Assessing the efficiency of an innovative method for onsite greywater treatment: Drawer compacted sand filter – A case study in Jordan

Almoayied Assayed^{a*}, Jonathan Chenoweth^b, Steven Pedley^b

^{a*} Royal Scientific Society, Water and Environment Centre, P.O. Box 1438, Amman 11941, Jordan

^b University of Surrey, Centre for Environmental Strategy GU2 7XH UK

This study evaluated the performance of a new treatment method for greywater called the Drawer Compacted Sand Filter (DCSF). This is a modified sand filter design in which the sand filter is broken down into several layers approximately 10 cm high, each of which is placed in a movable drawer that is stacked vertically, with each drawer separated by 10 cm of space. This treatment unit is seeking to overcome the problems commonly found in traditional sand filter designs, such as clogging, emission of bad odours and need for a large land area to house the filter. Nine pilot DCSF units were operated at different locations in Jordan during the period of 2011–2013. Composite water samples from the inlet and outlets of the DCSF over a period of 18 months were taken periodically and tested for BODs, COD, TSS, pH, EC and E.coli. A socio-economic study was conducted to evaluate the validity and feasibility of the DCSF. The results showed that DCSF removed 78–96% of BODs and COD and 69–98% of TSS. E.coli removal was various across the DCSF units, ranging from 1 log to 6 logs. The focus group discussion and the analysis of economic benefits showed that DCSF unit was acceptable and feasible treatment method for greywater with minimal maintenance requirements.

1. Introduction

The per capita availability of fresh water has declined significantly in recent years, yet 35–60% of scarce freshwater is currently being used for purposes that do not require that high water quality such as irrigation and toilet flushing (Karpiscak et al., 1990; Venot et al., 2007). Therefore, using alternative water resources, such as greywater, is crucial to lowering demands on limited freshwater resources.

Treatment technologies for greywater are many and diverse (Al-Jayyousi, 2003). However, major shortcomings have been identified for each treatment technique tested for greywater (Table 1), implying the importance of finding out a new treatment method, that can overcome problems commonly found in other greywater treatment methods.

The aim of this paper is to present the results of piloting a new method for greywater treatment called a “Drawer compacted sand filter (DCSF)”. DCSF is a modified design for a sand filter in which the sand layer is broken down into several layers, each of which is 10 cm high and placed in a movable drawer separated by 10 cm of air space from other layers. The new treatment design was based on two hypotheses: by placing the treatment media in separated movable drawers, oxygen access to the layers is facilitated, thus

improving the filter efficiency and facilitating maintenance requirements; and the second hypothesis was that DCSF can remove a high percentage of pollutants in greywater with minimum space requirements and consequently would allow sand filters to be used in locations where space is at a premium, such as dense urban areas, and the low maintenance requirements mean that a wide range of users could easily operate the DCSF. These hypotheses have been tested under laboratory conditions, where a bench scale of DCSF, with 75 cm width X 75 cm length X 1.6 m depth and 6 drawers, was designed and operated for 330 days and fed by synthetic greywater (Assayed et al., 2014). The results of the bench scale showed that DCSF was efficient and has a low maintenance requirement under laboratory conditions and could be piloted in the field. This paper documents the results of nine pilot units for greywater treatment which were designed and installed at different urban and peri-urban locations in Jordan in the period of 2011–2013. Composite water samples from inlet and outlets of the DCSF over the period of 18 months were taken periodically and tested for BOD₅, COD, TSS, pH, EC and E.coli. The perceptions and experiences of the users of the pilot units were evaluated using focus groups, and the cost effectiveness of the units was calculated. The paper evaluated the efficiencies of these field testing units in terms of organic and pathogens removal, and were then compared with the national Jordanian standards for reclaimed water.

2. Methodology

2.1. Site of study

The field sites were selected in four different regions of Jordan: in the Sweileh and Sahab districts of the Amman governorate, the Madaba governorate, the Tafeileh governorate and the Ma'an governorate (Fig. 1). The area selection was based on the following criteria:

1. Urban settings (i.e. not enough space to implement traditional sand filtration as houses are close to each other and thus sufficient land area is lacking).
2. Potential for reuse (i.e. agricultural activities).
3. Plumbing system (i.e. greywater is separated from black water or could easily be separated).

4. Not served by a central sewerage system.

5. Where possible, that they have had a previous experience with greywater reuse systems in order to allow a comparison between the previous experience with the current system.

2.2. Greywater separation and collection

In most cases where DCSF were installed, the separation of greywater from black water was uncomplicated. In a few locations, the separation required some excavation works including removing wall tiles and redirecting pipes. Based on the estimated greywater volume, a cylindrical tank with a volume that ranged from 0.5 m³ to 1 m³ was placed at the discharge point.

2.3. Greywater quality and quantity

Before installing each treatment unit, greywater quality and quantity were investigated. Quantities generated were estimated by collecting water in cylindrical tank and then measuring the height of collected greywater on daily basis. The formula of cylinder volume was used to calculate the quantity of greywater (i.e. $\pi r^2 h$). Composite samples were collected weekly for one month and several parameters were tested.

