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Research Article

Performance of a Grey Water Pilot Plant Using a Multi-Layer Filter for Agricultural Purposes in the Jordan Valley

A pilot grey water treatment system and collection network were designed, installed, and operated in Jordan Valley using natural filtration materials. Grey water from showers and washing sinks was collected from four houses. In order to evaluate the performance of multi-layer filter (MLF) ability to remove the pollutants from the collected grey water, the quality of treated and untreated grey water was examined and the suitability of treated grey water for irrigation was assessed. The results revealed that the efficiency removal of organic material before UV disinfection stage for BOD_5, COD, and TSS was about 88.6, 83, and 92.2%, respectively. The efficiency removal rates for nutrients by MLF were a bit low as 32.5% of total phosphorous and 19.8% of total nitrogen were removed, whereas the removal efficiency of heavy metals Zn, Fe, and Ba were 94.8, 81.2, and 15.7%, respectively. The results showed that the pilot plant has efficiently reduced the coliform organisms, thermo-tolerance coli count, and *Escherichia coli* by more than 99.9% removal efficiency by the double-filter stage and 100% after disinfection stage. The current MLF system has the transferability potential to other locations of the developing world.

Keywords: Diatomite; Natural filtration material; Semi-arid climate; Water scarcity; Zeolite

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1 Introduction

As the availability of fresh water resources becomes more limited throughout the world, there is an opportunity for grey water reuse to replace the use of freshwater or supplement existing water supplies. This is particularly true in Jordan, where grey water reuse is gaining acceptance. For instance, some hotels are using green practices that include grey water reuse as a notable part for hotel gardens, and some university dormitories are using recycling grey water for garden irrigation. In addition, individual homeowners and farmers connect their shower, wash machines, and hand wash basin to utilize grey water for backyard irrigation. The Ministry of Planning and International Cooperation of Jordan installed grey water treatment-units for >750 low-income households in >90 villages at rural areas for home garden irrigation [1].

Generally, Crook reported 2009 in a technical memorandum that grey water is defined as any wastewater not generated from toilet flushing, otherwise referred to as black water (www.nwri-usa.org/pdfs/CrookTechnicalMemorandumonGraywater.pdf). However, in the United States, the common definition of grey water is wastewater that generates from household clothes washers, showers, and bathtubs as well as sinks, but does not include wastewater from kitchen sinks, dishwashers, and toilets [2]. The common uses for grey water are toilet flushing, irrigation, and car wash as well as fire protection, which can reduce fresh water use by up to 50% [3–5].

Grey water irrigation systems have many advantages; however, the use of such systems has not become widespread due to concerns about safety issues. In addition, there is concern about the potential impacts on soil quality, plant, and groundwater quality, as well as human health, as a result of its use for housing landscape irrigation [6].

Al-Hamaiedeh and Bino [7] reported the effects of treated grey water application on the soil properties and plants at Al-Amer villages in Karak governorate in the middle part of Jordan. They showed that salinity, sodium adsorption ratio (SAR), and organic content of soil increased as a function of time. The chemical properties of olives trees and vegetable crops irrigated with grey water were not affected, while the biological quality of some vegetable crops was harmfully affected. Increase of soil salinity and SAR lead to decrease of soil permeability and reduction of crop yields due to toxic and osmotic effects [8, 9]. Furthermore, oil and grease from grey water can accumulate in soils and affect the ability of the soils to water retention and adsorption [10].

Grey water application practices started over a decade ago and numerous systems were constructed and operated. For instance, one fourth of the systems in Germany were assessed as unsatisfactory [11, 12]. A wide range of technologies can be utilized for grey water

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Abbreviations: **AAS**, atomic absorption spectrometry; **BOD_5**, biological oxygen demand; **COD**, chemical oxygen demand; **DO**, dissolved oxygen; **EC**, electrical conductivity; **MLF**, multi-layer filter; **PV**, photovoltaic; **SAR**, sodium adsorption ratio; **TDS**, total dissolved solid; **TKN**, total Kjeldahl nitrogen; **T-N**, total nitrogen; **T-P**, total phosphorous; **TSS**, total suspended solid; **TTCC**, thermo-tolerance coli count treatment and reuse, including natural systems, filtration, sequencing batch reactor, rotating biological contactor, and membrane bioreactors. Chlorination processes or ultra-violet units are commonly used for disinfection purposes [12–14].

The literature review shows that all types of grey water have good biodegradability. Li et al. [15] reported that for grey water treatment, the physical processes alone are not adequate for sufficient reduction of the organics, surfactants, and nutrients. The chemical processes are capable of removing the suspended solids, organic materials, and surfactants in the low strength grey water. The combination of aerobic biological, physical filtration, and disinfection process are considered to be the most feasible solution for improving grey water quality.

