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Evaluating greywater reuse potential for sustainable water resources management in Oman

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Abstract This study aims to evaluate the potential of greywater availability in Muscat Governorate in the Sultanate of Oman, to establish a methodology for greywater quantity estimation, to test greywater quality in order to assess reuse potential, and to examine public acceptance for reuse.Total fresh water consumption and greywater generation from different household sources were measured by water meters in five selected households during summer and winter. Additionally, a survey was designed and conducted in five administrative areas of Muscat Governorate, with the objective of testing a methodology for estimating greywater generation potential in these areas. Collected data were compared with that used by the Ministry of Housing, Electricity and Water, Sultanate of Oman. The survey covered a total of 169 houses and 1,365 people. Greywater samples were collected and analyzed from showers, laundries, kitchens and sinks in some of these households to determine their water quality parameters. Statistical analysis results indicated that there is no significant variance in the total fresh water consumption between data used by the ministry and those measured and estimated during this study, highlighting the applicability of the tested method. The study concluded that the average per capita greywater generation rate is 151 Lpcd. Greywater production ranged from 80 to 83% of the total fresh water consumption and most of the greywater is generated from showers. Further, 55 to 57% of the greywater generated in a typical Omani household originated from the shower, 28 to 33% originated from the kitchen, 6 to 9% originated from laundry, and 5 to 7% originated from sink, which constitutes approximately 81% of the total fresh water consumption. The physical, chemical, and biological analyses of the grab samples revealed that greywater contains significant levels of suspended solids, inorganic constituents, total organic carbon, chemical and biochemical oxygen demands, total Coliforms and Escherichia Coliform bacteria. The public acceptance survey illustrated that approximately 76% of the respondents accepted the reuse of greywater for gardening, 53% for car washing and 66% for toilet flushing.

Keywords Greywater · Sink · Shower · Laundry · Kitchen · Reuse · Public acceptance · Oman

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Nomenclature

BOD_5	five-day biochemical oxygen demand (mg/l).
COD	chemical oxygen demand (mg/l).
DO	dissolved oxygen (mg/l).
pH	-log hydrogen-ion concentration.
TOC	total organic carbon (mg/l).
EC	electrical conductivity (mS/m).
SUR	surfactants (mg/l).
TS	total solids (mg/l).
TSS	total suspended solids (mg/l).
TDS	total dissolved solids (mg/l).
TFS	total fixed solids (mg/l).
TVS	total volatile solids (mg/l).
FSS	fixed suspended solids (mg/l).
VSS	volatile suspended solids (mg/l).
TC	total coliforms
FC	fecal coliforms
MPN	most probable number.

Introduction

Greywater is the untreated wastewater that is generated and can be collected from showers, kitchens, sinks and laundries. Greywater is therefore the components of domestic wastewater which do not originate from the toilet (Lombardo 1982). Greywater comprises 50–80% of residential fresh water total consumption, which can be reused for other purposes, especially landscape irrigation (Stephenson and Judd 1998). The reuse and recycling of greywater has been practiced in several countries because of the obvious benefits in terms of fresh water savings and management. Sheikh (1993) conducted a study in the city of Los Angeles to utilize greywater effluents for irrigation, and concluded that greywater reuse resulted in savings in the range of 12–65% of fresh water usage. The study also noted that water savings potential of individual homes could be significant and as high as 50% of total water consumption. The Australian experience (Sheikh 1993; Fittschen and Niemezynowics 1997) shows that reuse of greywater for toilet flushing and lawn gardening could achieve water savings from 30 to 50% of total household water usage. Additionally, typical water savings in the range of 0.5–2 l were observed per event when hand wash water was used for toilet flushing. Dixon et al. (1999a) reported that reuse of greywater resulted in saving of up to 80% of total water consumption.

Greywater composition depends on the water source, plumbing system, living habits, personal hygiene of the users, and type of greywater (Badadoost 1998). As a result, the physical, chemical and biological characteristics of greywater vary greatly among families and industries (Dixon et al. 1999b). In addition, the cleaning products, dishwashing patterns, laundry practices, bathing habits, and disposing of household chemicals will influence the characteristics of greywater (Al-Jayyousi 2003a; Jamrah et al. 2004). Greywater generally contains pathogenic microorganisms including bacteria, viruses and parasites in concentrations high enough to cause health risks. Therefore, a level of caution must be exercised with greywater reuse (Jappesen 1996; Texas Water Commission 2003).

The Sultanate of Oman faces a shortage of water due to lack of and irregular rainfall and consequent poor recharge of groundwater resources. In the coastal region, there is evidence of high groundwater salinity due to seawater intrusion. Hence, proper planning to reduce water consumption is an immediate task in this region. Among several management plans, reuse of greywater is one of the suggestions and alternative plans to reduce fresh water consumption. As water is becoming a rare resource throughout the world, the reuse of greywater will reduce freshwater usage in all sectors, including households (Asano et al. 1996; Jefferson et al. 2001). Additionally, adoption of greywater reuse strategies diminishes the pressure on the potable water resources and creates a balance between available resources and demands.

In Oman, the government has shown an interest in greywater reuse and water conservation methods. The application of greywater reuse could be implemented on a large-scale that involves the whole community or on a small-scale available to individual homeowners (Al-Jayyousi 2003b). Typically, the Omani house sewer system is designed to collected greywater and blackwater (wastewater generated from the toilet) from the same effluent pipe. The treatment and reuse of the mixture of blackwater and greywater is somewhat expensive (Hodges 1998). However, separating the two types of water effluent and treating greywater only could be a cheaper option (Kreysig 1996). This is not a difficult task in new construction but can be problematic in existing buildings (Eriksson et al. 2003). The treatment and reuse of greywater have not been implemented in the Sultanate of Oman yet. In order to properly design a greywater system, accurate estimation of greywater quantities available for reuse is an essential task (Jamrah et al. 2006). Hence, a detailed study was carried out to evaluate the amount of greywater availability, greywater quality and public acceptance for greywater reuse in Muscat Governorate in the Sultanate of Oman. Additionally, this study attempted to establish and test a methodology for greywater quantity estimation. It is expected that this study will assist in management decisions related to greywater reuse.

