Treatment and potential reuse of greywater from schools: a pilot study
Abdalrahman D. Alsulaili, Mohamed F. Hamoda, Rawa Al-Jarallah and Duaij Alrukaibi

ABSTRACT
This study presented performance data on a low cost and easy maintenance pilot system for on-site treatment and reuse of water collected from wash sinks and fountains, as major sources of greywater (GW) at schools. Various treatment options were studied including screening, sand filtration, chlorination, and UV disinfection operated at different flow rates. Results showed that filtration operated at low rates is very effective in total suspended solids (TSS) removal, while UV proved to be more effective than chlorination for reduction of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total coliforms. Removal efficiencies up to 63%, 30% and 20% were obtained for TSS, COD and BOD, respectively and reductions of log TC (CFU/100 ml) from 6.5 to 2 were obtained at a filtration rate of 14 m3/d·m2. Treated effluent satisfied WHO standards for reclaimed water reuse in landscape irrigation and toilet flushing. The filtration-UV system is robust, showing the best and most reliable performance for low and high strength GW treatment even under a 10-fold increase in flow rate. A 5 m3/d pilot plant was developed for schools having 500 students and detailed cost-benefit analysis indicated a net saving value, a surplus of $1,600 per year, and pay back after 6 years and 11 months.

Key words | greywater treatment, pressure filter, schools, treatment costs, UV, water reuse

INTRODUCTION
Increasing demand for fresh water and scarcity of fresh water resources in arid and semi-arid regions of the world have created an urgent need for alternative water resources and optimization of water use through reuse options. This has created a growing interest in the reuse of wastewater in many parts of the world. In particular, reuse of greywater (GW), which is defined as wastewater without any input from toilets and kitchens, can be a cost-effective, alternative source of water (Christova-Boal et al. 1996) and is becoming an increasingly important factor for potable water saving in many countries (Mourad et al. 2011). The reuse will lower the total costs for wastewater handling, since there will be reduced wastewater loads to treatment plants as well as cost savings in water and energy consumption. This is primarily related to its availability and low concentration of pollutants compared to the combined household wastewater. However, until recently, lack of data on this aspect has been a barrier to arriving at such a conclusion (Prathapar et al. 2005).

It is estimated that GW accounts for about 75% by volume of the combined residential wastewater (Eriksson et al. 2002; Hamoda 2005; Jamrah et al. 2011; Kulabako et al. 2011; Mandal et al. 2011). In the US household, GW accounts for half of water consumed for an estimated 114 L/person/d (Beck et al. 2013). Possibilities of reuse of GW have come into special focus since it can serve as a valuable resource offsetting potable supplies for many uses. This fraction of wastewater is less polluted than municipal wastewater in the absence of faeces, urine and toilet paper (Eriksson et al. 2002). Using GW for household toilet flushing alone can reduce urban water consumption by an estimated 10–20% (Friedler 2004) and up to 30% (Karpiscak et al. 1990). Reuse of GW from bathrooms has been successfully used in Germany, where it has been shown that it is technically feasible and health requirements can be met. Substantial volumes of water (15–55 L/capita/d) can be reused and a dual system is possible (Nolde 1999). In addition to helping
preserve scarce water resources, GW reuse can also reduce water supply costs and decrease the load on centralized wastewater treatment systems (Beck et al. 2013).

Characteristics reported by several studies indicate that GW has to be considered as dilute sewage because it has most constituents of raw wastewater (Hrudey & Raniga 1985; Christova-Boal et al. 1996; Eriksson et al. 2002; Lu & Leung 2003; Li et al. 2009; Boyjoo et al. 2013; Ghaitidak & Yadav 2013). GW characteristics have to be determined, before deciding on its reuse. Depending on such characteristics, the type and extent of treatment can be determined, since there are a number of problems related to the reuse of untreated GW. The risk of spreading of diseases due to exposure to microorganisms in the water is a crucial point if the water is to be reused outdoors for irrigation, or indoors for toilet flushing and household cleaning (Maimon et al. 2010; March et al. 2004). The risk of pollution of soil and receiving waters due to the content of different pollutants is another question that has been raised concerning infiltration and irrigation with GW (Eriksson et al. 2002). Microbial quality of household GW was assessed by O’Toole et al. (2012), who found GW to be a potential transmission pathway for enteric pathogens, which supported the premise that waterborne pathogens in GW may contribute to illness in households using GW for non-potable domestic uses. Meanwhile, Winward et al. (2008) showed that adequate treatment of grey water prior to reuse is important to reduce the risks of pathogen transmission and to improve the efficacy of subsequent disinfection.

