **2008**

Greywater Generation and Characterization in Major Cities in Jordan

Ahmad Jamrah [1] ***and Safa Ayyash*** [2]

[1], [2] Department of Civil Engineering, University of Jordan, Amman 11942, Jordan, e-mail: jamrah@ju.edu.jo

ABSTRACT

The objectives of this study is to estimate quantities of greywater generated in typical Jordanian households in the major cities of Irbid, Rusaifa and Zarqa, to investigate greywater quality and to gauge public acceptance towards greywater reuse. A social survey was designed and administered to identify quantities of greywater generated. The survey covered a total of 150, 100 and 150 households in the cities of Irbid, Rusaifa and Zarqa, respectively, over a period of 12 weeks. Greywater samples were collected form households to represent the different sources of greywater. Results of the study showed that the average per capita water consumption in the cities of Irbid, Rusaifa and Zarqa was 82.67, 69.63 and 82.34 liters per day, respectively, and that greywater generated constituted 71% to 77% of total consumption. Quality data showed that greywater treatment is necessary, and public acceptance survey indicated that the majority of people oppose greywater reuse.

KEYWORDS: Greywater, Quantity, Quality, Public acceptance, Irbid, Rusaifa, Zarqa.

INTRODUCTION

Jordan is a semi-arid country with low amounts of rainfall and high evaporation. Water sources in Jordan are far below the water poverty line (1000 m^3 per capita per year). As a result, the development of new resources of water is necessary. Treated wastewater and greywater constitute potential alternative resources for water. Jordan is already reusing approximately 70% of the treated wastewater effluents for irrigation purposes (Jamrah et al., 2006; Surani, 2003).

There is an increasing interest in the reuse of wastewater in many parts of the world, including both industrial and developing countries. One reason is water shortage, caused by too low amounts of rainfall in combination with high evaporation (e.g., Australia) or too large demands of freshwater from the population (e.g., Japan). On the other hand, some countries are driven towards the reuse of wastewater because of environmental and economical considerations (Eriksson et al., 2002).

Greywater is water generated from homes (shower, sinks and laundry) except water generated from toilets. Some sanitary experts define greywater as water that is lower in quality than potable water, but of higher quality than black water (Jamrah et al., 2006; Prathapar et al., 2005; Al-Jayyousi, 2003; Ottoson and Stenstrom, 2003; Surani, 2003). It is called greywater because the color of the water turns grey when it is stored without treatment. Dish washer, shower, sink and laundry water comprise 50-80% of the total residential wastewater (Al-Jayyousi, 2003; Jamrah et al., 2008).

A greywater amount that is generated will vary depending on the number of people, their age, their water usage pattern and time. For example, the average annual household greywater generation in Arizona is estimated at 30000 to 40000 gallons (Al-Jayyousi, 2003). Approximately equal quantities of greywater and blackwater are produced in the United Kingdom (Prathapar et al., 2005), whereas 70% to 80% of domestic

Accepted for Publication on 1/10/2008.

water becomes greywater in Amman and Muscat (Jamrah et al., 2006; Jamrah et al. 2008).

Experience in several arid and semi-arid countries indicates that greywater can be a cost-effective alternative source of water. However, until recently, lack of data on this aspect has been a barrier to arriving at such a conclusion (Prathapar et al., 2005). Prathapar et al. (2005) pointed out several factors constraining treated greywater reuse. They categorized these factors as quantity, quality, financial, legal, social and institutional constraints.

Quality of greywater varies depending on the source and use of greywater, geographical location, social habits, demographics and level of occupancy (Prathapar et al., 2005; Al-Jayyousi, 2003; Jefferson et al., 1999). Greywater may be polluted, and as a result may cause health risks, and it contains certain environmental pollutants. This would mandate the identification of characteristics of greywater and the treatment of greywater prior to reuse. It should be noted that the characteristics of greywater depend on the quality of fresh water, the distribution network and the activity and habits of the residents (Prathapar et al., 2005; Al-Jayyousi, 2003).

Greywater may be reused for groundwater recharge, irrigation, plant growth, washing of vehicles and windows, fire protection, boiler feedwater and concrete production. In addition, grey wastewater could be used to develop and preserve wetlands (Jamrah et al., 2006; Al-Jayyousi, 2003; Al-Jayyousi, 2002; Eriksson et al., 2002; Nolde, 1999). Greywater has been used to promote sustainable development and resource conservation without compromising public health and environmental quality (Prathapar et al., 2005). Japan, the US and Australia maintain the highest profile in greywater reuse (Ottoson and Stenstrom 2003).

In Jordan, the information about greywater generation is very limited and there is lack of data about greywater characteristics. The objective of this study is to collect enough information about greywater in the cities of Irbid, Rusaifa and Zarqa and to judge if this greywater can be employed as part of the overall sustainable management of the limited water resources. As a result, this study is an attempt to (1) estimate the quantities of greywater generated in typical Jordanian households in the cities of Irbid, Rusaifa and Zarqa (2) investigate the quality of the different greywater sources generated from selected cities to assess the risks of greywater use (pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), alkalinity, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), chlorides (Cl^-), calcium (Ca), sodium (Na), magnesium (Mg), potassium (K), lead (Pb), Total Coliforms (TC), Total Fecal coliforms (TF), Total Solids (TS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and nitrate (NO_3^-) and (3) investigate the public acceptance towards greywater reuse.

METHODOLOGY

A questionnaire in the form of a social survey was designed to identify the quantity of greywater generated in typical Jordanian households. The survey was administered in three main Jordanian cities: Irbid, Rusaifa and Zarqa over a period of 12 weeks. The number of households covered by the survey in the cities of Irbid, Rusaifa and Zarqa was 150, 100 and 150 respectively, and the total number of residents participating in the survey was 947, 726 and 966. The questionnaire included questions dealing with the number of occupants in a given household, water bill, frequency of bathing, hand washing, teeth brushing, ablution and hair washing, frequency cloth washing and type of laundry machines, floor area of the house, existence of garden and frequency of garden watering. An estimate of the total household water consumption was obtained from last household quarterly water bill for the first quarter of the year 2007. Some assumptions were made for the purpose of calculating the amount of greywater generation. These assumptions are generally adopted by the Jordanian Ministry of Water and Irrigation (MWI). These assumptions are given in Table (1). Greywater generation was estimated from the sum of sink, shower and laundry. Black water generation was calculated from the difference between the total household water consumption and the sum of greywater generation, garden water consumption and water used for cooking and drinking. The data collected was analyzed for total daily per capita greywater generation, daily per capita fresh water consumption, and daily per capita black water generation. A statistical analysis was carried out on the collected data to examine the variability, correlation, distribution and statistical inference.

