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RESEARCH ARTICLE

Extended use of grey water for irrigating home gardens in an arid environment

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Abstract The use of treated grey water (GW) for home gardens, peri-urban agriculture and landscaping is becoming popular in many water stressed countries such as Oman. This study aims to investigate the treatment efficacy, health and chemical concerns, cost-benefits and maintenance protocol of a GW treatment system as well as the effect of irrigation with GW on crop yield. Therefore, a decentralized homemade GW treatment system was installed in a newly constructed house in Muscat, Oman and studied over a 2-year period. The treated GW was found to be suitable for irrigation as per Omani standards. GW when mixed with kitchen effluent substituted the use of nutrient supplements for plants and did not show any harmful chemical or biological contamination. The capital cost of the system was around US $980, and the annual operating cost was US $78 with annual income and savings from the system being around US $572 indicating a payback period of nearly 2 years. It was found that the system required simple but regular maintenance particularly cleaning of the top layer of the filter. It can be concluded from this study that such a GW system should be technically, economically and environmentally feasible in Oman. Also, wider acceptance by the general public to the idea of GW reuse will help in mitigating the water shortage problem of the country to some extent.

Keywords Grey water reuse · Decentralized · Homemade · Efficiency · Economy · Irrigation

Introduction

In some countries, home garden irrigation consumes up to 40% of the total water consumption in an individual dwelling during the summer time (Finley 2008). In recent years, a smart way of saving water around the home through the installation of a grey water system is gaining wide acceptance. Grey water (GW) includes all non-toilet water used in the home such as water used in bathrooms, washbasins, laundry and kitchen (Casanova et al. 2001; Mohamed et al. 2013). However, Christova-Boal et al. (1996) suggested excluding kitchen effluent from GW treatment and reuse systems because it contains too much fat, oil residues and food scraps, and it accounts for only 5% of the household water consumption. Yet, other studies reported higher percentages of kitchen effluent such as 10% (Ahmed et al. 2003), 27% (Mandal et al. 2011), 28% (Prathapar et al. 2005) and 25–30% (Friedler 2004). Because GW is lightly contaminated with pathogens and other detrimental constituents (WHO 2006b), only a simple purification system would be sufficient to make this water usable again for non-potable uses, e.g. irrigation (Finley 2008).

Grey water systems reuse and recycle wastewater from the home for irrigating backyard gardens or even in the home for toilet (WC) flushing (Christova-Boal et al. 1996; March et al. 2004; Mandal et al. 2011). Other applications of treated GW include vehicle and window washing, fire extinguishing, boiler feed water, concrete production, golf course irrigation, fertilization of crops (Okun 1997; McIlwaine 2010) and groundwater recharge (Asano and Levine 1996; Santala et al. 1998; Bertrand et al. 2008). Grey water systems need to be well set up and maintained to ensure that they do not have any

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negative effects on the environment or human health. All GW systems require some behavioural changes and a maintenance regime; therefore, careful consideration of relevant uses is needed before installing such a system (Eriksson et al. 2009).

Grey water quality, quantity, treatment and other related issues have been widely discussed. Surendran and Wheatley (1998) reported that in the UK, there are, on average, approximately equal volumes of GW and lavatory flush water. A similar finding was also stressed by Mandal et al. (2011). Hodges (1998) and Finley (2008) reported that about two thirds of domestic water is GW. In Oman, around 80% of wastewater produced from city households is considered GW (Prathapar et al. 2005) which coincides with what was conveyed by Jamrah et al. (2004, 2008). Similarly, Al-Jayyousi (2003) reported that residential GW accounts for 50 to 80% of the total domestic household discharge.