A review of possible treatment processes for GW (Li et al. 2009) revealed that physical processes alone are not sufficient to guarantee an adequate reduction of the organics, nutrients and surfactants from GW. The chemical processes can efficiently remove the suspended solids, organic materials and surfactants in the low strength grey water. The combination of an aerobic biological process with physical filtration and disinfection is considered to be a feasible solution for grey water recycling (Li et al. 2009). The membrane bioreactor appears to be a very attractive solution in collective urban residential buildings. A study by Abu Ghunmi et al. (2010) aimed at treatment of GW for irrigation, focusing on a treatment technology that is robust, simple to operate and with minimum energy consumption resulted in the development of an optimized system consisting of an anaerobic unit operated in upflow mode with a subsequent aerobic step equipped with mechanical aeration. Lamie et al. (2007) investigated the application of sequencing batch reactor (SBR) technology for treating grey water collected at the outlet of shower rooms of students, and found that SBR performance was satisfactory as the treated GW effluent had 20 and 5 mg/L of chemical oxygen demand (COD) and biochemical oxygen demand (BOD), respectively. Halalsheh et al. (2008) examined treatment systems comprising a septic tank followed by an intermittent sand filter; a septic tank followed by wetlands; and a UASB-hybrid reactor. It was concluded that the UASB-hybrid reactor would be the most suitable treatment option in terms of compactness and simplicity in operation. Santos et al. (2012) developed an experimental filtration/UV treatment system that showed potential for GW recovery because of the simple, low-cost and easy maintenance features. However, concentrations of suspended solids (SS) and BOD after treatment were not low enough to reach the limits presented in legal and reference documents, hence further improvement procedures were suggested. Unlike previous studies employing physical and/or biological treatment methods, Pidou et al. (2008) studied chemical methods for treatment of household GW, and their results revealed that magnetic ion exchange resin and coagulation were suitable treatment solutions for low strength GW sources. However, they were unable to achieve the required level of treatment for the reuse of medium to high strength GW. Finally, a review of GW treatment methods was conducted by Ghaitidak & Yadav (2013), who included around 22 treatment systems comprising different treatment processes and discussed removal efficiency of pollutants, effluent concentrations and their compliance with wastewater reuse guidelines and standards. In a more recent study (Ghaitidak & Yadav 2016), these researchers made a comparison of reuse options using analytic hierarchy process. Meanwhile, unlike household GW, there is still a need to develop technologies to treat GW at schools by targeting the type of reuse.

Based on the review of published research work, the treatment system selected in the present study included both physical and chemical methods rather than biological methods, keeping in mind that, due to the unsteady nature of GW collected at schools, operation of the on-site treatment system has to be intermittent. This is tied to the short cycle of activities at schools (i.e. 8 hours-working day) and almost no weekend activities. Meanwhile, operation of a physical and chemical treatment system does not require highly skilled operators, which goes well with schools as compared to biological treatment systems.

The ultimate objective of the present study was to develop an on-site, low-cost, and easy to operate and maintain treatment system for GW collected at schools, built to provide short residence time for the collected GW and to disinfect it immediately before its reuse, in order to
minimize the possibility of the regrowth of microorganisms: Specifically, this study aimed to: (i) examine the performance of sand filtration and the effect of filtration rate on GW treated effluent quality; (ii) compare chlorination and UV options for GW water disinfection; (iii) assess the quality of treated GW for reuse; and (iv) determine the costs/benefits of GW treatment and reuse. Three treatment options were examined. The first option was related to physical filtration and the other two options were related to chemical disinfection using chlorine or UV irradiation.

MATERIALS AND METHODS

Sample collection

Based on information collected from surveys and site visits in Kuwait, seven schools (Table 1) were selected in this study representing both boys and girls schools (a separate schooling system is adopted in public schools) at the primary, intermediate, and secondary schooling levels. A GW collection system was installed on the drains of wash sinks in washrooms at each school. In each case, GW was allowed to travel down into the drain, on which a flow meter was installed. The GW samples were collected over a period of 4 months excluding a 2-week, mid-year break. The school day extends for 6–8 hours, during which the flow was recorded daily (except at weekends) and a composite sample was collected once a week. Details can be found in an earlier paper by Alsulaili & Hamoda (2015).