This paper has investigated the performance of an innovative pilot grey water filtration system utilizing natural materials available worldwide to produce high quality water for irrigation purposes. Also, a comprehensive characterization of treated grey water quality was also interpreted and presented.

2 Materials and methods

2.1 Study Area

Deir Alla (Um-Ayyaash area) is located in the Middle Ghor (the area situated between the villages of Kreymeh and Karameh) along the main Jordan Valley road, a short distance southwest from Ajloun and 50 km north of the Dead Sea (Fig. 1). The climate is semi-arid, with mean annual rainfall ranging from 100 to 150 mm, and mean annual temperature varying from 19 to 36.5°C [16]. Agriculture is one of the primary economic activities in the studied area, as it is throughout the Jordan Valley. Intensive irrigated agriculture has been in place in this region since the 1960 s. The main planted crops are vegetables and fruit trees, with 98% of them irrigated [17]. The vegetable cultivation under greenhouses covers 50 to 70% of the total irrigated area [18]. Al-Mashaqbeh et al. [19] reported that large areas of Deir Alla are planted with crops, with houses in clusters nearby the fields. The main source of irrigation water in the study area is King Abdullah Canal. This source is mainly a blended water (treated wastewater mixed with fresh water), which is provided from the King Talal Dam and from Yarmouk River via the King Abdullah Canal. The average number of family members in Um-Ayyaash-Deir Alla is 8.8 members, which is higher than the average household family size of 5.4 in Jordan [20].

2.2 Grey water pilot treatment plant

A pilot grey water treatment system was installed in the community of Deir Alla using natural available filtration materials (Fig. 2). Grey water, which was collected from four houses, was isolated from the black water through installing two wastewater networks. The black water network includes waste flows from toilets, the kitchen sink and laundry. The grey water network collects flows from hand wash basins and shower facilities. The pilot treatment plant for the greywater flows starts with a septic tank for grey water, which is designed to separate heavy particles by sedimentation and light particles and foam by flotation. The septic tank only allows the grey water from the middle layer to pass to the double filter. Each filter has eleven layers of sandstone and rocks aggregates with different particle sizes along with natural adsorbents such as zeolite, diatomite and activated carbon. A plastic tank of 1 m^3 in size

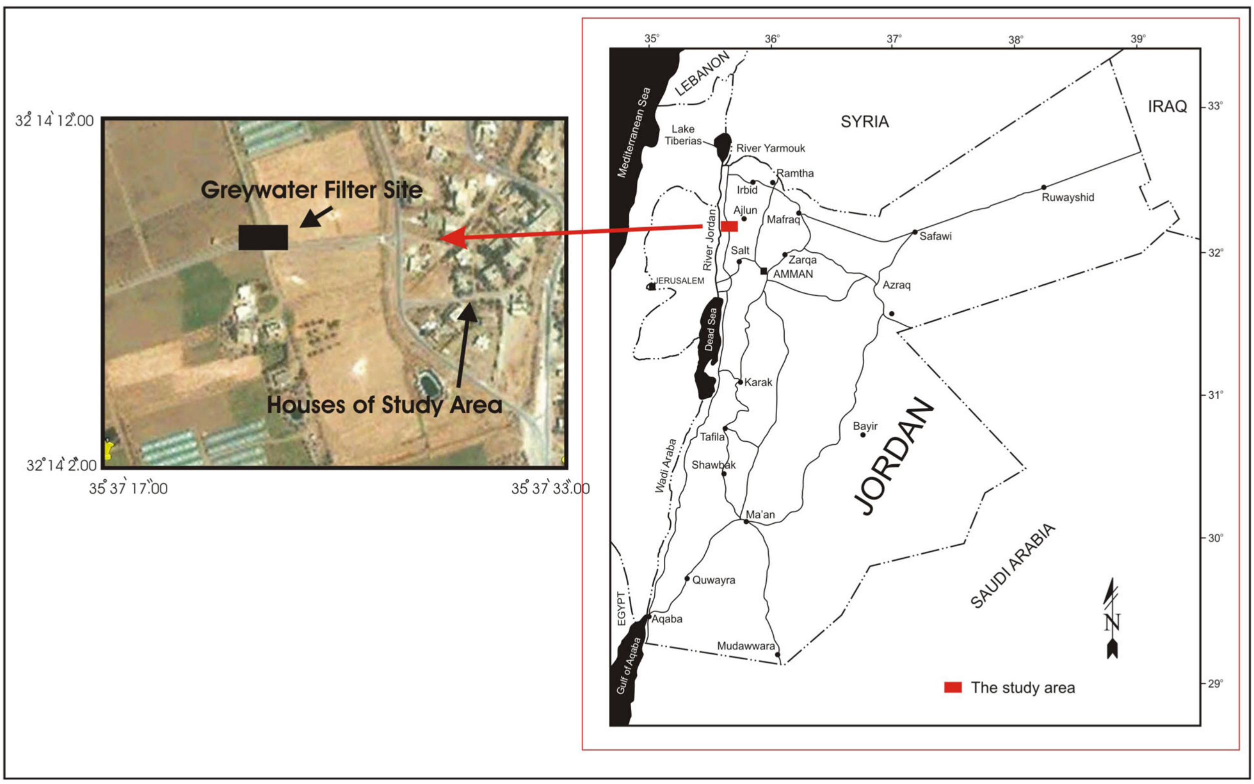

Figure 1. Location map of the studied area Um-Ayyaash Sector, Deir Alla, Jordan (after Al-Mashaqbeh et al. [19]).

