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ORIGINAL ARTICLE

Treatment and effective utilization of greywater

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Abstract
Sustainable management aims at the governance of natural resources to meet the needs of future generations. The limited resources of freshwater in arid regions have led to the development of alternative water management strategies. To meet the future challenges of water scarcity, an attempt has been made in this study to utilize treated greywater obtained by gravity-governed filtration technique and disinfection for domestic usage. The study addresses the possibilities of groundwater recharge with the treated greywater. The method focuses on a gravity-governed flow through a column containing activated carbon, sand and gravel. The greywater used for the treatment contains a mixture of equal proportions of water collected from three different sources such as kitchen sink, shower and washing machine in Fahaheel, Salmiya and Farwaniya areas of Kuwait. The study concluded that for a volume of 1167 cm^3 filtration media used, the designed column was 34% effective for first 1100 mL of greywater. Later, the column was regenerated by washing with distilled water and the regenerated column still proved to be effective with a removal efficiency of 26% for next 600 mL of greywater. The quality of the treated greywater was assessed in terms of physical, chemical and microbiological parameters as per the standard methods to check the suitability for domestic purposes. The results obtained were also compared with the groundwater quality of Kuwait group and Dammam aquifers, and it was inferred to be at par with their quality. The TDS of treated greywater has been reduced from 4910 to 1508 mg/L, which is also lower than the TDS in groundwater of both the aquifers, and pH was reduced from 10.29 to 7.94. The present study proved its efficiency equally to other existing methods, and the efficiency of removal for some of the analyzed parameters was measured as 23%, 95%, 52%, 88%, 100% and 100% for pH, color, TDS, turbidity, total coliform and *E. coli*, respectively. Hence, the study is simple and cost-effective approach that can be adopted for the treatment and reused greywater for domestic and agriculture and also for recharging the aquifers to prevent saltwater intrusion along the coastal aquifers.

Keywords Greywater · Filtration · Disinfection · Regeneration · Aquifer

Introduction

Greywater is the wastewater usually generated from the kitchen sink, shower, laundry or washing machine, AC outlet, etc., which is sent through as a waste. This can be reused subsequently by a simple and cost-effective treatment technique. Kuwait is one among the top countries generating greywater followed by Uganda and Oman, but the utilization of treated greywater is not so effective.

The data in Table 1 signify that the generation of greywater in different countries ranges from 39 to 85%. The data bring out the fact that the consumption of domestic water varies from country to country and can be reduced up to 30% in Kuwait by using treated greywater. It has been observed that many countries focused on greywater treatment and reusing for several purposes like irrigation, firefighting, toilet flushing, etc. The above data infer that there is a great dependency on the quantum of greywater in near future, especially in Kenya, Syria, and Kuwait as the consumption of freshwater is not at par with the production of freshwater.

Kuwait being an arid region receives about 140 mm rainfall annually (Abusam 2008). This country has very limited freshwater and brackish water resources. The brackish water resource is mainly from Kuwait group and Dammam aquifer stretching east of the Arabian Peninsula and sloping toward the Arabian Gulf. Kuwait group is composed of layers of sediments and clastic rocks, and Dammam formation

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Table 1 Percentage of greywater generation and probable reduction of domestic water in different countries

S. no.	Literature source	Country	Generation of grey-water (%)	Probable reduction of domestic water consumption by using treated greywater (%)
1.	Abusam (2008)	Kuwait	85	30
2.	Revitt et al. (2011)	Australia	50	29
3.	Mourad et al. (2011)	Syria	46	35
4.	Kariuki (2011)	Kenya	50–80	33–54
5.	Al-Mashaqbeh et al. (2012)	Jordan	50–80	–
6.	Al-Jarallah (2013)	Oman	82	–
7.	Abedin and Rakib (2013)	Dhaka	67	–
8.	Beler-Baykal (2015)	Istanbul	75	25
9.	Katukiza et al. (2014)	Uganda	85	–
10.	Juan et al. (2016)	Brazil	–	29–35
11.		Malaysia	67	30
12.		South Korea	–	26.5
13.		Los Angles	13–65	–
14.	Redwood et al. (2013)	La Soukra, Tunisia	55–80	–

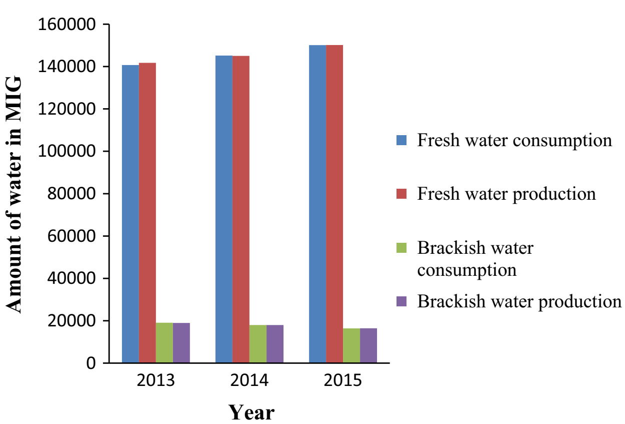

Fig. 1 Statistics on the Consumption and Production of Fresh Water and Brackish Water in Kuwait (Statistical Year Book (Water), Kuwait 2016). **MIG* Million Imperial Galloon

contains layers predominantly of limestone saturated with water. In general, brackish water is used for irrigation, landscape, livestock watering and construction.