Sample analysis

Physical, chemical and bacteriological analyses of the GW included pH, total suspended solids (TSS), total dissolved solids (TDS), turbidity, electrical conductivity, dissolved oxygen, sodium, alkalinity, hardness, chlorides, COD, 5-day biochemical oxygen demand (BOD$_5$), ammonia – nitrogen (NH$_3$–N), total phosphorus, total coliforms (TC), and faecal coliforms. Samples were collected in acid-rinsed and sterilized glass bottles, respectively. Samples were stored in a cool box at 4°C and transported for analysis to the analytical laboratory at Kuwait University. All the analyses were conducted according to Standard Methods (APHA 2005).

Design of pilot plant

A pilot scale treatment system was designed according to the scheme displayed in Figure 1, which shows the scheme of the pilot scale treatment system. The system consists of the following: screening, sand filtration, UV lamp unit, and chlorination as shown in Figure 2. The GW was stored, under mixing, in a tank of 350-liter capacity made of galvanized iron (GI) material. The GW was pumped, from the tank to a METALife screen, then to a self-cleaning, pressure filter with an AISI 316 stainless steel cartridge. The filter is cylindrical with a Pentair outer structural Polyglass and PE inner shell. The filtered water can either be chlorinated or treated with UV light. The chlorination is done using Sigma-Aldrich sodium hypochlorite solution reagent grade, available chlorine 4.00–4.99% added to the filtered water in

Table 1 | Schools selected for the study

<table>
<thead>
<tr>
<th>No.</th>
<th>School name</th>
<th>School level</th>
<th>Student gender</th>
<th>No. of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al-Khalil Bin Ahmed</td>
<td>intermediate</td>
<td>boys</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>Ashbilia</td>
<td>primary</td>
<td>girls</td>
<td>424</td>
</tr>
<tr>
<td>3</td>
<td>Al-Ma’amoon</td>
<td>primary</td>
<td>boys</td>
<td>317</td>
</tr>
<tr>
<td>4</td>
<td>Naela</td>
<td>intermediate</td>
<td>girls</td>
<td>377</td>
</tr>
<tr>
<td>5</td>
<td>Hamad essa Al-regayeb</td>
<td>secondary</td>
<td>boys</td>
<td>397</td>
</tr>
<tr>
<td>6</td>
<td>Al-Jazair</td>
<td>secondary</td>
<td>girls</td>
<td>416</td>
</tr>
<tr>
<td>7</td>
<td>Gurnata</td>
<td>intermediate</td>
<td>girls</td>
<td>258</td>
</tr>
</tbody>
</table>

Figure 1 | Scheme of the pilot plant for treatment of GW.
a PVC tank of 175-liter capacity. A motor driven mixer was attached to the tank to allow mixing of the chlorine with water. Another option was to pass the filtered water through UV light using a Sterilight S12Q-PA unit with a 39 watt UV lamp model S36RL. After treatment with chlorination or UV irradiation, the water is pumped to a storage tank of 500-liter volume capacity prior to reuse. The pilot plant contained a control panel as well as several taps to collect samples after each process. The system allows bypass of every treatment process except the screening, which is the first step to insure that the GW is free of impurities that can affect performance of the next process. The plant capacity is 50 m$^3$/d, but it was operated at different flow rates to examine filter performance in the slow and rapid filtration modes.

**Experimental program**

The pilot plant was operated at flow rates of 5.5, 8, 15, 20, 30 and 40 Lpm (liters per minute) using samples of GW alone or GW spiked with bentonite clay (average particle size 0.001 mm, i.e. in the colloidal range) added at concentrations of 0.25 g/L or 0.5 g/L to simulate any increase in TSS of GW and to examine the effect of high solids concentration on plant performance. Each experimental run lasted for 6 hours.

**RESULTS AND DISCUSSION**

**Treatment efficiency**

The efficiency of the treatment system was evaluated based on solids and organics (TSS, BOD and COD) removal as well as microbial (TC) reduction.

