Water Science & Technology

IWA PUBLISHING

Water Science & Technology Vol 85 No 6, 1952 doi: 10.2166/wst.2022.080

Greywater reuse: an assessment of the Jordanian experience in rural communities

Saleh Al Arni [a,*], Mahmoud Elwaheidi[b], Alsamani A. M. Salih[a,c], Djamel Ghernaout[a,d] and Mohammed Matouq[e]

[a] Department of Chemical Engineering, College of Engineering, University of Ha'il, P.O. Box 2440, Ha'il 81441, Saudi Arabia
[b] Geology & Geophysics Department, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia
[c] Department of Chemical Engineering, Faculty of Engineering, Al Neelain University, Khartoum, Sudan
[d] Chemical Engineering Department, Faculty of Engineering, University of Blida, P.O. Box 270, Blida 09000, Algeria
[e] Faculty of Engineering Technology, Chemical Engineering Department, Al-Balqa Applied University, P.O. Box 4486, Amman-11131, Jordan
*Correspondence author. E-mail: arnisaleh@hotmail.com; s.alarni@uoh.edu.sa

SAA, 0000-0002-4592-8254

ABSTRACT

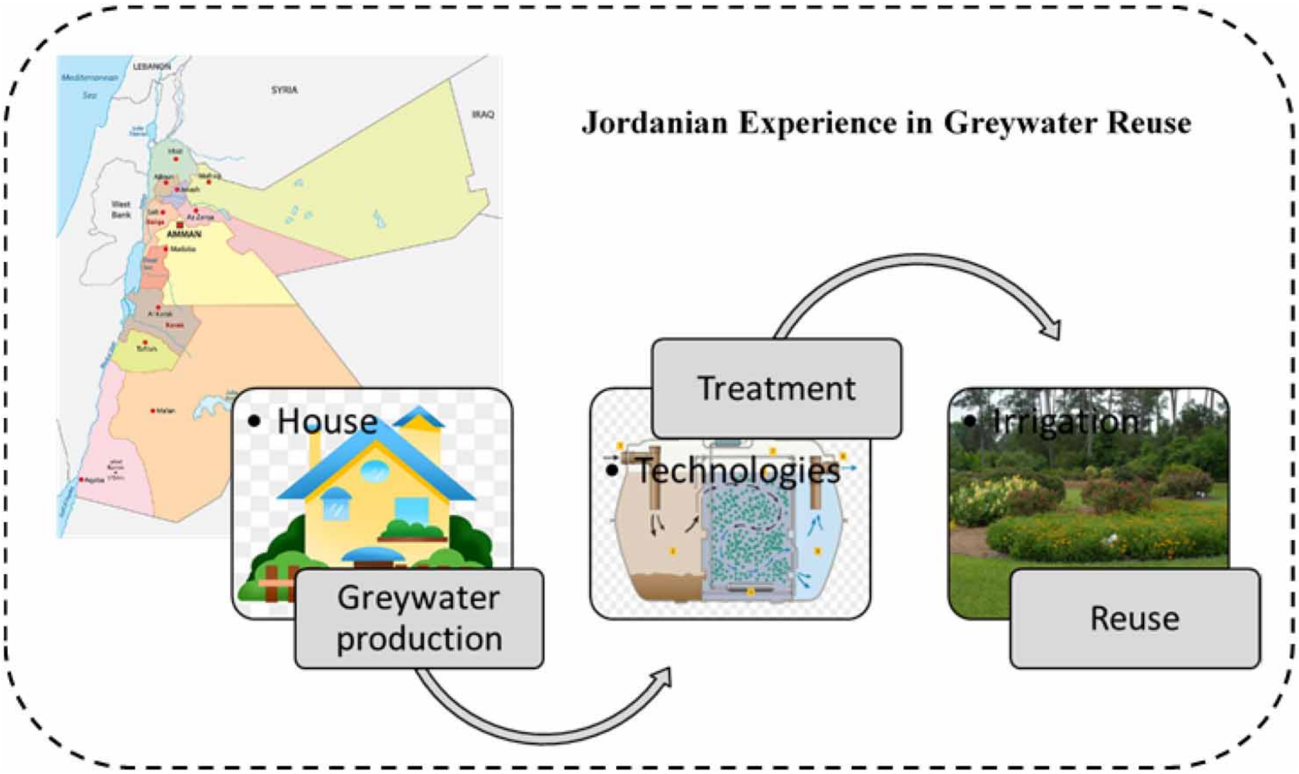
Water conservation is a critical issue, particularly in arid countries and countries that suffer a lack of natural water resources. Jordan is one of the most water-scarce countries in the world; this fact has forced the search for alternative sustainable solutions. With the support of several regional and international organizations, tens of projects were implemented across the country over the past 30 years that aimed to reuse greywater in rural communities. The current review provides a wide overview of Jordan's experience in greywater treatment and its reuse for non-potable purposes in rural areas. To the best knowledge of the authors, the present review is the first to assess the Jordanian experience in this field. Many governmental authorities and non-governmental organizations have been involved in Jordan's experience. The greywater reuse systems were established to achieve advantageous environmental and socio-economic consequences on the rural communities. The strategy of greywater treatment was based on a local on-site greywater treatment system in households or the so-called 'autonomous water management'. The applied greywater treatment technologies in households were found efficient in rendering greywater adequate for agricultural uses. However, further improvements and territorial expansion of the experiment are needed.

Key words: greywater, Jordan, water recycling, water treatment

HIGHLIGHTS

- The manuscript provides a wide overview of Jordan's experience in greywater treatment and reuse.
- Tens of projects have been experimented over a period of three decades.
- Reuse of greywater was implemented in rural areas that severely suffer from lack of water resources.
- Most projects are based locally using on-site household implemented systems.
- They provided a valid support to socio-economic benefits to urban region inhabitants.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water pollution is variable in quantity and type of pollutants based on the source of water use (Al Arni *et al.* 2021). In the case of domestic wastewater, such as washbasin water and household cleaning water, the pollutant concentration is low compared to toilet water and it is thus called 'greywater'. On the other hand, toilet water is a highly polluted water that is rich in organic materials such as feces and urine, which contain microorganisms such as various bacteria, viruses and parasites; this water is known as 'blackwater'.