There is an increase in the consumption and production of freshwater every year (Fig. 1). The total consumption of freshwater and brackish water per day is around 473.2 MIG. The supply and demand for freshwater in Kuwait are chiefly dependent exclusively on desalination techniques like reverse osmosis (RO), electrodialysis and distillation. The distilled water obtained from desalination units of various plants in Kuwait is blended in a specific ratio with brackish groundwater extracted from different wells like Sulaibiya, Shigaya, Al-Wafra, Um-Gudair and Al-Atraaf (Statistical Year Book 2016) leading to increase in the consumption of brackish groundwater. The process of desalination results in the emission of greenhouse gases, salt or brine disposal obtained either by distillation or by RO which may deplete the oxygen in the water and affect the marine life (Terry 2018), thereby enriching the concentration of metals and other organic constituents. Though the freshwater produced by the above methods meets the demands, it results in consumption of brackish water, high energy and even leads to environmental pollution. Hence, for sustainable development it is essential to think about the alternative sources for fulfilling the water needs. The demand for alternative sources has also been stressed by considering the importance of greywater use in Kuwait (Abusam 2008; Al-Jarallah 2013; Alaziz and Al-Saqer 2014). Few studies even supported the artificial recharge of aquifers using treated wastewater (Leas et al. 2013; Packialakshmi et al. 2015). There are many reported methods for the greywater treatment studies (Table 5), but the cost-effectiveness and the quantity of the treatment materials used for the proportion of treated greywater are more significant for considering the applicability of the method.

Therefore, to replenish the declined water resources for future sustainability a low-cost method with a unique household technique was attempted for greywater treatment which can subsequently reduce the groundwater extraction. Hence, the main objective of the present study is to develop an effective treatment of greywater using gravity-governed filtration technique and to determine its suitability for groundwater recharge by comparing the treated greywater quality with that of Kuwait group and Dammam aquifers.

Materials and methodology

Materials

The treatment for the greywater was based on gravity-governed slow sand filtration and disinfection using bleaching powder. The filtration was done through a column packed with filtration media. The selection of materials used in the column was purely based on the earlier removal studies (Huisman and Wood 2005; MWRI–GOSS 2009; Bagundol et al. 2013), such as sand and gravel remove microorganisms and suspended solids; sieve removes floating matter; and activated carbon removes organic pollutants, color and odor. The size and volume of the materials used in the column are presented in Table 2.

Experimental design

The treatment of greywater is represented in a schematic diagram (Fig. 2).

Method

One liter of greywater from each source, kitchen sink, shower and the washing machine, was collected separately and blended. Three liters of the greywater was passed through the column of height 25 cm and radius 4.5 cm, containing the following layers from bottom to top, viz. cotton, activated carbon, fine and coarse sand, small and big gravel.

Five hundred milliliters of greywater was allowed to flow through the column batch-wise, at the rate of 6.5 mL/min, and collected. Once the filtration process reached the saturation point, the column was regenerated by passing 500 mL of distilled water twice at the rate of 4.5 mL and 6.0 mL/min without removing the materials and the filtration was continued. The column was replaced with the fresh materials when it was completely clogged. The filtered greywater was subjected to disinfection using bleaching powder 0.05 g/L.

The physical, chemical and microbiological analysis were carried out in the Water Research Center laboratory, KISR for greywater by adopting standard methods for the examination of water and wastewater SMEWW (Rice 2017) for pH, EC, TDS, alkalinity, turbidity, total coliform, *E. coli* and anions F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}. The major cations NH_4^+, K^+, Na^+, Ca^{2+} and Mg^{2+} were analyzed in ion chromatography using American Standard Test Method D6919-17 (ASTM 2017) and trace metals in inductively coupled plasma-optical emission spectrometry by USEPA 200.7 method (U.S. EPA 1994).

The small-scale treatment setup was arranged at each location Fahaheel, Salmiya and Farwaniya in Kuwait and the sampling process was carried out on a daily basis for a week continuously at all the three locations and the column was replaced three times in all these locations.

Results and discussion

Untreated and treated greywater characteristics

Untreated greywater

Greywater mainly consists of organic as well as inorganic pollutants. Few important parameters were measured before the treatment. pH plays a vital role to determine the acidic or basic nature of the water. The pH of untreated greywater of all the three locations had an average of 10.29. Electrical conductivity (EC) is one of the significant parameters that determine the total dissolved solids (TDS). The average EC and TDS of untreated greywater were 4910 µS/cm and 3140 mg/L, respectively. Turbidity, a part of suspended matter, helps to know the amount of suspended solids though both are not directly proportional. It was recorded as 199 NTU. In Salmiya, the untreated greywater had a higher pH, but the EC and TDS were lower than the Fahaheel and Farwaniya areas. The microbiological parameters, total coliform and *E. coli*, were more than 2419.6 MPN/100 mL.