**Removal of solids and organics**

Performance of the treatment system was evaluated at different flow rates, ranging from 5.5 to 30 Lpm, using light GW collected from schools as well as higher strength simulated GW to which either 0.25 or 0.5 g/L of bentonite was added. Figure 3 displays successive removal of TSS, BOD, and COD along the treatment system using GW + 0.25 g/L bentonite as an example. It is evident that filtration removed the majority of SS and, to a lesser extent, BOD and COD associated with the TSS (i.e. organics present in the suspended form). Conversely, the majority of organics (BOD and COD) were removed by UV or chlorination. Similar trends were observed for low strength GW and high strength GW + 0.5 g/L bentonite. Meanwhile, the removal efficiency generally decreased (i.e. the fraction remaining increased) as the flow rate was increased. This was observed after UV or chlorine treatments. However, differences do not look significant within the flow rates studied.

For the filter, the rate of filtration (expressed in m$^3$/d.m$^2$) was calculated by dividing the flow rate in L/min, (lpm) applied to the system by the surface area of the filter (m$^2$).

Figure 3(b) and 3(c) illustrate the effect of flowrate on the BOD and COD, respectively with 0.25 g/L added bentonite to raw GW. They show that each of UV and chlorination contribute to the reduction of organics (BOD, COD) with clear effect of the flowrate on the chlorination process. As the flowrate increases, removal of organics decreases, since the contact time is shorter at higher flow rates, thus slowing down the oxidation of organic matter. Also, Figure 3(c) indicates that disinfection using UV or chlorine have a similar effect on the COD reduction. Either one showed an average COD reduction of 30 to...
50%, by decreasing COD level from about 0.8 (80%) in the sand filter effluent to as low as 0.4 (40%) in the chemically treated effluent. Similar results were obtained with bentonite 0.5 g/L added to the GW.

With two different bentonite concentrations added, 0.25 g/L and 0.5 g/L, the initial TSS was increased from an average of 23 mg/L for the GW alone to 380 mg/L and 750 mg/L at 0.25 and 0.5 g/L bentonite, respectively. In general, removal efficiencies of TSS, BOD, and COD were higher at lower flow rates, as displayed in Figure 4. Removal efficiency was also higher at higher GW strength, shown by initial TSS concentration. Removal efficiencies of up to 63%, 30% and 20% were obtained for TSS, COD and BOD, respectively at a filtration rate of 14 m³/d·m², as shown in Figure 4. These results are comparable to those reported in the literature (Ghaitidak & Yadav 2013; Melgarejo et al. 2016). Meanwhile, the removal efficiency was lower at higher filtration rates as efficiencies were down to 40%, 7%, and 5% for SS, COD, and BOD, respectively at a very high filtration rate of 105 m³/d·m². In practice, slow sand filters are operated at filtration rates in the range of 3 to 8 m³/d·m², while rapid sand filters are often operated at filtration rates in the range of 120 to 235 m³/d·m² (Metcalf & Eddy Inc. 2002). Meanwhile, either UV or chlorine further reduced the organic content (BOD, COD) of the GW possibly through chemical oxidation.

**Microbial reduction**

TC were selected as the indicator for microbial content of GW based on results reported by Winward et al. (2008). Figure 5 displays the reduction of microbial content expressed as log CFU/100 ml. It can be seen that, although the sand filter is used primarily to remove solids, it also reduced TC by 1 to 2 logs, probably those TC present in the suspended form. It is also possible that bentonite particles could have
removed bacteria by adsorption as well. To rule out its effect on disinfection. Meanwhile, UV irradiation or chlorine addition at 10 mg/L, as alternative means of filtered water disinfection, can effectively reduce the TC in the filtered water by 3 logs, thus the combined sand filter-UV system reduces the TC in the raw GW by about 4.5 logs, leading to an acceptable level of TC for reuse in irrigation. Although UV and chlorination showed comparable results, UV proved to be slightly better in terms of TC reduction and was less affected by increased flow rates. This agrees with results obtained by other researchers (Ghaitidak & Yadav 2013).

Overall performance of treatment system

The treatment system using either UV or chlorination for filtered GW disinfection proved to be effective in reducing TSS, BOD, COD, and TC concentrations in the GW to acceptable levels. The sand filter removed primarily the solids, whereas UV or chlorination removed mainly the organics and microbial content from the GW. Chemical oxidation reduces the organic and microbial concentrations, while some pollutants such as TC, BOD and COD may have also been removed by adsorption on the suspended particles retained in the sand filter. This is supported by earlier results reported by Hamoda et al. (2004) in their evaluation of tertiary treatment of wastewater by sand filtration in municipal wastewater treatment plants. Meanwhile, as for the effect of flow rate on overall system performance, Figures 3 and 4 show a slight effect of flow rate on the efficiency of screening, UV, and chlorination units, but considerable effect on filtration. In general, as the flow rate increases the efficiency of all the studied processes decreases. This reduction in the efficiency may be due to the shorter time available for pollutant removal at higher flow rates. The main reduction in the total solids concentration is due to sand filtration, whereas the majority of COD, BOD and TC is removed by chemical treatment, with UV being relatively more effective than chlorine.