Study area and methodology

Muscat Governorate has an area of 3,900 Km^2 with a total population of 631,031. The Governorate is divided into five administrative areas: Al-Amirat, Muscat, Al-Seeb, Mutrah, and Boushar. The region represents an important part of Oman for development. Groundwater is generally supplied to consumers in some parts of the region by pipelines and tankers. Other parts of the region receive potable water by pipelines from desalination plants (Moosa 2005).

In this study, water consumption data along with distribution of internal domestic fresh water use in households were collected from houses through water meter reading and formal questionnaire survey. Water meters were installed in five houses in Sultan Qaboos University campus to estimate the total fresh water consumption as well as to measure the amount of water usage for individual purposes such as bathroom shower, bathroom sinks, kitchen sink, washing machine and gardening. The houses selected for the study were part of the staff housing at the university; and enjoyed a higher living standard compared to the main stream populated neighborhoods in some of the administrative areas of Muscat. The objective behind the installation of meters in these houses was to collect enough data that will enable the examination of assumptions related to the rate of water consumption adopted by the Ministry of Housing, Electricity and Water. Consequently, the derived actual values of the rates of water consumption will be compared to the assumed ones so that a conclusion can be made regarding the applicability of the proposed method for the estimation of greywater generation. The information collected through these meters contains the daily reading of each meter for 3 months during summer. Additionally, meters of three of these five houses were monitored for another 3 months during winter. Simultaneously, a questionnaire in the form of a social survey was designed and administered in these houses about water consumption for individual purposes to cross check the water meter readings. This survey was employed to assess water consumption and frequency of each activity of the participants. After the data collection, greywater generation of individual events was calculated indirectly by subtracting the amount of total greywater generation (meter-readings) from the total greywater generation by other different events. Statistical analyses were then carried out to correlate the different greywater quantities of each event. Additionally, based on the questionnaire survey and water meter readings, the amount of freshwater consumption was quantified. The estimation procedure adopted in this study was consistent with the assumptions adopted by the Ministry of Housing, Electricity and Water in order to establish the proposal of estimating greywater quantities in Omani households (Ministry of Housing, Electricity and Water (MHEW) 2005). Data obtained from the Ministry indicates that the amount of freshwater consumption is assumed to be 75 l per use for automatic washing machines, 60 l per use for manual washing machines, 50 l per shower, and 3 l per minute per sink-use. An average time of 0.33 min was assumed for teeth brushing and hand washing, 2 min for ablution, 1 min for hair washing and 1.5 min for children cleaning. It was also assumed that drinking and cooking consume about 5% of the total fresh water consumption in households, and that gardening consumes 5% of the total fresh water consumption. Toilet flushing was also assumed to consume 6 l per flush.

Further, a social survey in the form of questionnaire was designed and conducted to assess potential greywater quantities in Muscat Governorate in the Sultanate of Oman. The survey covered 169 family houses constituting 1,365 people. These 169 families were equally distributed among the different areas of the study. The data and information collected through the social survey included the type of dwelling, the number of occupants, area of residence, water meter reading, the type of washing machine (manual, semi-automatic, or automatic), the number of washing cycles per week, frequency of showering (bath tub), frequency and type of sink use (hand washing, teeth brushing, ablution, and hair washing), frequency of toilet flushing, frequency of kitchen and bathroom floor-washing, and frequency of garden watering. The data collected in the social survey was then analyzed and the total daily per capita volume of greywater was calculated using the earlier assumptions for fresh water use in shower, sink, kitchen and laundry. Additionally, total fresh water consumption and blackwater generation were analyzed. Statistical analyses were then carried out to examine the variability, correlation, distribution and statistical inference for the data collected from each social survey area.

Simultaneously, greywater samples were collected on a bi-weekly basis for a period of 6 weeks from different sources of greywater (shower, laundry, kitchen and sink). Samples were collected from several locations in the different areas of the study; including the five houses at Sultan Qaboos University. Samples were then analyzed for physical, chemical and biological water quality parameters. All analyses were carried out according to the standard method for the examination of water and wastewater (American Public Health Association (APHA) 1999).

Results and discussion

This investigation started with the measurement of quantities of total fresh water consumption and greywater generation in five Omani households during summer and three of the five households during winter. All of these houses were located in Sultan Qaboos University as part of the staff housing. Measured quantities of fresh water used in each household included shower, kitchen, laundry and sink. Results of this investigation for one household are shown in Figs. 1 and 2, which present the variation of distribution of internal domestic fresh water use in an Omani household during summer and