Griggs et al. (1998) identified GW reuse for irrigation and WC flushing as a major water conservation measure. In Oman, increasing water availability by treating and reusing wastewater, particularly for irrigation, is a government policy (Al-Obaidani and Atta 2003). Grey water reuse reduces the amount of freshwater needed to supply a household and reduces the amount of wastewater entering sewer or septic system. The use of GW for irrigation alone can result into water saving of about 12 to 65% (Sheikh 1993). In Australia, another study showed that water saving was in the range of 30–50% when GW was used for toilet flushing and lawn irrigation (Jeppesen 1996). In addition to water savings, likely benefits include reduction in wastewater treatment costs and reduction in the threat to groundwater pollution from septic tanks (Prathapar et al. 2005). Therefore, with proper management, GW reuse will bring significant environmental and economic benefits. A simple calculation shows that for only 20,000 houses, having GW systems with an individual treatment capacity of 1 m^3/day will save 20,000 m^3/day in the consumption of desalinated water, i.e. equivalent to daily production of a mid-size desalination plant. In a recent study, Malinowski et al. (2015) reported that GW reuse would significantly reduce the energy consumption (needed for water purification, delivery, treatment, etc.) which would result in remarkable savings in electricity bills at US national scale. Little savings in water and energy costs at a micro-scale (i.e. individual houses) will definitely bring significant savings in water and energy profiles at a macro-scale (i.e. national level) (Azar and Menassa 2014).

Ahmed et al. (2008) presented a GW system that was designed and tested in Oman. This system consisted of settlement pond, underground GW storage tanks, a small trap filter and a main multi-layer filter. The performance efficiency of the treatment unit was enough to satisfy the Omani regulations of wastewater reuse for irrigation. The financial analysis showed that internal rate of return (IRR) for such a system after 10 years was attractive (14.9%) considering the prevailing bank interest rates in Oman. Costs of the system and the amount of GW treated were the main factors affecting the IRR. Based on this study, it was concluded that under certain conditions, GW treatment and reuse are technically and financially feasible in Oman and the Arabian Gulf countries (Ahmed et al. 2008). By considering GW practices in many arid and semi-arid countries, Ahmed et al. (2005) and Prathapar et al. (2005) reached to a similar finding that GW can be a cost-effective alternative source of water. In this study, we aim at conducting further investigations on the performance of a GW collection, treatment and reuse system in a typical Omani household over an extended period of 2 years. This investigation will include the evaluation of the treatment efficacy, health and chemical concerns, cost-benefits and maintenance protocol of a GW treatment system as well as the effect of irrigation with GW on crop yield.

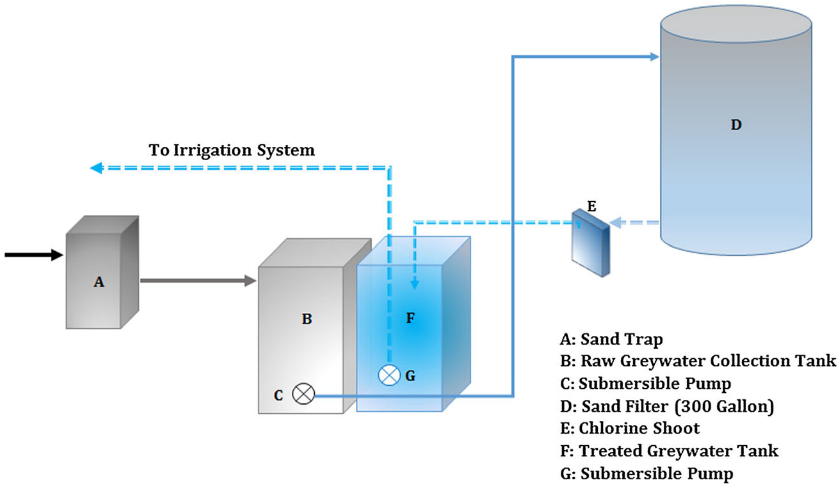
Methodology

Description of GW system

A GW treatment system, similar to the one reported by Ahmed et al. (2008), was installed in a newly constructed house in Muscat, Oman. In this system (Fig. 1), raw GW was collected in a storage tank and then pumped to a sand filter which is a regular 300 gal (1136 l) polyethylene water tank. This filter is filled with layers of washed dune sand at the top, fine gravel at the middle and then small and large stones at the bottom (Fig. 2). The GW, which undergoes physical treatment through the filter, is then passed through chlorine tablets in the chlorine chute for disinfection. At this stage, the treatment process is over and the recycled GW is ready to be used for irrigating home garden crops such as salad vegetables and ornamentals. This water is also used to irrigate some trees including date palms, lime, fig and grapes.