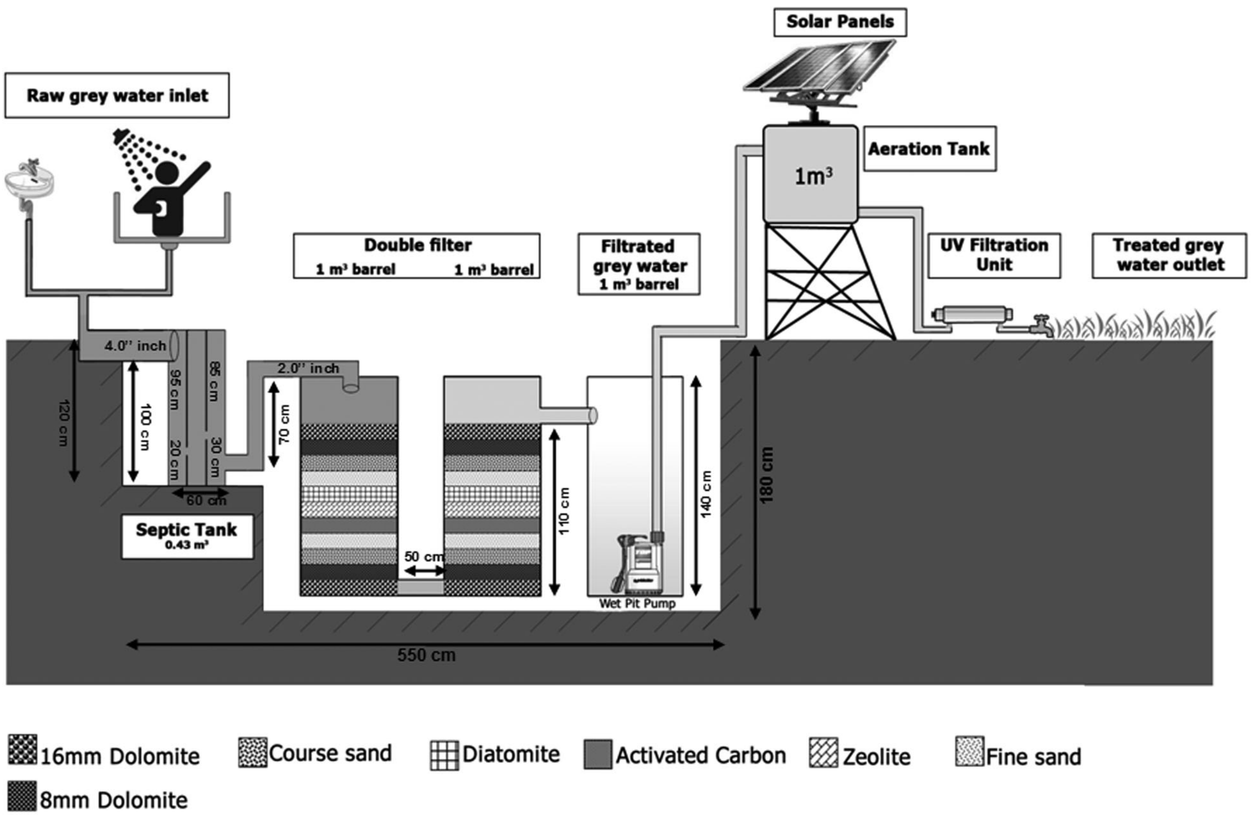

Figure 2. Schematic of grey water pilot treatment plant.

contains each filter. The grey water network system, septic tank and the double filter run by gravity. The filtrated grey water is accumulated in aplastic tank 1 m^3 which uses as temporary storage. The tank is equipped with wet pit pump. The treated grey water is pumped to an aeration tank at the house roof where it is disinfected using ultra violet (UV) disinfection units before the final use for irrigation. In addition, 40 W light, 40 W UV unit and wet pit pump ¾ horsepower are powered by a solar electrical photovoltaic (PV) system (Fig. 2). In order to implement backwash to the multi-layer filter (MLF), firstly the influent valve is closed and the waste line is opened. Secondly, clean treated water is pumped to the top of the second stage of the double filter up to 15 cm above the solid material surface. The clean water will move in a reverse direction "down-flow then up-flow" through the backed layer in the double filter. The backwash water is collected in a separated tank and allowed to settle. This process can be carried out when the filter clogged or the treated water becomes turbid. The backwash rate is slowly and under gravity influence. The main components of the PV system design are PV generator, charge controller, inverter and Batteries. According to the electricity load profile, the PV system was designed to generate adequate power to operate the pilot plant day and night. Thus, the system is sustainable and running automatically. The system running cost is zero and the filtration efficiency is 100% (there is no rejected water).