Greywater is further divided into two types based on the source of contamination: dark greywater produced by laundries, dishwashers and kitchen sinks; and light greywater that is produced by bathrooms, showers and tubs. To be noted that while several researchers consider kitchen water as blackwater because it contains high levels of organic materials such as oil, fat and food leftovers (Christova-Boal *et al.* 1996; Al-Jayyousi 2003; Abu & Lina 2009), others do not (Friedler *et al.* 2006; WHO 2006).

The consumed water, in particular the ablution water used in mosques, schools, hotels and domestic use, can be re-utilized to the fullest extent. In fact, this type of water does not contain high quantities of pollutants compared to the water produced by the industrial sector or sewage plants. Furthermore, the quantity of water to be treated is not large, thus its local treatment is advantageous and less complicated than treatment of industrial water and sewage.

Several countries have adopted different local water treatment methods seeking to mitigate water scarcity crisis and to reach an efficient management system of available water resources (Halalsheh & Kassab 2018). Countries such as South Africa, Mali, Nepal, Costa Rica, Malaysia, Sri Lanka, Palestine, Jordan, Lebanon and Yemen have implemented numerous projects in the field of greywater reuse (Al Arni 2014). However, a major part of these projects is experimental and partially addressed the reuse of household water. Furthermore, such projects are characterized by extreme simplicity in application that seeks to satisfy individual needs. So far, to the best of our knowledge, there is no compulsory comprehensive national policy for reusing greywater at national levels; however, extensive governmental efforts are being employed to encourage water reusing.

The municipal supply of water in Jordan is not regular over the weekdays, especially in summer and in rural areas. To overcome the issue, most Jordanian households use tanks for water storage with a capacity of 1–2 m^3 to assure water availability during the whole week. In this regard, household reuse of greywater is encouraged to further enhance water sustainability. The quantity of greywater produced in Jordan is estimated to be between 50 and 80% of a person's daily water consumption (Ammari *et al.* 2014; Albalawneh & Chang 2015). However, the average quantity of greywater produced at the household level is between 51–63 Liters/capita per day (Jamrah & Ayyash 2008), and about 54 million m^3/year (Assayed *et al.* 2018).

The current research aims to explore the Jordanian experience in greywater recycling during the last thirty years. To be noted, however, that wastewater treatment plant reclamation projects are excluded; the scope is limited to the evaluation of greywater reuse projects in rural communities that lack sewage systems.

2. HISTORICAL OVERVIEW OF GREYWATER RECYCLING IN JORDAN

The Inter-Islamic Network on Water Resources Development and Management (INWRDAM) was established in 1987 by the Organization of the Islamic Conference Standing Committee on Scientific and Technological Cooperation. INWRDAM established guidelines polices for research in the field of water resources development and management for its 16 member states, including Jordan (Bino & Al-Beiruti 2007). The organization is actively involved in research; it conducts research projects in water resources management and wastewater treatment and reuse. These projects are funded by several international agencies. In 1990, INWRDAM provided training on the greywater reuse, and distributed greywater kits to several villages located in rural areas of Jordan (McIllwaine 2003b).

In 1997, CARE Australia established, in cooperation with the Voluntary Local Society, permaculture pilot projects and greywater reuse systems in Ein Al-Baida, south of Tafila in Jordan for the benefit of 50 local families (Bino & Al-Beiruti 2007).

Since February 2000, INWRDAM-Jordan, supported by the Government of Jordan and other regional and international organizations, conducted several greywater reuse projects in rural areas of Jordan. In the period 2001–2003, INWRDAM installed 25 greywater reuse units for low-income families in Ein Al-Baida in Tafila Governorate that were funded by the International Development Research Centre (IDRC). Furthermore, international cooperation among INWRDAM, CARE International and Ministry of Planning resulted in the installation of more than 750 greywater reuse units in more than 90 villages all around Jordan (Bino & Al-Beiruti 2007).

The implemented greywater reuse projects had positive impacts at the socio-economic and environmental levels; this encouraged expanding the experience into a second phase that started in 2004. In this phase, about 110 greywater reuse systems were installed in six peri-urban areas in the Al-Amer villages in the Governorate of Karak, southern part of Jordan. These projects were the result of fruitful cooperation among researchers and stakeholder ministries such as the ministries of Agriculture, Social Development, Environment, Public Health and others (Bino & Al-Beiruti 2007).

On February 15th, 2007, an international conference was held in Aqaba, Jordan, in which 29 experts, researchers and practitioners from eight different countries and representing 17 institutions, were participated. A significant declaration was issued by the participants, known as the 'Aqaba Declaration on Greywater Use in the Middle-East and North Africa Region' that emphasized several issues. These are: (a) greywater provides an important potential to mitigate water scarcity in dry countries; (b) greywater should be seen as a water source instead of a waste product; (c) the reclaimed greywater can be environmentally, socially and economically beneficial and culturally acceptable.

3. WATER SITUATION IN JORDAN

Water scarcity in Jordan is well known (Mustafa *et al.* 2016; Hussein 2018); in fact, Jordan is considered one of the most water-scarce countries in the world (Assayed *et al.* 2013; Hammouri *et al.* 2017). The international annual water availability per capita is 500 m^3/year, while in Jordan the annual per capita is 145 m^3/year (Abu Saud 2009). The increasing gap between water demand and supply in Jordan is currently a serious problem and will remain so in the near future. This is essentially due to the rapid increase in population and the large number of immigrants hosted by the country (Hammouri *et al.* 2017).

