

Assessing the Efficiency of Grey-Water Reuse at Household Level and its Suitability for Sustainable Rural and Human Development

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ABSTRACT

In arid and semi-arid regions where water is in short supply, grey-water treatment offers the possibility of supplemental water resources for reuse in irrigation at household and farm levels.

The gravest environmental challenge that Jordan faces today is water scarcity. Jordan has one of the lowest per capita levels of water resources in the world. Most experts consider countries with a per capita water production below 1000 m³ per year to be water-poor – in Jordan in 1996; per capita share of water was < 175 m³ for all uses. The country's population increase, and the periodic massive influxes of refugees from neighboring countries, has created an increasing demand. New unconventional water resources are needed to counteract the negative water balance between supply and demand. Responding to this challenge, grey-water management in the rural and peri-urban communities of Jordan has been adopted as a solution in a collaboration between the International Centre for Agricultural Research in the Dry Areas and the National Centre for Agricultural Research and Extension.

The general goal of the project is to improve the quality of life and well-being for rural Jordanians through adopting appropriate grey-water treatment units for the purpose of crop production and income generation.

A monitoring program was implemented in August 2010 in six locations. Of these locations, three used volcanic tuff material as the filtration media and the others used white gravel. The monitoring program included collection of water, soil and plant samples. The water sample analyses showed that using medium-sized volcanic tuff as a filtration media is more effective than using medium-sized gravel. There was a 73% reduction in the biological oxygen demand when using volcanic tuff and a 49% reduction when using gravel. Moreover, grey-water quality after treatment was within the permissible limits of the Jordanian standards for its use in irrigation. The salinity – expressed as electrical conductivity of grey-water – increased from 1.28 to 1.49 dS/m when using volcanic tuff as the grey-water treatment media; it increased slightly, from 1.50 to 1.54 dS/m, when using gravel as the treatment media.

Keywords: Grey-water; Community participation; Constructed wetland; Quality

1. INTRODUCTION

The most severe water scarcity in the world is in the Middle East, and critical water shortages in the Eastern Mediterranean region as a whole affect the region's social and economic potential, increase the land vulnerability to salinization and desertification and raise the risk of political conflict around this limited resource (Brooks & Mehmet 2000, Tropp&Jagerskog 2006). According

to Allan (2002), the region “ran out of water in the 70s” and is currently surviving on virtual water and in cases on over-exploiting its own renewable water resources.

Jordan is one of the most water-deprived countries in the world. Available per capita fresh water lags far behind that available in most other countries. Daily per capita water consumption rate is quite low, and the cost of supplying water continues to rise. This extreme water scarcity and increasing cost of supply is a very serious constraint to Jordan’s economic growth. The renewable internal freshwater resources per capita in Jordan was 115.30 m³ in 2009, according to a World Bank report, published in 2010, while the point of concern for water scarcity is estimated at 500 m³ per capitaper year.

Grey-water can be considered as a good alternative providing non-potable water for household usage, and thus reducing per capita water use by 50% (Oschmann et al, 2005). For this reason it is an attractive and sustainable low cost water source especially in arid and semi-arid areas, such as Jordan, due to water scarcity and fluctuation in rainfall patterns (Al-Jayyousi, 2003).

This paper presents the results of using an integrated approach to manage grey-water at the household level in Jordan. The main project community (benchmark) site was in Madaba Governorate, Jordan, where the households were not connected to a sewer system. In the absence of a sewer system, the households spend a considerable amount of time and effort in collecting and disposing of domestic wastewater.

2. MATERIAL AND METHODS

2.1 Site Selection

In consultation with the farming communities, local leaders and NGOs, and from field visits undertaken, Al-Faisalia, Al-Areash and Jraineh villages were selected within the Madaba Governorate as the main project implementation sites. This selection was based on the selected project sites facing a shortage of freshwater resources for different uses – average annual rainfall of < 200 mm – and the limited agriculture-related activities in summer because of this lack of water for irrigation.

The selection of the pilot sites was according to different indicators established in a multi-criteria participatory approach:

- Presence of a home garden;
- Family size, i.e. number of family members;
- Rate of water consumption per household;
- Willingness of the household to cooperate in implementing grey-water collection, treatment and use for irrigation of the home garden or olive trees;
- Ability of the household to contribute to the construction of the grey-water collection and treatment system;
- Cropping pattern.

An initial assessment study for each household was conducted in order to facilitate the selection process. In Al-Faisalia, Al-Areash and Jraineh villages, 98 houses were considered for project implementation. From these, 13 pilot houses were selected based on their close compliance with the criteria. The selected households and sites were then characterized.