2.4. Pilot units' set up

Based on the laboratory experiments and the variations in greywater quality and quantity, DCSFs were designed and fabricated. The laboratory trials showed that one rack with 6 perforated drawers was efficient to deal with up to 142 L m⁻² day⁻¹ and 30 g BOD₅ m⁻² day⁻¹ of hydraulic and organic loading rate, respectively (Assayed et al., 2014). A metal rack was fabricated at a metal workshop located in Amman. Six PVC drawers with dimensions of 75 cm X 75 cm X 14 cm were obtained and placed on the rack (Fig. 2). Each drawer, except the lowest drawer, was perforated with a 10 cm spacing between orifices and a dimension of 4 mm each (Fig. 2b). The lowest drawer was linked with a 200 PVC pipe to transfer the treated water to the effluent tank. A distribution manifold was designed and placed above the top drawer by 8–10 cm space. The space between laterals in the distribution manifold was 11 cm, between orifices was 10 cm and the diameter of each

orifice was 3 mm (Fig. 2c). The media used for treatment was gravels and silica sand, arranged as following: gravels with 2.5 effective size placed in drawer one – at the top-, silica sand with 1.3 mm effective size was placed in drawers two and three, whereas silica sand with 0.7 mm effective size was used in drawers four and five. The last drawer was filled with gravels and granular activated carbon with 2.5 mm effective size arranged in two separated layers. A submersible pump was used to pump water from the collection tank. This pump was controlled by a digital timer to give eight doses per day, based on Metcalf and Eddy design parameters for the intermittent sand filter (1991). Each unit was preceded by a 1 m³ collection tank, which also acts as sedimentation and dosing tank. The collection tank was provided with overflow pipe, which afterward, was connected to the cesspool that was being used to discharge the wastewater. Table 2 shows the design details for the DCSF installed at the nine locations, including the flow rate and organic loading rate.

2.5. Efficiency and performance of the treatment units

Efficiency of the DCSF treatment system was measured by analyzing greywater samples from two locations:

1. Collection tank: gives the quality of the untreated greywater,
2. Outlet of DCSF: gives the quality of the treated greywater.

Where 72 samples were taken from the collection tank and 58 samples from the outlet in all treatment units over the time period of 18 months. The total number of analyses for all parameters was 345 analyses (Table 3). The samples were analyzed for the physical, chemical and microbiological parameters according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1995). Table 3 shows the method used to analyze each parameter and the number of analyses conducted for each parameter.

2.6. DCSF users' satisfaction

In order to measure the level of satisfaction and the socio-economic impacts of using DCSF units, focus group discussion was conducted with all beneficiaries. Three focus groups were conducted at different locations i.e. Tafeilah governorate, Ma'an governorate and

Amman governorate. Participants for the focus groups were invited from the households that had been provided with a DCSF. In total, 18 participants were invited and attended the focus groups. The participants were divided into three groups; two male groups and one female group. The female group was targeted separately to encourage them to speak freely and share all of their ideas and opinions. Each group had six participants aged between 32 and 58 years. Each focus group session addressed mainly four themes: reliability of the treatment unit, including operation and maintenance; social aspects; health risks and economic benefits. After the focus groups were completed, voice recording files were transcribed and compared to the written notes. All responses and comments were then classified and analyzed according to aforementioned themes.

2.7. Economic benefits

The net present value (NPV) for the cost and revenues was calculated, including the operational and maintenance cost, and for the total revenues, according to the equation of NPV showed below (Eq. (1)). The discount rate was assumed 5%, based on the latest Jordanian figure. The project span is assumed 12 years, based on the expiry time for DCSF components. The calculations were conducted by using Microsoft Excel software (2010):

$$NPV = \sum_{t=0}^n \frac{(Benefits-costs)_t}{(1-r)^t}$$

where

r = discount rate,

t = year,

n = analysis horizon (in years).

3. Results and discussion

3.1. Greywater characteristics

The variation of greywater quality and quantity generated from the different case studies were considerably varied as shown in Table 4. This was expected as the greywater quality and quantity depend substantially on the source of greywater, lifestyle, level of water

supply service, level of occupancy, households' daily activities, number of inhabitants and the geographical location (Eriksson et al., 2009; Jamrah et al., 2008). In this study, including kitchen water to the greywater stream played a major role in increasing the concentration of organic matter and total suspended solids, reaching up to 1350 mg/L and 350 mg/L, respectively. This was in agreement with the findings of Al-Hamaiedeh and Bino (2010), Eriksson et al. (2002), Assayed et al. (2010) and Halalsheh et al. (2008). Excluding kitchen water considerably reduced the organic load and total solids as was shown in dwelling numbers 5, 6 and 9, where BOD₅ ranged from 80–250 mg/L and TSS values were from 30–125 mg/L. The quantity of greywater was also found to be very variable across the different households and fluctuated from less than 100 L per day up to 300 L per day (Table 4).