2.3 Materials

The main components of the filters are the following naturally occurring and locally available materials: zeolites, diatomite, activated carbon, rock aggregates and sandstone. 80 kg of zeolitic tuff was used in the double filter. Granularity size is 1.4–2.4 mm and cation exchange capacity is 130 mmol/100 g. Zeolites are hydrated alumino-silicates of the alkaline and earth metals, principally Na, K, Ca and Mg. Zeolite minerals were generated from alteration of volcanic tuff in northeast and central of Jordan. It occurs as a cementing material to the volcanic tuff granules [21]. Phillipsite, chabazite and faujasite are the most abundant zeolite minerals found in the Jordanian zeolitic tuff (Fig. 3). Zeolitic tuff is located at north east of Jordan (Tal Rimah volcano, Jabal Aritayn and Tlul Al-shahba) and other small deposits in the South Jordan (Tell Burma, Tell Juhaira and Wadi El-Hisa) as well as in central Jordan (Makawer, Al-Zara, Wadi Heidan and Wadi Al-Walah). Natural zeolite minerals are available worldwide in Africa, East and West Europe, Japan, USA and USSR [22, 23]. In addition, Katsou at el. [24] reported that 1–3 M KCl concentrations was the most effective solution for the regeneration process for zeolite. They found that backwash efficiencies was >98.5%.

20 kg of calcined diatomaceous earth was utilized in the double filter. Median particle size is 45 μm. Diatomite is a fossiliferous sedimentary rock that consists of micro-amorphous silica of microscopic single algae cell called diatom (Fig. 4). The diatomite is available in Azraq area approximately 110 km northeast of Amman, Jordan, covered an area of more than 150 km^2 [25]. The channels of diatomite can be blocked by the organic molecules. The deposited organic inside the channels of diatomite can be removed by calcining at 550°C or refluxing with dilute hydrogen peroxide. Consequently, the performance of the diatomite is recovered completely [26]. The United States leads the world in the production

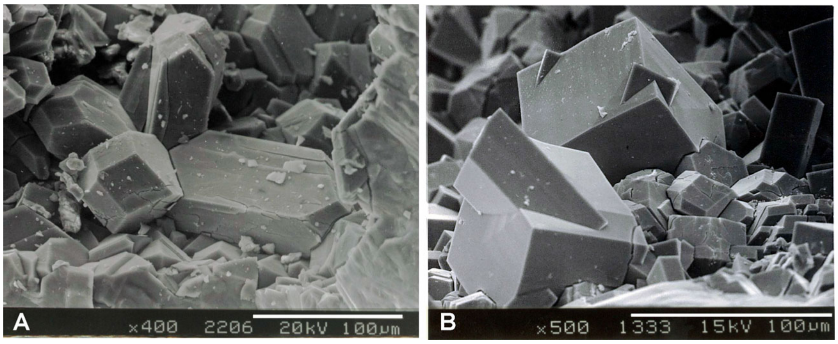

Figure 3. SEM image of crystals growth of raw zeolite minerals (after Ibrahim [23]).

of diatomite. The second-largest producer in the world is China. Denmark ranks the third followed by the countries of Mexico, Japan, France, Spain, Argentina, Turkey, Iceland, Italy, Australia, Algeria, and Thailand (www.mapsofworld.com/minerals/world-diatomite-producers.html).

100 kg of granular activated carbon was purchased from the local market and utilized in the double filter. Particle size is 0.5–2.4 mm. Packing is 25 kg which is equivalent to 46 L. Guoa et al. [27] found that *n*-pentane solvent was very effective for activated carbon regeneration. The optimum regeneration time was 20 min at 25 °C. Moreover, an activated carbon drying time was 300 min at 150 °C. Two aggregate size of dolomite rock were utilized in the double filter: 320 kg of gravels with median particle size 16 mm and 320 kg of gravel median particle size 8 mm. Finally, two types of sandstone were utilized in the double filter: 320 kg of coarse-sandstone white color with median particle size 0.85 mm and 320 kg of red color medium-sandstone with median particle size 0.36 mm.

