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Effect of treated grey water reuse in irrigation on soil and plants

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ABSTRACT

The use of treated grey water (GW) for irrigation in home gardens is becoming increasingly common in Jordan. In this study treated GW produced from 4-barrel and confined trench (CT) treatment units were used for irrigation of olive trees and some vegetable crops. The quality of treated and untreated GW was studied to evaluate the performance of treatment units and the suitability of treated GW for irrigation according to Jordanian standard. Effect of treated GW reuse on the properties of soil and irrigated plants at Al-Amer villages, Jordan, has been investigated. The results showed that salinity, sodium adsorption ratio (SAR), and organic content of soil increased as a function of time, therefore leaching of soil with fresh water was highly recommended. The chemical properties of the irrigated olive trees and vegetable crops were not affected, while the biological quality of some vegetable crops was adversely affected.

1. Introduction

Wastewater and grey water (GW) reuse is emerging as an integral part of water demand management, promoting the preservation of high quality fresh water and reducing both environmental pollution and overall supply costs. Recent developments in technology and changes in attitudes towards wastewater reuse suggest that there is a potential for GW reuse in the developing world [1]. Grey water is defined as wastewater generated from domestic activities such as dish washing, laundry and bathing, whereas black water consists of toilet water. GW represents the largest potential source of water savings in domestic residences, accounting for as much as 50–80% of the total water use [2–5].

The most common application for GW reuse in urban areas is toilet flushing which can reduce water demand within dwellings by up to 30% [6,7]. However, other applications such as irrigation of green areas in parks, school yards, cemeteries, golf areas, car wash, and fire protection are practiced [8]. The use of GW for irrigation is one of the methods which is currently widely used. This is particularly important in arid zones, where water is scarce and reuse of GW for irrigation could reduce potable water use by up to 50% [9]. In some arid and semi-arid areas municipal water consumption typically increases by 40–60% in summer months due to landscape irrigation [3]. Although irrigation with treated GW and treated wastewater effluents can mitigate the utilization of natural water resources, it may also result in environmental problems. One particular concern is long-term sustainability issue (e.g. the increase of salinity and sodium content in soil). Sodium content is the ratio of sodium concentration (detrimental element) to the concentrations of calcium and magnesium (beneficial elements) which is also known as sodium adsorption ratio (SAR). High values of soil salinity and SAR cause soil structure deteriorations, decrease of soil permeability and reduction of crop yields due to toxic and osmotic effects [10–16]. Many researches had conducted to study the impact of reused GW quality on soil. A study conducted by Travis et al. [17], suggests that oil and grease from GW can accumulate in soils and affect the ability of the soils to absorb water essentially making it water repellent. Another study conducted by Gross et al. [18] found evidence that, long-term irrigation of arid loess soil with GW may result in accumulation of salts and surfactants in the soil, causing changes in soil properties and toxicity to plants. In his research [19], Patterson showed that loss of soil permeability commenced as low as SAR 3 when the electrical conductivity was about the same from domestic wastewater. Internationally, SAR 6 is accepted as a level above which soil permeability and structural stability may be affected [19]. According to reference [20], SAR 8 was suggested as the higher limit for irrigation of non-tolerant plants. According to the data presented in reference [21], long-term irrigation using water with SAR higher than 4 can negatively alter the soil properties. Madyiwa et al. [22], investigated the effect of using treated effluent for irrigation of pasture for over 30 years. The results showed that Pb and Cd were taken up by plants from the soil, thereby making plants as potential sources of contamination for humans and animals.