The total water consumption of the house is approximately 1.16 m^3/day and GW averages between 0.58 and 0.93 m^3/day. The GW treatment system is an automatic operating system. In the collection tank, whenever the accumulated volume reaches nearly 0.40 m^3/day, the submersible pump sends the GW to the sand filter for treatment. The sand filter requires a regular maintenance every 6 to 8 weeks. The top 5 to 10 cm of the dune sand is replaced with new sand in order to remove the accumulated debris. Once this layer is removed, the filtration rate gets back to normal. The removed sand (approximately 0.04 m^3) is either taken to landfills or exposed to direct solar radiation for drying. The total cost of this maintenance process is around US $4. The sand filter also requires another rigorous maintenance once every 3 years. In this maintenance, all layers of the filter are removed and only the dune sand has to be replaced with new sand. Other layers can be washed and used again. The total cost of this maintenance process is around US $60.

Fig. 1 Schematic of the household GW treatment system



Experimental setup

The garden area of the selected house was divided into two plots (split plot design) each of which is irrigated with one type of irrigation water. Beefsteak tomatoes (*Lycopersicon esculentum*) and eggplants (*Solanum melongena*) were cultivated in each plot, Fig. 3. The two crops were planted in two separate lines and irrigated twice daily by drip irrigation system to avoid any contact between the GW and the above-ground portions of the plants. Both plots were irrigated early in the morning and mid-afternoon for 5 min intervals. One dripper, having a capacity of 4 l/min, was used to irrigate each plant. In each plot, 6 eggplants and 12 tomato plants were cultivated and thus their average yield was considered.

In plot 1, tap water with regular nutrients was used in irrigation as the control treatment. The added nutrients included nitrogen, phosphorus and potassium (N/P/K—15:15:15) in addition to the trace elements. These nutrients were very soluble and applied intermittently as a top dressing in the root vicinity of each crop in a frequency of approximately once every week. In plot 2, two types of GW (treatments) were studied in two different seasons. The GW, in both treatments, included a mix of water collected from washbasins and bathtubs and excluded the laundry water. In the first season, GW without kitchen effluent was used, whereas GW including kitchen effluent was used in the second season. Both GW treatments were not provided with any supplemental nutrients other than those readily available in the soil. The first season extended from 10 December 2013 to 10 May 2014, and the second season extended from 22 October 2014 to 5 April 2015. Between the two seasons, although the GW system continued working to irrigate other crops, the experimental plots were not used for any cultivation but left unutilized. Rainfall, infiltration and evaporation are expected to have a positive effect in resetting the soil conditions for the second season.