3.2. Drawer compacted sand filter performance

The performance of each unit was evaluated by taking samples from the influent and effluent on a regular basis. Sampling frequency was related to the stage of operation; start-up stage or steady-state stage. The start-up stage lasted 40 days and aimed at optimizing the hydraulic and organic load according to laboratory trials documented in Assayed et al. (2014). The duration of start-up stage was based on Dalahmeh et al. (2012) study, who tested sand with (1.4 mm) effective size for synthetic greywater treatment and found that 62% of organic pollutants (mainly BOD₅ and COD) was removed from the first day of treatment. According to the same study, the maximum BOD₅ reduction (82%) was observed after 36 days of operation (Dalahmeh et al., 2012).

The samples in start-up stage were collected weekly whereas in steady-state stage, samples were initially collected biweekly, then monthly, and afterward, bimonthly. However, the behavior of the drawer compacted sand filter in removing pollutants during startup and steady-state needs to be further studied in view of their physical characteristics (effective size and specific surface area). Table 4 shows the treatment performance of DCSF for all parameters (average $\pm$ standard deviation)

3.2.1. Performance of DCSF in BOD₅ and COD removal

High treatment efficiency in terms of BOD5 and COD was achieved in DCSF (Table 4). The efficiency of BOD5 removal ranged 78–98% and for COD 76–95%, depending on the source of greywater being treated. The behavior of filter during start-up and steady- state stages had not substantially changed which was in agreement with Dalahmeh et al. (2012) research who observed only 15–20% improvement in removal of BOD5 during the start-up and steady- state stage, when using sand. Pollutants removal i.e. BOD5 and COD, reached in some batches 90%, immediately after starting up and likewise in later stages, which might be attributed to the adsorption characteristics of silica sand. A similar treatment efficiency has been reported for sand filtration, using conventional design sand filters by several researchers. Kang et al. (2007) and Assayed et al. (2010) reported that intermittent sand filters were able to remove 95% of BOD5 and 90% COD from greywater. The ability of sand to remove pollutants was broadly discussed in USEPA manual (2002) and Rodgers et al. (2004) who attributed this ability to physical processes such as straining and sedimentation and to biological process through the formation of a bio-film layer on the upper surface of sand.

3.2.2. Total suspended solids TSS

The ability of sand to remove the solids is highly dependent on the sand's effective size, the hydraulic load, the organic load and the permeability of the sand layers. The TSS removal efficiency in all units fluctuated between 69–98% (Table 4). However, in dwellings 4, the TSS removal efficiency was relatively lower (44%) which was attributed to the elevated operational hydraulic and organic load. The DCSF in dwelling number 4 was designed to receive 10–120 L/day with <30 g BOD5m² day, but the actual hydraulic and organic loads were doubled, as the homeowners included kitchen water in the greywater stream after the treatment unit had been installed, which affected its overall performance. However, according to statistical principles, this value is considered as an outlier as it was lower than the mean by two standard deviations (Gupta and Gao, 2014). The negative impacts of increasing hydraulic and organic loads on the performance of porous media filters are widely discussed in Cuyk et al. (2001); Beach et al. (2005); Torrens et al. (2009) and Dalahmeh et al. (2012), where all showed that increasing the hydraulic and organic loads during operation will increase the hydraulic conductivity, thus reduce the

contact time with treatment media, causing low performance in pathogens, solids and organic removal.

3.2.3. *pH and EC*

Acidic pH was observed in the raw greywater when water from kitchen sinks was included in the greywater stream (dwellings 1, 4, 7 and 8). This was in agreement with Al-Jayyousi (2003) who attributed this to food leftovers and other kitchen waste. Also, acidic pH is probably caused by anaerobic conditions of the raw greywater especially when exhibiting elevated BOD₅ and COD concentration (Chen et al., 2008). Electrical conductivity (EC) in the treated water was more than in the untreated input water, which was attributed to the presence of dust and fine particles within sand layers and the extremely limited salt adsorption capacity of sand (Dalahmeh et al., 2012). Washing up the sand media before being placed in drawers will slightly lower the EC value at the effluent point as noticed by Al-Hamaiedeh and Bino (2010), who used washed gravels for greywater treatment.

3.2.4. *Escherichia coli (E.coli)*

It is well-documented that greywater has a high number of *E. coli*, ranging from 10¹ to 10⁸ cfu/100 mL (Ottosson and Stenstrom, 2003; O'Toole et al., 2012; Winward et al., 2008). Generally, sand filtration is deemed as an attractive option to remove bacteria from wastewater as discussed by Hagedorn et al. (1981) and Gerba (1975) who attributed this to immobilization of bacteria by straining in small sand pores and adhesion between cells and sand media. DCSF ability to remove *E.coli* from the nine greywater units was inconsistent and fluctuated from 1 to 7 logs (Table 4) which, according to Stevik et al. (2004), can be attributed to variations in hydraulic load. As shown in table 2, DCSF was designed based on four wide ranges of flow rates i.e. 10–60; 60–120; 10–120 and 120–240 L/day, whereas the performance of sand in removing bacteria changes with lower intervals (<10 L/day) as demonstrated by Stevik et al. (2004) and Jenkins et al. (2011). Therefore, further studies are required to optimize the DCSF in microbial removal versus lower hydraulic loads.