The concentration of TSS in the GW affected the performance of the treatment system, since removal of TSS by filtration was influenced by solids loadings to the filter. However, the results indicate that a 25-fold increase in GW strength and/or 10-fold increase in the operating filtration rate can still produce a treated effluent with suitable quality for reuse. In a school, it is more advantageous to operate the filter in the slow rate filtration.

Table 2 | Summary of results on plant performance at successive treatment stages

<table>
<thead>
<tr>
<th>Parameter unit</th>
<th>Grey water</th>
<th>Screening</th>
<th>Filter</th>
<th>UV</th>
<th>KEPA Standards (2001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>SD</td>
<td>Average</td>
<td>SD</td>
<td>Average</td>
<td>SD</td>
</tr>
<tr>
<td>Total solids (mg/l)</td>
<td>211.0</td>
<td>47.4</td>
<td>164.7</td>
<td>54.9</td>
<td>148.3</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>23.3</td>
<td>9.9</td>
<td>18.5</td>
<td>8.8</td>
<td>9.8</td>
</tr>
<tr>
<td>TDS (mg/l)</td>
<td>187.7</td>
<td>45.2</td>
<td>140.8</td>
<td>47.8</td>
<td>134.8</td>
</tr>
<tr>
<td>Chloride (mg/l)</td>
<td>49.0</td>
<td>2.0</td>
<td>49.0</td>
<td>1.9</td>
<td>48.4</td>
</tr>
<tr>
<td>Sulphate (mg/l)</td>
<td>24.2</td>
<td>8.3</td>
<td>25.3</td>
<td>7.9</td>
<td>22.3</td>
</tr>
<tr>
<td>Nitrate (mg/l)</td>
<td>18.2</td>
<td>42.1</td>
<td>1.3</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Nitrite (mg/l)</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>66.7</td>
<td>21.8</td>
<td>65.1</td>
<td>18.0</td>
<td>53.4</td>
</tr>
<tr>
<td>BOD (mg/l)</td>
<td>29.8</td>
<td>7.1</td>
<td>28.8</td>
<td>6.1</td>
<td>20.9</td>
</tr>
<tr>
<td>Sodium (mg/l)</td>
<td>29.5</td>
<td>3.2</td>
<td>29.8</td>
<td>5.1</td>
<td>30.5</td>
</tr>
<tr>
<td>TC (MPN/100 ml)</td>
<td>11.0</td>
<td>9.9</td>
<td>16.0</td>
<td>11.3</td>
<td>11.0</td>
</tr>
<tr>
<td>TC (CFU/ml)</td>
<td>3.31E7</td>
<td>3.14E7</td>
<td>2.57E6</td>
<td>1.32E6</td>
<td>1.05E6</td>
</tr>
</tbody>
</table>

SD, standard deviation (±).
mode (in the range of 3 to 8 m³/d m²) compared to the rapid rate filtration mode, so filter cleaning will be much less frequent, i.e. the filtration runs will be much longer and filter cleaning will be less frequent, knowing that both the flow rate of GW generated at schools and its strength are often low. Either UV or chlorination could be used to disinfect water and would also contribute greatly to organics removal. However, comparatively, UV appears to be more effective in TC and organics reduction, is less affected by the contact time (i.e. flow rate), does not need mixing equipment, and could be run by unskilled operators at schools. Although chlorination leaves the treated water with a chorine residual for more protection, this may not be necessarily required in the case of on-site water reuse in greening or toilet flushing at schools, depending on treated water storage requirements.

Treated effluent quality

The effluent produced from the treatment plant tested in this study using UV as final treatment stage, operated at different flow rates (5.5 to 40 Lpm–8 to 55 m³/d) and initial TSS concentrations (25 to 700 mg/L), is summarized in Table 2. The treated effluents produced satisfy the requirements for water reuse in landscape irrigation in Kuwait (KEPA 2001) and those set by WHO (2006). The treated effluent is to be collected in storage tanks for pumping to a piping system feeding the toilet flushing tanks and /or to an irrigation system for landscape greenery in the school site. The demand for the treated effluent would be high at schools. In arid and semi-arid regions, watering of green areas is more frequent and would allow storage of treated GW in the tank for only a short period that should not change its good quality. Moreover, toilet flushing uses considerable quantities of water, constituting up to 25% of total water consumed at schools (Alsulaili & Hamoda 2015), which results in a high demand period during the school work hours.