Table (1): Assumptions adopted for the purpose of estimating fresh water consumption and greywater generation in typical Jordanian households (MWI, 2007).

Amount of fresh water consumption for automatic washing machines	90 L/use
Amount of fresh water consumption for manual washing machines	60 L/use
Amount of fresh water consumption for shower	60 L/shower
Average time for tooth brushing	0.33 minute
Average time for hand washing	0.33 minute
Average time for Ablution	2 minutes
Average time for hair washing	1 minute
Average hand basin flow	6 L/minute
Percent of cooking and drinking from total household water consumption	5%
Percent of garden watering from total household water consumption	6%

Greywater samples in this study were collected from different households in the cities of Irbid, Rusaifa and Zarqa. Samples were collected from shower, sink and laundry in various locations of the study to represent different sources of greywater generation. Samples were collected in sterile bottles from households and were analyzed for pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), alkalinity, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), chlorides (Cl^-), calcium (Ca), sodium (Na), magnesium (Mg), potassium (K), lead (Pb), Total Coliform (TC), Total Fecal coliform (TF), Total Solids (TS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and nitrate (NO_3^-). All analyses were carried out according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Sampling bottles were kept in an ice box below 4 ^oC during transportation to the laboratory and were rapidly analyzed, except for Ca, Na, Mg, K and Pb, where samples were preserved in nitric acid and stored at 4^oC.

A survey questionnaire was also designed and administered in the selected cities over a period of three months to gauge public reaction towards greywater reuse. The survey aimed at measuring opinion of the public towards acceptance and/or opposition of greywater reuse, and find out reasons behind the public opinion.

RESULTS AND DISCUSSION

Data related to water quantity was collected during a period of 12 weeks from January through March, 2007. Table (2) shows the statistical summary of the distribution of internal domestic fresh water use in Irbid, Rusaifa and Zarqa. The table shows that greywater generation ranged in Irbid from 30 Lpcd to 137 Lpcd with an average of 63 Lpcd, in Rusaifa from 28 Lpcd to 88 Lpcd with an average of 51 Lpcd, and in Zarqa from 24 Lpcd to 127 Lpcd with an average of 58 Lpcd. The table also shows that sink constituted the higher percentage of greywater generation, followed by shower and finally laundry. The three cities followed a similar trend in terms of greywater generation.

Table (3) shows a statistical summary of the relative contribution of various sources of greywater, black water and the various components constituting sources of greywater generated for Irbid, Rusaifa and Zarqa. Investigation of the table indicates that the percentage of greywater generated from total fresh water consumption for Irbid, Rusaifa and Zarqa is 78%, 75%, and 71%, respectively. For the three cities, sink water has higher percentage and stands at 50%, 54% and 64%, followed by shower water which contributes 33%, 26% and 22%, and finally, laundry water which contributes 18%, 20% and 15% of the total greywater generated, respectively. The contribution of black water to the total wastewater generation follows the following order: Zarqa > Rusaifa > Irbid and constitutes 19%, 14% and 11%, respectively.

Table (2): Statistical summary of the distribution of internal domestic fresh water use for Irbid, Rusaifa and Zarqa. Units are in Lpcd.

		Sink	Shower	Laundry	Greywater	Water Consumption	Garden	Cooking and Drinking	Black Water
Irbid	Average	31.2	20.2	11.8	63.2	82.7	5.3	4.1	13.7
	Weighted average	29.9	19.2	10.7	59.9	77.1	5.3	3.9	8.1
	Minimum	7.1	8.6	4.3	30.0	39.0	0.0	2.0	3.3
	Maximum	68.0	60.0	38.6	136.6	154.8	8.9	7.7	39.6
	Standard deviation	1.6	9.9	5.6	19.1	21.9	2.6	1.1	9.3
Rusaifa	Average	25.1	13.4	10.5	51.3	69.6	5.3	3.5	13.2
	Weighted average	26.7	13.0	9.7	49.4	66.0	5.3	3.3	9.2
	Minimum	12.8	6.4	3.4	28.2	42.7	0.0	2.1	3.3
	Maximum	50.7	40.0	25.7	87.9	119.1	7.1	6.0	30.9
	Standard deviation	9.2	4.9	5.1	12.6	15.6	2.1	0.8	7.9
Zarqa	Average	35.9	13.2	9.1	58.1	82.3	5.4	4.1	18.2
	Weighted average	34.8	11.9	8.0	54.6	77.4	5.4	3.9	14.6
	Minimum	10.2	4.3	2.9	24.2	47.6	0.0	2.4	0.1
	Maximum	74.4	51.4	38.6	127.3	142.9	8.1	7.1	40.5
	Standard deviation	12.8	6.6	4.7	17.1	21.0	2.7	1.1	10.2

Table (3): Statistical summary of the relative contribution of various sources of greywater and black water, and the various components constituting sources of greywater generated for Irbid, Rusaifa and Zarqa.

		Greywater (%)	Black water (%)	Laundry (5)	Shower (%)	Sink (%)
Irbid	Average	76.5	16.6	19.2	31.9	49.0
	Weighted average	77.7	10.5	17.9	32.1	50.0
	Minimum	43.4	3.2	7.7	10.2	9.7
	Maximum	91.8	45.6	54.1	67.5	79.5
	Standard deviation	10.3	10.4	8.0	10.3	12.6
Rusaifa	Average	74.1	18.6	20.3	26.6	53.1
	Weighted average	74.9	13.9	19.7	26.3	54.0
	Minimum	51.0	5.8	7.7	10.4	29.1
	Maximum	89.2	42.2	42.5	53.7	72.8
	Standard deviation	9.8	9.6	7.2	8.4	9.9
Zarqa	Average	70.7	22.1	15.8	23.1	61.1
	Weighted average	70.5	18.9	14.6	21.7	63.7
	Minimum	40.0	0.1	4.2	6.6	29.3
	Maximum	91.1	55.0	33.4	48.1	80.3
	Standard deviation	11.1	11.0	6.2	7.8	11.2

Table (4): The equations, coefficients of determination (R^2) and coefficients of correlation (r) generated in Irbid, Rusaifa, Zarqa and Amman.