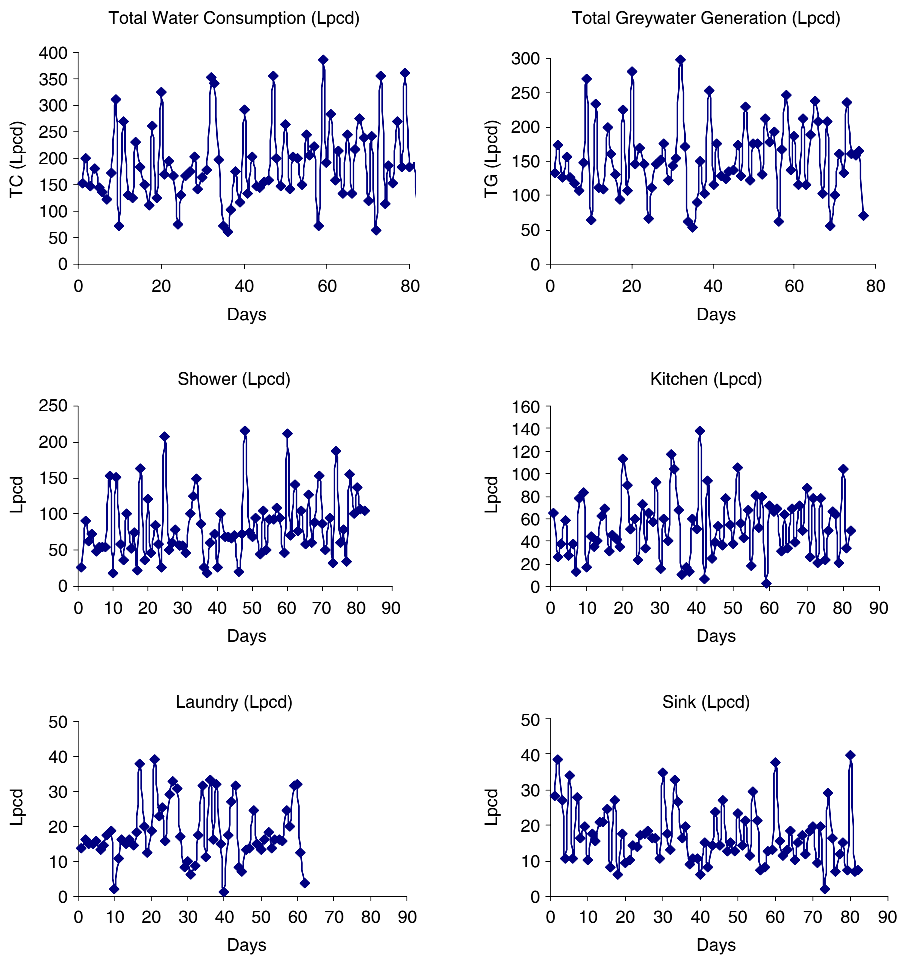

Fig. 1 Variation of distribution of internal domestic fresh water use in an Omani household during summer. Lpcd indicates liter per capita per day

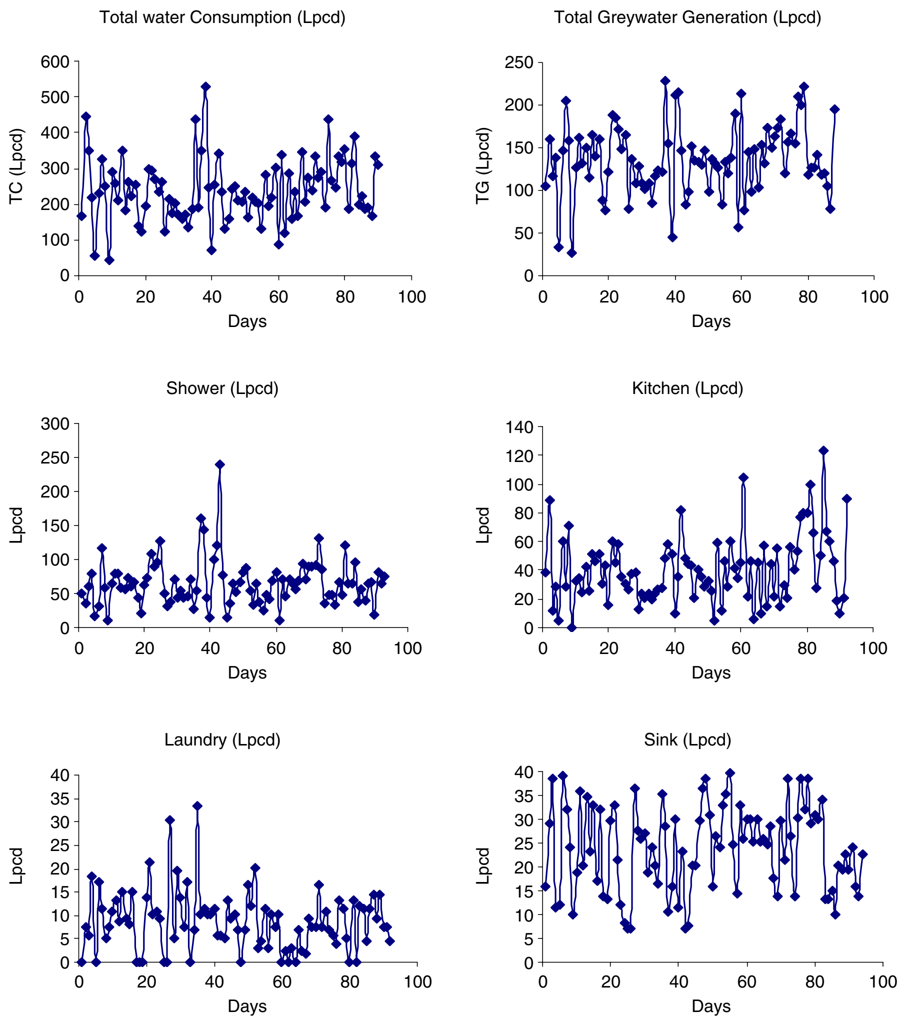

Fig. 2 Variation of distribution of internal domestic fresh water use in an Omani household during winter. Lpcd indicates liter per capita per day

winter; respectively. Similar patterns were observed in the other four households. A statistical summary of the results is shown in Table 1, which presents summary of the three-month meter-readings during summer and winter for the distribution of internal domestic fresh water use. Investigation of Table 1 shows that the total water consumption during summer varied from 69.4 to 369 l per capita per day (Lpcd), with an average of 184 Lpcd. Similarly, the total greywater generation ranged from 49 to 263 Lpcd, with an average of 154 Lpcd. During winter, the total water consumption varied from 58 to 482 Lpcd with an average of 215 Lpcd. Similarly, the summer greywater production ranged from 37 to 302 Lpcd with an average of 183 Lpcd. Hypothesis testing was employed on the confidence interval for the underlying mean difference between summer and winter data. The water consumption and greywater generation data were assumed to be two independent samples with unequal variances. For 95% confidence, the hypothesis testing results indicated that both water consumption and greywater generation are greater during winter compared to summer. It should be noted that this finding was observed for the data generated for the five households located in Sultan Qaboos University as part of the staff housing. One possible explanation for this finding is that families occupying these houses generally leave for extended periods for holidays during summer. This can significantly affect the water consumption as well as greywater generation on a per capita basis. As a result, such finding can only be of significant practical value after further thorough investigation.