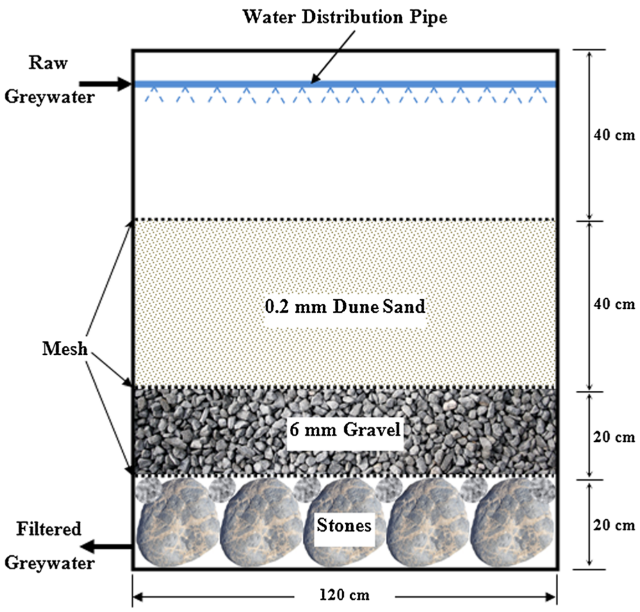


Fig. 2 Schematic of the sand filter in the GW treatment system

Sampling and analysis

Mature fruit quality and quantity of both crops under the three irrigation water treatments (i.e. freshwater with fertilizers (FW + F), GW without kitchen effluent and GW with kitchen

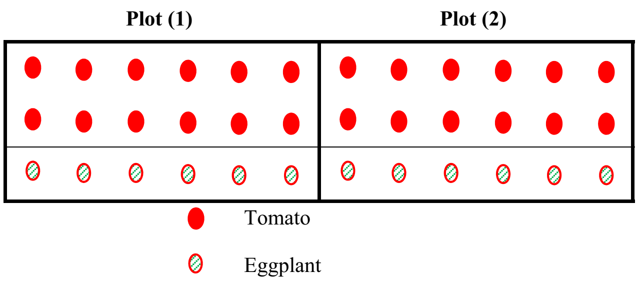


Fig. 3 Schematic diagram of *Plot (1)* irrigated with freshwater and fertilizers (FW + F) as a control plot and *Plot (2)* irrigated with grey water alone (GW)

effluent) were monitored and assessed. Treated and untreated water samples were weekly taken for EC, pH, turbidity, coliform, *E. coli* and chemical analysis, and the average values of eight samples were reported. Forty-eight soil samples from the root zone depth (0–30 cm) were taken at the beginning and end of the study. Physical, chemical and biological analyses were conducted on fruits and soil samples. Soil EC and pH were measured from saturated paste extract. Chemical analysis (e.g. Na, Ca, Mg, K, Cd, Cu, Fe, Zn, Mn, Cr, Pb and Ni) for soil and fruits was done in the soil and water laboratories, SQU, Oman, following standard methods and using inductively coupled plasma mass spectrometry (ICP-MS)-mass (PerkinElmer). Similarly, nitrogen content analysis for fruits and soil was performed in the soil and water laboratories, SQU, following Kjeldahl digestion method described by Huang et al. (2004).

The biological analysis of fruit samples was conducted in Muscat Municipality laboratories. This analysis included total aerobic plate count, total coliform, *E. coli* bacteria, *Staphylococcus aureus*, *Salmonella* spp., *Bacillus cereus* and yeast and mould. Total and faecal coliform numbers were determined according to most probable number (MPN) method. For plant samples, four samples per treatment were taken and their average values were reported. Data were analysed statistically using the analysis of variance, and the means were compared at the probability level of 5% using least significant difference (LSD).

Results and discussion

Efficacy of grey water treatment system

The efficacy of the GW treatment system was assessed based on its ability to purify and disinfect the raw GW before using it for irrigation. Table 1 presents a comparison between physical, chemical and biological properties of raw and treated GW. In this table, the treated GW is also compared against the local

Table 1 Physical, chemical and biological properties of raw and treated GW with the Omani standards for wastewater reuse in irrigation

