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Ablution greywater treatment with the modified re-circulated vertical flow bioreactor for landscape irrigation

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ABSTRACT

Mounting pressure to conserve water supplies has stimulated greywater recycling to be reused for non-potable uses such as landscape irrigation. A potential greywater source in Jordan as well as other countries is ablution water generated in mosques from prayers' washing rituals. In this study, ablution greywater treatment with the low cost and easy to operate modified re-circulated vertical flow bioreactor was evaluated in terms of its treatment efficiency in order to supply some of the landscape irrigation needs in Al-Balqa' Applied University. The treatment system adequately removed BOD_5, chemical oxygen demand, total suspended solids, chloride, and Na by up to 94, 88, 90, 48, and 33%, respectively. Dissolved oxygen was significantly increased by up to 133%. Concentrations of Mg, Ca, and K were also increased by up to 29, 63, and 95%, respectively. Nitrate concentration of the treated ablution greywater (TA) increased but remained less than the maximum allowable limit. Treatment efficiency fluctuated with time and quality of untreated ablution greywater concerning electrical conductivity, total dissolved solids, and SO_4. Concentrations of these water quality indicators were much less than the maximum allowable limits of the Jordanian guidelines. In addition, according to the WHO guidelines, TA is considered suitable for irrigation of ornamentals, fruit trees, and fodder crops. Removal efficiencies of the treatment system were higher than those of other systems previously operated in Jordan. The modified re-circulated vertical flow bioreactor demonstrates great potential for treating low-quality ablution greywater. The wide application of this treatment system in mosques will achieve economic and ecological benefits.

Keywords: Ablution water; Constructed wetlands; Decentralized treatment systems; Environmental pollution; Greywater reuse

1. Introduction

Jordan severely suffers from water shortage. The tremendous deficit between the supply and the demand, if not properly managed, will damage people's health and the economy. This deficit is mainly attributed to the increasing population, unexpected influx of refugees from neighboring countries, rapid urbanization, and absence of new water resources [1]. Consequently, Jordan is obliged to

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improve wastewater treatment and reuse. Treated wastewater used in restricted irrigation is forecast to increase to 205 million cubic meters by the year 2020 [2]. Indeed, treated wastewater reuse in Jordan reaches one of the highest levels in the world [1]. Mounting pressure to conserve water supplies, however, has lead to the proposal that the separation of wastewater at its source may enable greywater to be reused for non-potable uses as landscape irrigation. Greywater is untreated domestic wastewater that has not come into contact with toilet waste (i.e. black water). Separating greywater from a residential or commercial wastewater stream allows a large volume of water to be efficiently recycled and reduces the volume of wastewater that has to be collected and treated. In fact, the average amount of domestic greywater ranges from 50 to 80% of the total domestic wastewater generated in the households [3,4], thus making greywater a potential sustainable water resource. However, this potential non-conventional water resource has marginally contributed to the augmentation and conservation of the water resources in Jordan during the past few decades [1]. On the long run, greywater is expected to play an important role in securing a sustainable water supply in Jordan; therefore, different technologies (i.e. treatment units) for greywater recycling should be tested and continuously developed. Moreover, greywater recycling for irrigation brings about various socioeconomic and ecological benefits. These benefits are, particularly, reflected in reduced potable water demand. Radcliffe [5] documented that reduction of 30–70% in the urban potable water demand can be achieved by the reuse of greywater in households. In rural areas, benefits are, however, reflected in an increase in the household income mainly due to a reduced frequency of desludging of cesspits and the application of less fertilizer for food/feed production [1,6–8]. For beneficial use of greywater in irrigation, greywater has to be efficiently treated because it might contain many chemicals, used in households, of which some may lead to gradual soil degradation. In addition, greywater may contain pathogens given the likelihood of cross-contamination with excreta [1]. Another important aspect of greywater recycling systems is that these systems should be inexpensive and maintained by unskilled operators [9]. These technical and economical aspects are still very challenging in the locally implemented systems.

A low-polluted greywater source is ablution water generated in mosques from prayers' washing rituals. Ablution water can be considered a potential source in Jordan as well as other Muslim countries for having thousands of mosques. Providing practical and sustainable solutions or modified solutions for recycling ablution greywater in a country; considered one of the poorest countries in water resources in the world, where thousands of mosques (more than 5,500 mosques) hosting hundreds/thousands of prayers five times a day, deserves more attention. Therefore, the recycling of ablution water generated in mosques represents another significant area for greywater application. In this study, ablution greywater treatment with the modified re-circulated vertical flow bioreactor was evaluated in terms of its treatment efficiency in order to supply some of the landscape irrigation needs in Al-Balqa' Applied University.