Results obtained from the water-meter readings were then used to estimate the quantities and percentages of

Table 1 Summary results of the three-month meter-readings (expressed in liters per capita per day and as a percentage of the total water consumption) during summer and winter for distribution of internal domestic fresh water use

Sources		Summer season						Winter season					
		TC	TG	Shower	Kitchen	Laundry	Sink	TC	TG	Shower	Kitchen	Laundry	Sink
House (3)													
Minimum	Quantity (Lpcd)	61	53	18	3	4	2	43	27	9	6	3	6
	Percentage		59	15	5	2	3	Percentage	56	13	2	3	1
Maximum	Quantity(Lpcd)	387	297	215	138	39	40	445	228	143	90	21	68
	Percentage		99	74	62	19	31	Percentage	92	80	82	28	45
Average	Quantity (Lpcd)	191	153	83	54	14	17	162	145	62	38	8	25
	Percentage		87	49	32	8	11	Percentage	84	45	29	6	20
Maximum/Average		2.03	1.94	2.59	2.56	2.79	2.35	2.75	1.57	2.31	2.37	2.63	2.72
Minimum/Average		0.32	0.35	0.22	0.06	0.29	0.12	0.27	0.19	0.15	0.16	0.38	0.24
House (4)													
Minimum	Quantity (Lpcd)	146	94	45	20	11	11	89	42	20	5	11	5
	Percentage		63	33	12	6	8	Percentage	60	15	5	1	2
Maximum	Quantity (Lpcd)	382	244	126	41	42	39	576	250	165	159	78	51
	Percentage		94	70	27	38	23	Percentage	93	71	70	55	36
Average	Quantity (Lpcd)	202	178	65	23	20	17	213	135	135	62	31	22
	Percentage		88	49	22	16	13	Percentage	86	38	32	19	11
Maximum/Average		1.89	1.37	1.94	1.78	2.10	2.29	2.70	1.85	1.22	2.56	2.52	2.32
Minimum/Average		0.72	0.53	0.69	0.87	0.55	0.65	0.42	0.31	0.15	0.08	0.35	0.23
House (5)													
Minimum	Quantity (Lpcd)	45	18	6	7	6	9	42.00	42	25	12	11	16
	Percentage		50	11	7	5	2	Percentage	61	16	5	2	4
Maximum	Quantity (Lpcd)	380	236	160	120	45	94	427	427	135	123	94	83
	Percentage		93	87	49	35	14	Percentage	91	89	46	54	44
Average	Quantity (Lpcd)	153	127	67	64	25	39	270	270	57	52	51	44
	Percentage		83	51	25	18	6	Percentage	87	43	20	19	18
Maximum/Average		2.48	1.86	2.39	1.88	1.80	2.41	1.58	1.58	2.37	2.37	1.84	1.89
Minimum/Average		0.29	0.14	0.09	0.11	0.24	0.23	0.16	0.16	0.44	0.23	0.22	0.36
House (1)													
Minimum	Quantity (Lpcd)	56	48	11	5	1	2						
	Percentage		51	15	6	4	3						
Maximum	Quantity (Lpcd)	340	287	139	39	35	21						
	Percentage		84	93	39	36	22						
Average	Quantity (Lpcd)	207	168	52	25	16	8						
	Percentage		81	52	25	15	8						
Maximum/Average		1.64	1.71	2.67	1.56	2.19	2.63						
Minimum/Average		0.27	0.29	0.21	0.20	0.06	0.25						
House (2)													
Minimum	Quantity (Lpcd)	39	32	12	6	5	3						
	Percentage		67	2	6	4	1						
Maximum	Quantity (Lpcd)	354	250	84	42	35	24						
	Percentage		95	88	60	31	25						
Average	Quantity (Lpcd)	169	146	52	25	14	9						
	Percentage		86	52	25	14	9						
Maximum/Average		2.09	1.71	1.62	1.68	2.50	2.67						
Minimum/Average		0.23	0.22	0.23	0.24	0.36	0.33						
All Houses													
Minimum	Quantity (Lpcd)	69.4	49	18.4	8.2	5.4	5.4	58	37	18	8	8	9
	Percentage							Percentage					
Maximum	Quantity (Lpcd)	369	263	145	76	39	44	483	302	148	124	64	67
	Percentage							Percentage					
Average	Quantity (Lpcd)	184	154	64	38	18	18	215	183	85	51	30	30
	Percentage							Percentage					
Maximum/Average		2.03	1.72	2.24	1.89	2.27	2.47	2.34	1.67	1.97	2.43	2.33	2.31
Minimum/Average		0.37	0.30	0.29	0.29	0.30	0.32	0.28	0.22	0.24	0.16	0.32	0.28

TC indicates total consumption, *TG* indicates total greywater, *Lpcd* indicates liters per capita per day

Table 2 Comparison between assumed and derived values related to the distribution of internal domestic fresh water use in Omani households

Components	Shower (l/use)	Kitchen (l/minute/use)	Laundry (l/use)	Sink (l/min/use)	Garden % from TC
Summer (Calculated)	51	3.3	62	2.6	3.5
Winter (Calculated)	52	2.8	60	3.6	6.4
Assumptions	50	3	60	3	5