	Raw GW	Treated GW	Standard A[a] (vegetables eaten raw)	Standard B[a] (vegetables eaten cooked)
Physical properties				
EC (µS/cm)	453	522	2000	2700
pH	7.5	8.2	6–9	6–9
Turbidity (NTU)	16.1	9.65	N/A	N/A
Chemical properties (mg/l)				
Residual chlorine	–	0.4		
Na	59.6	69.1	200	300
Mg	11.5	15.7	150	150
K	9.49	10.3	N/A	N/A
Ca	22.7	22.1	N/A	N/A
Mn	>0.001	>0.001	0.1	0.5
As	>0.001	>0.015	0.1	0.1
Cd	>0.001	>0.001	0.01	0.01
Cu	>0.001	>0.001	0.05	1
Fe	>0.001	>0.001	1	5
Zn	>0.001	>0.001	5	5
Si	5.03	6.81	N/A	N/A
S	19.9	24.0	0.01	0.01
B	0.258	0.368	0.5	1
Pb	0.105	0.070	0.1	0.2
SAR ($mol^{1/2}/m^{3/2}$)	14.4	15.9	N/A	N/A
Biological properties (MPN/100 ml)				
Coliform	129.8	0	200	1000
E. coli	50	0		

Samples were collected from raw and treated GW with kitchen effluent as it includes all possible contaminants that may exist in GW

N/A not available

[a] Source: WHO (2006a)

Omani standards of treated GW reuse for irrigating crops eaten raw (standard A) and crops eaten cooked (standard B). These results match well with what was reported earlier by Ahmed et al. (2008). It is clear that the quality of treated GW was within the Omani standards for wastewater reuse in irrigation. Yet, the concentration of some elements (e.g. Na and Mg) has increased after passing through the sand filter. This indicates that the initial concentration of these elements in the dune sand was higher than their concentration in the raw GW. Therefore, GW leached some of these elements as it passes through the sand filter, resulting in higher concentration of these elements in the treated GW (Fig. 4).

The treatment (filtration) system used is unlikely to remove any dissolved chemicals or elements. For parameters like Na, Mg and Ca, including B after treatment will have pretty much the same concentration as in the raw water. The values after treatment are relatively low and will have no impact on crop growth. Currently, the boron concentration in drinking water is allowed up to 2.4 mg/l as per the new Oman drinking water standards (DGSM 2012, OS8/12). As such, the after treatment boron concentration will also be high. It may even exceed the current standard A of 0.5 mg/l. The vegetables that will be commonly grown (e.g. tomato and lettuce) with treated GW are relatively boron tolerant and water of even up to 4–6 mg/l boron can be used (http://www.fao.org/docrep/003/T0234E/T0234E05.htm). The slight increase of boron after treatment may be due to its original presence in the dune sand of the filtration unit.

Although the concentration of these elements was within the Omani standards, this increase could have been avoided by proper washing of the sand before using it in the filter. The treated GW had a medium-level SAR, i.e. 10–18 (Fipps 2003), which casts no harm on the soil in the short run and doing proper leaching will be necessary to avoid adverse impacts in the long run. Al-Hamaiedeh and Bino (2010) stressed the importance of leaching soils irrigated with GW. In this study, chemical oxygen demand (COD), BOD and total suspended solids (TSS) analyses were not conducted, yet Ahmed et al. (2008) reported removal efficiency of 86% for COD, 74.2 for BOD5 and 88.8% for TSS for a similar treatment system.

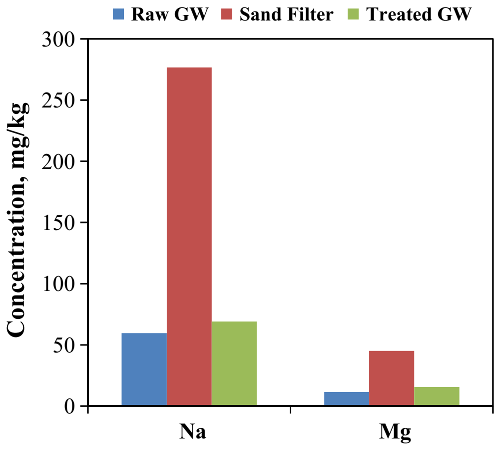


Fig. 4 Changes in element concentration of raw and treated GW as it passes through the sand filter