3.3. *Reuse of the reclaimed greywater*

Greywater produced from the DCSF from all units was in compliance with Jordanian Standards for greywater reuse JS1776:2008 (Jordan Standards and Metrology Organization, 2008). Based on the laboratory analysis, the treated greywater was appropriate for the irrigation of olive and fruit trees, vegetables and ornamental plants.

3.4. Operation and maintenance

The first DCSF unit started working in July 2011 and others were installed and started working between the periods of January 2012 and March 2013. Several operation and maintenance issues were identified which are listed in Table 5.

As shown in the Table 5, sliding out the drawer, mixing up the media and then keeping the drawer off-line for 24–48 h would restore the DCSF filtering media without interpreting the operation of the whole system. These easy maintenance requirements were sufficient to control physical and biological clogging. This reduces unpleasant odors and prolongs the operation of the filter without any breaks or down time for maintenance. This maintenance procedure is very convenient comparing to the laborious procedure in conventional intermittent sand filter where the whole filter must be stopped and the first 5–10 cm of a 6 m² bed must be skimmed out (Assayed et al., 2010).

3.5. DCSF users' satisfaction

The participants' enthusiasm for the DCSF units was generally very high, with most participants openly contributing their ideas and concerns about the system. There were a variety of positive and negative responses in each of the different themes presented. Gender issue (males and females) was not seen as a significant factor in differentiating between male and female perceptions towards the DCSF. The discussion over the technical issues and maintenance requirements took a relatively significant amount of the available time. This was quite normal as the level of users' satisfaction is closely related to their unit's performance and its reliability (Ryan et al., 2009). It was clearly noticed from the discussion with all groups that all users were satisfied with units operation and performance as they were happy with the color and appearance of greywater being produced. When users were asked if the system met their expectations, they all agreed that the DCSF was satisfactory and met their expectations (100% satisfaction). This was in contrast to the

study conducted by Domenech and Sauri (2010) who studied the level of satisfaction for using commercial greywater treatment unit in Spain and found that 60% of users dissatisfied with the greywater units' performance as a result of technical failures and bad odours.

Generally, unpleasant odors were not seen as problematic with the DCSF units as these units were generally placed on the top of roofs or in isolated corners of backyards. Therefore, they were not close to the main living or recreation areas, but in areas with excellent ventilation. However, occasional odors in some DCSF units were noticed but users would deal easily with these odors by carrying out simple and quick maintenance procedures (as shown in Table 5). According to the related literature, emission of unpleasant odours has been a common problem in most units tested for greywater treatment (March et al., 2004; INWRDAM, 2007; Assayed et al., 2010; Paulo et al., 2013). Based on focus group discussion, the DCSF units would not produce unpleasant odors when the movable drawers were checked regularly to ensure that sand layers were not clogged and the holes inside were open. Unlike other treatment methods for greywater, the maintenance of DCSF was convenient and easy and did not need a lot of effort or time. Participants stated that they were able to do the required maintenance within half an hour; it was just sliding out the drawer, mixing up the treatment media and ensuring that all holes were open and then putting the drawer back in again. Mosquitoes were noticed in three of the DCSF units, which was often due to accumulation of untreated greywater discharged from the overflow pipe. Another reason was keeping treated water inside a closed barrel for a long period of time. Moreover, several social and economic points were raised by the participants, which showed that users benefited from the DCSF unit either by reducing the frequency of emptying the cesspool or/and reducing the consumption of freshwater or/and by improving the productivity of their home garden.

3.6. Economic benefits

The cash inflows are the direct benefit of the project in a form of reducing the frequency of cesspools emptying, producing more olives and crops and reducing the wasted fresh water. This cash inflow was calculated on annual basis. The cash outflows include the operational and maintenance cost of the system, in addition to the capital cost of the system

at the beginning of the project. Two main financial indicators were calculated; the net benefit was estimated by subtracting the cash inflows from the cash outflows, and the benefit/cost ratio was derived by dividing the cash inflow over the cash outflow (Table 6).

According to Table 6 the net present benefit (NPV benefits) for the using DCSF in urban agriculture equals to (NPV for revenues) _ (NPV for costs) = (1177.67) - (633) = 545 JD (769 \$), at the end of a prospective life span of 12 years. The benefit/cost ratio (B/C) is 0.54 which reflects intermediate financial validity of the project. Therefore, the direct benefits from the unit should be maximized by considering other benefits i.e. increased production of olive oil, and by minimizing the cost of DCSF unit through replacing of using metal frames with PVC or using local reliable materials.