2. Materials and methods

2.1. Working principle and components of the modified re-circulated vertical flow bioreactor

The greywater treatment method is a modification of the recycled vertical flow constructed wetland described by Gross et al. [9]. The re-circulated vertical flow bioreactor is based on a combination of vertical flow bioreactor with "treated" water re-circulation and rapid-trickling filter media. The re-circulated vertical flow bioreactor was constructed as shown in Fig. 1. Two galvanized metal tanks of 650 l each (1 mW × 1 ml × 0.65 mH) were placed over each other; the upper "filter media tank" was placed over the lower "reservoir tank" in which a submerged pump was installed. Holes were punctured at even intervals at the bottom side of the filter media tank allowing water to freely drain into the lower reservoir tank.

A submerged re-circulating pump (0.5 HP) was installed in the lower reservoir tank in order to continuously re-circulate the "treated" greywater through the filter media tank, dilute "untreated" greywater, and reduce the risk of organic overload or other damage to the filter [9]. An overflow pipe was set from the upper filter media tank to the reservoir tank to prevent overflow in case of the bioreactor clogging.

2.2. Filter media of the modified re-circulated vertical flow bioreactor

The filter media tank consisted of:

(1) 5 cm bottom layer of lime pebbles (up to 1.5 cm in diameter).
(2) 5 cm middle layer of zeolite (0–6 mm in diameter).
(3) 25 cm middle layer of lime pebbles (~3–4 cm in diameter).
(4) 20 cm top layer of zeolite (3–6 mm in diameter).

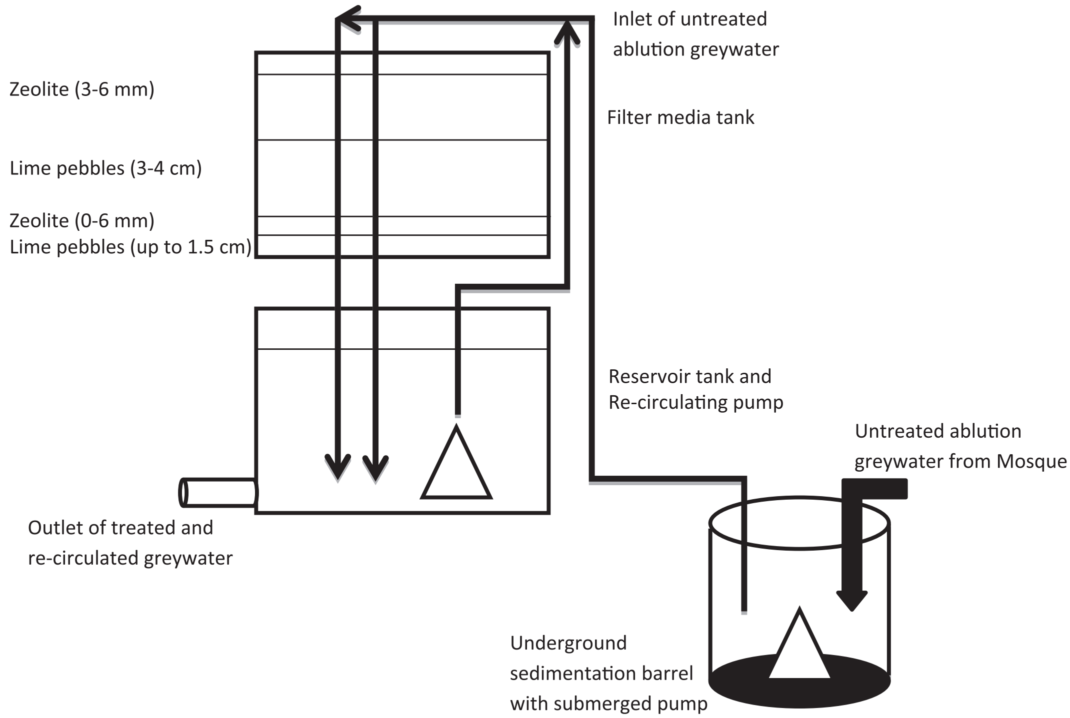

Fig. 1. Major parts of the modified re-circulated vertical flow bioreactor greywater treatment unit.

2.3. Design criteria of the re-circulated vertical flow bioreactor

The following model of Kadlec and Knight [10] was used to modify the area of the re-circulated vertical flow bioreactor, taking into consideration that BOD_5 of the treated greywater is the main design parameter:

$$A = \frac{Q}{k} x \mathrm{Ln} \frac{(\mathrm{BOD}_5 i - \mathrm{BOD}_5 b)}{(\mathrm{BOD}_5 e - \mathrm{BOD}_5 b)} \quad (1)$$

where A denotes the required bioreactor area (m^2), Q denotes the water flow rate (m^3 d^{-1}), BOD_5e denotes the BOD_5 concentration (mg l^{-1}) in the treated greywater, BOD_5i denotes the BOD_5 concentration (mg l^{-1}) in the untreated greywater, BOD_5b denotes the background concentration (mg l^{-1}), and k denotes the first-order areal rate constant (m d^{-1}). The k value for BOD is estimated for low-quality greywater as 0.16 m d^{-1}. The BOD concentration of the treated greywater was chosen as 300 mg l^{-1}; the maximum allowable concentration according to the Jordanian guidelines for reclaimed greywater in rural areas. Based on that, for a water flow of 0.2 m^3 d^{-1} and a re-circulation rate of about 1 m^3 h^{-1}, the area was calculated to be approximately 1 m^2. The depth of the re-circulated vertical flow bioreactor was 0.65 m, which is within the range typically recommended (0.5–0.8 m) for vertical flow constructed wetlands [9,11,12].