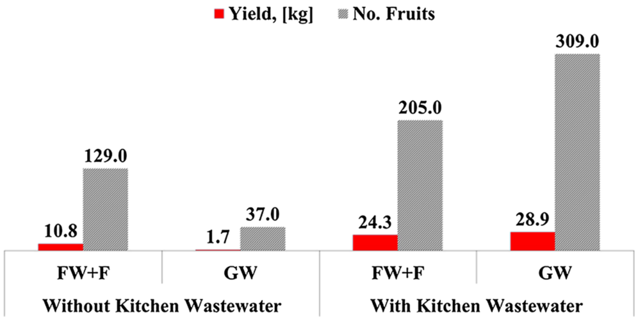


Fig. 5 Variations in yield and fruits for tomato crop irrigated with freshwater and fertilizers (*FW* + *F*, control) against tomato crop irrigated with grey water (*GW*) without kitchen wastewater in one season and GW with kitchen wastewater in the second season

Table 1 also revealed that the GW system was successful in disinfecting the treated GW, as it killed all biological contaminants via the chlorination treatment without leaving any harmful levels of residual chlorine in the treated GW. The measured residual chlorine (0.4 mg/l) was even less than the maximum allowable limits for drinking water (0.5 mg/l; MCI 2006). The source of *E. coli* bacteria in the raw GW was either from an aging elderly or from a young child (Christova-Boal et al. 1996). In the case of this study, the latter source was attributed to the presence of *E. coli* in the raw GW. From above, the efficacy of the GW treatment facility to purify and disinfect the raw GW was very satisfactory.

Grey water without and with kitchen effluent

In the first season, kitchen effluent was not included in the GW treatment and reuse system but in the second season, it was included in order to bulky up its volume and to study its effect on plants and soil. Figures 5 and 6 show the variations in yield and number of fruits for tomato and eggplant crops,

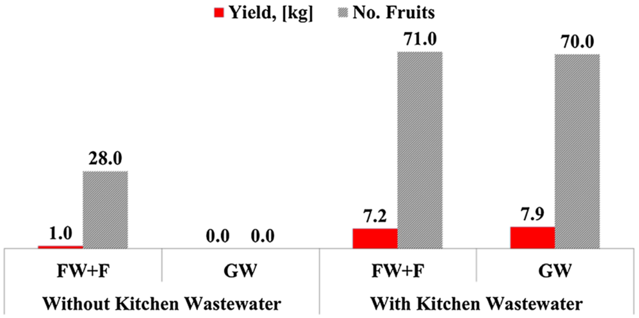


Fig. 6 Variations in yield and fruits for eggplant crop irrigated with freshwater and fertilizers (FW + F, control) against eggplant crop irrigated with grey water (GW) without kitchen wastewater in one season and GW with kitchen wastewater in the second season

Table 2 Concentration of heavy metals in fruit samples of tomato and eggplants irrigated with freshwater and fertilizers (FW + F) and greywater (GW)

Heavy metals (mg/kg)	Tomato		Eggplant		Max. permissible levels (mg/kg)[b]
	FW + F	GW[a]	FW + F	GW[a]	
Cadmium, Cd	0.001	0.11	0.10	0.10	0.2
Copper, Cu	10.54	7.33	6.64	8.31	40
Iron, Fe	52.15a	136.2b	42.97a	78.85b	450
Zinc, Zn	12.36	21.87	11.34	12.17	60
Manganese, Mn	0.14	5.33	6.35	7.84	500
Chromium, Cr	2.87	1.54	0.88	1.36	5
Lead, Pb	0.21	0.10	0.08	0.08	5
Nickel, Ni	2.20	1.10	0.92	1.68	10

Level of significance at $P < 0.05$

[a] Samples were collected from the plot irrigated with GW with kitchen effluent as it includes all possible contaminants that may exist in GW