4. Conclusions

A new and innovative method for greywater treatment was piloted in Jordan. Nine DCSF units were installed during 2011–2013 and are currently in operation for greywater treatment for the purpose of greywater reuse for food production and irrigation. The following conclusions can be withdrawn from the present research:

1. The DCSF units were able to remove 78–96% of organic matter (BOD5 and COD) found in greywater, depending on the hydraulic and organic load, solubility and biodegradability of organic matter.
2. Total Suspended Solids (TSSs) were reduced by the DCSF, achieving 69–98% removal. However, one unit achieved only 44% TSS removal efficiency which was attributed to the elevated operational hydraulic and organic load. Based on statistic principles, this value was considered outlier as it was distant from other values by two standard deviations.
3. The DCSF units achieved varying extents of E.coli log reduction, ranging from 1 to 6 log reduction. Therefore, at this stage, DCSF did not show reliable and consistent E.coli removal. However, further investigation is required to find out the factors that control E.coli and other pathogens removal by DCSF units.
4. The DCSF units were able to produce effluent that meets the requirements of Jordanian greywater standards for restricted irrigation.

5. The maintenance of DCSF units was easy and convenient, unlike most other greywater treatment systems. Sliding out the drawers and mix up the media or remove the blockage materials around the holes in each drawer was almost the only maintenance procedures required and was very easily accomplished by household members after minimal training

The DCSF system showed to be a reliable treatment method for greywater with a very low land footprint and minimal maintenance requirements, thus making it suitable for a wide range of geographical settings. However, the efficiency of pathogens removal by DCSF should be further studied and improved. Furthermore, based on the data collected from the focus group sessions and the NPV calculations, financial feasibility of the DCSF could be improved by increasing the scale of effluent reuse and reducing the unit cost.

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References

- Abdel-Kader, A., 2013. Studying the efficiency of greywater treatment by using rotating biological contactors system. *J. King Saud. Univ. Eng. Sci.* 25, 89–95.
- Al-Hamaiedeh, H., Bino, M., 2010. Effect of treated greywater reuse in irrigation on soil and plants. *Desalination* 256, 115–119.
- Al-Jayyousi, O.R., 2003. Greywater reuse: towards sustainable water management. *Desalination* 156, 181–192.
- APHA, 1995. Standard methods for the examination of water and wastewater, nineteenth ed. American Public Health Association, Washington.

Assayed, A., Dalahmeh, S., Suleiman, W., 2010. Onsite greywater treatment using septic tank followed by intermittent sand filter – a case study of Abu Al-Farth village in Jordan. *Int. J. Chem. Environ. Eng.* 1, 67–71.

Assayed, A., Chenoweth, J., Pedley, S., 2014. Drawer Compacted Sand Filter: a new and innovative method for on-site greywater treatment. *Environ. Technol.* 35, 2435–3446.

Beach, D., McCray, J., Lowe, K., Siegrist, R., 2005. Temporal changes in hydraulic conductivity of sand porous media biofilters during wastewater infiltration due to biomat formation. *Journal of Hydrology* 311, 230–243.

Chen, Y., Cheng, J., Creamer, K., 2008. Inhibition of anaerobic digestion process: a review. *Bioresour. Technol.* 99, 4044–4064.

Cuyk, S.V., Siegrist, R., Logan, A., Masson, S., Fischer, E., Figueroa, L., 2001. Hydraulic and purification behaviours and their interactions during wastewater treatment in soil infiltration systems. *Water Res.* 35, 953–964.

Dalahmeh, S., Assayed, M., Suleiman, W., 2009. Themes of stakeholder participation in greywater management in rural communities in Jordan. *Desalination* 243, 159–169.

Dalahmeh, S., Pell, M., Vinneras, B., Hylander, L., Oborn, I., Jonsson, H., 2012. Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater. *Water Air Soil Pollut.* 7, 3657–3671.

Dallas, S., Scheffe, B., Ho, G., 2004. Reedbeds for greywater treatment- a case study in Sant Elena-Monteverde, Costa Rica , Central America. *Ecol. Eng.* 23, 55–61.

Domenech, L., Sauri, D., 2010. Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the metropolitan area of Barcelona. *Resour. Conser. Recy.* 55, 53–62.

Elmitwalli, T.A., Otterpohl, R., 2007. Anaerobic biodegradability and treatment of grey water in upflow anaerobic sludge blanket (UASB) reactor. *Water Res.* 41, 1379–1387.

Eriksson, E., Andersen, H., Madsen, T., Ledin, A., 2009. Greywater pollution variability and loadings. *Ecol. Eng.* 35, 661–669.

Eriksson, E., Auffarth, K., Henze, M., Ledin, A., 2002. Characteristics of grey wastewater. *Urban Water* 4, 85–104.

Gerba, C.P., 1975. Fate of wastewater bacteria and viruses in soil. *J. Irr. Dr. Div.* 101, 157–173.

Gupta, M., Gao, J., 2014. outlier detection for temporal data: a survey. *IEEE Trans. Knowl. Data Eng.* 25 Number 1.

Hagedorn, C., McCoy, E.L., Raha, T.M., 1981. The potential for groundwater contamination from specific effluents. *J. Environ. Qual.* 10, 1–8.

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. *Bioresour. Technol.* 99, 6635–6641.