City	Equation	R^2	r
Irbid	Greywater = 0.76 × Total Water Consumption (lpcd)	0.765	0.791
Ruasifa	Greywater = 0.73 × Total Water Consumption (lpcd)	0.735	0.694
Zarqa	Greywater = 0.70 × Total Water Consumption (lpcd)	0.705	0.703
Amman	Greywater = 0.69 × Total Water Consumption (lpcd)	0.941	0.970

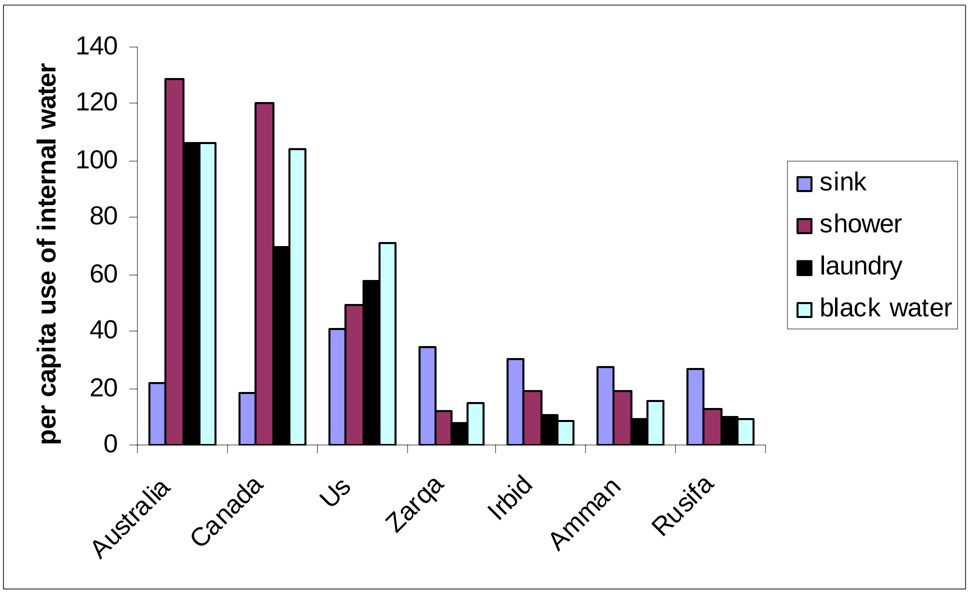


Figure (1): Comparison between the per capita rate of internal water consumption for the different internal water uses for Irbid, Rusaifa, Zarqa, Amman and other countries.

A study which aimed at evaluating the amount of greywater generation in the city of Amman was carried out by Jamrah et al. (2006). The study showed that the water consumption in Amman averaged 84 Liters per capita per day; the generated greywater averaged 59 Liters per capita per day. Figure (1) shows a comparison between the per capita rate of water consumption for the different internal water uses for Irbid, Rusaifa, Zarqa and Amman compared to other countries. The figure shows that the per capita rate of water consumption in all of the Jordanian cities is lower than that of other countries. Figure (2) shows a comparison between the percent use of internal water for the different internal water uses for Irbid, Rusaifa, Zarqa and Amman compared to other countries. The figure indicates that Jordanian cities have higher percentage of water consumption for sink, but lower percentage of water consumption for shower and laundry as well as lower percentage for black water generation.

Jamrah et al. (2008) conducted a study to estimate greywater generation in the Sultanate of Oman. They reported that household freshwater consumption was about 195 Lpcd and that greywater generated constituted about 82% of freshwater consumption. Figure (3) shows the comparisons between the percentage of greywater generation from typical households in Irbid, Rusaifa, Zarqa, Amman and other countries. The figure shows that percentage of greywater generation from total fresh water consumption in Oman, Irbid, Rusaifa, Amman, Zarqa, Canada, US, Australia, Germany and United Kingdom accounted for 82%, 78%, 75%, 71%, 71%, 65%, 59%, 55%, 52% and 48%, respectively.

Table 5. Comparisons between physical, chemical, and biological greywater generated quality for household in Irbid, Rusaifa, and Zarqa.

Quality parameter	Rusaifa				Irbid				Zarqa			
	Shower	Laundry	Sink	Greywater	Shower	Laundry	Sink	Greywater	Shower	Laundry	Sink	Greywater
pH	7.7	8.6	7.7	8	8.3	8.6	7.9	8.3	8.0	8.5	8.3	8.3
DO (mg/L)	8.5	8.7	8.5	8.6	8.6	7.4	8.4	8.1	8.0	8.5	8.3	8.3
EC(mS/cm)	1.9	4.7	1.9	2.8	1.0	4.3	1.2	2.2	1.6	4.7	1.4	2.6
Alk.(mg/L $CaCO_3$)	440.0	1271.7	440.0	717.2	412.2	1053.4	200.2	555.3	298.5	760.2	267.3	442
COD(mg/L)	194.7	126.7	194.7	172	85.3	310.9	116.0	170.7	144.0	191.8	260.0	198.6
BOD(mg/L)	120.6	86.3	120.6	109.2	55.6	207.1	67.8	110.2	94.0	125.8	176.6	132.1
Cl (mg/L)	276.7	359.4	276.7	304.3	60.5	190.4	157.1	136	201.7	424.6	253.7	293.3
Ca (mg/L)	135.5	286.2	135.5	185.7	83.9	104.6	87.5	92	91.4	154.4	73.2	106.3
Na (mg/L)	405.1	1531.5	405.1	780.6	82.5	1326.9	78.5	496	275.7	1182.9	203.7	554.1
Mg (mg/L)	49.1	53.2	49.1	50.5	45.0	52.3	45.8	47.7	49.2	53.6	45.0	49.3
K (mg/L)	48.4	133.9	48.4	76.9	8.2	117.6	6.3	44	38.6	178.6	23.7	80.3
Pb (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TC(MPN/100ml)	555.0	3000.0	555.0	1370	633.3	11000.0	2950.0	4861.1	1300.0	6600.0	2100.0	3333.3
TF(MPN/100ml)	380.0	700.0	380.0	486.7	433.3	1700.0	1350.0	1161.1	750.0	650.0	1215.0	871.7
TS (mg/L)	1729.3	4335.0	1729.3	2597.9	781.7	3795.7	1076.7	1884.7	1173.3	3526.7	1348.3	2016.1
TSS (mg/L)	376.0	368.0	376.0	373.3	230.0	492.9	221.7	314.9	180.0	276.7	266.7	241.1
TDS(mg/L)	1353.3	3967.0	1353.3	2224.5	551.7	3302.9	855.0	1569.9	1026.7	3250.0	1115.0	1797.2
NO_3^-(mg/L)	74.4	238.8	74.4	129.2	27.3	218.1	18.9	88.1	119.1	356.9	34.3	170.1

Table 6. Public reaction toward different uses for greywater .