The treatment of greywater and recycling is one of the adopted solutions to mitigate water scarcity. The reclamation is considered as an alternative source of water supply for non-drinking uses, especially in rural areas that are very far from the centralized wastewater treatment plants or in areas where it is not technically applicable to make the connection with sewage networks. Several researches estimated that about 15–35% of fresh water can be recovered from greywater (McIllwaine 2003b; Bino & Al-Beiruti 2007; Halalsheh *et al.* 2008; Jamrah & Ayyash 2008; Stanley 2010). In Jordan, about 64% of houses are not connected to a municipal wastewater system (Ulimat 2012) thus, can benefited from greywater reuse. The activities of greywater treatment and reused water in Jordan are classified according to the Jordanian Ministry of Environment Regulations to the third category that indicates no significant environmental and social risks and impacts for the treatment and reuse processes (UN Habitat 2019).

4. JORDANIAN STANDARDS FOR GREYWATER REUSE

Several countries take severe measures to mitigate the impact of waste on public health and natural resources; the first step in this is by setting and implementing related regulations, standards and codes (Al Arni & Elwaheidi 2021). Among these regulations come the standards adapted to reclaim municipal wastewater, including greywater, and its reusing. The World Health Organization (WHO) established a global guideline to minimize the risks of greywater reuse; these include restrictions on its use for crop irrigation, and hygienic food handling (WHO 2006). The standards and regulations of municipal wastewater treatment were adopted to be applied to greywater in most countries of the world (Albalawneh & Chang 2015). Lately, however, several countries have established specialized standards for greywater reusing such as the UK, Japan, Germany, Australia and Jordan (Albalawneh & Chang 2015).

In Jordan, several standards and criteria for the reuse of treated wastewater were issued by the Water Authority of Jordan and the Ministry of Water and Irrigation in past three decades. Jordanian Standard 893 that it is dedicated for irrigation by treated wastewater was approved in 2006. Several additional regulations were issued that include Standard 893/2006 for Reclaimed Domestic Wastewater, Jordan Standard 202/2007 for Industrial Reclaimed Wastewater and Jordanian Standard No. 1766/2014 for Irrigation Water Quality Guideline.

In 2008, however, the Permanent Technical Committee for Water and Wastewater of the Jordan Standards and Metrology Organization approved the first Jordanian standard to control greywater reuse in Jordan and reusing reclaimed greywater in restricted irrigation uses (JS 1776/2008). This standard was subjected to an update to include all irrigation purposes and use restricted to surface soil around plants and not directly on plant leaves (JS 1776/2013) (JSMO 2013; Assayed *et al.* 2018; UN Habitat 2019; Alrousan & Dunlop 2020). Table 1 shows the allowable values of the pollution measured parameters for greywater reuse in Jordan based on its end use.

5. THE JORDANIAN EXPERIENCE IN GREYWATER MANAGEMENT

Greywater management constitutes an important issue, particularly in countries with limited water resources such as Jordan. An increasing recognition of greywater reuse has provided a valid alternative water source for purposes of irrigation and toilet flushing. Several related projects have been implemented in Jordan; those led to reducing the average consumption of freshwater for irrigation uses in the range 40–70% per family (Alrousan & Dunlop 2020). Greywater physicochemical characteristics, treatment technologies and typical projects that have been implemented in Jordan are provided and discussed in the following sections.

5.1. Sources of greywater and its physicochemical characteristics

Greywater characteristics depend on its source; for example, greywater produced by washing machines and dishwashers contains a variety of substances. These substances include chemical compounds that are derived from clothes' colors, detergents, suspended solids such as organic materials and others. Pollutants in greywater can be classified into chemical, physical, and biological categories including microorganisms. Furthermore, their concentration is variable with time, source and type of water usage.

Greywater samples were collected for analysis by INWRDAM from various geographic zones in Jordan. Sample locations included Tafila (12 households' samples, 6 samples in Phase I of the project of INWRDAM, 6 samples of Ministry of Planning project in Ruwem and Busera); Karak (8 households' samples) and Irbid Governorate (3 households' samples) (DPMN 2004). The samples were analyzed at the National Centre for Agricultural Research and Transfer of Technology and Water Authority of Jordan laboratories (DPMN 2004). Table 2 provides the physicochemical characteristics of untreated and treated greywater collected from difference areas in Jordan (McIllwaine 2003a; Suleiman *et al.* 2005, 2010; Jamrah *et al.* 2006; Ammari *et al.* 2014).

Compared to dark greywater, light greywater in Jordan is less contaminated by microorganisms (coliform and non-coliform bacteria), which total $1.52\ \text{x}10^6$ and 2.12×10^4 CFU/100 ml, respectively. The average BOD_5 and COD concentrations values of greywater are 724.5 and 1,986.6 mgL^{-1}, respectively. Cossu *et al.* (2012) used the ratio BOD_5/COD to calculate the

Table 1 | Jordanian greywater standards (JS 1776/2013)[a]

Parameter	Irrigating cooked vegetables, gardens green lands and other crops	Irrigating raw eaten vegetables	Toilet flushing
BOD_5 (mg L^{-1})	60	60	≤10
COD (mg L^{-1})	120	120	≤20
TSS (mg L^{-1})	100	50	≤10
pH	6–9	6–9	6–9
NO_3 (mg L^{-1})	70	70	70
ions (as Cl^-; SO_4^{2-})	500	500	500
Total nitrogen, TN (mg L^{-1})	50	50	50
Total phosphorous, TP (mg L^{-1})	15	15	15
Turbidity (NTU)	Not available	Not available	≤5
Electrical conductivity, EC (μS cm^{-1})	Not available	Not available	Not available
E.coli (CFU/100 ml)	10^4	10^3	<10
Intestinal helminths, egg nematodes (egg number L^{-1})	≤1	≤1	≤1
Fat, oil and grease, FOG (mg L^{-1})	8	8	8

[a]Ref. JSMO (2013).

biodegradability, which was found to be 0.36 for all source types. This value is indicative of the stability of the organic loads present in the greywater (Halalsheh *et al.* 2008; Cossu *et al.* 2012).