2.4 Grey water analyses

In order to evaluate the performance of multi-layer filter ability to remove the pollutants from the collected grey water, the quality of treated and untreated grey water was studied and the suitability of treated grey water for irrigation according to Jordanian standard was assessed. Samples were collected and analyzed twice in two different occasions; July and September 2012. In each time, three samples were collected from three sites; the septic tank (inflow), outflow of the MLF unit that acts as a temporary water collection tank, and a point after the UV disinfection unit. Sampling bottles were soaked overnight in diluted hydrochloric acid before use and were rinsed two times with the sample to be collected before filling. Two additional water samples were collected from the experimental site. The first was tap water supply at the houses providing grey water were collected and analyzed in order to evaluate the contaminants in the grey water inflows; the second was the available irrigation water at the Jordan valley. Samples of this irrigation water were collected and analyzed in order to be compared its characteristics with the quality of the treated grey water produced by the pilot plant.

The collected samples were transferred to labs at the Royal Scientific Society of Jordan, where they were analyzed for pH and electrical conductivity (EC). Total dissolved solids (TDS) and total suspended solids (TSS), biological oxygen demand (BOD_5), and chemical oxygen demand (COD) were analyzed using titration methods. Total phosphorous (T-P) and nitrite (NO_2) are analyzed using spectrophotometric methods (colorimetric methods). Total Kjeldahl nitrogen (TKN) and ammonia (NH_3) were analyzed after digestion using a distillation system. Nitrate (NO_3^-) and sulfate (SO_4^{-2}) are analyzed using ion chromatography. Fat oil and the fats, oils and grease test is performed using gravimetric and liquid–liquid extraction methods after evaporation using a rotary evaporator. Phenol and MBAS are analyzed using liquid–liquid extraction methods and spectrophotometric methods (colorimetric). Chloride (Cl^-) was analyzed using potentiometric titration methods, cyanide (CN) and fluoride (F) are analyzed using ion selective electrode methods. Cyanide is measured after going through distillation for the whole sample as a pretreatment step. Calcium (Ca) and magnesium (Mg) are analyzed using EDTA titration methods. Sodium (Na), copper (Cu), iron (Fe), lithium (Li), manganese (Mn), nickel (Ni), lead (Pb), cadmium (Cd), zinc (Zn), chromium (Cr), and

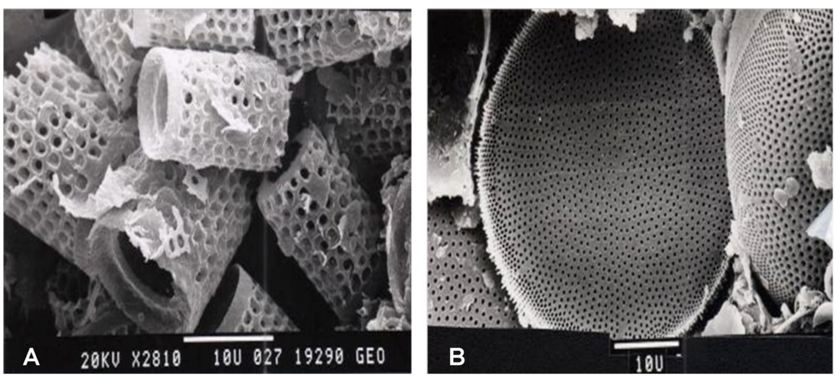

Figure 4. SEM image of two types of diatoms. A) Pennate types of diatoms, B) centric types of diatoms (after Khoury et al. [25]).

cobalt (Co) were analyzed using spectroscopic methods, air–acetylene flame, atomic absorption spectrometry (AAS) (AA-6300, Shimadzu, Japan). Barium (Ba), aluminium (Al), and beryllium (Be) are measured using spectroscopic methods, nitrous oxide–acetylene flame AAS. Arsenic (As) and selenium (Se) were measured using spectroscopic methods, air–acetylene flame, hydride vapor generation technique HVG-1, AAS. Mercury was analyzed using spectroscopic methods, cold vapor generation technique, AAS. Molybdenum (Mo) and vanadium (V) were analyzed using spectroscopic methods, graphite furnace atomizer GFA-EX7i, AAS.

Finally, thermo-tolerance coli count (TTCC) and *E. coli* bacteria and all chemical analyses were carried out according to the standard methods for the examination of water and wastewater [28].

Intestinal pathogenic nematodes eggs were determined by standard methods [29]. In addition, the Jordanian standards for reclaimed grey water in rural areas [30] are presented in the results tables as a basis of comparison for the grey water results.

3 Results and discussion

3.1 Physical properties

Results presented in Tab. 1 show that the average dissolved oxygen (DO) and grey water temperature for inflow and outflow from MLF and UV disinfection unit were 0.2, 0.8, 1.6 mg/L and 32.5, 35, and 35.3°C, respectively. The lowest value of the DO was occurred at septic tank which is due to BOD_5. The DO value of tap water (4.8 mg/L) was lower than the irrigation water (7.2 mg/L). This is due to the difference in temperature between the two types of water. It is well known in the literature that DO is inversely related to temperature and salinity, and directly related to partial pressure across the water surface.