Recently in some rural areas of Jordan, GW is being used for irrigation in home gardens to provide additional water source. In the

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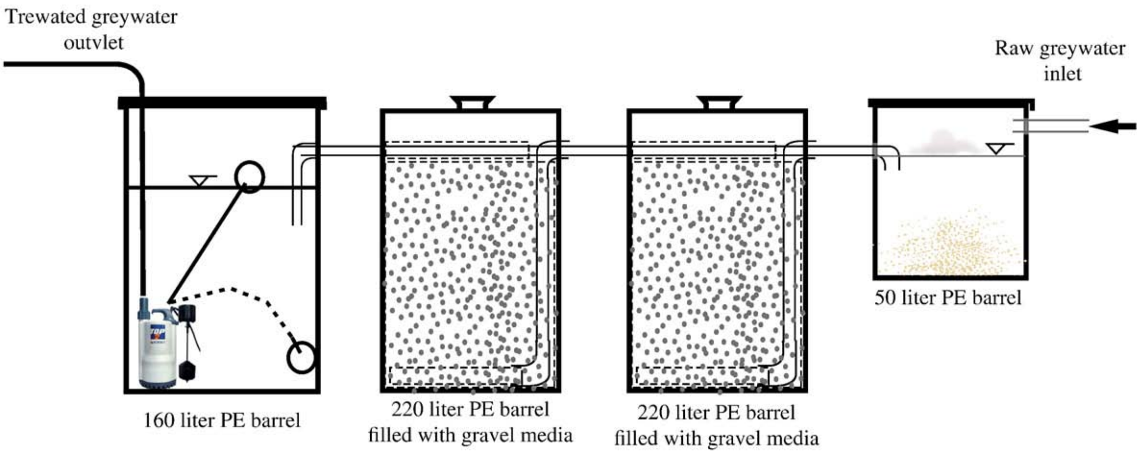

Fig. 1. 4-barrel treatment unit. 1—first barrel; 2—second barrel; 3—third barrel; 4—fourth barrel.

year 2003, the Ministry of Planning and International Cooperation of Jordan provided more than 750 low-income households in more than 90 villages in rural areas of Jordan with GW treatment units for home garden irrigation [23]. Although GW was used for irrigation purposes, the effect of their use on the properties of irrigated soil and plants was not fully investigated. This study involves evaluation of the environmental impact of GW reuse project in Al-Amer villages, Jordan. The project included 110 GW treatment units and aimed to help the local population preserve fresh water and protect the environment. The objectives of this study are to:

- estimate the average production rates of GW in the study area.
- evaluate the suitability of treated GW produced from 4-barrel and confined trench (CT) units for irrigating olive trees and vegetable crops according to Jordanian standards.
- study the impact of treated GW reuse for irrigation on some chemical properties of the irrigated soil and plants.

2. Treatment of grey water

Many new technologies have been developed to treat GW [24–30]. The major difficulty presented for treatment of GW is the large variation in its composition. Reused GW should fulfill four criteria: hygienic safety, aesthetics, environmental tolerance, and technical and economical feasibility [9].

In this study 4-barrel and confined trench (CT) units developed by Inter-Islamic Network on Water Resources Development and Management (INWRDAM) were used for GW treatment. The 4-barrel unit (Fig. 1), consists of four plastic barrels made from high density polyethylene (HDPE). In the first barrel that receives GW from the house, grease, oil and settleable solids are removed. The second and third barrels were filled with gravel filter media of 2 to 3 cm diameter. They are connected in such a way that water passes through them in an upward fashion. The fourth barrel was fitted with a small electric submersible pump and float switch to deliver treated GW to a trickle irrigation system. The CT unit (Fig. 2) is a modification of the 4-barrel unit. The modification was accomplished by replacing the second and third barrels with a dug trench of about 3 m^3 capacity, filled with a gravel media and lined with thick impermeable plastic sheet. This modification resulted in increasing the unit hydraulic load [23]. Treated GW was pumped through a trickle irrigation system to home garden.