Table 2 Measurements of materials used in the column for filtration

S. no.	Filtering media (bottom to top)	Size of the material in mm	The volume of the material used in cubic cm	% Volume of the material
1.	Cotton	–	–	–
2.	Activated carbon	< 1.0	85	7.28
3.	Fine sand	< 0.5	191	16.37
4.	Coarse sand	1.0/0.5	191	16.37
5.	Small gravel	4.0/2.0	318	27.25
6.	Big gravel	4.0/12.0	382	32.73
7.	Sieve	0.5	–	–

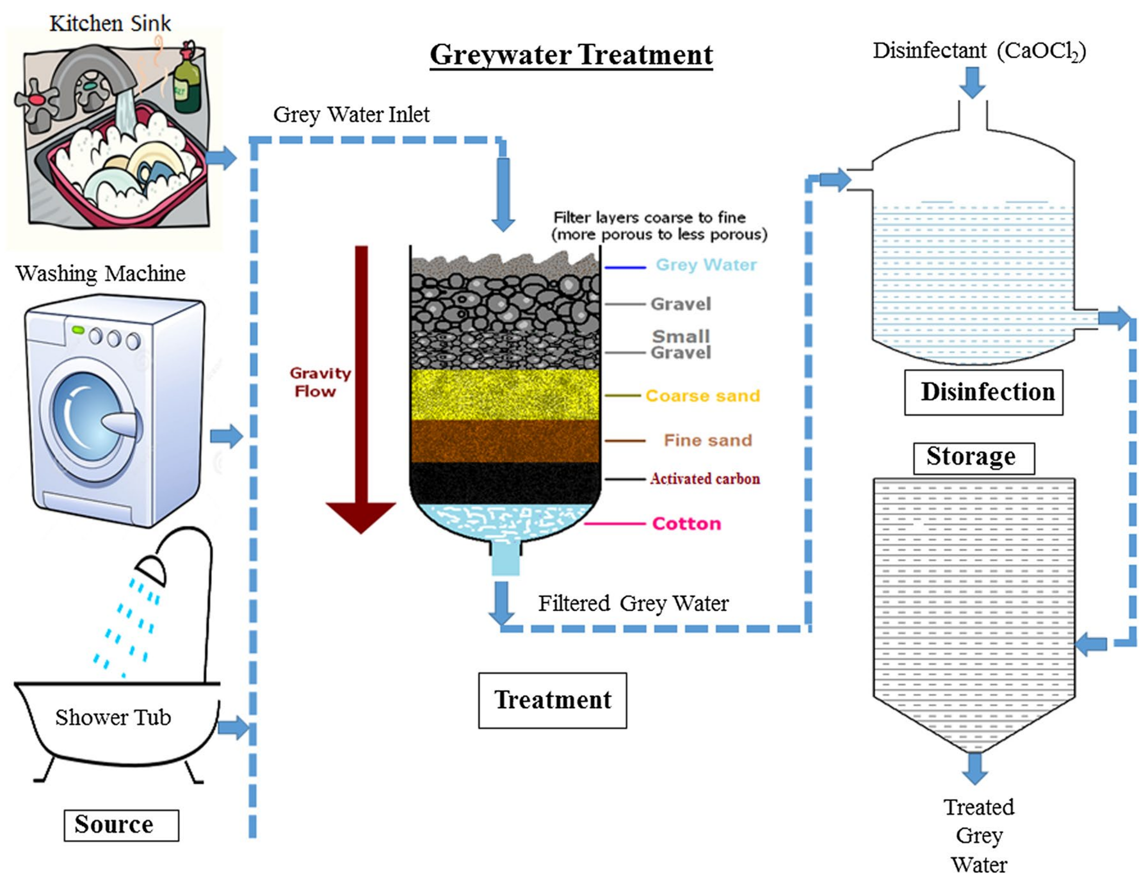

Fig. 2 Schematic diagram for the treatment of greywater

Treated greywater

The blackish brown color of the greywater turns nearly colorless after the treatment. The whole analysis results of treated greywater are presented in Table 3. In the present study, the treated greywater pH varies in all the three areas but found to be higher in Salmiya. Its average value has been reduced significantly from 10.29 to 7.94. EC of the treated greywater ranged from 1298 to 3682 µS/cm, and the average was 2325 µS/cm, which is usually lower because the raw water used in the houses for domestic purposes is desalinated. Turbidity reduces because of the reduction of suspended and dissolved solids. Few research studies reported that the sand filtration using activated carbon is a superior method and reduces mainly pH, TDS, turbidity and COD when the wastewater is passed through it (Prasad et al. 2006; Khalaphallah 2012; Saad et al. 2016). The same has been observed in the present study using the above technique. The nutrients ammonium, nitrate, potassium and phosphate were found to be slightly higher in Farwaniya. Sodium ion, one of the major ions, is lower in Salmiya compared to the other two areas. Since the household water itself is desalinated, the metals are present in traces. A further decrease in concentration of metals was noticed in the treated greywater due to a decrease in the rate of flow and presence of active sites on the surface of sand and activated carbon (Mohan and Chander 2001; Barkouch et al. 2018). The greater is the surface area on the filtering media, the larger is the adsorption of trace metals.

The microbiological parameters such as total coliform (TC) and *Escherichia coli* (*E. coli*) were analyzed using Colilert-18 media. The disinfection of the filtered greywater was carried out using bleaching powder in Fahaheel area, whereas trichloroisocyanuric acid was used in Salmiya and Farwaniya areas. It was noticed that total coliform and *E. coli* were present in Salmiya and Farwaniya areas. The sample analysis results of total coliform in Salmiya and Farwaniya were recorded as 196 and 56 MPN/100 mL and *E. coli* as 57.6 and 14.5, respectively. The same sample of those two areas was disinfected using bleaching powder and analyzed for total coliform and *E. coli* which were found to be less than 1.0 MPN/mL.