The TDS of grey water was 806 mg/L which is higher than the tap water supply (TDS 723 mg/L). This increase in TDS is mainly due to dissolved inorganic salts in the detergents at the laundry cleaning and the dissolved salt content of dirt cleaning at the sinks. The results also showed the TDS of the pilot plant outflows was 751 mg/L, which is lower than the irrigation water source used at study area and within the Jordanian standard for grey water reuse [29]. The level of total dissolved solids of treated grey water is slightly increased in the outflow after UV disinfection. The total solids in grey water contained of about 93.3% dissolved and 6.7% suspended solids.

The average pH value of grey water was 7.91. It was relatively higher than that of the tap water source at study area (pH $\sim$ 7.66). This is mainly due to the alkalinity produced by the used detergents and soaps. It is important to note that the pH, TSS, and TDS values for inflow, outflow from MLF and UV meet Jordanian standards; therefore, the grey water does not require additional treatment for these parameters before reuse.

3.2 Chemical properties

3.2.1 Organic components

The results in Tab. 1 show that the BOD, COD, and TSS values of grey water for inflow and outflow from MLF and UV were 60.1 and 86.1 and 58 mg/L, respectively. These values are considered as low organic strength compared to literature data for grey water from similar sources. For example, Friedler [31] reported BOD values of between 173 and 424 mg/L, COD values of between 230 and 645 mg/L and total suspended solids values of between 78 and 303 mg/L for grey water from the bath, shower, and wash basin. Moreover, Winward et al. investigated the characteristics of grey water collected from bathroom sinks, baths and showers of student flats on the Cranfield University campus. He reported that BOD_5, COD, and TSS of low strength grey water were 20, 87, and 29 mg/L while for high strength were 164, 495, and 93 mg/L [32].

3.2.2 Inorganic components

Different inorganic (cations/anions) parameters were analyzed for sampling points and presented in Tab. 1. Most of them were slightly higher than that of the tap water except CN, F, and Mg. The concentrations of inorganic parameters of outflow from MLF and UV are still slightly higher than that of tap water except Ca and SO_4.

SAR is the ratio of sodium concentration to the concentrations of calcium and magnesium, which is also called as the sodium content. Based on the values of Na, Ca, and Mg, the SAR value of inflow and outflows from MLF and UV were 1.9, 2.1, and 2.1, respectively. These values of grey water are considered as low sodium content of the irrigation water, which may be used with little harmful effects on the plant and soil [8].

3.3 Nutrients components

The values of the parameters analyzed (T-P, total nitrogen (T-N), TKN, NH_3-N, NO_2-N, and NO_3-N) for the inflow and outflows from MLF and UV and the irrigation water and drinking water supply at study area are presented in Tab. 1. The results showed that the T-P, T-N, and TKN values of grey water were 1.0, 12.2, and 12 mg/L, respectively. The main source of phosphates found in grey water is coming from using washing detergents. Therefore, many countries, but not Jordan, have banned phosphorus-containing detergents to minimize the phosphate in wastewater [33].

3.4 Microbiological properties

Similar to wastewater, there is many types of microorganisms may be present in grey water such as viruses, bacteria, protozoa, and intestinal parasites (helminths). In spite of the organic strength of the grey water is lower than that of domestic wastewater still the faecal coliform can be exist. Total coliform, faecal coliform, and *E. coli* concentrations in the inflow grey water were 6.58×10^5, 2.78×10^5, and 2.75×10^5 million colony forming units per 100 mL, respectively (Tab. 1).

Presence of faecal coliforms and *E. coli* bacteria is usually considered to be adequate indicator of faecal contamination of water samples and the possible presence of transmitted pathogenic bacteria [31, 34–36]. Although TCC, TTCC, and *E. coli* are not specified in grey water reuse Jordanian standards, it should be stressed that the average concentration of the outflow after UV step fulfils the limit of Jordanian drinking water standards [37].

3.5 Heavy metals components

Characteristics of grey water reuse systems have been extensively studied by focusing on pathogenic microorganisms and conventional

Table 1. Physical, organic, inorganic, nutrients, and microbial parameters quality (average concentration) of samples collected from the inflow, outflows from MF and UV as well as the irrigation water and drinking water supply at study area