2.4. Location and operating procedure of the re-circulated vertical flow bioreactor and water quality monitoring

This study was implemented in Al-Balqa' Applied University in Al-Salt. Before operating the modified re-circulated vertical flow bioreactor, ablution greywater generated in the mosque from prayers' washing rituals was separated from the "black water", water of the toilet. The study was conducted after three months of a continuous working period after being thoroughly washed with tap water. This procedure ensured the development of biofilm in the wetland and stabilization of the system performance in terms of removal efficiency and flow [9]. Thereafter, the modified re-circulated vertical flow bioreactor was evaluated in spring and early summer months during which the quantity of ablution greywater is significant. Greywater samples were collected according to standard methods in 14 February, 6 and 21 March, 16 April, and 9 May.

2.5. Chemical analyses

The chemical analyses as water quality indicators were carried out according to standard procedures

Table 1
Chemical characteristics of UTA generated in study site and chemical and biological characteristics of reclaimed greywater in rural areas (Jordanian guidelines)

Parameter	Value[a]	Maximum allowable concentration
pH	6.5–7.2	6–9
EC ($\mu S\,cm^{-1}$)	320–2,520	–
K ($mg\,l^{-1}$)	2.2–4.4	–
Na ($mg\,l^{-1}$)	20–27	–
Ca ($mg\,l^{-1}$)	32–63	230
Mg ($mg\,l^{-1}$)	8.7–52.6	100
Cl ($mg\,l^{-1}$)	102–200	350
SO_4 ($mg\,l^{-1}$)	8.8–120	500
NO_3 ($mg\,l^{-1}$)	6.6–65.2	50
TDS ($mg\,l^{-1}$)	303–960	1,500
TSS ($mg\,l^{-1}$)	420–588	200
DO ($mg\,l^{-1}$)	3.3–5.9	≥2
BOD_5 ($mg\,l^{-1}$)	410–600	300
COD ($mg\,l^{-1}$)	435–950	500
COD:BOD_5	1.06–1.58	–
E. coli (CFU/100 ml)	–	Not determined for restricted irrigation
Fecal coliform (CFU/100 ml)	–	Not determined
TCC (CFU/100 ml)	–	Not determined

[a]Values are minimum and maximum values.

[13]. Chemical characteristics of untreated ablution greywater (UTA) generated in the study site are shown in Table 1. Analyses included: Dissolved oxygen (DO), Five-day biological oxygen demand (BOD_5), Chemical oxygen demand (COD) by the potassium dichromate oxidation method, pH, electrical conductivity (EC), Nitrate (NO_3), Sulfate (SO_4), Potassium (K), Sodium (Na), Magnesium (Mg), Calcium (Ca), Chloride (Cl), total dissolved solids (TDS), and total suspended solids (TSS).

3. Results and discussion

3.1. Ablution greywater recycling in Jordan

Constructed wetlands are treatment systems that replicate natural wetlands to improve water quality through physical, chemical, and biological treatment mechanisms [10], and are commonly employed to treat municipal wastewater [14,15]. While treatment wetlands have been shown to effectively treat whole wastewater, their effectiveness in treating ablution greywater has had limited research, especially in Jordan. This is mainly due to the low availability of water as a resource, intermittent nature of supply, greywater quality, and user education and acceptance [1]. Past studies involving greywater wetland treatment have shown promising pollution removal efficiencies [9,16,17].

In general, greywater recycling in the rural areas of Jordan has shown positive impacts on the socioeconomic status of householders; recycling their greywater for use in restricted irrigation increases household's income and agricultural produce. The recycling of the low-polluted ablution greywater water generated in mosques was previously reported in Jordan [1]. Exemplary to this is the King Abduallah Mosque in Amman, which has been reusing its ablution water for irrigation and toilet flushing since over 10 years with positive ecological and economical impacts. The significant cost savings made as a result of the reduced freshwater consumption has been a high incentive for the initiation of similar projects such as the Abu Obeida Mosque in the Jordan Valley and Hamlan Mosque in Amman [1]. However, no technical data were reported. The modified re-circulated vertical flow bioreactor was never tested or optimized with ablution greywater, not only in Jordan but also internationally, which gives the current research significant importance.