Hernandez, L., Temmink, H., Zeeman, G., Marques, A., Buisman, C., 2008. Comparison of three systems for biological grey water treatment. *Proceedings of Sanitation Challenge: New Sanitation Concepts and Models of Governance*, Wageningen, the Netherlands, pp. 357–364.

INWRDAM, (2007). *Studies of IDRC Supported Research on Greywater in Jordan* conducted by INWARDAM. Published by INWRDAM, Amman, Jordan.

Janczukowicz, W., Zewczyk, M., Krzemieniewski, M., Pesta, J., 2001. Settling properties of activated sludge from a sequencing batch reactor (SBR). *Pol. J. Environ. Stud.* 10, 15–20.

Jamrah, A., Al-Futaisi, A., Prathapar, S., Al Harrasi, A., 2008. Evaluating greywater reuse potential for sustainable water resources management in Oman. *Environ. Monit. Assess.* 137, 317–327.

Jenkins, M., Tiwari, S., Darby, J., 2011. Bacterial, viral and turbidity removal by intermittent slow sand filtration for household use in developing countries: experimental investigation and modeling. *Water Res.* 45, 6227–6239.

Jordan Standards and Metrology Organization (JSMO), (2008). Greywater Jordanian Standard JS:1776:2008.

Kang, Y., Mancl, K., Tuovinen, O., 2007. Treatment of turkey processing wastewater with sand filtration. *Bioresour. Technol.* 98, 1460–1466.

Karpiscak, M.M., Foster, K.E., Schmidt, N., 1990. Residential water conservation: Casa Del Agua. *Water Res.* 26, 939–948.

Lamine, M., Bousselmi, L., Ghrabi, A., 2007. Biological treatment of greywater using sequencing batch reactor. *Desalination* 215, 127–132.

Lesjean, B., Gnirss, R., 2007. Grey water treatment with a membrane bioreactor operated at low SRT and low HRT. *Desalination* 199, 432–434.

Li, F., Wichmann, K., Otterpohl, R., 2009. Review of the technological approaches for greywater treatment and reuses. *Sci. Total Environ.* 407, 3439–3449.

March, J.G., Gual, M., Orozco, F., 2004. Experiences on greywater re-use for toilet flushing in a hotel (Mallorca Island, Spain). *Desalination* 164, 241–247.

Merz, C., Scheumann, R., El Hamouri, B., Matthias, K., 2007. Membrane bioreactor technology for the treatment of greywater from a sports and leisure club. *Desalination* 215, 37–43.

Metcalf, Eddy, 1991. *Wastewater Engineering, Treatment, Disposal, Reuse*, third ed. McGraw Hill Inc., New York.

O'Toole, J., Sinclair, M., Malawaraarachchi, M., Hamilton, A., Barker, S.F., Leder, K., 2012. Microbial quality assessment of household greywater. *Water Res.* 46, 4301–4313.

Ottosson, J., Stenstrom, T.A., 2003. Faecal contamination of greywater and associated microbial risks. *Water Res.* 37, 645–655.

Paris, S., Schlapp, C., 2010. Greywater recycling in Vietnam – application of the HUBER MBR process. *Desalination* 250, 1027–1030.

Pidou, M., Avery, L., Stephenson, T., Jeffery, P., Parsons, S., Liu, S., Memon, F., Jefferson, B., 2008. ‘Chemical solutions for greywater recycling. *Chemosphere* 71, 147–155.

Paulo, P., Azevedo, C., Begosso, L., Galbiati, A., Boncz, M., 2013. Natural systems treating greywater and blackwater on-site: Integrating treatment, reuse and landscaping. *Ecol. Eng.* 50, 95–100.

Rodgers, M., Mulqueen, J., Healy, M.G., 2004. Surface clogging in an intermittent stratified sand filter. *Soil Sci. Soc. Am. J.* 68, 1827–1832.

Ryan, A., Spash, C., Measham, T., 2009. Socio-economic and psychological predictors of domestic greywater and rainwater collection: evidence from Australia. *J. Hydrol.* 379, 164–171.

Stevik, T., Aa, K., Ausland, G., Hanssen, J., 2004. Retention and removal of pathogenic bacteria in wastewater percolating through porous media: a review. *Water Res.* 38, 1355–1367.

Tandlich, R., Zuma, B., Whittington-Jones, K., Burgess, J., 2009. Mulch tower treatment system Part I: overall performance in greywater treatment. *Desalination* 242, 38–56.

Torrens, A., Molle, P., Boutin, C., Salgot, M., 2009. Impact of design and operation variables on the performance of vertical-flow constructed wetlands and intermittent sand filters treating pond effluent. *Water Res.* 43, 1851–1858.

U.S. Environmental Protection Agency USEPA, (2002) On-site wastewater treatment systems manual. EPA/625/R-00/008.

Venot, P., Molle, F., Hassan, Y., 2007. Irrigated Agriculture, Water Pricing and Water Savings in the Lower Jordan River Basin. International Water Management Institute, Colombo, Sri Lanka.