The sand filtration techniques are effective in reducing the microbes (Yogafanny et al. 2014), but the complete removal was observed only by disinfection with bleaching powder. Bleaching powder (calcium hypochlorite) when dissolved in

Table 3 Treated greywater results of three areas and its average

S. no.	Parameter	Fahaheel area ($N=7$)				Salmiya area ($N=7$)				Farwaniya area ($N=7$)				Avg. of all three areas	KEPA limits of potable water	WHO Guidelines
		Min	Max	AVG	SD	Min	Max	AVG	SD	Min	Max	AVG	SD			Treated wastewater
1	Electrical conductivity (EC-μS/cm)	1298	3208	2640	755	1154	2025	1445	277	1480	3682	2890	854	2325	–	–
2	pH	7.36	8.46	7.75	0.41	7.85	8.86	8.48	0.41	6.89	8.9	7.58	0.68	7.94	6.5–8.5	6.5–8.4
3	Total dissolved solids (TDS-mg/L)	830	2061	1690	483	764	1369	981	193	984	2360	1853	535	1508	1000	1500
4	Total suspended solids (TSS-mg/L)	10	20	16	3.76	13	24	17	3.96	34	48	41	5.20	25	–	15
5	Turbidity (NTU)	2.2	16.3	10	5.12	18	28.6	23.8	3.97	30.5	40	37.5	3.25	23.6	5	–
6	Carbonate (CO_3^{2-}-mg/L)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	–	–
7	Bi-carbonate (HCO_3^--mg/L)	61.6	140	98	28	101	155	129	18	141.5	167.2	156	10.47	128	100	–
8	Sodium (Na^+-mg/L)	211	474	343	100	201	230	209	10	261	567	437	124	330	200	–
9	Potassium (K^+-mg/L)	3.8	15.6	9.2	3.59	3.2	8.2	5.8	1.73	3.2	5.4	4.5	1.03	6.50	10	–
10	Calcium (Ca^{2+}-mg/L)	83	149	112	24.93	72	122	98	18	201	245	231	17	147	200	–
11	Magnesium (Mg^{2+}-mg/L)	5	23.45	12.7	5.79	2.24	7.49	4.7	2.21	21.5	26	24.2	1.89	14	150	–
12	Sulfate (SO_4^{2-}-mg/L)	323.9	615.6	434	93	170	349.9	271	60	310	962	649	301	451	250	–
13	Chloride (Cl^--mg/L)	85.6	422	242	121	64.79	122.3	88	22	99	647	308	201	213	250	–
14	Fluoride (F^--mg/L)	0.579	2.292	1.73	0.64	0.035	0.269	0.159	0.08	0.419	2.5	1.58	1.05	1.16	1.53	25
15	Phosphate (PO_4^{3-}-mg/L)	1.27	3.19	2.11	0.70	0.37	3.8	1.79	1.11	0.81	4.56	2.81	1.32	1.65	–	30
16	Ammonium (NH_4^+-mg/L)	< 0.1	0.78	0.64	0.11	< 0.1	1.78	0.89	0.54	2.19	5.00	3.80	1.15	1.78	0.50	15
17	Nitrate (NO_3^--mg/L)	2.87	14.12	8.14	3.53	2.56	8.21	3.59	2.05	4.98	22	17	6.685	9.58	50	
18	Boron (B-mg/L)	1.09	1.26	1.2	0.07	1	1.26	1.1	0.08	1.99	2.5	2.3	0.176	1.53	2.4	2.0
19	Chemical oxygen demand (COD-mg/L)	64	102.9	83.5	12.73	49.2	105	77.95	21	71.98	106.7	85.8	12.2	82.4	–	100
20	Aluminum (Al-μg/L)	0.189	0.214	0.21	0.008	< 0.001	0.066	0.046	0.019	0.046	0.068	0.053	0.007	0.103	0.200	5.0
21	Barium (Ba-μg/L)	< 0.001	0.021	0.016	0.006	0.02	0.022	0.021	0.001	0.019	0.021	0.020	0.001	0.045	0.700	2.0
22	Cadmium (Cd-μg/L)	0.019	0.02	0.020	0.000	< 0.001	0.013	0.012	0.001	0.015	0.016	0.015	0.000	0.016	0.003	0.01
23	Cobalt (Co-μg/L)	0.14	0.2	0.18	0.021	0.018	0.02	0.018	0.001	0.021	0.04	0.033	0.007	0.023	–	0.2
24	Iron (Fe-mg/L)	0.205	0.212	0.21	0.002	0.014	0.015	0.014	0.001	0.051	0.125	0.095	0.028	0.106	0.300	5.000
25	Manganese (Mn-μg/L)	0.023	0.027	0.025	0.002	0.011	0.023	0.018	0.005	0.01	0.014	0.011	0.001	0.018	0.100	0.2
26	Total coliform (TC)-MPN/100 mL)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	–	400
27	Escherichia Coli (*E. Coli*-MPN/100 mL)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	–	–

Min Minimum, *Max* Maximum, *Avg* Average and *SD* Standard Deviation water reacts to form hypochlorous acid. Since the pH of the filtered greywater is alkaline, hypochlorous acid dissociates into hypochlorite ion and undergoes the oxidation reaction, which kills the microorganisms (EPA 2011) and simultaneously reduces the pH of the treated greywater.

The characteristics of treated greywater differed from each area since the detergents, soaps and dishwashing liquid used are not the same. The average results from three selected areas Fahaheel, Salmiya and Farwaniya of the treated greywater are within the WHO guidelines (WHO 2006).

For a few parameters, the treated greywater values are higher than the groundwater values, but still within the potable limits of Kuwait Environmental Protection Agency (KEPA 2017) except for phosphate and ammonium. Though the groundwater is used for various purposes, the basic utility of the water extracted from the aquifers is to serve the domestic needs but not for drinking purpose. Hence, this treated greywater is compared with groundwater.