The average values for all the physicochemical parameters of greywater in Jordan exceed the limits of the latest Jordanian standards for greywater reuse that are reported in Table 1, except for the pH value, which is in the accepted range. This implies that the greywater in Jordan must be adequately treated to be reusable and safe for various reuses.

5.2. Utilized greywater treatment technologies

Several greywater treatment technologies have been developed and adapted in Jordan. Table 3 summarizes the typical technologies that are adapted in Jordan. However, there are mainly two widely used on-site household treatment systems that are known as 'autonomous water management'. These are briefly described below:

Simple screen filter: The system is used to treat particle materials and thus protect the irrigation pipes. It is widely used to irrigate plants such as ornamental shrubs and trees around the house in the rural areas. The screen filter, however, requires periodic maintenance and cleaning.

Sedimentation system: the system uses simple septic tanks that allow suspended particles in greywater to flow slowly and settle down at the bottom of the tank, thereby providing purification of the greywater. Usually, it uses one or more sealed barrels standing in a hole outside the house. In some cases, an installed sensor activates pumping when the greywater reaches a certain level. Activated charcoal is used rarely to reduce bad odors.

5.3. Typical greywater reuse projects

Jordan has a valuable experience in reusing greywater; this is demonstrated by the realization of numerous projects in almost all over the Jordanian territories. The projects were piloted and managed over the past 30 years, to meet their objectives such as socio-economic, environmental and health benefits (Sarant *et al.* 2016). The main purposes of greywater reuse projects conducted in Jordan were for irrigation and Toilet flushing. In the year 2003, the usage of greywater was extended to over than 90 villages in the rural areas of Jordan with support from INWRDAM, CARE International and the Ministry of Planning and International Cooperation in Jordan (Bino & Al-Beiruti 2007).

Three successful projects on greywater reusing of rural households to irrigate the shrub and trees planted in their own yards were tested in Adasiyyah, north of Jordan (McIllwaine 2003a). In the first experiment, the greywater produced by dish washing and clothes washing was stored in an open natural pool without treatment, then it was manually used to irrigate olive trees via plastic buckets. In the second experiment, the washing water was routed directly into a row of banana and olive trees.

Table 2 | Physical, chemical and biological characteristics of greywater produced from different sources and regions in Jordan

	Parameter (unit)													
Classification of greywater sources	**pH**	**Electrical conductivity (μS cm^{-1})**	**TDS (mg L^{-1})**	**TSS (mg L^{-1})**	**BOD_5 (mg L^{-1})**	**COD (mg L^{-1})**	**Total Nitrogen, TN (mg L^{-1})**	**Total phosphorous, TP (mg L^{-1})**	**Potassium K (mg L^{-1})**	**Boron, B (mg L−1)**	**Methylene blue active substances, MBAS (mg L^{-1})**	***E. coli* (CFU/ 100 ml)**	**Fat, oil and grease, FOG (mg L^{-1})**	**References**
Untreated greywater collected from the place of ablution at King Abdullah Mosque in May 2003	7.2	8,400	NA	NA	23	NA	NA	NA	NA	0.53	NA	700	NA	McIllwaine (2003a)
Greywater collected from shower in a typical household in the city of Amman	7.42	89,000	565	94	40.2	77	10.9	1.12	NA	NA	NA	NA	NA	Jamrah *et al.* (2006)
Greywater collected from ablution and hand washing places	7.6	1,836		573	597	1,489	105	26	NA	NA	28	3.00E+04	124	Halalsheh *et al.* (2008)
	8.3	2,812	1,271	698	650	1,915	177	34	11	1.6	43	4.70E+04	164	Suleiman *et al.* (2005, 2010)
	6.9	859	567	448	544	1,063	33	18	11	0.4	12	7.20E+03	84	Suleiman *et al.* (2005, 2010)
Greywater collected from laundry in a typical household in the city of Amman	8.98	703,000	2,444	209	44.3	58	14.3	51.58	NA	NA	NA	NA	NA	Jamrah *et al.* (2006)
Untreated greywater collected from an automatic washing machine from a household in Amman, it was stored for 18 hours before the analysis test conducted.	7.4	138,000	NA	NA	103	NA	NA	NA	NA	5.85	NA	1.60E+07	NA	McIllwaine (2003a)
Same above, but it was stored for 4 weeks in a sealed barrel standing outside the house before the analysis test conducted.	7.5	149,000	NA	NA	48	NA	NA	NA	NA	5.73	NA	1.60E+06	NA	McIllwaine (2003a)
Greywater collected from kitchen sink	5.5	870	649	655	827	1,852	31	32	9	0.8	46	2.50E+05	124	

(*Continued.*)