Winward, G., Avery, L., Frazer-Williams, R., Pidou, M., Jeffrey, P., Stephenson, T., Jefferson, B., 2008. A study of the microbial quality of greywater and an evaluation of treatment technologies for reuse. *Ecol. Eng.* 32, 187–197.

Fig. 1. The four areas where the 9 drawer compacted sand filters were installed.

Fig. 2. (a) Schematic diagram for metal frame. (b) Dimensions of each drawer; the drawers are perforated with 4 mm holes and 10 cm space between holes. (c) Schematic diagram for distribution manifold, showing the diameter of each orifice and the distance between them.

Table 1 Shortcomings found in greywater treatment techniques as documented in academic literature.

Treatment method	Shortcomings/major problems	References
Sequencing batch reactor (SBR)	SBR requires highly skilled operators and continuous power supply to ensure appropriate concentration of dissolved oxygen and Mixed Liquor Suspended Solids (MLSS).	Dalahmeh et al. (2009); Janczukowicz et al. (2001); Lamine et al. (2007).
Upflow anaerobic sludge blanket (UASB)	UASB was not able to achieve more than 70% of COD removal and was completely inadequate in terms of E.coli reduction. UASB is highly dependent on ambient temperature as the anaerobic bacteria requires more than 35C_ to give satisfactory results which is not easily achievable in many locations.	Hernandez et al. (2008); Elmitwalli and Otterpohl, 2007; Halalsheh et al. (2008).
Membrane bioreactor technology (MBR)	High operational and investment cost and requires advanced technical support. MBR is not seen as an appropriate treatment system for greywater in local communities, particularly poor urban ones, which would be required to manage the operation of the system themselves	Merz et al. (2007); Lesjean and Gnirss, 2007; Paris and Schlapp (2010); Winward et al. (2008).
Constructed wetland (CWT) and intermittent sand filter (ISF)	Large land footprint, emission of bad odors due to anaerobic conditions in the lower parts of the sand beds and excavation difficulties in some regions were the main problems associated with the use of constructed wetlands and intermittent sand filters	Dalahmeh et al. (2012); Li et al. (2009); Dallas et al. (2004); Torrens et al. (2009).
Rotating biological contactor (RBC), mulch towers, and using chemical coagulants.	All have been tested for greywater treatment and shown good results under laboratory conditions but there is insufficient information available on their suitability under field conditions.	Abdel-Kader (2013); Tandlich et al. (2009); Pidou et al. (2008).

Table 2: Design parameters for DCSF across various hydraulic and organic loads.

Dwelling #	Flow rate (L/ day)	Hydraulic load	Organic load	Source of greywater	No. of racks	Types of reuse	Greywater Jordanian standard
7,8	10-60	18– 107 L m ⁻² d ⁻¹	30-49 g BOD ₅ m ⁻² d ⁻¹	Total greywater	1	For restricted irrigation.	BOD ₅ : 300 mg/L COD: 500 mg/L TSS: 150 mg/L pH: 6–9 E.coli: no limits
1,2,3	60-120	107–214 L m ⁻² d ⁻¹	30–49 g BOD ₅ m ⁻² d ⁻¹	Total greywater	2	For restricted irrigation.	BOD ₅ : 300 mg/L COD: 500 mg/L TSS: 150 mg/L pH: 6–9 E.coli: no limits
4,5,9	10-120 ^a	18– 214 L m ⁻² d ⁻¹	<30 g BOD ₅ m ⁻² d ⁻¹	Greywater excluding the kitchen sinks	1	For restricted irrigation and vegetables eaten cooked.	BOD ₅ : 60 COD: 120 TSS: 50 pH: 6–9 E.coli: <10
6	120-240	214– 429 L m ⁻² d ⁻¹	<30 g BOD ₅ m ⁻² d ⁻¹	Greywater excluding the kitchen sinks	2	For restricted irrigation and vegetables eaten cooked.	BOD ₅ : 60 COD: 120 TSS: 50 pH: 6–9 E.coli: <10

Table 3 Number of tests and method used for analysis of each parameter.

Parameter	Number of analyses	Method	Reference no. in Standard Method
BOD ₅	65	5-day BOD test	5210 A
COD	50	Open reflux, titrimetric method	5220 C
TSS	81	Total solids dried at 103–105°C	2520
pH	62	pH method	4500-H+
EC	60	Electrical conductivity method	2540
E.coli	27	Multiple-tube fermentation technique for members of the coliforms groups	9221 F
Total	345		

Table 4: Influent characteristics and treatment performance (average $\pm$ standard deviation) of the different DCSF.