Mechanism of the adsorption process in the sand filtration

The sand acts as a good filtration medium. The sand filtration is a combination of physical, chemical and biological process as it removes turbidity, organic matter and microorganisms (Verma et al. 2017; Lechevallier and Au 2004). Coarse particles help to remove suspended solids, whereas fine particles remove ions by adsorption and ion exchange mechanism (Chidambaram et al. 2003). Further, the removal process is more effective with the increase in surface area.

Pure carbon is hydrophobic in nature, but the oxygen associated with the carbon surface increases the hydrophilic nature of the activated carbon. The nature of adsorption of various compounds from water by activated carbon reveals the fact that granular activated carbon has different functional groups which have the capacity to adsorb negative ions, positive ions and trace metals (Ghoneim et al. 2014). The mechanism of adsorption of compounds present in the greywater is inferred to be removed by surface interactions between the compounds in water and activated carbon through van der Waal forces of attraction, among which induced dipole–dipole interactions is observed to be more effective (Nowicki and Nowicki 2016). Activated carbons are hydrophobic and contain small amounts of neutral C–O surface groups. The chemisorbed oxygen C–O in activated carbon is present as CO_2 and CO. CO_2 is acidic and makes the surface hydrophilic and polar, which enhances the adsorption of polar chemical or ionic species, whereas CO is neutral and makes the surface hydrophobic and nonpolar. Hydrophilic compounds interact with water by polar–polar interactions, which cause adsorption of the ionized micropollutants on the surface of the activated carbon due to electrostatic interactions and sorbent–sorbent interactions. Further, it is also inferred by researchers that the optimal dosage of activated carbon increases the efficiency of treatment (Nam et al. 2014).

There exists an electrostatic attractive or repulsive interaction between the metal cations present in the greywater and the carbon–oxygen surface groups on the active carbon surface. The positive electro-charge of activated carbon attracts negatively charged organic anions on the surface, which is observed by a decrease in the pH of treated greywater. At high pH, adsorption rate has increased which might be due to competition between H^+ ions and M^+ ions (Fernando et al. 2009). Adsorption of organic compounds is chiefly due to dispersive interactions, electron donor–acceptor interactions and electrostatic attractive or repulsive interactions between the charged carbon surface and the ions in the water (Bansal and Goyal 2005).

The micropores in the activated carbon also play a vital role in the adsorption to take place. The higher the degree of microporosity, the greater is the adsorption capacity on the surface. The relatively large adsorption capacities of activated carbons are attributed to their external surface areas, their large pore volumes and a high degree of surface reactivity (Gonzalez-Serrano et al. 2004). It is also noted that activated carbon has removed the color of the greywater which is identified by the colorless nature of the treated greywater. It is also to be noted that if the time of contact between the flow of water and the materials present in the column increases, the efficiency in removal also increases (Silva 2000).

Comparison of treated water quality and treatment techniques with the literature

The characteristics of greywater and its treatment of the present study are compared with the previous studies in Table 4. The treated greywater quality in terms of pH, COD, nutrients, metals and microbial was relatively equivalent to other reported methods. There are several methods available for the treatment of greywater, but only a few methods were based on sand filtration and chlorinate ion. The present method adopted was similar to Gual et al. (2008), but it was modified by using a small amount of activated carbon. Further, there is effective removal of color, dissolved solids, ions, metals, microbes and turbidity in the treated water. In addition, this method is also advantageous by considering that the volume of the material used for treatment is lesser compared to the volume of treated greywater.

The volume of the materials used for the total treatment of 21 L of greywater was 3.5×10^{-3} m^3, with a specific volume of each material mentioned in Table 2. Further, the regeneration of the materials in the column was also proved to be effective, which states that there was a further increase

Table 4 Comparison of physical, chemical and microbiological quality of treated greywater with other reported studies (The values are in mg/L except for pH)

Parameters	Finley et al. (2008)	Christova-Boal et al. (1996)	Friedler (2004)	Surendran and Wheatley (1998)	Saroj and Sane (2011)	Kuwait (present study)	WHO Guidelines
	Shower and washing machine	Bathroom and laundry	Shower and laundry	Shower and laundry	Bathroom, basin	Kitchen, shower and washing machine	Treated wastewater
pH	6.7–7.9	6.4–10.0	7.4–7.5	7.6–8.1	7.43	7.94	6.5–8.4
Total solids	330–633	–	1091–2021	631–658	204	1533	1515
Sodium	18–27	7.4–480	151–530	–	17.11	330	–
Potassium	0.6–4.4	–	–	–	1.98	6.5	–
Calcium	28–44	3.5–12	–	–	0	147	
Magnesium	8.0–10.1	1.1–2.9	–	–	0	14	–
Phosphorus as P	0.24–1.21	0.062–42	3.3–55.0	1.63–101	0	0.73	10.2
NH_4–Nitrogen	4.1–5.1	< 0.1–15	1.2–4.9	1.56–10.7	0.21	1.38	15
Nitrate–Nitrogen	–	–	–	–	0.21	2.16	–
COD	161–348	–	319–996	424–725	58	82.4	100
Aluminum	ND	< 1.0–21	–	–	–	0.103 (μg/L)	5
Cadmium	ND	< 0.001	–	< 0.001	–	0.016 (μg/L)	0.15
Cobalt	ND	–	–	–	–	0.023 (μg/L)	0.2
Iron	0.08–0.45	0.29–1.1	–	–	–	0.106	5.0
Manganese	ND	–	–	–	–	0.018 (μg/L)	0.2
Chromium	ND	–	–	0.11–0.32	–	–	0.15
Copper	ND	< 0.05–0.27	–	–	–	–	0.2
Molybdenum	ND	–	–	–	–	–	–
Sulfur	3.3–8.0	1.2–40	–	0.003–0.03	–	–	0.1
Zinc	0.01–0.42	0.09–6.3	–	0.059–0.31	–	–	2.0
Total Coliform (MPN/100 mL)	–	–	–	–	–	< 1.0	400
Fecal Coliform (MPN/mL)	2.2×10^4–1.4×10^6	110–3.3×10^3	4×10^6	600–728	–	–	–
Escherichia coli (MPN/mL)	–	–	–	–	–	< 1.0	–