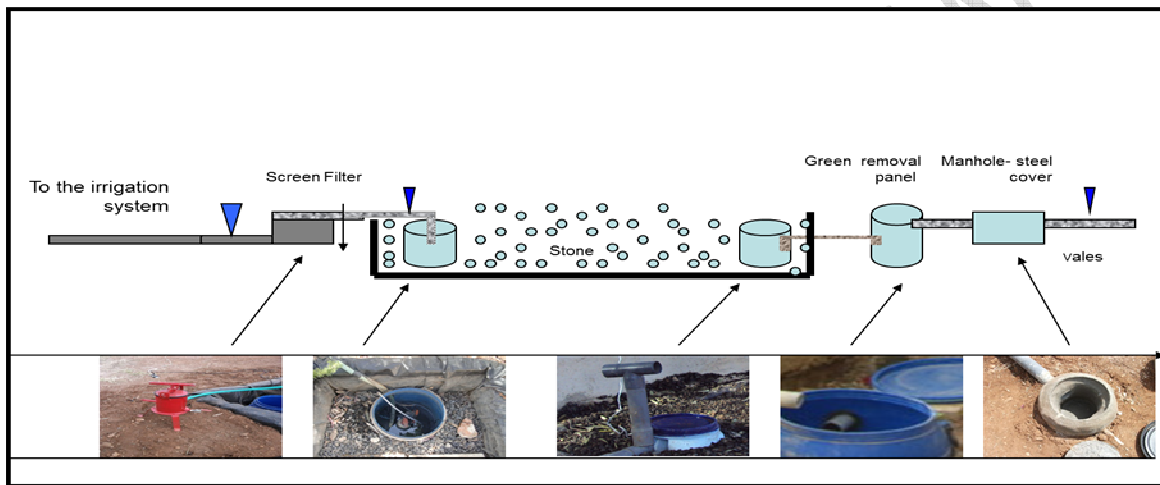
2.2 Implementation of Treatment Units

A needs assessment was carried out for the houses selected for the pilot installations of the grey-water collection, treatment and use systems.

A contract between the project and each household involved in the project was signed. This covered taking care of the grey-water system installed, using the house as a demonstration site for project activities and agreeing to follow the instructions of the project team in implementing the project activities.

The project conducted several initial meetings in the project area, to increase knowledge and understanding about grey-water as an alternative source of irrigation water. Then benchmark site and households were selected and characterized, and 13 grey-water treatment units were installed at Al-Faisalia, Al-Areash and Jraineh villages of Madaba Governorate (the project target area). A comprehensive program for networking, awareness and dissemination was implemented.

Grey Water Treatment Unit



2.3 Participatory approach

The project beneficiaries started their own grey-water reuse association. This society was considered a byproduct of the project and the beneficiaries were very enthusiastic to succeed in their tasks.

There were 28 training sessions undertaken in a multi-criteria participatory approach that aimed to address different issues related to grey-water management and best management practices dealing with different aspects of grey-water: irrigation scheduling, grey-water treatment, water quality, operation and maintenance of the grey-water system, and health risk mitigation. The training targeted women, the local community and institutions in order to achieve efficient grey-water treatment and prevent any undesirable odor and health problems.

2.4 Follow-Up and Monitoring Plan

Six pilot sites from the 13 implemented units were chosen to constitute a research network for the monitoring program. In three of the six locations, volcanic tuff material was used as the filtration media; while in the other three locations, white gravel played this role. The monitoring program involved collecting water, soil and plant samples.

The objective was to monitor and compare the quality of the treated and untreated grey-water. In addition, the site monitoring plan assessed the chemical and biological changes in the soil and in plant parameters after using treated grey-water for irrigation.

3. DATA COLLECTED

A program of periodic visits to the project sites was prepared along with a checklist of tasks to be undertaken during the visits. These tasks included any necessary water, soil and plant sampling; testing of the system's operation; meeting with the households; discussing issues related to grey-water and obtaining feedback.

The monitoring program included collection of the following data:

Water data: Within the monthly sampling framework, 18 grey-water samples were collected before, in the middle and at the end of the grey-water treatment period (2 years). These water samples were analyzed for the same parameters as were checked for the soil samples. In addition, certain biological parameters were determined: including the biological oxygen demand (BOD), chemical oxygen demand (COD) and a pathogen count.