Table 2 | Continued

Classification of greywater sources	pH	Electrical conductivity (μS cm^{-1})	TDS (mg L^{-1})	TSS (mg L^{-1})	BOD_5 (mg L^{-1})	COD (mg L^{-1})	Total Nitrogen, TN (mg L^{-1})	Total phosphorous, TP (mg L^{-1})	Potassium K (mg L^{-1})	Boron, B (mg L–1)	Methylene blue active substances, MBAS (mg L^{-1})	*E. coli* (CFU/ 100 ml)	Fat, oil and grease, FOG (mg L^{-1})	References
														Suleiman *et al.* (2005, 2010)
	5.8	875	821	527	832	1,930	33	9	10	0.6	88	6.60E+04	226	Suleiman *et al.* (2005, 2010)
	5.6	1,357	918	410	1,092	2,085	80	13	6	1.7	36	1.90E+04	147	Suleiman *et al.* (2005, 2010)
	5.4	1,163	934	985	1,648	3,109	58	19	17	0.6	51	2.50E+06	85	Suleiman *et al.* (2005, 2010)
	5.58	1,066		644	1,100	2,244	51	18.25	NA	NA	55	7.00E+05	146	Halalsheh *et al.* (2008)
Greywater collected from sink in a typical household in the city of Amman	7.7	97,000	619	203	40.8	85	6.44	0.69	NA	NA	NA	NA	NA	Jamrah *et al.* (2006)
Mixed greywater without kitchen sink	7.3	2,422	1,409	1,789	1,285	3,202	186	25	21	0.8	77	1.70E+05	257	Suleiman *et al.* (2005, 2010)
	7.2	2,373	1.724	1,569	1,423	5,501	90	25	7	0.7	207	1.00E+06	405	Suleiman *et al.* (2005, 2010)
	7.25	2,398		1,679	1,354	4,352	138	25	NA	NA	142	6.00E+05	331	Halalsheh *et al.* (2008)
Mixed greywater except kitchen and ablution sinks	7.3	1,286	793	810	657	1,543	75	25	20	1	53	2.30E+04	91	Suleiman *et al.* (2005, 2010)
	8.2	2,496	1,138	558	716	1,745	200	29	31	0.6	54	6.40E+05	67	
Mixed greywater	7.0	2,100	1,140	700	977	2,257	161	16	27	1	45	9.30E+04	202	Suleiman *et al.* (2005, 2010)
	5.7	1,560	1,007	990	1,134	2,878	94	23	21	0.7	33	2.80E+05	319	Suleiman *et al.* (2005, 2010)
	6.35	1,830	NA	845	1,056	2,568	128	19.5	NA	NA	39	2.00E+05	261	Halalsheh *et al.* (2008)
	7.81	191,000	893	168	41.2	78	9.17	8.98	NA	NA	NA	NA	NA	Jamrah *et al.* (2006)
Untreated greywater, average values	5.44	232,250	2,021.5	508	1,155	1,688	NA	NA	NA	N	NA	2.21E+05	NA	Ammari *et al.* (2014)
Average of light greywater	**7.5**	**20,581.4**	**801.0**	**453.3**	**370.8**	**1,136.0**	**81.5**	**19.8**	**11.0**	**0.8**	**27.7**	**2.12E+04**	**124.0**	
Average of dark greywater	**6.8**	**80,634.0**	**1,056.3**	**779.4**	**817.5**	**2,186.8**	**84.7**	**21.3**	**16.9**	**1.7**	**71.2**	**1.52E+06**	**204.7**	
Overall average	**6.9**	**68,123.0**	**1,011.2**	**717.2**	**724.5**	**1,986.6**	**84.0**	**21.0**	**15.9**	**1.5**	**63.1**	**1.22E+06**	**189.6**	

Table 3 | Typical greywater treatment technologies adapted in Jordan

#	Method of greywater treatment	Reference
1	Photoreactor systems: combining different treatment methods of advanced oxidation processes (AOPs) such as ozonation (O_3), solar ozonation (O_3/solar irradiation), hydrogen peroxide oxidation (H_2O_2), hydrogen peroxide under solar irradiation (H_2O_2/solar irradiation), peroxonation (H_2O_2/O_3), and solar peroxonation (H_2O_2/O_3/solar irradiation).	Alrousan & Dunlop (2020)
2	Three different treatment methods: septic tank followed by intermittent sand filter; septic tank followed by wetlands; and UASB-hybrid reactor.	Halalsheh *et al.* (2008)
3	Drawer compacted sand filter (DCSF).	Assayed *et al.* (2015)
4	A septic tank followed by an aerobic biochar filter.	Dalahmeh *et al.* (2016)
5	A re-circulated vertical flow bioreactor.	Ammari *et al.* (2014)

However, the landlord has noticed that the banana trees had a stress reaction to the laundry water while the olive trees did not; therefore, the laundry water was diverted to irrigate the olive trees only. The last experiment was conducted in a house with one water tap, which supplied water for all household uses. Greywater was naturally flowed to plant roots slowly without storage or treatment along with any occasional rain. No adverse effects were noticed on the roots of the trees due to irrigation using the greywater (McIllwaine 2003b).

Another pioneer experiment was the reuse of the ablution waters of the King Abdullah Mosque in Amman; the water was collected and stored on the roof, then it was filtered and reused to irrigate the ornamental plants in the mosque park. No adverse effects were observed on plants after five years of greywater use. Furthermore, the project costs were recovered within one year of project execution due to the savings made in the bill of water consumption (McIllwaine 2003a).

Several projects were also conducted in the southern part of Jordan: namely in the Karak and Tafila provinces. The Tafila project had a duration of two years staring 1st of May 2001 to the 30th of April 2003. It was founded in favor of a small number of households in Ein AlBaida village, province of Tafila. In this project, twenty-five greywater treatment and reuse systems were designed, constructed and installed. The goals were to help the peri-urban poor people to generate income by preserving freshwater and improving gardening with permaculture practices. Furthermore, the systems will provide an environment protection by encouraging best greywater treatment practices application. The project was implemented by INWRDAM and funded by the IDRC (DPMN 2004).

In Karak, a project was implemented between February 2004 and October 2007. In this project has a total 110 units of greywater systems were installed. The quality of treated of greywater that obtained by this project was in accordance with both Jordanian and WHO guidelines for the use of treated wastewater (Bino *et al.* 2010). The projects of Tafila and Karak were connected by goals and so called 'Phase I' and 'Phase II', respectively (DPMN 2004; Bino *et al.* 2010).

Another project was conducted in Rawdat Al-Amir Ali village in the northeastern Badia of Jordan during the period March–August 2005. Members of the local community were also involved in all project activities including a training seminar on the use of project methodologies and tools. Another two pilot plants were designed and installed for two families using two different treatment methods; a septic tank followed by an intermittent sand filter, and a septic tank covered with upward anaerobic sludge (up-flow anaerobic sludge blanket (UASB reactor)). The generated greywater quality and quantity were assessed for potential reuse opportunities; however, the quality of greywater must be firstly improved to take into consideration health aspects. Furthermore, it is not recommended to use the World Health Organization guidelines of 1989 as a reference guide lines (Suleiman *et al.* 2010).