3.2. The modified re-circulated vertical flow bioreactor

Untreated greywater pumped from the sedimentation tank was introduced onto fine zeolite layer (Fig. 1). Zeolites are characterized by a porous structure with cages and large interconnected spaces and channels. The porosities of zeolites range between 18 and 47%. In addition, the large negatively charged available surface area allows adsorption of contaminants [18]. Indeed, the porous nature of many zeolites allows for the diffusion of charge-satisfying cations and water molecules into and out of the structure. The ability of zeolites to retain cations is indicated by the cation exchange capacity (CEC), which ranges from 229 to 568 $cmol_c\,kg^{-1}$ [18]. The other material of the filter media is lime pebbles. Lime pebbles were used for additional physical filtration and to buffer the effluent's natural acidity, as well as that produced by nitrification and biodegradation [9]. These unsaturated porous materials were used to increase the available surface area and allow significant microbial growth [17]. Untreated greywater moved vertically through the filter media and trickled down into the reservoir tank form which treated greywater was continuously pumped/re-circulated back to the filter media tank. Treated greywater re-circulation increases the concentration of DO of both the untreated greywater when mixed together in the filter media tank as well as of treated greywater being re-circulated. In addition,

Table 2
Greywater quality characterization

Parameter	Eriksson et al. [20]	Rose et al. [21]	Casanova et al. [22]	Faruqui and Al-Jayyousi [23]; Al-Jayyousi [7][a]	Bino et al. [8][a]	Suleiman et al. [24][a]	Gross et al. [9,17]
pH	7.6–8.6	6.5	7.5	6.7–8.4	5.29	5.7–7.0	6.3–7.0
EC (dS m^{-1})	–	–	–	0.475–1.135	–	1.83	1.2
BOD_5 (mg l^{-1})	25–130	–	64.9	275–2,287	942	1,056	466
COD (mg l^{-1})	–	–	–	–	1,712	2,568	839
TSS (mg l^{-1})	4–207	–	35.1	150–1,500	275	845	158
NO_3 (mg l^{-1})	<0.02–0.26	0.98	–	–	–	–	13.3
SO_4 (mg l^{-1})	–	22.9	59.6	–	–	–	–
Cl (mg l^{-1})	–	9	20.5	–	–	–	–

[a]Kitchen greywater has been included.

continuous re-circulation of greywater through the filter media reduces the area required to attain certain water quality properties (e.g. BOD_5 target value). Higher DO as shown in Fig. 2(a) might enhance nitrification process of nitrogen content of greywater, keep insects particularly flies and mosquitos away, and promote the removal of enteric micro-organisms sensitive to high concentrations of DO. Under the conditions of the current study, higher concentration of DO and higher temperature are expected to increase rates of chemical as well as biological reactions, i.e. removal efficiencies.

Beneath the filter media tank, there is the re-circulation system (reservoir tank). According to Gross et al. [17], this functions as a flow equalizer. Because treated greywater is continuously re-circulated, malfunction due to changes in composition and/or quantity of untreated greywater is mitigated. Moreover, re-circulating treated greywater from the reservoir tank back to the filter media tank dilutes untreated greywater, particularly BOD, COD, and TSS, which reduces organic overload or clogging of the filter media.

3.3. *Efficiency of the modified re-circulated vertical flow bioreactor*

Table 1 shows the chemical characteristics of the UTA generated in the study site as well as the chemical and biological characteristics of reclaimed greywater in rural areas according to the Jordanian guidelines.

The results of the current study reflected the efficiency of the modified re-circulated vertical flow bioreactor after being previously tested and optimized. Comparing the characteristics of the generated ablution greywater of the study site with the Jordanian guidelines for reclaimed greywater in rural areas shown in Table 1 and the WHO guidelines for greywater reuse for different purposes [19], it can be concluded that the quality of the ablution greywater in terms of particularly the concentrations of NO_3, TSS, BOD_5, and COD was not proper for reuse.

In addition, comparing the chemical properties of the ablution greywater generated in the study site with greywater quality characterization in Table 2, it can be concluded that ablution water treated in the current study was not a low-polluted greywater source.

Figs. 2–7 show the concentrations of the chemical contaminants of the (UTA, the influent), their concentrations in the treated ablution greywater (TA, the effluent), and the removal efficiency of the modified re-circulated vertical flow bioreactor. The modified re-circulated vertical flow bioreactor adequately removed BOD_5, COD, TSS, Cl, and Na by up to 94, 88, 90, 48, and 33%, respectively (Figs. 2(b), (c), 3, 4(a), and (b)). The removal efficiency for these water quality indicators varied slightly with time except for Na at the 21 March (Figs. 2(b), (c), 3, 4(a), and (b)). The observed reduction in the concentration of Na is assumed to be as a result of adsorption by the zeolite and, therefore, it is necessary to estimate the time after which the zeolite layer should be replaced. Natural zeolite of 150 Meq/100 g CEC would theoretically be able to take up 0.034 g Na (from solution; i.e. ablution greywater) per gram of zeolite. The total amount of natural zeolite used in the filter media of the current study was approximately 190 kg. This quantity would take up 6,460 g of Na from ablution greywater. The 200 L ablution greywater supposed to be treated per day would have 5.4 g Na. Consequently, the period required to replace the zeolite is after 39.9 months with a total amount of ablution greywater of 239.3 m^3.