[b] Source: WHO/FAO (2007)

respectively, irrigated with GW without kitchen effluent in one season and GW with kitchen effluent in the second season compared with crops irrigated with freshwater and fertilizers (FW + F) as the control. In the first season, the yield and number of fruits of both crops irrigated with GW were inferior to those in the control. This indicates that the GW without kitchen effluent was lacking some of the elements necessary for plant growth and production. This becomes evident when the yield and number of fruits of the grey water-irrigated plants in the second season are compared to the control. The grey water-irrigated tomato crop showed a significant increase in yield (18.9%) and number of fruits (50.7%) while eggplant crop exhibited a moderate increase in yield (9.7%) and approximately a similar number of fruits (−1.4%) compared with the control. This implies that GW becomes nutrient-rich when kitchen effluent is incorporated and thus can offer, at least, similar results to the freshwater with nutrients supplements. From both figures, it can be clearly seen that the yield and number of fruits in the second season for both crops have increased even for the control (FW + F) as compared to the first season. This is attributed to the difference in beginning and duration of both seasons as explained in the "Experimental setup" section.

Chemical and biological analyses of fruit samples from grey water-irrigated crops did not display any kind of harmful contaminants. The concentration of heavy metals in the analysed samples was always less than the maximum permissible levels as clearly seen from Table 2. Results of the biological analysis confirmed the absence of all types of biological contaminants. Therefore, irrigation with treated GW is chemically and biologically safe, yet further investigations are still encouraged.

The results from the chemical analysis of soil irrigated with treated GW and soil irrigated with FW + F (control) are provided in Fig. 7. It can be seen that GW can add more nutrients to the soil compared to the control. Table 3 provides a closer look into the toxicity level of heavy metals present in both types of irrigation water. It can be clearly seen that heavy metals in soils irrigated with both types of irrigation water (i.e. GW and FW + F) were always below the maximum allowable limits. Nitrogen content analysis of soil samples indicated an increase in nitrogen when kitchen effluent was

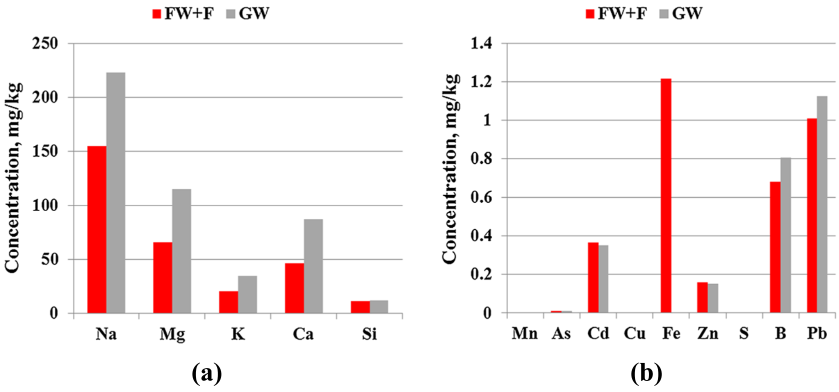


Fig. 7 Concentration of chemical elements in soil irrigated with freshwater and fertilizers (*FW + F*) and soil irrigated with grey water (*GW*) for **a** high-concentration and **b** low-concentration elements

Table 3 Concentration of heavy metals in soil samples from plots irrigated with freshwater and fertilizers (FW + F) and greywater (GW)

Heavy metals (mg/kg)	FW + F	GW[a]	Permissible levels (mg/kg)[b]
Cadmium, Cd	0.365	0.352	3
Copper, Cu	0.0002	0.0002	50
Iron, Fe	1.215a	0.001b	1000[c]
Zinc, Zn	0.158	0.150	200
Manganese, Mn	0.0002	0.0002	80
Lead, Pb	1.008	1.125	300

Level of significance at $P < 0.05$

[a] Samples were collected from the plot irrigated with GW with kitchen effluent as it includes all possible contaminants that may exist in GW

[b] Source: USEPA (2010) unless specified otherwise

[c] Source: Kabata-Pendias and Pendias (2010)

integrated in the GW reuse system. Figure 8 illustrates the nitrogen content (%) in soil samples taken from the plots before irrigation with GW and FW + F and after irrigation with GW (without kitchen effluent) and FW + F in the first season and GW (with kitchen effluent) and FW + F in the second season. Therefore, the increase in the concentration of essential nutrients and nitrogen content of GW as depicted in Figs. 7 and 8, respectively, is attributable to the augmented yield and number of fruits (Figs. 5 and 6). This reveals that the nutrient-rich GW represents a good alternative that substitutes the use of freshwater for irrigation and the use of supplementary nutrients.