3. Study area

The study area was at Al-Amer villages in Karak governorate in the middle part of Jordan. The area is dominated by the Mediterranean climate, that is characterized by dry and hot summer seasons from May to September with a max temperature of 34 °C and wet winter season extending from October to April with a mean temperature of 14 °C. The mean annual rainfall is about 340 mm, the average wind

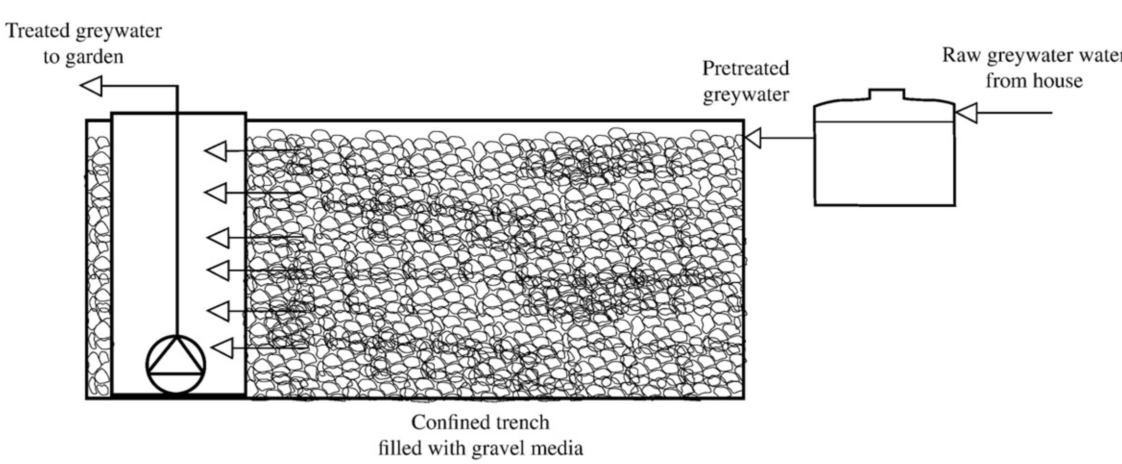

Fig. 2. Confined trench treatment unit. 1—first barrel; 2—confined trench; 3—barrel; 4—submersible pump.

speed is about 7.2 km/h and the evaporation average is 13.3 mm/day. The population in the study area was estimated to be about six thousand in 2006 [23].

4. Methodology

The research methods involved collection of GW, soil and plant samples and analyzing them for selected parameters.

4.1. Grey water

The average daily flow rate of treated GW generated from five representative households was measured using graduated barrels. Flow measurement was carried out in 2006 on a weekly basis and lasted for six months. Samples of raw and treated GW from five households were collected once a month starting from December 2006 to March 2007. Raw GW samples were taken from barrels that received water over 24 h while treated GW samples were collected from barrels that received treated GW. The barrels were cleaned before GW collection and the contents of the barrels were mixed thoroughly before sampling. Sampling bottles were soaked overnight in diluted hydrochloric acid before use and were rinsed two times with the sample to be collected before filling.

Collected samples were analyzed for pH, total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (T-N), nitrate as well as cadmium (Cd) and lead (Pb). Analyses of GW were carried out following the standard methods for the examination of water and wastewater [31].

Concentration of TSS was measured using drying method at 103–105 °C described by standard methods 19th edition 2540 D, total nitrogen by Kjeldahl Method, biological oxygen demand (BOD) using 5-day BOD test described by standard methods 19th edition 5210 D, while chemical oxygen demand (COD) was measured using closed reflux, titrimetric method was described by standard methods 19th edition 5220 D. Finally Cd and Pb were analyzed using an atomic absorption spectrophotometer equipped with a graphite furnace (Perkin Elmer; Model Analyst 300).

4.2. Soil quality and texture

The soil texture was classified as silty clay according to the United States Department of Agriculture (USDA) soil texture classification [32]. Soil sampling was conducted twice a year for two years starting from February 2006. The samples were collected from five designated home gardens irrigated with GW. Six soil samples were collected from each garden, three samples from the surface layer at depths of 0 to 30 cm and the other three at depths of 30 to 60 cm. Reference samples were collected in 2004 from the same gardens before irrigation.