Dwelling #	Quantity L/day	BOD ₅			COD			TSS			pH		EC		E.coli		
		In	Out	%	In	Out	%	In	Out	%	In	Out	In	Out	In	Out	log reduction
1 (n=18)	200-250	1965 $\pm$ 1124	224 $\pm$ 155	89%	3646 $\pm$ 91	242 $\pm$ 121	93%	298 $\pm$ 46	55 $\pm$ 45	82%	5.9 $\pm$ 0.38	7.3 $\pm$ 0.25	1428 $\pm$ 42	1787 $\pm$ 571	NA	NA	NA
2 (n=21)	200-250	341 $\pm$ 122	22.0 $\pm$ 10.0	94%	394 $\pm$ 45	26.0 $\pm$ 15	93%	127 $\pm$ 14	13.0 $\pm$ 10.0	90%	6.5 $\pm$ 0.3	6.5 $\pm$ 0.29	841 $\pm$ 106	950 $\pm$ 33	2.35E+02	82	2 logs
3 (n=8)	250-350	785 $\pm$ 25	18.5 $\pm$ 13	98%	NA	26 $\pm$ 10	NA	114 $\pm$ 67	2 $\pm$ 1	98%	7.00 $\pm$ 0.2	7.6 $\pm$ 0.0.2	1132 $\pm$ 30	980 $\pm$ 28	2.40E+07	13	7 logs
4 (n=4)	300-350	2603 $\pm$ 1308	453 $\pm$ 76	83%	NA	NA	NA	304 $\pm$ 55	170 $\pm$ 35	44%	5.7 $\pm$ 0.3	6.7 $\pm$ 0.15	1912 $\pm$ 100	2266 $\pm$ 175	NA	NA	NA
5 (n=18)	150-200	217 $\pm$ 61	9.0 $\pm$ 6.0	96%	385 $\pm$ 126	18.0 $\pm$ 9.0	95%	78 $\pm$ 29	3.0 $\pm$ 3.0	96%	7.18 $\pm$ 0.2	7.9 $\pm$ 0.18	937 $\pm$ 173	960 $\pm$ 85	2.30E+02	4	2 logs
6 (n=15)	100-150	248 $\pm$ 133	19.0 $\pm$ 8.0	92%	376 $\pm$ 111	47 $\pm$ 28	88%	76 $\pm$ 51	11.0 $\pm$ 6.0	86%	8.2 $\pm$ 0.62	7.9 $\pm$ 0.4	1779 $\pm$ 420	2189 $\pm$ 103	33	12	NA
7 (n=25)	<100	587 $\pm$ 161	132 $\pm$ 30.0	78%	816 $\pm$ 139	195 $\pm$ 72.0	76%	91 $\pm$ 47	28.0 $\pm$ 6.0	69%	5.53 $\pm$ 0.43	7.48 $\pm$ 0.2	693 $\pm$ 74	1244 $\pm$ 245	5.24E+02	6.35E+02	NA
8 (n=17)	100-150	520 $\pm$ 63	70.0 $\pm$ 27.0	87%	676 $\pm$ 121	121.0 $\pm$ 48.0	82%	206 $\pm$ 86	25.0 $\pm$ 8.0	88%	6.7 $\pm$ 0.25	7.5 $\pm$ 0.39	1610 $\pm$ 125	1855 $\pm$ 245	1.60E+04	1.60E+03	1 log
9 (n=4)	<100	259 $\pm$ 25	10 $\pm$ 3.0	96%	385 $\pm$ 42	42.0 $\pm$ 18.0	89%	101 $\pm$ 11	11.0 $\pm$ 3.0	89%	7.29	7.70	1470	2650	1.30E+03	2	3 logs

Table 5 Operational problems and maintenance procedures required for DCSF.

Problem	Reason	Maintenance procedures	Frequency of occurrence
Clogging in drawers	Excessive organic and hydraulic loadings; Biofilm developed on the sand particles surface.	Slide out the drawer, mix up the media and then keep the drawer off-line for 24 h. This procedure restores the filtering media without stopping the whole system	Every 3–6 months, depending on organic and hydraulic load.
Odor	Accumulation of organic matter on the sand surface; Clogging in sand layers.	As for Clogged Drawers.	After 3–5 months of operation, depending on organic and hydraulic load.
Blockage of drainage holes in the drawers	Growth of organic matter in the holes; Physical obstruction (i.e. stones, straw, etc.)	Slide out the drawer and clear the holes using a pin or spike.	Every 3–6 months, depending on organic and hydraulic load.

Table 6 NPV for the costs and revenues, calculated according to the equation number 1.

Year	Cost JD	Benefits JD	$(1+r)^t$	Cost 5% JD discounted	Benefits 5% JD discounted	B/C
0	385	0	1.00	385	119.4	3.22
1	28	119.4	1.05	27	113.71	0.24
2	28	119.4	1.10	25	108.30	0.23
3	28	119.4	1.16	24	103.14	0.23
4	28	119.4	1.22	23	98.23	0.23
5	28	119.4	1.28	22	93.55	0.24
6	28	119.4	1.34	21	89.10	0.24
7	28	119.4	1.41	20	84.86	0.24
8	28	119.4	1.48	19	80.81	0.24
9	28	119.4	1.55	18	76.97	0.23
10	28	119.4	1.63	17	73.30	0.23
11	28	119.4	1.71	16	69.81	0.23
12	28	119.4	1.80	16	66.49	0.24
Total				633	1177.67	0.54