Economic and technical considerations

In almost every Omani household, there are big lawns and/or green yards which are often irrigated with potable water supply. This leads to high water bills and draining of limited water resources. Installation of household GW treatment system at each household is a promising solution for the country. The cost of setting up the system is circa US $980, and the annual operating and maintenance cost is around US $78. On the other hand, the annual materialistic (i.e. savings in water bills and nutrient supplies and monetary value of produced fruits and flowers) and non-materialistic (i.e. green scenery) income is estimated to be US $572. Therefore, the payback period of the GW system is approximately 2 years (24 months). Currently, the GW system produces more treated water than what is required for irrigation in the small garden. The excess treated GW can be sent via small pumps for washing or flushing toilets if it satisfies Omani water standards for potable water use. This would inevitably further reduce the consumption of supplied water.

On the technical side, it should be noted that the GW treatment system is not a maintenance-free system. It requires a regular maintenance particularly for the top layer of the sand filter due to the accumulation of grease, food particles, hair, lint and other impurities. In the first season, when kitchen effluent was not integrated in the GW system, it was adequate to replace the top 5 cm of the sand once every 6 months. However, when kitchen effluent was included in the second season, it was necessary to replace the top 5 cm every 2 months due to the presence of more fats in the kitchen effluent.

Conclusions and recommendations

The 2-year study focusing on the operational aspects of a grey water treatment system clearly demonstrated that such systems are suitable for individual households. This is because they require minimum maintenance and pose no significant operational difficulties. Large-scale adoption would reduce the demand for freshwater and will reduce the amount of wastewater entering the sewer or septic systems. The treated grey water was found to be suitable for small-scale garden irrigation from chemical, physical and biological considerations. Heavy metal concentrations in irrigated soils were within acceptable limits, and in the short term, it will pose no threat. It was found that including kitchen grey water in treatment and irrigation resulted in the increase of plant growth and yield due

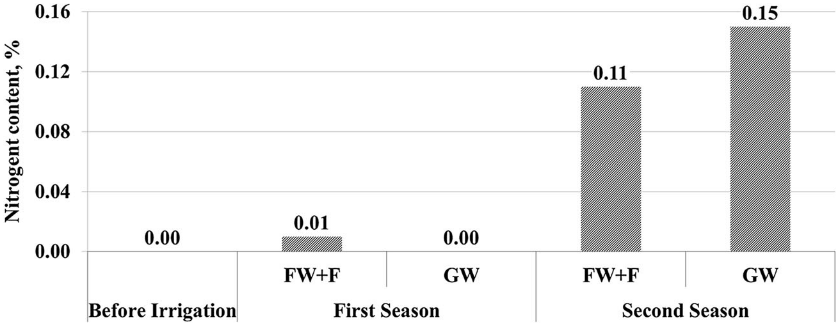


Fig. 8 Nitrogen content in the soil before irrigation and after irrigation with GW (without kitchen wastewater) and freshwater with fertilizers (FW + F) in the first season and *GW* (with kitchen wastewater) and *FW + F* in the second season

to increased input of nitrogen in the soils. Chemical and biological analyses proved that the produced fruits were safe in terms of heavy metal concentration and biological contaminants. From economic considerations, the system is attractive for installation as the payback period is around 2 years. We would recommend that the government should clearly establish rules and regulations for installation of such systems in all new residential building. Providing subsidy should also be considered for promoting large-scale adoption of such systems.

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