TC indicates total consumption.

the distribution of internal domestic fresh water use of each household. Percentages of water consumption were then compared with the assumptions adopted by the Ministry of Housing, Electricity and Water. The results of this comparison are presented in Table 2, which shows a comparison between assumed and derived values related to the distribution of internal domestic fresh water use of these households. It should be noted that these assumptions are generally adopted by the agency responsible for water supply, and are made based on their previous experience. These assumed values may differ from one agency to another and from one country to another. For example, assumed water use values adopted by the Ministry of Water and Irrigation in Jordan include 90 l per use for automatic washing machines, 60 l per use for manual washing machines, 60 l per shower use, 2 l per minute per sink use, and 5% of total household consumption for gardens (Jamrah et al. 2006). These values are very much similar to those reported in Table 2 for Oman. The comparison between assumed and derived values related the distribution of internal domestic fresh water use shown in Table 2 clearly indicates that these numbers are very similar. One can then conclude that the amounts of greywater generated in a typical Omani household can be estimated without the need to install meters. Administration of a social survey that aims at gathering data related to the internal use of domestic fresh water can produce results equivalent to those obtained when water meters are installed. This, in turn, highlights the applicability of the methodology adopted in this investigation which employs a social survey for the estimation of greywater generation.

Statistical summary of the distribution of internal domestic fresh water use data obtained from the social survey is presented in Table 3. It should be noted from the table that the coefficient of variation, especially for total water consumption and greywater production, indicates uniformity and similarity of the collected data. Additionally, the table shows that the average per capita water consumption in Muscat Governorate is about 186 Lpcd, and that the average per capita greywater production is about 151 Lpcd. This indicates the reasonable potential of water savings that can be achieved when greywater reuse projects are adopted. Similar statistical analysis was carried out for each of

Table 3 Statistical summary of the distribution of internal domestic fresh water use data obtained from the social survey

	Laundry	Shower	Sink	Kitchen	Greywater	Blackwater	Garden	D and C	Consumption
Min:	0	0	0	0	6	0	0	0.89	17.79
1st Qu:	5	56	4	18	107	1	8.94	6.43	128.6
Mean:	12.1	85.93	7.95	44.34	150.76	7.82	18.63	9.31	186.24
Median:	11	79	7	38	134	6	14.5	8.31	166.14
3rd Qu:	16	110	11	54	187	12	24.65	11.55	230.96
Max:	80	275	33	376	538	30	88.54	31.93	638.65
Total N:	169	169	169	169	169	169	169	169	169
NA's:	0	0	0	0	0	0	0	0	0
Std Dev.:	9.96	47.93	5.12	41.42	74.79	8.13	14.06	4.57	91.45
C.V.:	0.82	0.56	0.64	0.93	0.50	1.04	0.75	0.49	0.49
Sum:	2,045	14,522	1,343	7,493	25,479	1,322	3,147.97	1,573.74	3,1474.71

Relevant greywater data are expressed in the units of liter per capita per day (*Lpcd*). *D and C* indicate Drinking and Cooking. Sum indicates the sum of water consumption or greywater generation for the source in the units of liters per capita per day (Lpcd).

Table 4 Distribution of internal domestic fresh water consumption and greywater generation in typical households in the five administrative areas of Muscat

Area	% from total greywater generation				% from total water consumption			
	Laundry	Shower	Sink	Kitchen	Greywater	Blackwater	Garden	Drinking and cooking
Amirat	9	57	5	29	83	4	8	5
Muscat	9	57	5	29	83	4	8	5
Seeb	8	57	7	28	81	3	11	5
Mutrah	8	57	7	28	81	3	11	5
Bousher	6	55	6	33	80	4	11	5

the administrative areas of Muscat. Table 4 presents the distribution of internal domestic fresh water consumption and greywater generation in typical households in the five administrative areas of Muscat. Table 4 shows that, in Muscat Governorate region, the greywater production ranges between 80% and 83% of the total internal domestic fresh water consumption. This observation is slightly higher than the internationally reported average of 50–80%. Further, it is observed that 55–57% of the greywater generated in a typical Omani household originates from the shower, 28–33% originates from the kitchen, 6–9% originates from laundry, and 5–7% originates from sink. It should be noted that the water consumption for gardens ranges between 8 and 11% of the total internal domestic fresh water consumption as shown in Table 4, whereas the number shown in Table 2 indicate 3.5 and 6.4%. This mainly is due to the fact that Table 2 shows the results of the average percent of garden water consumption from the social survey for one season, while Table 4 represents the average value from the survey and meter readings for the five administrative areas during the period of the study. Table 4 shows that greywater produced in Muscat constitutes 80–83% of the total internal domestic fresh water consumption.

In addition to the estimation of greywater quantities, the relation between the quantity of greywater generated and common surrounding environmental factors such as area of household, family size, and location were evaluated using the social survey data. The influences of these factors on greywater quantity are presented in Figs. 3, 4 and 5. Survey data presented in Fig. 3 indicate that the amount of greywater generated in an Omani household is independent of the area of residence. However, Figs. 4 and 5 indicate clearly that greywater generation is affected by family size. Figure 4 indicates that the quantity of greywater generated is directly proportional to the family size; while Fig. 5 indicates that the per capita greywater generation rate is inversely proportional to the family size, which can be explained by the limited amount of freshwater available per Omani household in the study area. This is evident from the fact that the relationships presented in Figs. 4 and 5 have coefficients of determinations (R^2) of 0.16 and 0.25; respectively, leading to coefficients of correlations (r) of 0.40 and −0.5; respectively. Rosner (2005) stated that the coefficient of determination (R^2) indicates the proportion of the variance of the dependent variable that can be explained by the independent