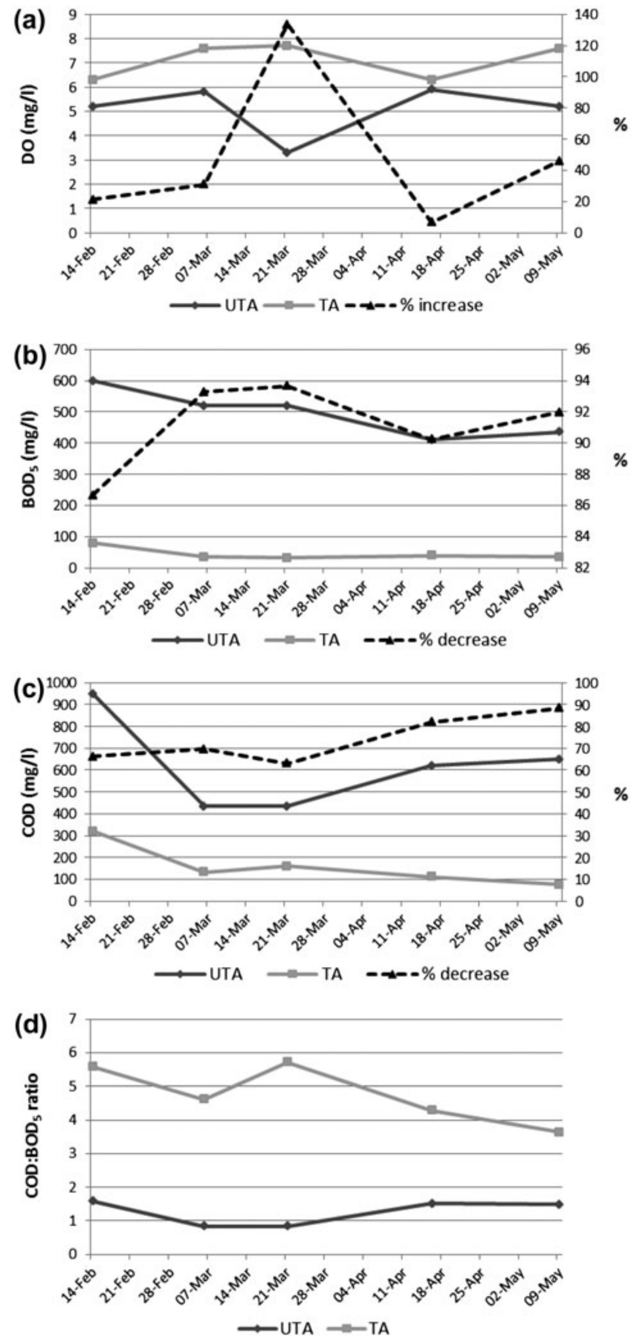

Fig. 2. The concentration of DO, BOD_5, COD, and COD: BOD_5 of the UTA, their concentration in the TA, and the removal efficiency of the re-circulated vertical flow bioreactor.

In addition, natural zeolite of 400 Meq/100 g CEC would theoretically be able to take up 0.092 g Na from ablution greywater per gram of zeolite. The approximately 190 kg of zeolite would take up 17,480 g of Na from ablution greywater. The 200 L ablution greywater supposed to be treated per day would have

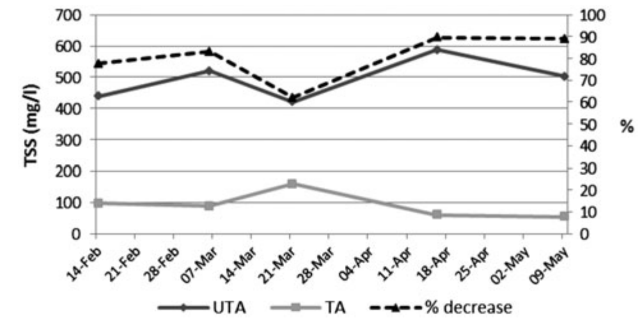

Fig. 3. The TSS of the UTA, their concentration in the TA, and the removal efficiency of the re-circulated vertical flow bioreactor.