Table 4 provides a summery data of typical greywater reuse projects that have been implemented in several Jordanian regions. These projects were implemented by Environmental, Social Management & Monitoring Plan (ESMMP), which includes necessary mitigation measures of environmental impacts (UN Habitat 2019).

6. CONCLUSIONS

Greywater could provide a vital source of water that contributes to the reduction of freshwater consumption and enhance its sustainability. However, adequate greywater reuse technologies need to be properly implemented. The present work aimed to

Table 4 | Summery data of typical greywater reuse projects implemented in Jordan

#	The study	Area	Average greywater generation	Purpose of greywater reuse	Reference
1	Integrated Wastewater Management Policies and Technologies for Marginal Communities in Jordan	Small villages in Mafraq governorate	14 (L/c.d)	irrigation	Halalsheh *et al.* (2008)
2	An Evaluation of the Re-circulated Vertical Flow Bioreactor to Recycle Rural Greywater for Irrigation	South-Shuna in the Jordan Valley	200 (L/c.d)	irrigation	Ammari *et al.* (2014)
3	The Feasibility of Adopting Non-Conventional Wastewater Management Policies for Rural Small Communities	Northeastern Badia	11.9–18.7 (L/c.d)	irrigation	Suleiman *et al.* (2005)
4	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	Rehab Secondary Agricultural School for Girls in Mafraq	400 (L/d)	irrigation	Assayed *et al.* (2018)
5	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	Al-Rubaie Primary School for Girls in Mafraq	500 (L/d)	irrigation	Assayed *et al.* (2018)
6	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	HRH-Princess Muna Centre for the care of the elderly in Zarqa	1,800 (L/d)	irrigation	Assayed *et al.* (2018)
7	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	Badr Al-Koubra Secondary School Girls in Zarqa	500 (L/d)	toilet flushing	Assayed *et al.* (2018)
8	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	Saqr Quraish Primary School for Boys in Ajloun	800 (L/d)	irrigation	Assayed *et al.* (2018)
9	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	Ajloun University College/Applied Balqa University in Ajloun	140 (L/d)	toilet flushing	Assayed *et al.* (2018)
10	Enhancing Resilience of Host Communities in Jordan by Promoting Sustainable Water Solutions	Al-Housn College/Applied Balqa University in Irbid	300 (L/d)	toilet flushing	Assayed *et al.* (2018)
11	Grey Water Reuse for Agricultural Purposes in the Jordan Valley	Deir-Alla municipality, Um-Ayyaash area	50 (L/d)	irrigation	Al-Mashaqbeh *et al.* (2012)
12	Greywater Treatment and Reuse for Poverty Reduction in Jordan	Households in Ein Al-Baida, Tafila	$<$ 500 (L/d)	irrigation	DPMN (2004); Bino & Al-Beiruti (2007); Bino *et al.* (2010)
13	Greywater Use in Rural Home Gardens in Karak Province	Al-Amer villages, Karak	200–300 (L/d)	irrigation	Bino & Al-Beiruti (2007); Bino *et al.* (2010)
14	Greywater Management in the Northeastern Badia of Jordan	Rawdat Al-Amir Ali	12–19 (L/c.d)	irrigation	Suleiman *et al.* (2010)
15	Environmental and Social Impact Assessment, Risks Management and Monitoring Plan	Mosques in the villages: Hashimya, Nuzha, Barha, Rabia, and Al Amanarha (Irbid), Zaatari farms (Mafraq)	NA	irrigation	UN Habitat (2019)

provide a review of the Jordanian experience in greywater reuse over the past 30 years in the country's search to find an efficient solution to the scarcity of water resources.

The Jordanian experience in greywater reuse is characterized by: (a) greywater projects were implemented in rural areas that severely suffer from the lack of water for various purposes; (b) most projects are based locally, using on-site household implemented systems, or the so called 'autonomous water management'; (c) the projects provided a valid support to the economic setting of urban regions inhabitants; (d) the projects contributed to raising the local public awareness towards water sustainability and the alternative methodologies of best practices of greywater reuse.

Furthermore, the physicochemical characteristics of greywater in Jordan were found to exceed the latest Jordanian standards for agricultural uses. Therefore, specific further treatment processes might deem necessary to avoid any controversy effects of the reuse of greywater.

In addition, the reuse of greywater in Jordan is still limited and needs to be expanded geographically to include most of the Jordanian regions. It seems, however, that financial issues represent the main obstacle to achieving this prospect. In particular, it is not financially convenient for families that consume a small amount of water due to the expensive cost of the treatment system taking in consideration the long time needed to recover the existing system modification costs. Furthermore, the greywater drainage system in the newly constructed homes is not separated from the black water due to lack of public awareness and the lack of appropriate regulations.

In conclusion, the overall Jordanian experience in greywater reuse, however, merits consideration for various reasons; it has been experimented over a period of three decades and has been implemented in numerous rural areas that lack sanitary systems and sustainable water resources for agricultural activities. The lessons learned from the extended Jordanian greywater reuse experience have different aspects. First, the experience proves the effectiveness of using simple treatment greywater plants in mitigating the problem of water shortage in rural areas in terms of saving freshwater consumption. Second, several simple low-cost technologies such as septic tank and sand filter methods are available and proved efficient. Finally, the selection of the most adequate greywater treatment system is based on the intended application; the operational, safety and environmental consequences of the system must also be taken into consideration.

AVAILABILITY OF DATA AND MATERIALS

All the data analyzed in this research were collected from published literature and are duly cited in this publication.

COMPETING INTERESTS

The authors declare they have no competing interests.