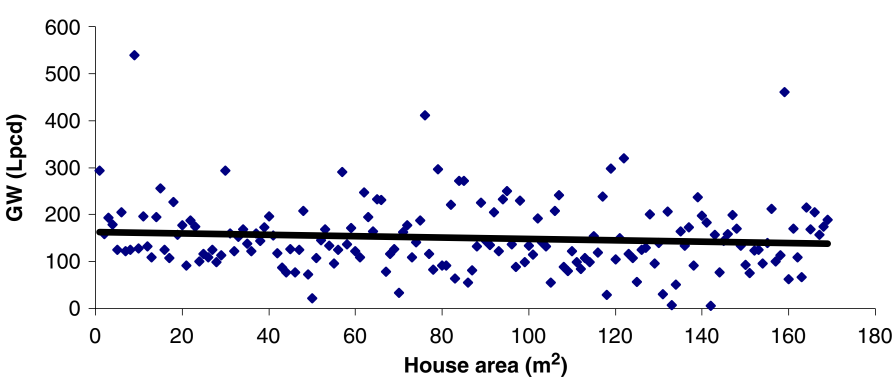

Fig. 3 Effect of house area on greywater production in Muscat Governorate. Lpcd indicates liter per capita per day

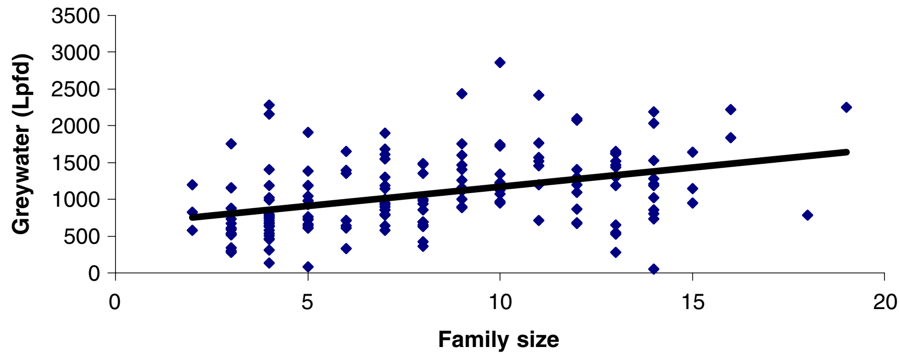

Fig. 4 Effect of family size on total greywater generation in Muscat Governorate. Lpfd indicates liter per family per day

variable. This is generally very useful when a specific relationship between two variables is needed so that one variable can be predicted by the other. Our primary interest is not in predicting one variable from the other but rather in investigating whether or not there is a relationship between two variables. As a result, the correlation coefficient is more useful for this purpose. Rosner (2005) stated that if the correlation coefficient is greater than zero, then the two variables are said to be positively correlated and as one variable increases the other tends to increase, whereas as one variable decreases the other tends to decrease. If the correlation coefficient is less than zero, the two variables are said to be negatively correlated and as one variable increases the other tends to decrease, whereas as one variable decreases the other tends to increase. If the correlation coefficient is equal to zero, then the two variables are said to be uncorrelated and there is no relationship between them.

Figure 6 shows a box diagram for the of greywater generation in the five administrative areas of Muscat. The figure shows the average per capita greywater generation for each area, along with the variability of data, and outlying data. The figure clearly shows that Al-Seeb city has the highest variability in the greywater generation data. This can be explained by the lifestyle and social composition of this city. It should be noted that the population of this city is very diverse, and that the nature of this city is mostly commercial and business oriented. Figure 6 also indicates that the range of per capita greywater generation in Muscat Governorate is between 100 and 200 l per capita day with a maximum of 300 l per capita per day in Al-Seeb city which clearly represents an outlying value. Figure 7 presents the distribution of greywater components and water consumption in the five administrative areas of Muscat Governorate. The figure shows that while the per capita greywater generation rate somewhat varies from one area to another, the distribution of the components or sources of greywater in an Omani household have a similar trend.

Results of the physical, chemical and biological water quality parameters of the different sources of greywater generated in a typical household in Muscat

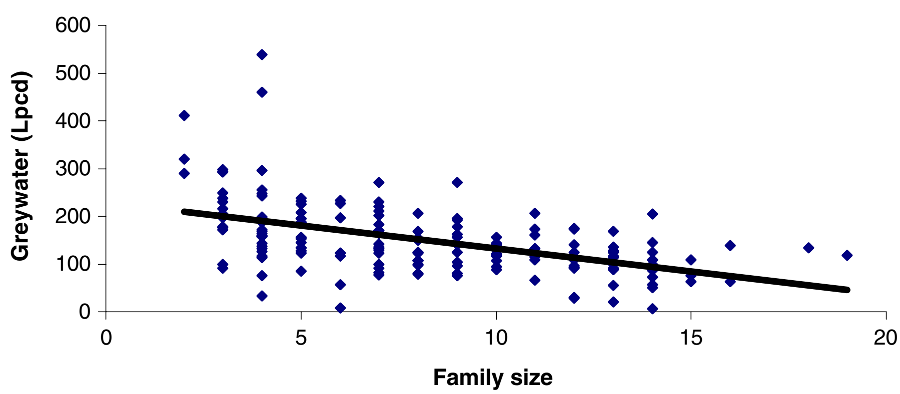

Fig. 5 Effect of family size on the per capita generation of greywater in Muscat Governorate. Lpcd indicates liter per capita per day