Potential for reuse

To assess the potential reuse of recycled GW in irrigation and toilet flushing, the starting point is to compare the freshwater consumption per school over an academic year with the proposal of this study for reuse of GW that is generated per student. Schools in Kuwait start by mid September until mid June with a 1 month break and a 2 day holiday/week, i.e. there are 160 total school days per academic year. The following analysis included seven different schools, to assess the quantity of GW that can be collected.

Table 3 presents GW generated per person per day. It was assumed that the total number of students represents 80% of the total school population, and school employees (e.g. teachers, support staff, janitors and guards) represent 20% of the total school population. It was also considered that the average GW flow is 7.3 L/C/d for all schools in this study (Alsulaili & Hamoda 2015).

Figure 6 shows the water consumption by the schools studied during the years 2010–2015 (MEW 2016). Water consumption rates for all selected schools were almost similar except during the last year, when there was a big difference, perhaps due to new greening projects in some schools. Considering the yearly average water consumption per day for each school, the results ranged between 23 to 32 m³/day. This leads to the assumption that the average water consumption for the school is 27 m³ per day.

Economic analysis of reuse of treated GW in irrigation at schools

Freshwater (potable water) in Kuwait is highly subsidized by the government, selling for 1,000 imperial gallons of freshwater at a cost of $2.64 (MEW 2016). The real value of production of 1,000 IG of freshwater costs the government...
about $33.33, which contains the cost of fossil fuels, mechanical and labor costs (MEW 2016).

Evaluation of the economic feasibility leads to the development of cost-benefit analysis for treated GW to be used in irrigation and toilet flushing at schools. The amount of treated GW per day (Q) is 3.5 m$^3$ to supply irrigation and toilet flushing based on Table 3. The purpose is to find a model that provides the net saving value (NSV) of using treated GW at schools. The NSV model has two components, benefits and costs. The definition of NSV is the difference between the value of the benefits (B) and the cost (C) of production of treated GW

$$\text{NSV} = \sum_i B - \sum_i C$$  \hspace{1cm} (1)

The cost component (C) of producing treated GW contains the following three parameters: (1) the capital cost for constructing a small GW treatment unit, (2) the operation and maintenance (O&M) cost, and (3) the energy cost. The capital cost is classified as the cost of the treatment unit, pipe network, collection system, and pumps. While the benefits (B) component refers to the value gained by recycling treated GW which consists of: (1) the cost saving on potable water flow to be used instead of GW and (2) wastewater reductions due to using the recycled GW. Details of the relevant cost parameters and benefit parameters are discussed below.

**Analysis of cost and benefits parameters**

The mechanism of calculating the cost components depends on the function of the actual cost and some equations from previous studies of recycled GW. Capital cost ($C_\text{c1}$) includes the initial cost of treatment unit and pumps ($C_\text{c1}$), installation and purchasing the collection and network for irrigation ($C_\text{c2}$), and indoor distribution system for toilet flushing ($C_\text{c3}$), which is expressed as units of $/life time. The cost of the treatment unit ($C_\text{c1}$) is $6,966.67 for a treatment system of a capacity up to 5 m$^3$/day. This price is based on the total cost of units and pumps ($a$) in the Kuwaiti market. The total cost of the network pipes, and collection for the toilet flushing and irrigation system is given by Equations (4) and (5), where $920 is the cost for installation of the first toilet, while each additional toilet costs $80, where ‘n’ represents the additional # of toilets considered in treatment (Yu et al. 2013). In this study, it was observed that each school has 20 toilets. The estimated total initial cost for installation and purchasing the storage and collection network for irrigation (β) as cost is $4,857 (Memon et al. 2005).

$$\sum_i C = \sum_i C_\text{c1} + C_{\text{M&O}} + C_e$$  \hspace{1cm} (2)

$$C_\text{c1} = a$$  \hspace{1cm} (3)

$$C_\text{c2} = \beta$$  \hspace{1cm} (4)

$$C_\text{c3} = 920 + \sum_i n (80)$$  \hspace{1cm} (5)