	Irbid			Rusaifa			Zarqa		
	Agree (%)	Disagree (%)	No opinion (%)	Agree (%)	Disagree (%)	No opinion (%)	Agree (%)	Disagree (%)	No opinion (%)
Use in Toilet flushing	61	33	5	70	25	5	65	28	7
Use in Irrigation	45	52	3	54	43	3	55	41	3
Use in Cleaning vehicles	26	67	7	53	43	4	38	57	5
Use in drinking	23	58	19	13	74	13	19	62	19
Use in develop wetlands	40	45	15	60	35	5	64	30	6
Use in Ground water recharge	24	75	9	16	78	6	20	77	3
Use in Fire protection	31	65	4	35	60	5	26	70	4

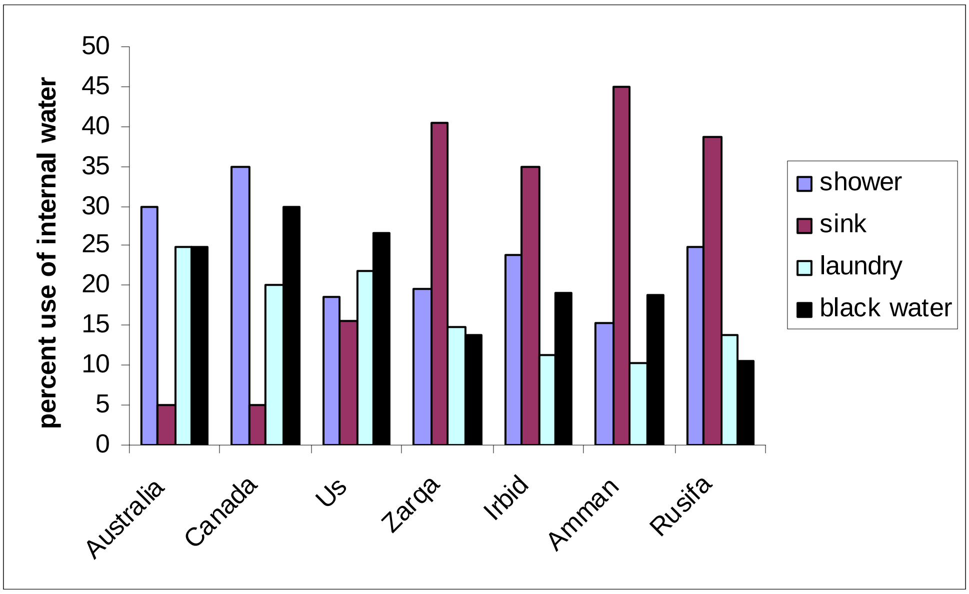
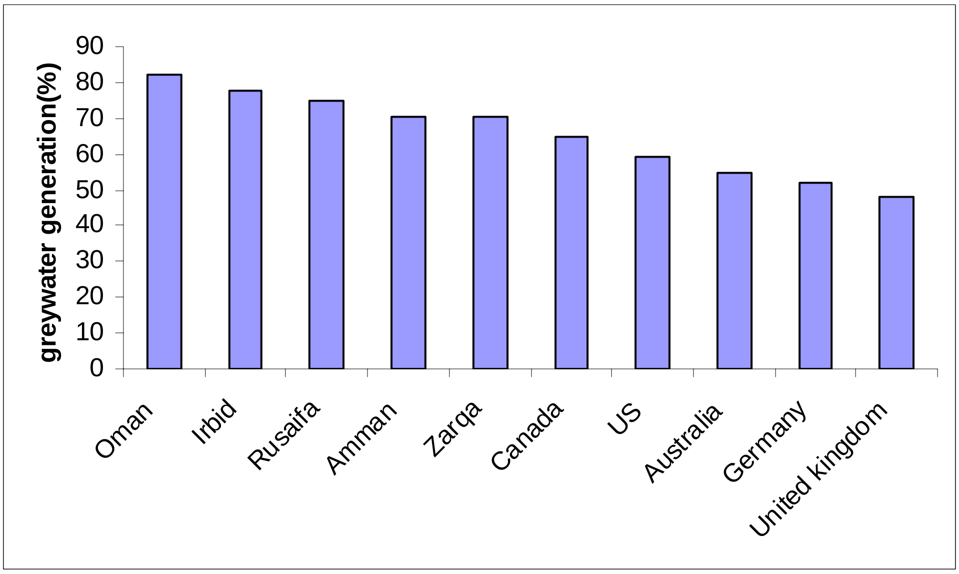


Figure (2): Comparison between the percent use of internal water for the different internal water uses for Irbid, Rusaifa, Zarqa, Amman and other countries.



Figurre (3): Comparison between the percent of greywater generation from the household for Irbid, Rusaifa, Zarqa, Amman and other countries.

Figure (4) shows a comparison between the weighted average of the daily per capita frequency of internal domestic water use for the major Jordanian cities of Irbid, Rusaifa, Zarqa and Amman. Sink water comes from the sum of hand washing, ablution, tooth brushing and hair washing. The figure indicates that hand washing frequency is higher than ablution followed by tooth brushing and finally hair washing. Additionally, the figure indicates that sink has higher frequency of use followed by shower and finally by laundry. Investigation of the figure indicates that water shortage in Jordan has affected the water use habits of people. This is consistent with the low fresh water consumption reported for the studied cities in Table (2). For example, the frequency of water use for shower purposes in Irbid, Rusaifa and Zarqa is 0.32, 0.2 and 0.2, respectively indicating that in a typical household in these cities, each person showers once in about 3days, 5 days and 5 days, respectively. Similarly, the frequency of water use for laundry in Irbid, Rusaifa and Zarqa is 0.15, 0.13 and 0.11m, respectively, indicating that in a typical household in these cities each person does laundry once in about 7 days, 8 days and 9 days, respectively. Jamrah et al.(2006) reported that the frequency of water use for shower purposes in Amman is 0.35 indicating that in a typical household in Amman, each person showers once in about 3days. Similarly, the frequency of water use for laundry is 0.12, indicating that in a typical household in Amman each person does laundry once in about 8 days.