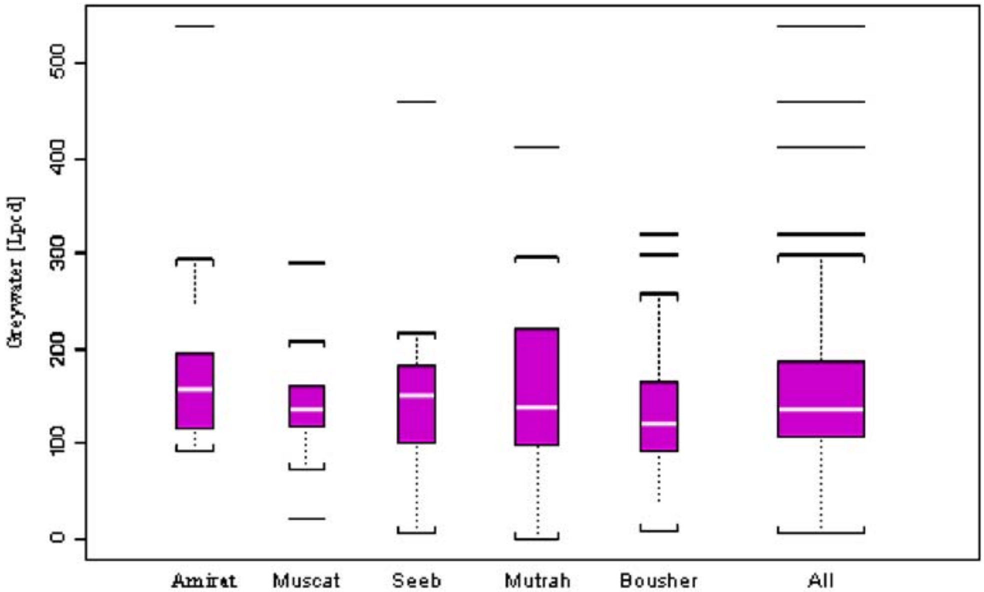

Fig. 6 Effect of region on the per capita greywater generation in Muscat Governorate. Lpcd indicates liter per capita per day

are shown in Table 5. Fifteen samples were collected from the different sources of greywater and were analyzed for the parameters shown. It should be noted that the greywater samples are composite ones that were collected from the different sources based on the proportions of individual greywater components. Table 5 shows that, with the exception of suspended solids, greywater generated in laundry contains significantly larger concentrations of all types of solids and alkalinity than that generated in sink, kitchen and shower. Further, levels of chemical oxygen demand present in greywater generated in kitchen and laundry are significantly high when compared to those generated in sink and shower. Investigation of the results presented in the table indicates that the reported parameters have values that are similar to those reported by Jappesen (1996) and Stephenson and Judd (1998). The water quality parameters presented in this table indicate the importance of appropriate treatment of greywater that concurs with the intended greywater reuse. This is consistent with the findings of Jappesen (1996) and Weizhen et al. (2003), who stated that treatment of

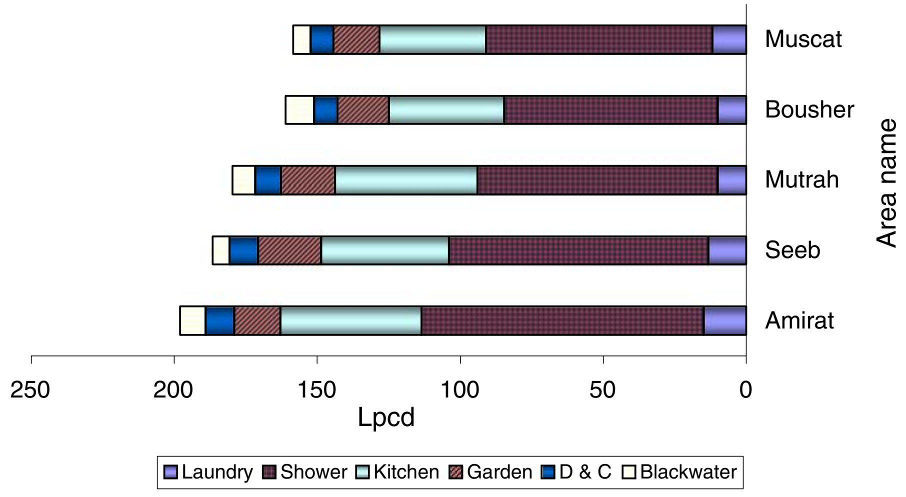

Fig. 7 Distribution of greywater components and water consumption in the five administrative areas of Muscat Governorate. Lpcd indicates liter per capita per day

Table 5 Physical, chemical, and biological water quality parameters of different sources of greywater generated in a typical household in Muscat

Parameter	Shower	Laundry	Sink	Kitchen	Greywater	Standard A	Standard B	Acceptability
pH	7.3	8.5	7.2	6.7	7.6	6–9	6–9	Y
DO (mg/l)	3.6	3.4	4.0	1.4	3.6			
EC (mS/m)	2	3.5	1.4	4.2	2.8	2	2.7	N
Alkalinity (mg/l as $CaCO_3$)	13.3	32.7	14.4	11.0	18.4			
NO_3^- (mg/l)	23.6	16.2	10.2	8.0	16.5			
SUR (mg/l)	14.9	101.4	41.9	26.5	56.3			
TS (mg/l)	520	2,384	679	1037	1,121			
TSS (mg/l)	242	244	318	134	236	15	30	N
TDS (mg/l)	279	2,140	361	903	884	1,500	2,000	Y
TFS (mg/l)	174	1,221	281	229	493			
TVS (mg/l)	346	649	397	808	492			
Turbidity (NTU)	346	328	211	140	279			
BOD_5 (mg/l)	380	296	100	562	408	15	20	N
COD (mg/l)	375	471	110	486	426	150	200	N
TOC (mg/l)	66	170	63	76	93			
Ca (mg/l)	15.7	18.7	19.7	–	–			
Mg (mg/l)	56.1	60.8	21	–	–	150	150	Y
Na (mg/l)	184.5	667	148.9	–	–	200	300	Y
K (mg/L)	43.1	23.4	5.5	–	–			
Zn (mg/l)	2.4	0.14	0.04	–	–	5	5	Y
Al (mg/l)	0.014	0.08	0.01	–	–	51	5	Y
Pb (mg/l)	0.1	0.08	0.06	–	–	0.1	0.2	Y
Cu (mg/l)	0.01	0.01	–	–	–	0.5	0.1	Y
Ni (mg/l)	0.035	0.12	0.04	–	–	0.1	0.1	Y
TC (MPN/100 ml)	> 200.5	> 200.5	> 200.5	> 200.5	> 200.5			N
FC (MPN/100 ml)	> 200.5	> 200.5	> 200.5	> 200.5	> 200.5			N