AUTHORS' CONTRIBUTIONS

Al Arni Saleh and Elwaheidi Mahmoud developed the research idea. Both authors have also contributed to writing the manuscript. Alsammani A. M. Salih, Djamel Gheraout and Mohammed Matouq have contributed in literature and manuscript review. All authors read and approved the final manuscript.

ACKNOWLEDGEMENTS

This research has been funded by the Research Deanship of University of Ha'il, Saudi Arabia, through the Project RG-20 113.

DATA AVAILABILITY STATEMENT

All relevant data that are cited in this paper were obtained from numerous references in the published literature. The links to these references are reported in the References section.

REFERENCES

Abu, G. & Lina, N. 2009 *Characterization and Treatment of Grey Water; Options for (re) use. Ph.D. Dissertation*, Wageningen Universiteit, The Netherlands. ISBN 978-90-8585-393-0. https://edepot.wur.nl/7849 Available on date 10/12/2021.

Abu Saud, R. 2009 *Report ' Water for Life: Jordan's Water Strategy 2008–2022*. PDF File, available in date 10/12/2021. Available from: https://jordankmportal.com/resources/download?id=water-for-life-jordans-water-strategy-2008-2022

Al Arni, S. 2014 Treatment and recycling of water resulting from the ablution and homes for help in solution of the water crisis in most countries of Islamic World. *Journal of King Saud University – Engineering Science* **1018–3636** (26), 15–36.

Al Arni, S. & Elwaheidi, M. 2021 *Concise Handbook of Waste Treatment Technologies*. CRC press, Taylor & Francis Group, New York, USA. ISBN:978-0-367-63130-7.

Al Arni, S., Ghareba, S., Solisio, C., Palma, M. S. A. & Converti, A. 2021 Methods of reactive red 141 dye decolorization, treatment, and removal from industrial wastewaters: a critical review. *Environmental Engineering Science* **38** (7), 577–591. http://doi.org/10.1089/ees.2020.0338.

Albalawneh, A. & Chang, T.-K. 2015 Review of the greywater and proposed greywater recycling scheme for agricultural irrigation reuses. *International Journal of Research – Granthaalayah* **3** (12), 16–35.

Al-Jayyousi, O. R. 2003 Greywater reuse: towards sustainable water management. *Desalination* **156** (1), 181–192. https://doi.org/10.1016/S0011-9164(03)00340-0.

Al-Mashaqbeh, O. A., Ghrair, A. M. & Megdal, S. B. 2012 Grey water reuse for agricultural purposes in the Jordan valley: household survey results in deir alla. *Water* **4** (3), 580–596. https://doi.org/10.3390/w4030580.

Alrousan, D. M. A. & Dunlop, P. S. M. 2020 Evaluation of ozone-based oxidation and solar advanced oxidation treatment of greywater. *Journal of Environmental Chemical Engineering* **8** (5), 104309. Available from: https://www.sciencedirect.com/science/article/pii/S2213343720306588.

Ammari, T. G., Al-Zu'bi, Y., Al-Balawneh, A., Tahhan, R., Al-Dabbas, M., Ta'Any, R. A. & Abu Harb, R. 2014 An evaluation of the re-circulated vertical flow bioreactor to recycle rural greywater for irrigation under arid Mediterranean bioclimate. *Ecological Engineering* **70**, 16–24. http://dx.doi.org/10.1016/j.ecoleng.2014.03.009.

Assayed, A., Hatokay, Z., Al-Zoubi, R., Azzam, S., Qbailat, M., Al-Ulayyan, A., Saleem, M. A., Bushnaq, S. & Maroni, R. 2013 On-site rainwater harvesting to achieve household water security among rural and peri-urban communities in Jordan. *Resources, Conservation and Recycling* **73**, 72–77. https://doi.org/10.1016/j.resconrec.2013.01.010.

Assayed, A., Chenoweth, J. & Pedley, S. 2015 Assessing the efficiency of an innovative method for onsite greywater treatment: drawer compacted sand filter – a case study in Jordan. *Ecological Engineering* **81**, 525–533. https://doi.org/10.1016/j.ecoleng.2015.04.042.

Assayed, A. M., Hazaymeh, A., Ayyash, R., Mashatleh, M., Al Ziq, N., Ardah, R., Jibril, F., Sa'doun, M. & Alhaj Qasem, M. 2018 *Greywater Treatment and Reuse, and Rainwater Harvesting and Collection at Home Guideline, English Version*. Royal Scientific Society Project Report of Water Studies Division, Water and Environment Centre, and Royal Scientific Society. Available from: https://www.researchgate.net/publication/325499152_Guideline_for_greywater_treatment_and_reuse_and_rainwater_harvesting_and_collection_at_home_-_English_Version available on date 10/12/2021.

Bino, M. J. A. & Al-Beiruti, S. N. 2007 *Studies of IDRC Supported Research on Greywater in Jordan Conducted by INWRDAM*. Outcomes of the 'Greywater Treatment and Reuse for Poverty Reduction in Jordan (Phase II)' Project, February 2004 to October 2007, Published by INWRDAM October 2007. Available from: https://inwrdam.org.jo/wp-content/uploads/2018/07/INWRDAM-booklet-on-greywater-research-outcomes-2008-English-Version.pdf available on date 10/12/2021.

Bino, M., Al-Beiruti, S. & Ayesh, M. 2010 Greywater use in rural home gardens in Karak, Jordan. In: *Greywater Use in the Middle East Technical, Social, Economic and Policy Issues* (McIlwaine, S. & Redwood, M. eds.), Warwickshire, UK. ISBN 978 1 55250 466 6 (e-book).

Christova-Boal, D., Eden, R. E. & Mcfarlane, S. 1996 An investigation into greywater reuse for urban residential properties. *Desalination* **106** (1), 391–397. https://doi.org/10.1016/S0011-9164(96)00134-8.