Soil samples were dried, sieved for <2 mm and stored at −20 °C until time of analysis. Then the samples were analyzed for SAR, electrical conductivity, and organic matter content. Soil paste extract salinity (dS/m) was measured by conductivity meter (ORION model 160), Ca and Mg was measured by EDTA titration method, Na^+ was measured using the flame atomic absorption spectroscopy (Spectra Atomic Absorption 800 Varian), and organic matter (OM) was measured using dichromate method. All analyses were conducted according to standard methods [33].

4.3. Plants leaves and fruits

Composite samples of fresh olive leaves and fruits were collected from five gardens irrigated with GW. Five leaf samples and the same number of fruit samples were collected from each garden annually for duration of two years starting from November 2006. The same number of olive leaves and fruit samples were collected from the same gardens before GW application in November 2003 to serve as reference samples. Olive and soil samples were collected from the same gardens before and after irrigation with GW. Vegetable crops okra, bean, corn, and sunflower were planted in one home garden in 2006 and upon maturation five fruit samples and five leaf samples from each crop were collected. Collected samples were analyzed for nitrogen, phosphorus, potassium, sodium, chloride, cadmium, and lead. Leaves and fruits were first washed with distilled water, dried at 50 °C until constant weight and then the samples were homogenized. Then 0.2 g was dissolved in 10-ml conc. HCl in a 100-ml beaker. The beaker was covered with a watch glass, and the contents were boiled on a hot plate for approximately 30 min. The contents were then evaporated to near dryness. After cooling, 20 ml of 0.1 M HCl was added, and the contents were gently boiled. The contents were quantitatively transferred into 100-ml volumetric flask by filtering through Whatman no. 2 filter paper. The residues were thoroughly washed with 0.1 M HCl and the volume was adjusted with the same solution to 100 ml [34,35].

The digest obtained was analyzed for Cd and Pb using an atomic absorption spectrophotometer equipped with a graphite furnace (Perkin Elmer; Model Analyst 300). Na^+ and K^+ were analyzed using the flame atomic absorption spectroscopy (Spectra Atomic Absorption 800 Varian), whereas Cl^- and P were analyzed using ion chromatography and N content was measured by Kjeldahl Method.

5. Results and discussion

The estimated average GW generation rate was 30 ± 3.6 L/c.d. This rate is low compared with average rates reported for Amman (59 L/c.d.) [29], and European communities ranged between 66 and 274 L/c.d. [36–39]. However, the rate in the study area was higher than the reported value (15 L/c.d.) for Um Alquttain, Mafraq area [40]. The low water consumption rate in the study area was responsible for producing GW characterized by high BOD, COD, and TSS values (Table 1). In comparisons these values are even higher

Table 1
Quality of raw and treated GW compared with allowable Jordanian standard limit for restricted irrigation.

Parameter	Raw GW			Treated GW			Allowable limit, (crop trees)
	Range	Average	SD	Range	Average	SD	
pH	6.9–7.8	7.2	0.25	6.8–7.9	7.2	0.23	6–9
TSS, mg/L	23–358	275	80.1	12–312	128	25.1	150
BOD, mg/L	110–1240	942	244.5	10–412	108	68	200
COD, mg/L	92–2263	1712	592.5	36–763	489	124.3	500
EC, dS/m	1.57–2.0	1.83	0.11	1.46–1.91	1.76	0.18	>2
Nitrate, mg/L	0.44–0.93	0.68	0.62	<0.2	–	–	40
Total nitrogen, mg/L	38–61	52		8–14	11	2.6	70
Cadmium, mg/L	–	0.008		–	0.008		0.01
Lead, mg/L	1.0–1.31	1.19	0.11	0.8–1.15	1.13	0.10	5
SAR	2.23–4.76	3.3	0.8	1.8–3.6	2.8	0.6	9

Table 2
Average concentrations (in mg/L) of some chemical contaminants found in grey water of different sources.