There should be a direct relationship between the total greywater generation and the fresh water consumption in a given household. Figure (5) presents the average per capita greywater generation versus average per capita total household water consumption in the three cities selected for the study. Greywater generation data were estimated throughout this study while household water consumption data were obtained from the quarterly water bill for the households participating in this study in the three cities. The figure shows a direct and well-established relationship between water consumption and greywater generation. This finding is similar to that reported by Jamrah et al. (2006) stating that any increase in sink, shower and laundry water use should result in an increase in greywater generation rate. The per capita rate of greywater generation also increases with the increase of total household water consumption. Table (4) shows predominant equations, coefficients of determination (R^2) and coefficients of correlation (r) for the relationships between fresh water consumption and greywater generation shown in Figure (5) for the cities of Irbid, Rusaaifa and Zarqa. The relationship for the city of Amman is also presented in the table as reported by Jamrah et al. (2006).

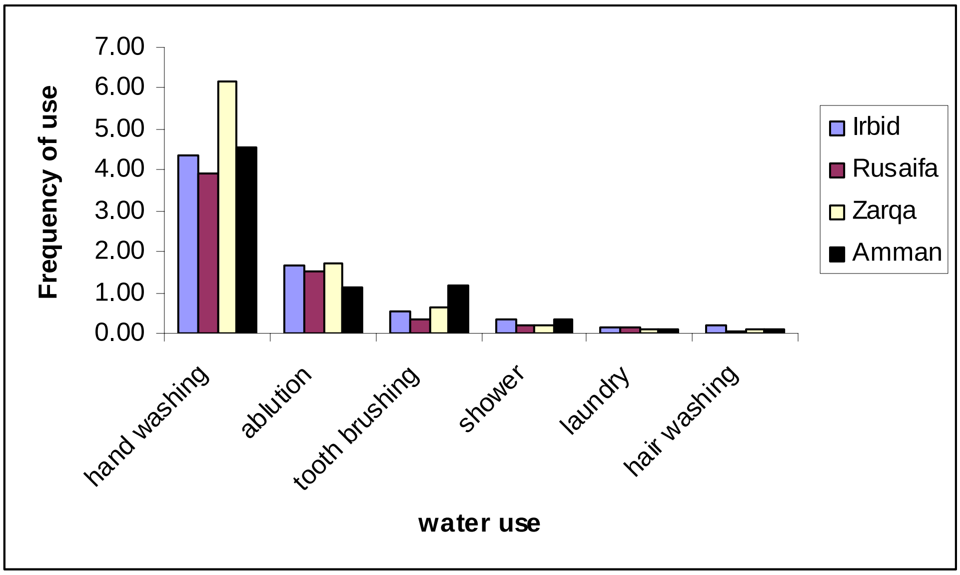


Figure (4): Comparison between the weighted average of the daily per capita frequency of internal domestic water use for Irbid, Rusaifa, Zarqa and Amman.

(a) Irbid

(b) Rusaifa

(c) Zarqa

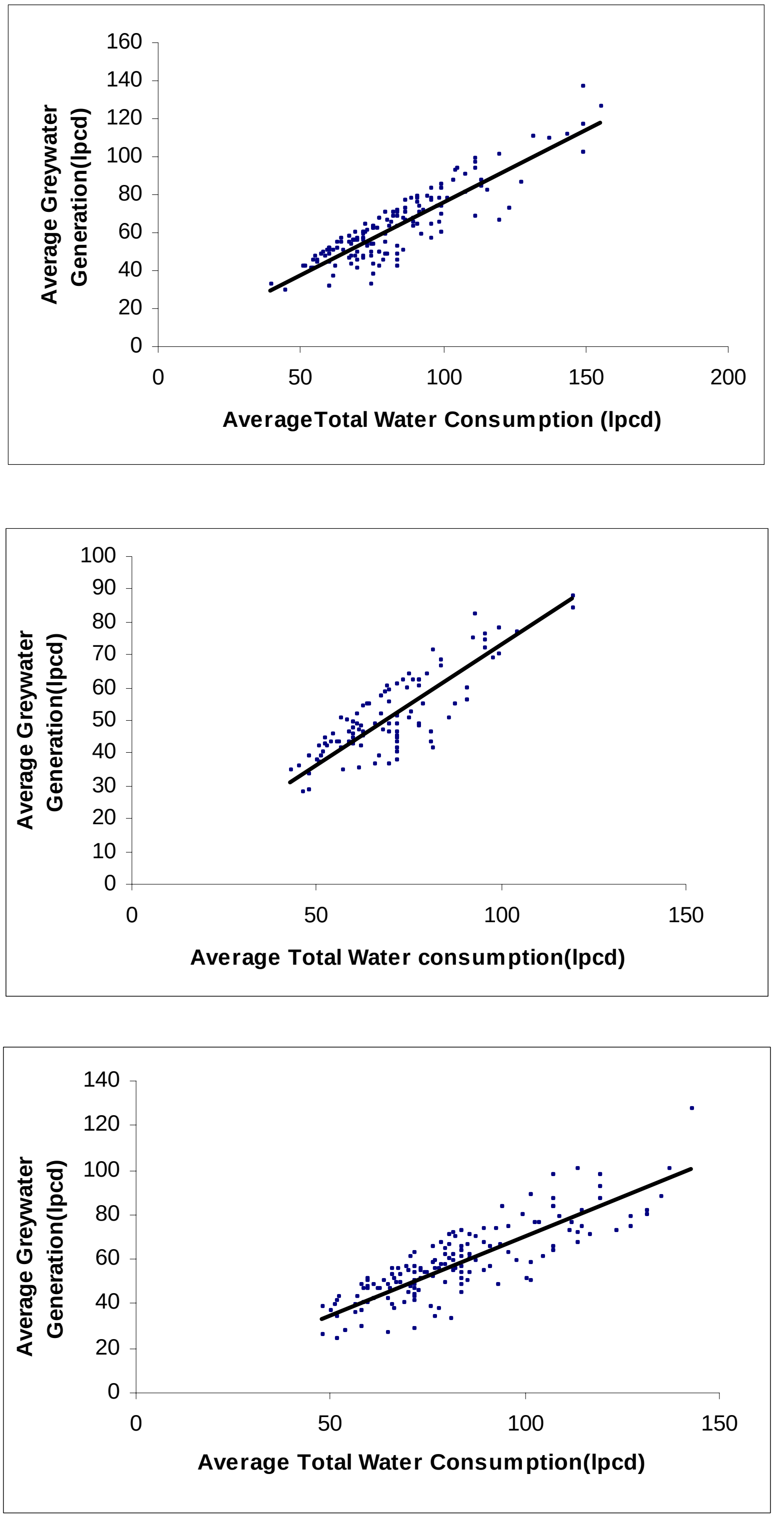


Figure (5): The average greywater generation versus average total household water consumption in (a) Irbid, (b) Rusaifa and (c) Zarqa.