greywater is needed as a pre-requisite for successful reuse. In addition to the quality data, Table 5 contains three more columns. It is generally required to treat water to standard A if it is to be reused to irrigate fruits and vegetables which are likely to be eaten raw. Treatment of water to standard B is required if the water is to be reused to irrigate fruits and vegetables likely to be cooked and eaten. Investigation of Table 5 indicates that reuse of greywater is acceptable according to pH, total dissolved solids, and metals. However, reuse of greywater is not acceptable according to electrical conductivity, total suspended solids, biochemical and chemical oxygen demands, and coliform bacteria. Similar findings were reported by Prathapar et al. (2005).

Successful implementation of greywater reuse projects within a community requires that such projects are accepted and supported by the general public. This acceptance becomes more important when questions regarding water quality and cost are raised. The public should be willing to encourage, support, and apply such projects even when reasonably extra cost is required. Table 6 shows the outcome of a survey designed to measure the public acceptance of greywater reuse projects in Muscat. Analysis of the survey data revealed that 87% of the respondents accepted installation of new plumbing system in their homes so that greywater collection can be achieved, while 7.7% of respondents opposed installation of such systems. Similarly, the survey data showed that about 76.3% would accept greywater reuse for gardening, 53.3% for car washing, and 66.3% for toilet flushing. On the other hand, people opposed to greywater reuse highlighted five main reasons to justify their rejection as shown in Fig. 8. Among those opposing reuse options; 88.2% think that reuse of greywater would not be safe, 52.6% think that greywater reuse would adversely impact the environment, 22.3% think that

Table 6 Outcome of a survey designed to measure the public acceptance for greywater reuse

Statement	Agree (%)	Disagree (%)	No opinion (%)
Accept new plumbing system in their homes	87.0	7.7	5.3
They think that it is economically beneficial	78.1	17.2	4.7
The think it is environmental acceptable	32.0	60.9	7.1
They think it is not harmful to human health	46.7	46.7	6.5
They would use greywater for garden watering	76.3	19.5	4.1
They would use it for car washing	53.3	42.6	4.1
They would use it for toilet flushing	66.3	29.6	4.1
They think that greywater can be treated to the level of drinking water	14.8	81.7	3.6
They would allow researchers from SQU install flow meters and measure flow rates from their homes	49.7	45.6	4.7

greywater reuse would lead to groundwater pollution, 60.1% oppose greywater reuse because of religious concerns, and 24.5% believe that greywater reuse would not be economically feasible.

Conclusions

This study was carried out to evaluate the availability of greywater and its quality in Muscat Governorate in the Sultanate of Oman, and to establish a methodology for greywater quantity estimation in Muscat area. The amount of freshwater consumption was calculated by daily water meter readings and a social survey. Domestic fresh water consumption was found to be 61 l per use for washing machines, 51 l per shower, 3.2 l per minute per sink-use, and 5% of the total fresh water consumption for garden. The results illustrated that the average per capita water consumption in Muscat Governorate is about 186 Lpcd and the average per capita greywater production is about 151 Lpcd. Greywater production ranged between 80 and 83% of the total fresh water consumption and most of the greywater is generated from showers. Further, 55–57% of the greywater generated in a typical Omani household originated from the shower, 28–33% originated from the kitchen, 6–9% originated from laundry, and 5–7% originated from sink. The survey results also highlighted that the quantity of greywater generated is directly proportional to the family size while the per capita greywater generation rate is inversely proportional to the family size, which seems to be due to the limited amount of freshwater availability.

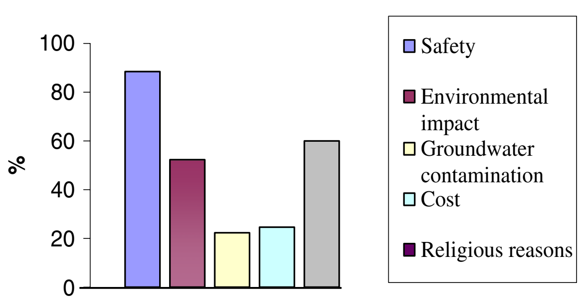

Fig. 8 Main reasons highlighted by people opposed to greywater reuse justifying their rejection

The quality of greywater revealed that it contains significant levels of suspended solids, inorganic constituents, total organic carbon, COD, BOD, total Coliforms and Escherichia Coliform bacteria. Also, among greywater sources, high variability is observed in the quality data, which seems to be due to factors such as greywater sources, size of family and individual lifestyles. Physical and chemical parameters in some cases reached unacceptable levels of effluent standards, indicating the importance and necessity of greywater treatment prior to reuse. The public acceptance survey illustrated that approximately 76% of the respondents accepted the reuse of greywater for gardening, 53% for car washing and 66% for toilet flushing. Among those opposing reuse options; 88.2% think that reuse of greywater would not be safe, 52.6% think that greywater reuse would adversely impact the environment, 22.3% think that greywater reuse would lead to groundwater pollution, 60.1% oppose greywater reuse because of religious concerns, and 24.5% believe that greywater reuse would not be economically feasible.

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