Parameter	Unit	Inflow	MF outflow	UV outflow	Irrigation water	Tap water	JS 1776:2008
Physical							
DO	mg/L	0.2	0.8	1.6	7.2	4.8	..
Temperature	°C	32.5	35	35.3	30.1	35.6	..
pH	SU	7.91	7.82	7.96	9.21	7.66	6–9
TSS	mg/L	58	4.5	4.5	30	<2	150
TDS	mg/L	806	735.5	751	854	723	1500
Organic							
BOD_5	mg/L	60.1	6.88	2.6	5.87	<2	300
COD	mg/L	86.1	14.6	5.9	38.7	<5	500
FOG	mg/L	<8	<8	<8	<8	<8	
Phenol	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	0.05
MBAS (MW 348.48 g/mol)	mg/L	<0.15	<0.15	<0.15	<0.15	<0.15	25
Inorganic							
Cl	mg/L	148.5	154	153.5	286	120	350
HCO_3	mg/L	405	418	416	116	282	400
Ca	mg/L	96.6	79.5	76.9	67.8	91.6	230
Mg	mg/L	50.5	51.7	53.8	31.2	54.5	100
F	mg/L	0.61	0.63	0.61	0.39	0.62	1.5
B	mg/L	0.265	<0.2	0.26	<0.2	<0.2	1
SO_4	mg/L	222	133	137	183	210	500
Na	mg/L	95.2	99	99.7	182	67.2	230
SAR	mg/L	1.9	2.1	2.1	4.6	1.4	3.2
Nutrients							
T-P	mg/L	1.0	0.7	0.7	0.92	<0.1	15
NH3-N	mg/L	7.2	8.4	8.6	<3.7	<3.7	
TKN	mg/L	12.0	9.1	9.3	<4.5	<4.5	70
NO_2-N	mg/L	0.005	0.447	0.186	0.014	0.368	
NO_3-N	mg/L	0.226	<0.226	<0.226	1.475	4.697	50
T-N	mg/L	12.2	9.8	9.7	6.0	9.6	
Microbial							
TTCC	MPN/100mL	278 000	7.4	<1.8	<1.8	<1.8	
E. coli	MPN/100mL	274 600	3.15	<1.8	<1.8	<1.8	
IPN	Egg/L	Not seen	Not seen	Not seen	Not seen	Not seen	<1

FOG, fats, oils and grease; MBAS, methylene blue active substances

water quality parameters. However, little is known about the fate of metals from grey water [38]. In this study, heavy metals (18 elements) were analyzed for five sampling points and are shown in Tab. 2. The average concentrations of heavy metals (13 elements; Al, As, Be, Cu, Mo, Ni, Pb, Se, Cd, Cr, Hg, V, Co) in the inflow were less than the detection limit, while the concentrations of heavy metals (Ba, Fe, Li, Mn, Zn) are slightly higher than that of tap water. The results showed the concentration of barium was a little bit high in the grey water. This might be due to the barium compounds (sulfate and sulfide) that are used as a depilatory agent or an opacifier used in depilatories, hair relaxers, and cosmetics. The concentrations of all heavy metals in the outflow from MLF and UV are satisfying the JS 1776 except Ba [30].

3.6 Performance of grey water pilot plant

The performance of the grey water treatment plant was evaluated over eight months. The grey water samples were collected from three sampling points; inflow (the septic tank), outflow from MLF unit, and UV unit. Table 3 showed the results of average concentrations of the grey water parameters along the treatment, specific removal efficiencies of each treatment unit (MLF and UV), and the overall removal achieved.

The pilot showed a high overall efficiency (92.2%) in removing the TSS. It is important to mention here that this removal efficiency was only achieved by MLF before UV step. The results showed that the overall efficiency of BOD_5 and COD were 95.7 and 93.1%, respectively, with 88.6% BOD_5 and 83% COD were removed by MLF. The results showed that BOD_5 removal (95.7%) was slightly higher than COD removal (93.1%). This suggests that the grey water contains slight amount of non-biodegradable organic matter. This is in consistent with similar findings by many studies in the literature [33, 39]. The removal efficiency of T-P, T-N, and TKN were 34.5, 20.7, and 22.6%, respectively. The performance of pilot plant toward removing nutrients was a bit low compared with the organic matters removal. The high performance of organic matters removing is due to the high biodegradation rate of organic matters during the retention time in the grey water filtration system and the adsorption on activated carbon and capturing of large organic molecules by diatomite. The rest of organic matter was oxidized by the UV unit. In addition, the organic large particles and light particles were removed by settling and flouting in the septic tank. Shariati et al. [40] reported that almost complete removal of hydrocarbon pollutants was achieved mainly by biodegradation at a hydraulic retention time of 8–24 h. According to Bohlin [41], the microbes have the ability of decomposing organic matter into substrates. Under anaerobic conditions, the microbes have the ability to denitrificate where compounds based on nitrogen, phosphorous, and sulfur will be used in the microbial metabolism.