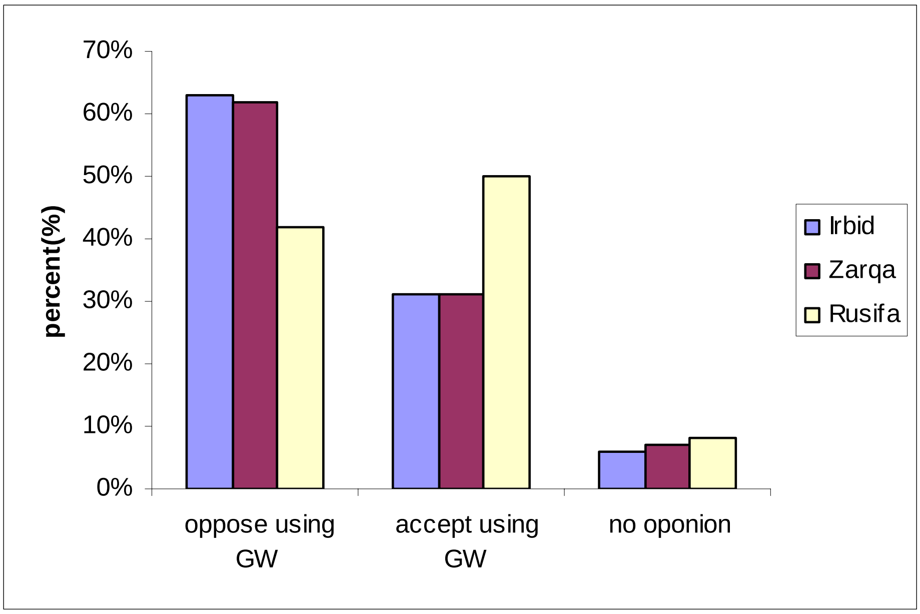


Figure (6): Percent of public acceptance of greywater projects.

Table (4) shows that the correlation coefficients for all of the cities are positive. It should be noted that when correlation coefficient is greater than zero then the two variables are positively correlated and as one variable increases the other tends to increase (Montgomery and Runger, 1999). This positive correlation indicates that the pressure on potable water use and pressure on wastewater treatment plants can be significantly reduced due to greywater reuse. Significant savings in water bill can also be achieved to the public through responsible greywater reuse.

A total of 57 greywater samples were collected from the different sources of greywater in the households participating in the study. The greywater samples were analyzed for the different water quality parameters. The numbers of the sample collected from the cities of Irbid, Rusaifa and Zarqa were 18, 21 and 18, respectively. Table (5) presents the results of analyses and shows a comparison between physical, chemical and biological quality parameters for greywater generated from the different sources in the cities of Irbid, Ruasifa and Zarqa. The table shows that total coliforms and total fecal coliforms were present in all analyzed samples over a two month period. Presence of fecal coliforms in generated greywater may be attributed to children and infants. The levels of total and fecal coliforms found in greywater indicate high contamination and necessitate greywater treatment prior to reuse.

Table (5) also indicates that COD in greywater for Irbid, Ruasifa and Zarqa is 170.7 mg/l, 172 mg/l and 198.6 mg/l, respectively, and that the BOD_5 is 110.2 mg/l, 109.2 mg/l and 132.1 mg/l, respectively. These results are very comparable to those reported for the greywater BOD_5 and COD in Oman which were 117.3 mg/l and 194.5 mg/l, respectively (Prathapar et al., 2005), are significantly higher than those for greywater generated in Amman which were 41.2 mg/l and 78.0 mg/l, respectively (Jamrah et al., 2006), and are higher than those for greywater generated in Dakar, Senegal where the BOD_5 and COD range from 31.0-40.0 mg/l and 67.7-97.9 mg/l (Sall and Takashi, 2006). Similar trend of results are also observed when the pH, EC and solids content of greywater generated in the cities of Irbid, Rusifa and Zarqa are compared to those of Amman, Dakar and Oman. Nitrate concentrations for greywater generated in Irbid, Rusaifa and Zarqa were 88.1 mg/l, 129.2 mg/l and 170.1 mg/l, respectively. NO_3^- concentrations were reported to be 12 mg/l in greywater from Dakar (Sall and Takashi, 2006). In Oman, the NO_3^- concentration in greywater was reported to be 21.6 mg/l (Prathapar et al., 2005). The NO_3^- concentration in Irbid, Rusaifa and Zarqa is much higher than in Oman and Dakar. This can be explained by the possible fecal and urinary discharges in greywater resulting from infants and children. Mars et al. (2003) and Ross et al. (1999) reported that treatment of greywater using wetlands can achieve nitrogen removal.