The operation and maintenance cost ($C_{\text{M&O}}$) is an annual cost to keep the system performing at good efficiency. Operating tasks ($γ$), such as disinfectants, costs $0.1 per day (based on Kuwaiti market cost). Maintenance costs ($ω$) are $20.38 per day, which represents the cleaning, repair, and change of filtering material. The following
equation was used to calculate the operation and maintenance cost \( C_{\text{M&O}} \), where \( Q \) is the daily flow rate of GW and \( t \) is the total days per academic year:

\[
C_{\text{M&O}} = [\gamma \cdot Q \cdot t] + [\omega \cdot t] \quad (6)
\]

The energy cost for producing treated GW is given by Equation (7), in which the cost of electricity \( (P_e) \) is considered as subsidized by the government at $0.67 per kwh. The treatment unit \( (T_e) \) was estimated based on treatment of 1 m³ of GW consuming 7.2 kwh \((\text{EMRC 2011})\).

\[
C_e = [Q \cdot t \cdot P_e \cdot T_e] \quad (7)
\]

The benefits from on-site utilization of treated GW can be monetary, by reducing water demand and wastewater collection and treatment. The benefits from reduction of water flow \( (Q) \) of freshwater is accounted as monetary by the following equation, where \( W_{\text{cost}} \) is the actual cost of production of freshwater.

\[
\sum_{i=1}^{t} B = B_w + B_{ww} \quad (8)
\]

\[
B_w = [W_{\text{cost}} \cdot Q \cdot t] \quad (9)
\]

The second parameter is wastewater flow reductions \( (B_{ww}) \) due to channeling GW as a component of the municipal wastewater to be utilized without being discharged into public sewers, which is calculated by Equation (10). The cost for wastewater treatment \( (W_{\text{cost}}) \) is $2.67 per m³ of wastewater.

\[
B_{ww} = [W_{\text{cost}} \cdot Q \cdot t] \quad (10)
\]

Overall, the purpose from finding the total cost \( (C) \) and benefits \( (B) \) is to provide the annual NSV and the payback period, which can be obtained by the following equation:

\[
\text{Pay back period(years)} = \frac{\sum_{i=1}^{t} C_i}{(C_{\text{M&O}} + C_e) - \left( \sum_{i=1}^{t} B \right)} \quad (11)
\]

Cost-benefit analysis

On-site treatment of the GW at schools provides economic, environmental and social benefits by integrating the role of school in national water conservation plans. The cost-benefit analysis curves for successive years are displayed in Figure 7. Using the NSV equation indicates that the benefits will exceed the cost, with $769 after 6 years and 11 months. The units used in expressing the flow are IG for potable water and m³ for wastewater, which are the customary units used in Kuwait by the Ministry of Electricity and Water (for potable water) and by the Ministry of Public Works (for wastewater), and Equation (11) was used to verify the payback period, which is 6 years and 11 months.

It is to be noted that the cost-benefit analysis considered in this study is based on a subsidized cost of water and energy since this is the case in the State of Kuwait (Ministry of Electricity and Water, MEW); this may be also the case in many other developing countries.

CONCLUSIONS

The results show that sand filtration of GW, collected from wash basins at schools as well as synthetic GW operated at low rates, is very effective in suspended solids removal. For reduction of COD, BOD, and TC concentrations, UV proved to be more effective than chlorination (at 10 mg/l chlorine dosages), and is recommended for removal of organics and disinfection of the GW. A schematic design and capital cost of a 5 m³/d pilot plant comprising screening, sand filtration and UV disinfection was provided and tested at different flow rates. Sand filtration and UV disinfection proved to be the most economical and feasible solution for GW treatment at schools. Removal efficiencies up to 63%, 30% and 20% were obtained for TSS, COD and BOD, respectively, at a filtration rate of 14 m³/d m². The system is robust, showing the best and most reliable
performance under low and high strength GW even under a 10-fold increase in flow rate. Produced effluent would satisfy water quality criteria set for reclaimed water reuse in unrestricted irrigation and for toilet flushing. A 5 m³/d plant was developed for a school having 500 students on average, and detailed cost analysis was performed. The feasibility analysis indicated that the system is sustainable and promising for GW treatment that can be run and maintained by moderately skilled operators at schools. Cost-benefit analysis indicate a NSV of $1,600 per year and payback after 6 years and 11 months, with social benefits by integrating the role of school in national water conservation plans.

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