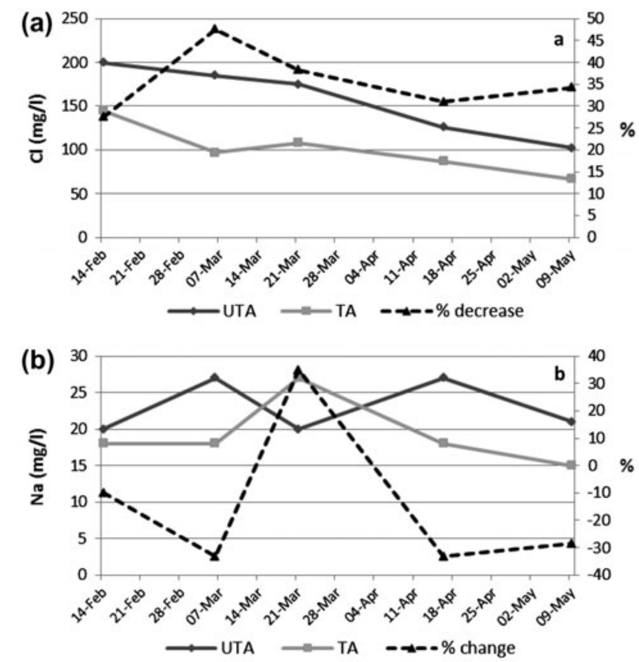

Fig. 4. The concentration of Cl and Na of the UTA, their concentration in the TA, and the removal efficiency of the re-circulated vertical flow bioreactor.

5.4 g Na. Consequently, the period required to replace the zeolite is after 107.9 months with a total amount of ablution greywater of 647.4 m^3. These estimated time periods would be even longer providing that the re-circulation of TA will continuously dilute the concentration of Na and other electrolytes of the "untreated" influent. Even though, the replacement of zeolite, when necessary, is very easy and can be done in a relatively short period of time by unskilled operators. Natural zeolite used in the current study is locally mined from Tal-Hassan in Al-Azraq region (in the Northern-Eastern part of Jordan) and sold for 20JD/700 kg (approximately US$28.6/700 kg; the 190 kg would cost only US$7.76). Thus, it is very feasible to use natural zeolite as a part of the filter media.

The DO was significantly increased by up to 133% and the efficiency of the treatment unit was steady with time except for the 21 March (Fig. 2(a)). Concentrations of Mg, Ca, and K in the TA were also increased by up to 29, 63, and 95%, respectively (Fig. 5(a)–(c)). The change percentage in Mg and Ca varied with time and quality of UTA (Fig. 5(a) and (b)). NO_3 concentration of the TA increased but remained less than the maximum allowable limit set by the Jordanian guidelines. NO_3 treatment efficiency fluctuated considerably with time and quality of UTA (Fig. 6). Concerning EC, TDS, and SO_4, treatment efficiency also fluctuated considerably with time and quality of UTA (Fig. 7(a)–(c)). The possible explanation for the observed lack of correlation

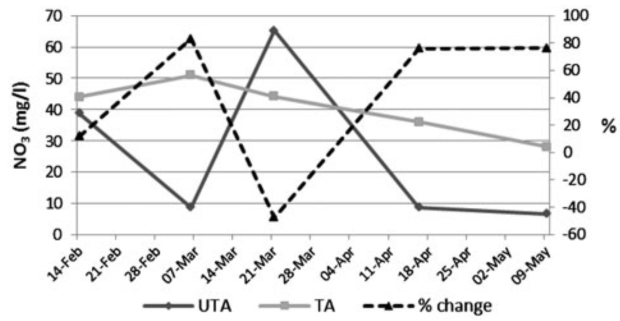

Fig. 6. The concentration of NO_3 of the UTA, its concentration in the TA, and the removal efficiency of the re-circulated vertical flow bioreactor.

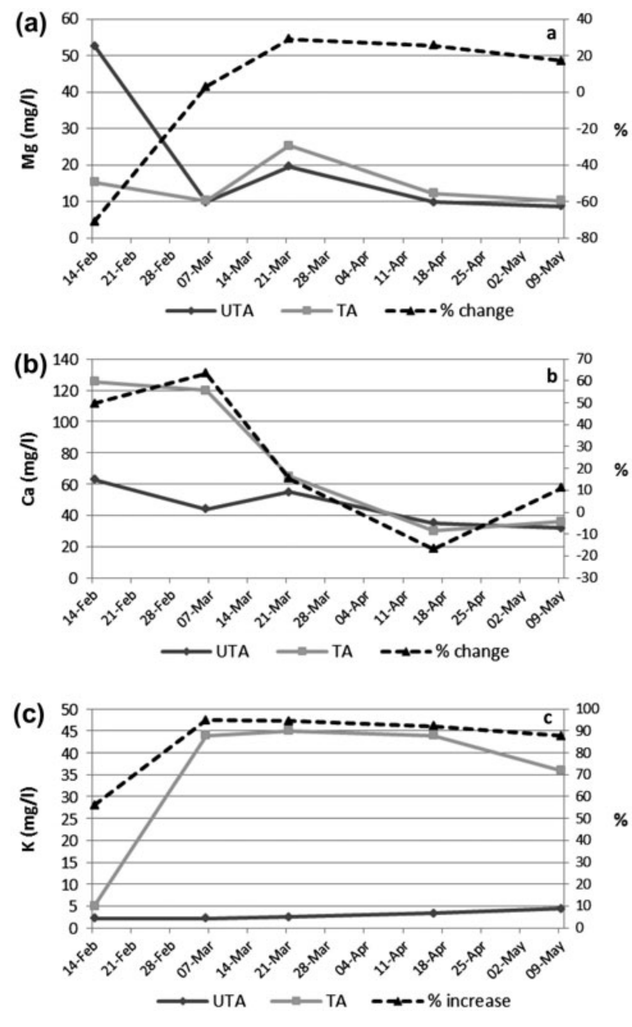

Fig. 5. The concentration of Mg, Ca, and K of the UTA, their concentration in the TA, and the removal efficiency of the re-circulated vertical flow bioreactor.