The pilot plant successfully removed faecal coliforms. Overall total coliform, faecal coliform, and *E. coli* (TCC, TTCC, and *E. coli*)

Table 2. Heavy metals quality (average concentration) of samples collected from the inflow, outflows from MF and UV, the irrigation water and drinking water supply at study area

Parameter	Inflow (mg/L)	MF outflow (mg/L)	UV outflow (mg/L)	Irrigation water (mg/L)	Tap water (mg/L)	JS 1776:2008 (mg/L)
Ba	0.26	0.22	0.22	<0.2	<0.2	0.1
Al	<0.7	<0.7	<0.7	<0.7	<0.7	1
Be	<0.02	<0.02	<0.02	<0.02	<0.02	0.1
Cu	<0.02	<0.02	0.03	<0.02	0.03	1
Fe	0.64	0.12	0.12	0.23	0.261	2
Li	0.016	0.02	0.02	0.02	0.013	2.5
Mn	0.033	0.123	0.102	0.02	<0.017	0.1
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Ni	<0.04	<0.04	<0.04	<0.04	<0.04	1
Pb	<0.09	<0.09	<0.09	<0.09	<0.09	0.1
Cd	<0.005	<0.005	<0.005	<0.005	<0.005	0.01
Zn	0.38	0.02	0.08	<0.016	0.14	2
Cr	<0.05	<0.05	<0.05	<0.05	<0.05	0.1
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Co	<0.03	<0.03	<0.03	<0.03	<0.03	0.05

removal efficiency was 100%, with >99.9% removal by MLF unit before disinfection.

A wide types of processes have been used to treat grey water and reuse include natural system (such as wetland); physical system (filtration) and chemical systems (oxidation, coagulation); biological systems (rotating biological contactor, sequencing batch reactor, membrane bioreactors) [42–45]. These processes were usually followed by UV or chlorination processes for disinfection before reuse [32, 46, 47]. The treatment process involved at this study is mainly combined of biological and filtration using different types of adsorbents (activated carbon, zeolite, and diatomite). The pilot plant is still working with an excellent performance. More than 94 m^3 of inflows were treated over 314 days without incurring any operational failure or maintenance actions. The estimated average rate of grey water produced by four houses was ~9 L per capita per day (L/C/D). This rate is very low compared with average rates reported for Jordan at urban area such as Amman city (59 L/C/D) [48], and at rural area such as Um Alquttain town (15 L/C/D) [49]. This is mainly due to the low water consumption at the houses which reflects the low income of the families in the study area [19].

Table 3. Grey water quality (average concentration) and removal efficiencies of pilot plant

Parameter	Efficiency removal of MF (%)	Overall efficiency removal of pilot (%)
BOD_5	88.6	95.7
COD	83.0	93.1
TSS	92.2	92.2
T-N	19.8	20.7
TKN	23.8	22.6
TDS	8.7	6.8
T-P	32.5	34.5
Ca	17.7	20.4
SO_4	40.0	38.4
Ba	15.7	15.7
Fe	81.2	81.2
Zn	94.8	79.3
TCC	99.9	100
TTCC	100	100
E. coli	100	100

In summary, the water quality produced by the pilot plant is very promising. The quality of treated grey water fulfils the requirements of Jordanian standards category (C) for irrigation of fodder crops and category (B) for tree crops, as well as the standard category (A) for irrigation cooked vegetables. Moreover, the results indicate that the treated grey water can be reused (recycled) not only for irrigation purposes, but also for other non-potable household activities. Such use of treated grey water would reduce the demands on the potable water system and potentially reduce water bills, Jordanian regulation have restricted the reuse of treated grey water for irrigation purposes only. Therefore, Jordanian officials may wish to consider allowing broader reuse if the water quality results of this pilot system can be replicated in other locations and over a long enough period of time.

4 Concluding remarks

In the present study, a novel grey water pilot plant using a multi-layer filter of natural materials and minerals was designed, installed, operated, and tested. The grey water treatment pilot plant is a sustainable running automatically and supported by renewable energy PV system. The system running cost is zero and the filtration efficiency is 100% (there is no rejected water).

The study results reveal that the pilot plant has high removal efficiency (>90%) toward organic pollutants and shows an excellent ability to reduce the microbial contaminants with >99.9% removal efficiency by the double-filter stage and 100% after UV. The efficiency removal rates for nutrients by MLF were a bit low as 32.5% of T-P and 19.8% of T-N were removed, whereas the removal efficiency of heavy metals Zn, Fe, and Ba were 94.8, 81.2, and 15.7%, respectively.

The pilot plant has produced outflow of excellent quality. The quality of treated grey water fulfils the requirements of Jordanian standards categories (A, B, and C) for irrigation purposes. In addition, the results reveal that the treated grey water can be recycled for other non-potable household activities.

Based on the worldwide distribution of the natural adsorbents, the current MLF small scale grey water system has the transferability to other locations of developing countries. The performance of the pilot plant was very stable and reliable over 8 months and there is a

CLEAN Soil Air Water

potential to expand the pilot to include additional sites. However, future research is needed to study the longevity of the pilot plant a multi-layer filter performance and the effect of treated grey water quality on the soil physical and chemical properties and soil microbiology as well as health care.

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