Parameter	Source					
	GW, this study	GW, Um Alquttain, Jordan	GW, Sweden	GW, Amman	Concentrated sewage	Domestic WW, As-Samra
pH	7.2	6.35	7.5	7.81	–	7.01
TSS, mg/L	275	845	–	168	–	853
BOD, mg/L	942	1056	418	41	350	709
COD, mg/L	1712	2568	588	78	740	1868
EC, dS/m	1.83	1.87	–	1.910	1200	–

Table 4
The long-term impact of GW irrigation on soil EC, SAR and organic matter OM content.

Soil depth, cm	Parameter	Sampling period		
		Before GW irrigation	2006	2007
0–30	SAR	$1.42 \pm (0.62)$[a]	$1.49 \pm (0.5)$	$3.04 \pm (1.83)$
	EC, dS/m	$0.53 \pm (0.14)$	$1.55 \pm (0.44)$	$1.83 \pm (0.87)$
	OM, %	$2.83 \pm (1.15)$	$3.99 \pm (0.64)$	$0.81 \pm (0.18)$
30–60	SAR	$1.88 \pm (0.83)$	$2.15 \pm (0.6)$	$4.0 \pm (2.09)$
	EC, dS/m	$0.63 \pm (0.22)$	$1.55 \pm (0.44)$	$2.27 \pm (1.85)$
	OM, %	$2.83 \pm (1.15)$	3.89 ± 1.09	$0.88 \pm (0.24)$

[a] Standard deviation.

than those reported for combined and concentrated sewage in Jordan (Table 2). For example, the average BOD, COD and TSS concentrations for the influent to As-Samra Waste Stabilization Ponds, which had served almost half of the population in Jordan, are 709 mg/L, 1868 mg/L and 559 mg/L respectively [39]. Reported mean COD values for raw GW in this study vary between sites from 92 to 2263 mg/L, and with similar variations arising at an individual site due to changes arising in the quantity and type of detergent products employed.

The average COD removal efficiency (72%) achieved in the 4-barrel and CT treatment units is satisfactory compared with those reported for examined popular onsite wastewater treatment methods [41–44]. The average COD removal efficiencies for septic tank followed by intermittent sand filter [41]; septic tank followed by wetlands [41]; conventional UASB [42] and UASB-hybrid [44], were 71, 75, 64, and 85%, respectively. Moreover, CT and 4-barrel treatment units are characterized by low cost, compactness, and easiness of operation besides producing GW that meets Jordanian standards for irrigation of tree crops (Table 3).

Soil properties mainly salinity, SAR, and organic content are important for plant health and growth. The average SAR value of treated GW in this study was 3.62 which is less than the values suggested in references [19–21] and the allowable limit (9) presented in Jordanian standards (Table 1), thus indicating the suitability of treated GW for irrigation. The average salinity value of treated GW was 1.76 ds/m which is lower than 2 ds/m stated in Jordanian standards. The detergents and soaps are more concentrated in GW because the toilet stream is excluded. The introduction of particulate and organic matter such as surfactants can alter soil permeability [21,45].

The long-term effect of GW reuse on soil properties was studied during the period extended from 2006 to 2007. The results showed a gradual increase of salinity and SAR with time (Table 4). This increase might be explained due to the following reasons: high evaporation rates, low rainfall and absence of drainage system. Due to low rainfall in 2007, households in the study area used tap water for irrigation. Irrigation with tap water caused soil leaching which reduced organic content of the soil. It was also noticed that increase in EC values in 2007 was less than in 2006 due to soil leaching by tap water and the stabilization of soil salinity.

There is no evidence of chemical impact on leaves and fruits of olive and crops due to irrigation with GW (Table 5). Olive trees are the prevailing plants in the study area and are classified as moderately salt tolerant plants [47,48]. This makes the reuse of treated GW for olive trees irrigation of high potential in the study area. Uptake of cadmium and lead by the plants did not take place due to their low concentrations in treated GW and soil. However, long-term use of reclaimed water can lead to salt and metal accumulation in the soil and subsequent uptake by the plants [22,46]. The chemical properties of vegetable crops irrigated with GW (Table 6), did not differ from the properties of the same crops irrigated with fresh water. The results of biological analyses of fruit and leaf samples of the vegetable crops, conducted by other researchers [23], showed that some okra and bean fruit samples have high concentration of total and fecal coliform bacteria.