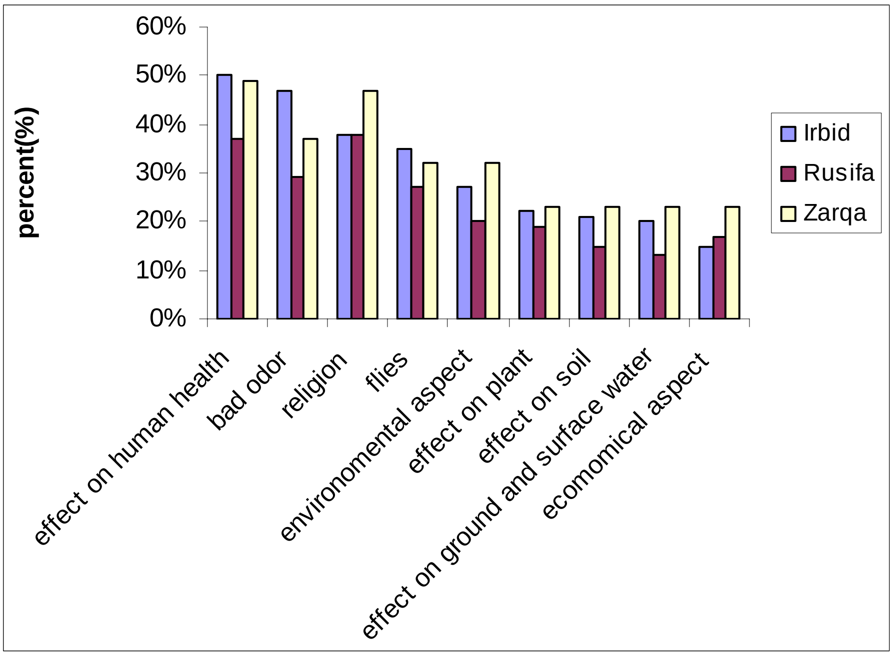


Figure (7): Reasons for opposing greywater reuse projects

Public is generally a pre-requisite for reuse projects. Figure (6) shows percent of the public accepting greywater reuse projects in the three cities chosen for the study. The figure shows that the percent of public accepting greywater reuse in Irbid and Zarqa is far less than the percent of people opposing reuse. The city of Rusaifa shows the opposite where the percent of public accepting reuse is higher than those opposing reuse. This finding was further investigated through Figure (7) which attempts to identify the reasons resulting in public opposition to greywater reuse projects. Figure (7) indicates that the majority of people in Irbid, Ruasifa and Zarqa oppose greywater reuse projects mainly due to possible health effects, possible bad odors, possible religious concerns and the possibility of flies being present in the vicinity of these projects. Figure (7) shows that all of these reasons and concerns resulted in more opposition to greywater reuse projects in Irbid and Zarqa compared to Rusaifa city.

Investigation of Figure (7) shows that the percents of public opposing greywater reuse projects in Irbid, Rusaifa and Zarqa are 50%, 37% and 49%, respectively because of its possible effect on human health, 47%, 29% and 37%, respectively because of possible bad odors, 38%, 38% and 47%, respectively due to religious concerns, 35%, 27% and 32, respectively because of the possibility of flies being present in the vicinity of these projects. Other reasons for opposition are also shown in the figure. These reasons include environmental concerns, soil pollution, effects on plants and groundwater pollution. In a previous study carried out in the city of Amman (Jamrah,2006), it was shown that 91.8% of people thought that greywater would pose health hazards, 61.2% thought that greywater reuse would not be economically feasible, and 2% thought that greywater reuse would lead to groundwater pollution.

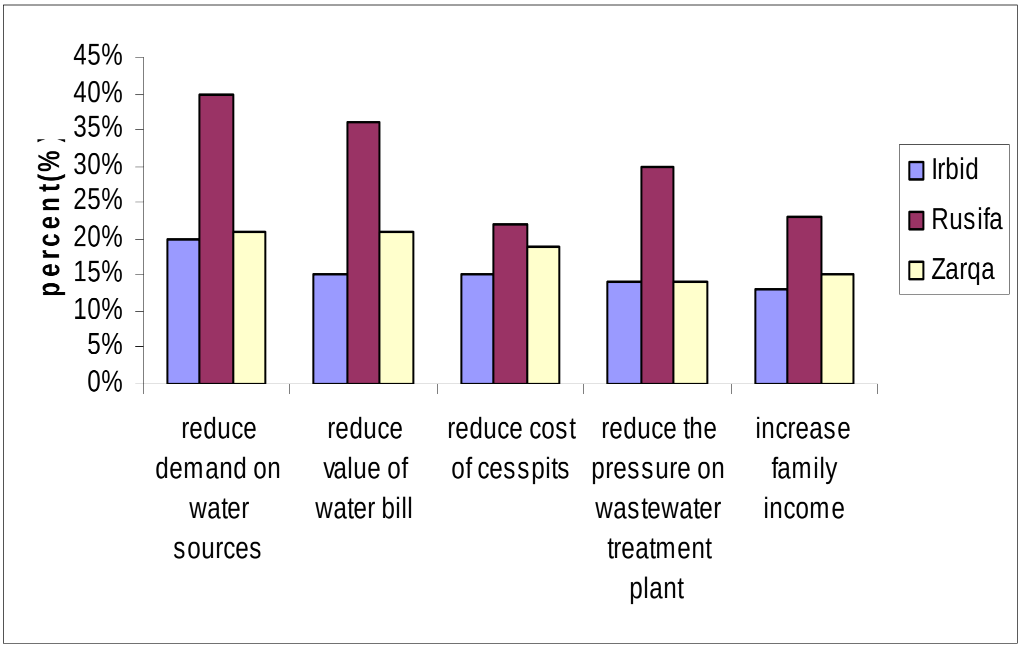


Figure (8): Reasons for accepting greywater reuse projects.

On the other hand, significant percent of the public support greywater reuse projects. Figure (8) shows reasons for accepting greywater reuse as stated by the public. The figure shows that among the public of Irbid, Zarqa and Rusaifa, about 20%, 40% and 21%, respectively would accept reuse of greywater projects because of their benefits in reducing demand on water sources, 15%, 36% and 21%, respectively think that greywater reuse may reduce water bills, 15%, 22% and 19%, respectively think that greywater reuse may reduce cost of cesspits, 14%, 30% and 14%, respectively think that greywater reuse may reduce pressure on wastewater treatment plants and 13%, 23% and 15%, respectively think that greywater reuse would increase family income.

Analysis of results of the public acceptance survey also showed public reaction toward different uses for greywater as presented in Table (6). The table shows that among the public surveyed in Irbid, Rusaifa and Zarqa, about 61%, 70% and 65%, respectively agree to use greywater for toilet flushing, 45%, 54% and 55%, respectively agree to use greywater for irrigation, 26%, 53% and 38%, respectively would use greywater for car washing, 23%, 13% and 19%, respectively think that greywater can be used for drinking purposes after proper treatment, 40%, 60% and 66%, respectively for developing wetlands, 20%, 16% and 10%, respectively for ground water recharge, and 31%, 35% and 26%, respectively for fire protection. The table shows that the most acceptable greywater reuse option to the public was toilet flushing and the least acceptable reuse option was for drinking purposes. These findings are consistent with those reported by Jamrah et al. (2006) for the city of Amman, where 66.4% of the public accepted greywater reuse for toilet flushing and 67.6% for car washing. Friedler et al. (2006) reported that the most feasible greywater reuse option is for toilet flushing. This can reduce individual in-house net water demand by 40–60 Liters per capita per day. Additionally, Jefferson et al. (1999) showed that reusing greywater for toilet flushing could save 30% of the total household water consumption. Sheikh (1999) reported that the city of Los Angeles reuses greywater effluents for irrigation, and 12–65% of water savings were observed. March et al. (2004) reported that, in a hotel in Mallorca Island, Spain, an average amount of water of 5.2 m^3/d was reused in flushing toilets, which represented 23% of the total water consumption of the hotel. Furthermore, the hotel customers understood the water shortage problem and accepted the reuse of greywater in toilet flushing to reduce fresh water consumption.