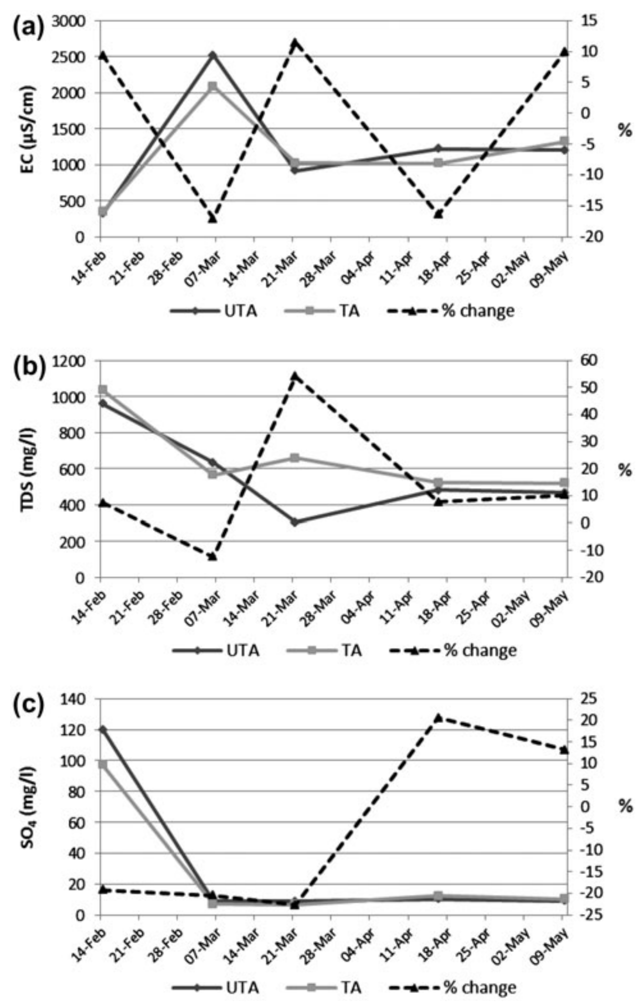

Fig. 7. The EC, TDS, and SO_4 of the UTA, their values in the TA, and the removal efficiency of the re-circulated vertical flow bioreactor.

Table 3
An overview of the greywater/ablution greywater management systems in Jordan[a]

Technology	Greywater sources	Efficiency (% reduction)	Capacity	Reuse	Unit cost
Upflow anaerobic filter system: a sedimentation barrel and two anaerobic filter stages (sand/gravel and Zeolite/faugasite)	Kitchen, bath	Relatively high microbial and organic load in greywater influent and effluent	n/a	Restricted irrigation	USD 550 (equi. to 385 JD[b])
Four-Barrel system: sedimentation barrel and grease filter, two upflow anaerobic gravel filters, a storage barrel	Kitchen, bath, washing machine	n/a	150–300 $l\,d^{-1}$	Restricted irrigation	USD 370 (equi. to 260 JD)
Confined trench system: sedimentation barrel and grease trap, unplanted horizontal flow gravel filter, storage barrel	Kitchen, bath	BOD_5: 47–75%	n/a	Restricted irrigation	USD 500 (equi. to 350 JD)
Upflow Anaerobic Sludge Blanket Reactor (UASB): sedimentation barrel, a UASB reactor, collection barrel	Kitchen, bath	BOD_5: 67% COD: 65% TSS: 73%	$300\,l\,d^{-1}$	Restricted irrigation	USD 500–600 (equi. to 350–420 JD)
Septic tank followed by an intermittent sand filter	Kitchen, bath	BOD_5: 88% COD: 84% TSS: 91%	150–200 $l\,d^{-1}$	Restricted irrigation	USD 570 (equi. to 400 JD)
Horizontal flow reed bed (constructed wetland)	Showers, hand basins and kitchen sink (minimal); high greywater generation rate $500\,l\,c^{-1}\,d^{-1}$	BOD_5: 82% COD: 82% TSS: 22%	$6\,m^3\,d^{-1}$	Irrigation (agricultural test plots)	n/a
Amman-King Abdullah Mosque/Simple filtration and disinfection (chlorine); underground storage tank ($1\,m^3$); 6 roof storage tanks ($10\,m^3$)	Ablution water	n/a	n/a	Irrigation, toilet flushing	USD 4,280 (equi. to 3,000 JD)
Jordan Valley Abu Obeida Mosque/Horizontal flow constructed wetland; 0.6 m Zeolix filter bed	Ablution water BOD_5 3–6 $mg\,l^{-1}$	n/a	$4\,m^3\,d^{-1}$	Irrigation	n/a
Modified re-circulated vertical flow bioreactor *(current study)*	Ablution greywater	DO: up to 133% increase BOD_5: up to 94% reduction COD: up to 88% reduction TSS: up to 90% reduction	up to $650\,l\,d^{-1}$	Preferably restricted irrigation	~USD 643 (equi. to ~450 JD