Cossu, R., Lai, T. & Sandon, A. 2012 Standardization of BOD5/COD ratio as a biological stability index for MSW. *Waste Management* **32** (8), 1503–1508. https://doi.org/10.1016/j.wasman.2012.04.001.

Dalahmeh, S. S., Lalander, C., Pell, M., Vinneras, B. & Jonsson, H. 2016 Quality of greywater treated in biochar filter and risk assessment of gastroenteritis due to household exposure during maintenance and irrigation. *Journal of Applied Microbiology* **121**, 1427–1443. https://doi.org/10.1111/jam.13273.

DPMN (Development planning and management network) 2004 *Report 'Post Project Evaluation of Greywater Treatment and Reuse Project in Tafila, Jordan'*. Development planning and management network, Canada. Available from: https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/31892/121749.pdf available on 10/01/2021.

Friedler, E., Kovalio, R. & Ben-Zvi, A. 2006 Comparative study of the microbial quality of greywater treated by three on-site treatment systems. *Environmental Technology* **27** (6), 653–663. https://doi.org/10.1080/09593332708618674.

Halalsheh, M. & Kassab, G. 2018 Setting the policy framework for wastewater irrigation: Jordanian experience. In: *Safe Use of Wastewater in Agriculture* (Hettiarachchi, H. & Ardakanian, R. eds.). UNU-FLORES, pp. 75–99. doi:10.1007/978-3-319-74268-7_5.

Halalsheh, M., Dalahmeh, S., Sayed, M., Suleiman, W., Shareef, M., Mansour, M. & Safi, M. 2008 Grey water characteristics and treatment options for rural areas in Jordan. *Bioresource Technology* **99** (14), 6635–6641.

Hammouri, N., Adamowski, J., Freiwan, M. & Prasher, S. 2017 Climate change impacts on surface water resources in arid and semi-arid regions: a case study in northern Jordan. *Acta Geodaetica et Geophysica* **52** (1), 141–156. https://doi.org/10.1007/s40328-016-0163-7 and http://real.mtak.hu/86556/1/40328_2016_163_OnlinePDF.pdf.

Hussein, H. 2018 Lifting the veil: unpacking the discourse of water scarcity in Jordan. *Environmental Science & Policy* **89**, 385–392. https://doi.org/10.1016/j.envsci.2018.09.007.

Jamrah, A. & Ayyash, S. 2008 Greywater generation and characterization in major cities in Jordan. *Jordan Journal of Civil Engineering* **2** (4), 376–390.

Jamrah, A., Al-Omari, A., Al-Qasem, L. & Ghani, N. A. 2006 Assessment of availability and characteristics of greywater in Amman. *Water International* **31** (2), 210–220. Available from: https://doi.org/10.1080/02508060.2006.9709671.

JSMO (Jordan Standards and Metrology Organization) 2013 Greywater Jordanian Standard JS:1776/2013.

Mcillwaine, S. 2003a *Graywater Reuse in Jordan*. Center for the Study of Built Environment (CSBE). Available from: https://www.csbe.org/greywater-reuse-in-jordan Available on date 10/12/2021.

Mcillwaine, S. 2003b *Graywater Reuse in Other Countries and its Applicability to Jordan*. Center for the Study of Built Environment (CSBE). Available from: https://www.csbe.org/greywater-reuse-in-other-countries available on date 10/12/2021.

Mustafa, D., Altz-Stamm, A. & Scott, L. M. 2016 Water user associations and the politics of water in Jordan. *World Development* **79**, 164–176. https://doi.org/10.1016/j.worlddev.2015.11.008.

Sarant, L., Kassam, S., Swelam, A. & George, B. 2016 *How to Scale-up Greywater Reuse in Jordan and Egypt*. Available from: https://wle.cgiar.org/how-scale-greywater-reuse-jordan-and-egypt available on date 10/12/2021.

Stanley, B. 2010 *Case Study: Jordan – Dealing with the Water Deficit in Jordan. Recycling Household Water to Irrigate Home Gardens Makes Good Environmental and Financial Sense*. IDRC – International Development Research Centre. Available from: https://www.idrc.ca/en/research-in-action/case-study-jordan-dealing-water-deficit-jordan available on date 10/12/2021.

Suleiman, W., Hayek, B. & Assayed, M. 2005 Integrated wastewater management for small communities in Jordan. In *EMPOWERS Regional Symposium: End-Users Ownership and Involvement in IWRM*, 13–17 November 2005, Cairo, Egypt. Available from: https://www.researchgate.net/publication/268418212_Integrated_Wastewater_Management_For_Small_Communities_in_Jordan

Suleiman, W., Al-Hayek, B., Assayed, M., Dalahmeh, S. & Al-Hmoud, N. 2010 Greywater management in the northeastern Badia of Jordan. In: *Greywater Use in the Middle East Technical, Social, Economic and Policy Issues* (McIlwaine, S. & Redwood, M. eds.). Warwickshire, UK. ISBN 978 1 55250 466 6 (e-book).

Ulimat, A. A. 2012 Wastewater Production, Treatment, and Use in Jordan. In *Second Regional Workshop 'Safe Use of Wastewater in Agriculture'*, 16–18 May 2012, New Delhi, India.

UN Habitat, Report 2019 *Environmental and Social Impact Assessment (ESIA) & Environmental and Social Risks Management & Monitoring Plan (ESMMP)*. Available from: https://unhabitat.org/sites/default/files/2020/03/4._af_jordan_environmental_and_social_risk_screening_and_impact_assessment_report_incl._esmp.pdf available on date 10/12/2021.

WHO (World Health Organization) 2006 *Guidelines for the Safe use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture*, Vol. 1. Policy and regulatory aspects and summary of the guidelines. World Health Organization. Available from: https://apps.who.int/iris/handle/10665/78265. Available on date 10/12/2021.

First received 11 December 2021; accepted in revised form 23 February 2022. Available online 7 March 2022