in the volume of treated water for the given volume of material. The amount of material used for the treatment of 1 l of greywater was estimated as 0.166×10^{-3} m^3 of which the activated carbon forms 7% of the material involved, i.e., about 11.62×10^{-6} m^3 for 1 l. Considering the cost of activated carbon and the other materials used, 1 l of treated water costs about 0.0011 KWD. This signifies the cost-effectiveness of the present treatment method and also the fact that the treated water characteristics were below the guidelines.

The efficiency of removal in the present study was calculated by using the formula (Untreated greywater–Treated greywater ÷ Untreated greywater × 100) and is presented in Table 5. It was observed that the efficiency was equivalent to other reported methods with the low capital and maintenance cost. From the data in Table 5, it is inferred that other methods involve high capital and maintenance cost compared to the present study.

The effectiveness of the column

Treatment effectiveness of the column was verified by collecting the greywater sample from the washing machine due to its high conductivity. At first, 500 mL of greywater collected from washing machine alone was passed through the column and the first drop was noticed at 3.32 min. Subsequently, it was sampled for every 100 mL and EC was measured. The rate of flow during the first batch was 6.5 mL/min, and later the rate of flow reduced to 3.0 mL/min. The variation in the rate of flow in the gravity-governed system may be due to various reasons: (1) head pressure, (2) permeability of the medium (grain size), and (3) heterogeneity of the medium. During this process, as the initial head pressure decreases, the rate of flow through the medium also decreases, resulting in more contact time with the medium, thereby enhancing the removal efficiency.

Table 5 Greywater parameters removal efficiency comparison by different treatment techniques of the present study with other reported and suggested methods

S. no.	Author and year	Sources of greywater	Suggested treatment methods	Parameters removal efficiency	Applications	Remarks
1.	Memon et al. (2007)	Washbasin, bath and shower	Reed beds, membrane bioreactors, membrane chemical reactors, green roof water recycling system	–	Use of TGW in constraint areas	–
2.	Zhang et al. (2009)	Kitchen, bathroom and laundry	Membrane bioreactors (MBRs) followed by UV disinfection	–	Garden irrigation and toilet flushing. Untreated GW for subsurface irrigation	Aquacycle modeling software is adopted for water balance
3.	Mohamed et al. (2013)	Shower, laundry, bathtub and sink	Greywater (GW) diversion device, sponge filter, GW reuse system—sedimentation tank, infiltration and ozone generator	Reduced levels of TSS, BOD and COD by GWRE and ozone treatment	Gardening, irrigation	High values for pH, BOD, COD and TSS compared to the guidelines
4.	Ghaitidak and Yadav (2013)	Bathroom, laundry, washbasin and sink	Coagulation and flocculation sequencing batch reactor, rotational biological contactor, membrane bioreactor, Up-flow anaerobic sludge blanket reactor	–	Agriculture, gardening, flushing and washing	(Review paper) Constructed wetlands and filtration are more efficient compared to others for treatment in large quantity. But no single method is capable of meeting the entire reuse standards
5.	Leas et al. (2013)	Dishwashing, laundering and bathing	Settling tank, anaerobic gravel-based filter tank and followed by charcoal filter	–	Irrigation, injection of TGW into Aquifers	International guidelines for GW use (Review paper)
6.	Edwin et al. (2013)	Bath, washbasin, laundry and kitchen sink	Soil biotechnology, constructed wetlands, and constructed soil filters are suitable alternatives for treatment.	High removal of COD, BOD, N, SS, Turbidity	Reuse to household	Suggested that diversion techniques are not suitable (Review paper)
7.	Beler-Baykal (2015)	Washbasin, shower, bathtub, laundry and sink	Constructed wetlands, rotating biological contactors, sequencing batch reactors, and membrane bioreactors	–	Irrigation, service/flush water and the water cycle. Applicable groundwater recharge	Review paper
8.	Saroj and Sane (2011)	Bathroom and basin	Physical (sedimentation) and biological (activated sludge)	Hardness (60%), COD (91%), TDS (81%), TSS (90%)	Landscaping, gardening, irrigation, plant growths, and toilet flushing	Alternative conventional treatment plant
9.	Gross et al. (2007)	Bath, dish, and laundry water	Physical (recycled vertical flow constructed wetland)	TSS (98%), BOD (100%), COD (81%), TP (71%), TN (69%), fecal coliform (99%)	Landscape irrigation	–
10.	Present Study	Kitchen sink, shower and washing machine	Physical (filtration and adsorption) and chemical (disinfection)	pH (23%), Color (95%), TDS (52%), turbidity (88%), total coliform (100%) and *E. coli* (100%)	Irrigation, carwash, watering lawns and aquifers	Economical method

Initially, the surface sites are free to get adsorbed and inferred that the rate of removal was higher during the initiation of the experiment. From Fig. 3, it was observed that the column was effective for 1100 mL of greywater which is around 34% efficient in removal. The regeneration of the column was attempted by cleaning with distilled water and the effectiveness of the regenerated column had an efficiency of 26% for 600 mL (Fig. 4).