[a]GTZ [1], [b]Jordanian dinar.

between EC and TDS is that sampling (using multi-sampling bottles) was carried out while the entire re-circulated bioreactor was operating under conditions of interrupted flow as well as variable quality of "raw" ablution greywater coming from the site of ablution (where wash-basins are available for prayers' washing rituals) even within a very short period of time. At time of sampling, number of prayers practicing washing rituals (i.e. some opening while others closing faucets), the time spent for these rituals, and personal hygiene were highly variable and uncontrolled making correlation not easily possible. Concerning EC and TDS of the TA collected from the reservoir tank, sampling was also carried out while the re-circulation (i.e. mixing TA with untreated one) was still on. Nonstop re-circulation of ablution greywater by the submerged pump resulted in continuous and rapid dilution with time.

The efficiency of greywater treatment units is usually evaluated by their removal efficiencies of chemical contaminants, which are of environmental and health concern, and whether the characteristics of the treated greywater meet local and/or international standards. The modified re-circulated vertical flow bioreactor under the conditions of the current study proved to be efficient in treating polluted ablution greywater. Re-circulated vertical flow bioreactor increased the concentration of DO to values much higher than $2\,\mathrm{mg\,l^{-1}}$. Regardless of being increased (Mg, Ca, K, and NO_3) or reduced (BOD_5, COD, TSS, Cl, and Na) or fluctuated (TDS and SO_4), the concentrations of all chemical contaminants in the TA were far below the levels considered allowable according to the Jordanian Standards of reclaimed greywater. The considerable decrease in BOD_5 is because large fraction of the organic load in the UTA was easily biodegradable, as indicated by the low ratio between COD and BOD_5 ranging from 0.84 to 1.58. However, this ratio increased in the TA to values ranging from 2.1 to 4.9. This is because the COD includes also the undegradable bit, so after treatment COD decreased less than the BOD_5. Although being fluctuating, the EC of the TA was less than 2 dS m^{-1}. Values of EC less than 2 dS m^{-1} are not considered harmful particularly in the study area where average annual rainfall is about 500 mm. The pH values of TA were within acceptable ranges for irrigation. Although NO_3 concentration of TA increased, it was less than the maximum allowable limit (Table 1). This can be attributed to the fact that DO was high in re-circulated TA, which favors nitrification process.

According to the WHO guidelines for greywater reuse for different purposes ([19]; $BOD_5 \leq 240\,\mathrm{mg\,l^{-1}}$ and $TSS \leq 140\,\mathrm{mg\,l^{-1}}$), the TA under the conditions of the current study is suitable for irrigation of ornamentals, fruit trees, and fodder crops. In addition, under the conditions of the current study, the removal efficiencies of BOD_5, COD, and TSS of the modified re-circulated vertical flow bioreactor were much higher than those of other treatment systems operated in different locations in Jordan (Table 3). Differences are mainly due to different environmental conditions under which the treatment systems were operated, differences in working principle, and the untreated greywater quality.

3.4. *Cost of the modified re-circulated vertical flow bioreactor*

Table 3 presents "economic/financial" information in US dollars and local currency (Jordanian Dinar) that prove for local as well as international business of "water treatment technologies" that the cost of the modified re-circulated vertical flow bioreactor is reasonable and competitive. The total cost of the system described here including all materials and labor was approximately US$643. However, the labor cost might vary significantly. In the current study, labor cost was about US$179. For comparison purposes, the cost of the current system is close to that shown in Table 3 of locally installed treatment systems. However, the performance of the system described here is much more efficient than that of other local treatment systems (Table 3). The application of the re-circulated vertical flow bioreactor in rural areas is likely encouraged with subsidization.

4. Conclusions

In Jordan as well as other developing countries, the potential of ablution greywater recycling for "restricted" irrigation is still under investigation. Greywater quality and user education and acceptance are among the major obstacles. The implemented treatment systems should be efficient, of low cost and easy to operate and maintain. This was achieved in the current study by treating ablution greywater generated in the mosque of Al-Balqa' Applied University from prayers' washing rituals using the modified re-circulated vertical flow bioreactor. As determined from water quality analyses, the treatment system demonstrates great potential for treating low-quality ablution greywater for landscape irrigation. Removal efficiencies of the treatment system were higher than those of other systems previously operated in Jordan. The wide application of this treatment system in mosques will achieve some economic and ecological benefits.

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