6. Conclusions

- The average GW production rate in the study area was found to be 30 L/c.d. and the quality of treated GW complies with Jordanian standard for irrigation of fodder crops (category C) and tree crops (category B), but does not meet the standard for irrigation cooked vegetables (category A).
- Irrigation of olive trees and vegetable crops with treated GW did not show any adverse effect on the chemical properties of the fruits and leaves.
- Soil leaching with fresh water is highly recommended because it reduces the accumulation of salts and organic matter in the soil.

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Table 3
Some important parameters set by Jordanian standard for reclaimed wastewater reuse in irrigation (effluent quality).

Parameter	Maximum allowable concentration		
	Cooked vegetables category A	Tree crops category B	Fodder crops category C
pH	6–9	6–9	6–9
TDS, mg/L	1500	1500	1500
TSS, mg/L	50	150	150
BOD, mg/L	30	200	300
COD, mg/L	100	500	500
Nitrate, mg/L	30	45	45
Total nitrogen, mg/L	45	70	70

Table 5
Concentration of selected minerals and metals in olive leaves and fruits.

Parameter	Olive trees irrigated with GW		Olive trees with no GW irrigation	
	Leaves	Fruits	Leaves	Fruits
Pb, mg/L	<0.01	<0.01	<0.01	<0.01
Cd, mg/L	<0.002	<0.002	<0.002	<0.002
N, %	1.75 ± 0.36[a]	0.52 ± 0.21	1.66 ± 0.53	0.34 ± 0.26
P, %	0.14 ± 0.05	0.08 ± 0.02	0.12 ± 0.04	0.07 ± 0.03
K, %	0.71 ± 0.23	1.72 ± 0.42	0.79 ± 0.21	1.34 ± 0.57
Na, %	0.03 ± 0.02	0.09 ± 0.02	0.06 ± 0.03	0.03 ± 0.01
Cl, %	0.21 ± 0.04	0.22 ± 0.04	0.22 ± 0.03	0.21 ± 0.04

[a] Standard deviation.

Table 6
Concentration of selected chemical parameters in crop leaves and fruits.

Parameter		N, %	P, %	K, %	Na, %	Cl, %	Cd, ppm	Pb, ppm
Okra	Fruit	2.62 ± 1.2[a]	0.36 ± 0.11	2.55 ± 1.12	0.07 ± 0.02	0.84 ± 0.2	nd	0.41 ± 0.18
	Leaves	2.67 ± 0.9	0.23 ± 0.13	2.23 ± 0.93	0.05 ± 0.01	0.86 ± 0.19	nd	0.90 ± 0.14
Bean	Fruit	2.52 ± 0.8	0.43 ± 0.18	2.97 ± 0.78	0.04 ± 0.02	0.97 ± 0.26	nd	–
	Leaves	3.06 ± 0.5	0.50 ± 0.13	2.63 ± 0.91	0.06 ± 0.02	1.97 ± 0.66	nd	0.48 ± 0.19
Corn	Fruit	2.03 ± 0.6	0.31 ± 0.09	1.0 ± 0.24	0.03 ± 0.01	0.21 ± 0.08	nd	0.95 ± 0.2
	Leaves	1.93 ± 0.7	0.37 ± 014	1.91 ± 0.47	0.06 ± 0.02	0.83 ± 0.26	nd	0.49 ± 0.21
Sunflower	Fruit	2.01 ± 0.5	0.23 ± 0.08	1.92 ± 0.64	0.03 ± 0.02	0.20 ± 0.07	nd	0.49 ± 0.2
	Leaves	3.17 ± 1.2	0.38 ± 0.12	3.03 ± 1.32	0.06 ± 0.03	1.11 ± 0.43	nd	0.46 ± 0.17

nd—not detected.
[a] Standard deviation.

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