Comparison of treated greywater with the groundwater of aquifers

The comparison was made between the parameters observed in the groundwater for the respective aquifers of the study area and treated greywater. The available groundwater in Kuwait is more or less equivalent to brackish water. The average of the reported values of Dammam and Kuwait group aquifers was considered for comparison of the quality. From Table 6 and Fig. 5, it inferred that the EC, TDS, Mg^{2+}, NO_3^-, Cl^-, K^+, Na^+ were very low in treated greywater than that of the groundwater in Dammam and Kuwait group aquifers. The pH of treated greywater in the present study was slightly higher than the groundwater, but lower than the WHO limits and the reported literature methods. Similarly, the Ca^{2+}, SO_4^{2-}, NO_3^- were lesser in greywater, but the HCO_3^- was almost of the same value to that of Dammam and Kuwait aquifers. The ionic concentration in Dammam group aquifer is less than Kuwait group aquifer, whereas the treated greywater was observed to have lesser concentration than the Dammam aquifer. Therefore, the treated greywater obtained by the present method was inferred to be suitable for recharging the aquifers.

Conclusion

The study has led to the development of domestic greywater treatment system by adopting the gravity filtration technique. The current study was attempted for the greywater with an EC of 4910 µS/cm. The present study has inferred that a volume of 1100 mL of treated greywater is produced from 1167 cm^3 of filtration medium. The study also reveals that the efficiency of removal varies with flow rate and proves to be effective even after regeneration.

The treated greywater has total dissolved solids of 1508 mg/L, which is lower than both the aquifers. pH of the

Fig. 3 Verification of column effectiveness

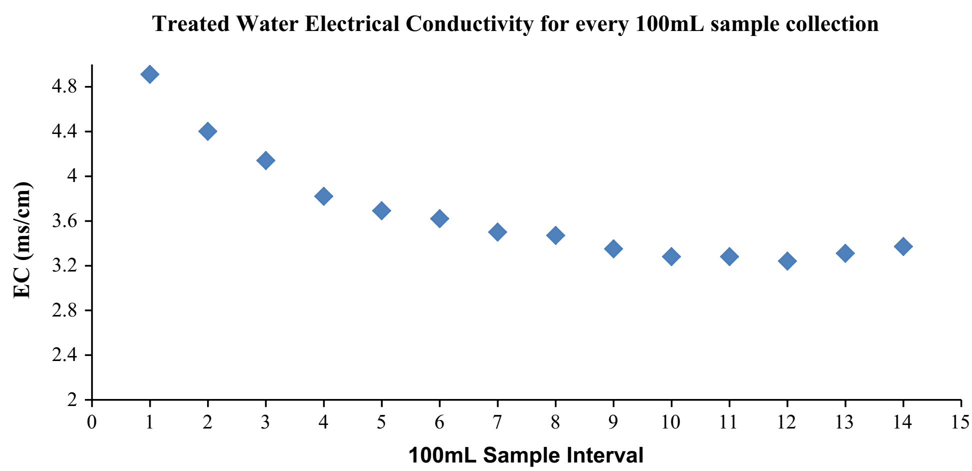

Fig. 4 Regenerated column effectiveness

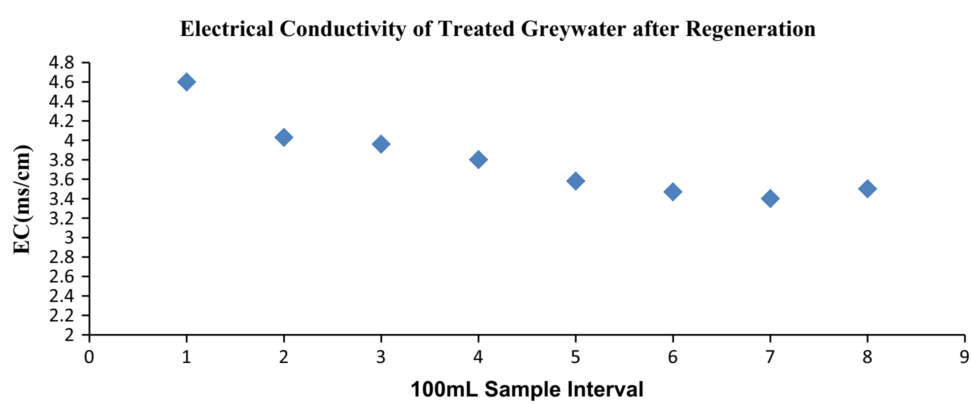

Table 6 Comparison of treated greywater quality with Kuwait group and Dammam aquifer literature (Sulami and Al Ruwaih 2004; Hadi and Al-Ruwaih 2005; Mukhopadhyay et al. 2012; Hadi et al. 2016)