Survey results also showed that for the public participating in the study in the cities of Irbid, Rusaifa, and Zarqa about 61%, 45% and 61%, respectively would agree to install separate plumbing to separate greywater from wastewater, while 19%, 27% and 16%, respectively, oppose such projects, and 20%, 28% and 23%, respectively were with no opinion. Collection of greywater in a separate system reduces sewage flows, and in turn, reduces the cost of construction of these systems, and ultimately reduces the pressure on fresh water resources, which seems to be an effective option for reducing increasing potable water demands (Jamrah et al., 2006; Al-Jayyousi, 2003; Memon et al., 2007). Burkhard et al. (2000) reported that the installation of separate plumbing for collection of greywater in large systems is generally more cost-effective when compared to small systems. Additionally, a significant saving can be achieved in the form of reduction in the water bill. Prathapar et al. (2005) emphasized that it is important to install greywater treatment systems in the new houses and new public buildings.

CONCLUSIONS

This study was carried out to evaluate the potential of greywater generation in three major cities in Jordan: Irbid, Rusaifa and Zarqa. The study employed a questionnaire in the form of a social survey which was administered to 150, 100 and 150 households in these cities, respectively, covering 947, 726 and 966 people. The study concluded that the average per capita water consumption for the cities of Irbid, Rusaifa and Zarqa is 82.7, 69.6 and 82.3 Lpcd, respectively. The quantity of greywater generated is 63.2, 51.3 and 58.14 Lpcd, respectively which constitute 76.5, 74.1 and 70.7 percent of total water consumption, respectively. Analysis of greywater samples from the different sources in typical households in the cities of Irbid, Rusaifa and Zarqa clearly indicated that greywater must be treated prior to reuse.

A survey of the public participating in the study was designed to gauge the public acceptance towards greywater reuse projects. Results of the survey indicated that among the public participating in the study in the cities of Irbid and Zarqa, the percents of public opposing greywater reuse projects were 63% and 62%, respectively which were higher than the percents of those accepting greywater reuse. The city of Rusaifa showed a different result where 50% of the public participating in the study accepted greywater reuse projects compared to 42% opposing such projects. Most of those opposing greywater reuse listed possible effects on human health, possible bad odors and religious concerns as reasons for their opposition. Most of the public accepting greywater reuse listed benefits in reducing demand on water sources, reduction in water bills and reduction in cost of cesspits as reasons for their acceptance. The most accepted greywater reuse options as stated by the public were toilet flushing, irrigation and car washing.

REFERENCES

Al-Jayyousi, O. 2003. Greywater Reuse: Towards Sustainable Water Management, *Desalination* (156): 18 l-l 92.

American Public Health Association (APHA). 2005. Standard Methods for the Examination of Water and Wastewater, 19th Edition, Washington DC.

Burkhard, R., Deletic, A. and Craig, A. 2000. Techniques for Water and Wastewater Management: A Review of Techniques and their Integration In Planning, *Urban Water* (2): 197-221.

Eriksson, E., Auffarth, K., Henze, M. and Ledin, A. 2002. Characteristics of Grey Wastewater, *Urban Water* (4): 85-104.

Friedler, E. and Hadari, M. 2006. Economic Feasibility of On-site Greywater Reuse in Multi-storey Buildings, *Desalination* (190): 221-234.

Jamrah, A., Al-Futaisi, A., Prathapar, S., Ahmed, M. and Al-Harrasi, A. 2008. Evaluating Greywater Reuse Potential for Sustainable Water Resources Management in Oman, *Environmental Monitoring and Assessment*, In Press.

Jamrah, A., Al-Omari, A., Al-Qasem, L. and Abdel Ghani, N. 2006. Assessment of Availability and Characteristics of Greywater in Amman, *Water International*, 2 (31): 210-220.

Jefferson, B., Laine, A., Parsons, S., Stephenson, T. and Judd, S. 1999. Technologies for Domestic Wastewater Recycling, *Urban Water* (1): 285-292.

March, J., Gual, M. and Orozco, F. 2004. Experiences on Greywater Re-use for Toilet Flushing in a Hotel (Mallorca Island, Spain), *Desalination* (164): 241-247.

Mars, R., Taplin, R., Ho, G. and Mathew, K. 2003. Greywater Treatment with the Submergent Triglochin Huegelii/A Comparison between Surface and Subsurface Systems, *Ecological Engineering* (20): 147-156.

Memon, F.A., Zheng, Z., Butler, D., Shirley-Smith, C., Lui, S., Makropoulos, C. and Avery, L. 2007. Life Cycle Impact Assessment of Greywater Recycling Technologies for New Developments, *Environmental Monitoring Assessment* (35): 129.

Ministry of Water and Irrigation (MWI). 2007. Open Files.

Montgomery, D. and Runger, G. 1999. Applied Statistics and Probability for Engineer, 2nd Edition, New York, John-Wiley and Sons.

Nolde, E. 1999. Greywater Reuse Systems for Toilet Flushing in Multi-storey Buildings - over Ten Years Experience in Berlin, *Urban Water* (1): 275-284.

Ottoson, J. and Stenstrom, T. 2003. Faecal Contamination of Greywater and Associated Microbial, *Risks Water Research* (37): 645–655.

Prathapar, S., Jamrah, A., Ahmed, M., Al Adawi, S., Al Sidairi S. and Al Harassi, A. 2005. Overcoming Constraints in Treated Greywater Reuse in Oman, *Desalination* (186): 177-186.

Ross, M., Mathew, K. and Ho, G. 1999. The Role of the Submergent Macrophyte Triglochin Huegelii in Domestic Greywater Treatment, *Ecological Engineering* (12): 57-66.

Sall, O. and Takashi, Y. 2006. Physical, Chemical and Biological Characteristics of Stored Greywater from Unsewered Suburban Dakar in Senegal, *Urban Water* (3): 153-164.

Sheikh, B. 1993. In: Kathering Hon, Editors, *Proceedings of the 20th Anniversary Conference*, Seattle, Washington, American Society of Civil Engineers, 907.

Surani, E. 2003. Research Influence on Policy: The Greywater Reuse Case of Jordan, The International Development Research Center, Canada, Final Report.