S. no.	Parameter	Unit	Dammam aquifer avg.	Kuwait group aquifer avg.	Treated greywater avg.
1.	EC	μS/cm	4555	14,192	2325
2.	pH	–	7.45	7.22	7.94
3.	TDS	mg/L	3772	12,626	1508
4.	HCO_3^-	mg/L	134	126	128
5.	Na^+	mg/L	558	2460	330
6.	K^+	mg/L	21	147	6.5
7.	Ca^{2+}	mg/L	419	716	147
8.	Mg^{2+}	mg/L	144	267	14
9.	SO_4^{2-}	mg/L	1338	1655	451
10.	Cl^-	mg/L	934	4542	213
11.	F^-	mg/L	2.1[a]	–	1.16
12.	NO_3^-	mg/L	16	51	9.58
13.	B	mg/L	1.4[a]	–	1.53
14.	COD	mg/L	9.9[a]	15[a]	82.4
15.	Total coliform	MPN/100 mL	< 1.0	< 1.0	< 1.0
16.	Fecal coliform	MPN/100 mL	< 1.0	< 1.0	< 1.0
17.	*Escherichia coli*	MPN/100 mL	< 1.0	< 1.0	< 1.0

[a]Fluoride, boron and COD values from the literature are available only for few samples of Dammam and Kuwait group aquifers

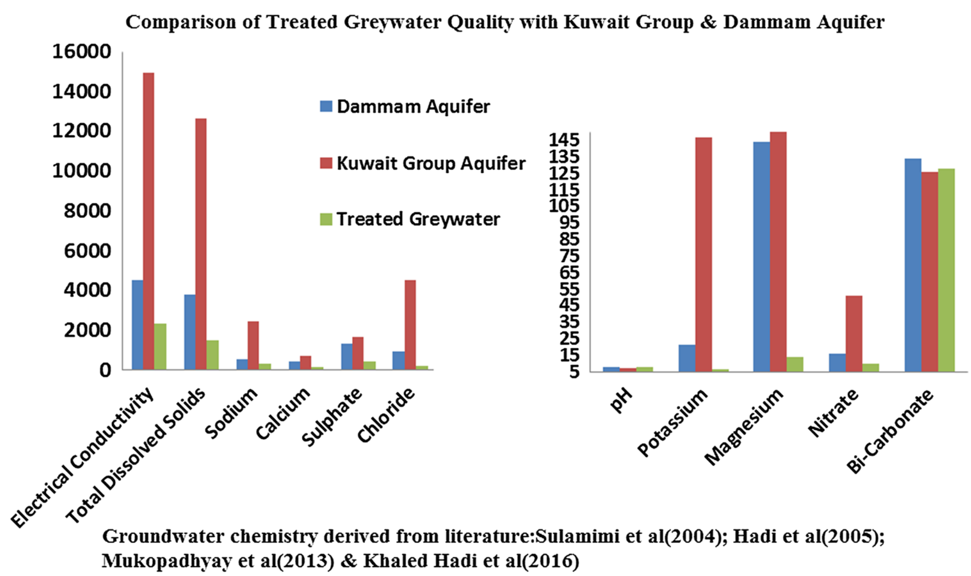

Fig. 5 Graphical representation of comparison of treated greywater quality with Kuwait Group and Dammam aquifers

treated greywater was reduced to 7.94; however, the pH was higher than the groundwater of the aquifers, but falls within the WHO safety limits. The greywater treatment was inferred to be effective by this study, and it reports that certain metals were higher than the drinking water limits. Though the metals are above the potable limits, they are still below the limits prescribed for irrigation and domestic purposes. The study proved its efficiency equally to other existing methods, and the efficiency of reduction after treatment for some of the analyzed parameters was observed to be 23%, 95%, 52%, 88%, 100% 100% for pH, color, TDS, turbidity, total coliform, and *E. coli*, respectively.

The greywater thus produced is recommended for artificial recharge of groundwater as the ionic concentrations are comparatively lesser than the groundwater of both the aquifers. Further recharge or infiltration of the treated greywater into the aquifers will also have reduction of ion by a specific property like adsorption for the removal of these elements

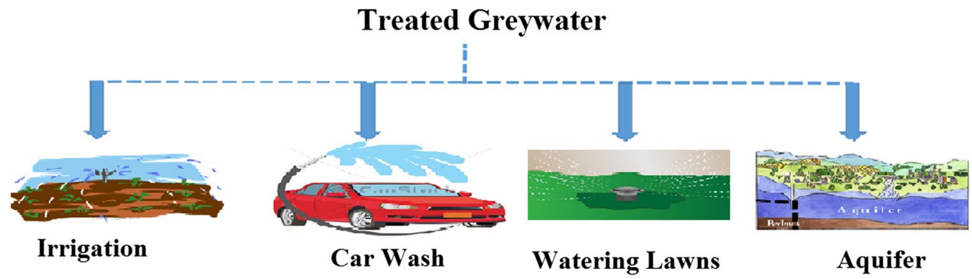

Fig. 6 Applications of treated greywater

through ion exchange, selective adsorption, biosorption, etc., from the greywater. Though the method was successful in the laboratory, more extensive study in this line is being carried out by varying the size of the particles, the size of the column, the volume of the materials, the rate of flow, and change in the design of the column, but still this technique is unique for the greywater treatment in Kuwait. Also studies on greywater with higher EC ranges and varying organic compounds could throw more light upon the effectiveness of the study.

This study motivates a new outlook toward the large-scale benefit, i.e., the rate of water scarcity could be reduced, and sustains the water for future generations, since the available freshwater in Kuwait is very limited and considered as a strategic reserve. The treatment unit is user-friendly and can be installed in every house, and the treated greywater is suitable for car washing, irrigation, watering lawns, and, recharge of aquifers (Fig. 6). Finally, the study illustrates that the gravity-governed filtration is eco-friendly, economically viable and as effective as other existing expensive methods.

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