Soil data: Soil samples were taken down to a depth of 90 cm at 30-cm intervals. The first set of samples was collected at the beginning of the project. The sample locations were near the drippers (at olive tree bases), 1 m from olive trees and between olive trees. A total of 54 soil samples were collected.

A second set of soil samples were collected from the same sites at the end of the project (after two years of using grey-water for irrigation). These samples were analyzed for a range of parameters including pH, electrical conductivity (EC), nitrate nitrogen (NO₃-N), sodium (Na), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), zinc (Zn), lead (Pb), cadmium (Cd) and organic matter (OM).

Plant data: Plant samples were collected and analyzed for the nutrient elements (N, P and K) and heavy elements (Zn, Cd and Pb). A total of 18 soil samples were collected – three samples from each monitoring site. The plant samples were collected twice – before using grey-water for irrigation and after three years of treatment with grey-water. The samples were analyzed for the same parameters to evaluate the effect of using grey-water for irrigation. Moreover, the fruit and oil yields of the olive trees were evaluated for each site. The olive trees were also monitored for the presence of pathogens.

4. RESULTS AND DISCUSSION

4.1 Water Quality

The analysis of the water samples showed that using both media-size volcanic tuff and media-size gravel as the treatment media was effective. The quality of the grey-water after treatment was within the permissible limits of the Jordanian standard for using grey-water for irrigation.

However, volcanic tuff was more effective as a treatment media than gravel. Elsewhere in Jordan, a septic tank followed by an intermittent sand filter was piloted in the northern-eastern Badia to deal with grey-water generated from one household – efficiency of OM removal (five-day Biological Oxygen Demand represented by BOD₅) and the Total Suspended Solids (TSS) were 87 and 85%, respectively (Assayed et al., 2010). In the present study, the reduction in BOD₅ was 73 and 49% when using volcanic tuff and gravel, respectively (Table 1); corresponding increases in TSS were 16.7 and 2.4%.

However, the reduction in the fecal coliforms (FC) count using white gravel as the media (decreased from 452,844 to 4657 coliform/100 mL) was much higher than that for volcanic tuff (decreased from 784,163 to 661,259 coliform/100 mL). The EC of the grey-water increased from 1.28 to 1.49 dS/m for volcanic tuff as the treatment media, and increased slightly from 1.50 to 1.54 dS/m for gravel (Table 1).

Table1. Quality of grey-water after using two different treatment media and comparison of the treated grey-water quality with Jordanian standards for grey-water for irrigation

Treatment material	Parameters	Pre-treatment1	Post-treatment2	Change3	Jordanian standard
Volcanic tuff	BOD5 (mg/L)	444	121	-73	300
	COD (mg/L)	860	301	-65	500
	pH	6.2	6.7	+0.5	6-9
	EC (dS/m)	1.28	1.49	+16	-
	Cd (ppm)	0.002	0.002	unchanged	0.01
	Pb (ppm)	0.01	0.01	unchanged	0.1
	FC(coliform/100 mL)	784,163	661,259	-15,67%	Unlimited
Gravel	BOD5 (mg/L)	407	209	-49	300
	COD (mg/L)	731	354	-52	500
	pH	6.9	6.8	-0.1	6-9
	EC (dS/m)	1.50	1.54	+3	-
	Cd (ppm)	0.002	0.002	unchanged	0.01
	Pb (ppm)	0.01	0.01	unchanged	0.1
	FC (coliform/100 mL)	452,844	4657	-99	Unlimited

1 Average of 22 grey-water samples before treatment
2 Average of 22 grey-water samples after treatment
3 Increase (+) or decrease (-) compared to pre-treatment level

The Na concentration and sodium absorption ratio (SAR) both decreased under the treatment using the white gravel media; however, both parameters increased slightly when using the volcanic tuff. The increases or decreases in Na content did not affect pH of the treated water, which remained acidic. The concentrations of the other cations and anions generally increased for both media, mainly because of evaporation losses from the treatment bed. Finally, there were no problems with Pb and Cd as their concentrations remained constant and were not affected by either treatment media.

4.2 Soil Characteristics

The impact of grey-water reuse on soil characteristics was examined using soil samples taken before and after two years of grey-water application (Table 2).

220 **Table2.Soil properties before and after using grey-water for two years**

Parameters	Unit	Before	After
NO3-N	%	93	51
K	ppm	969	670
Cd	ppm	0.35	0.18
Pb	ppm	1.5	0.94
Zn	ppm	16	18
P	ppm	47	28
OM	%	2.9	2.8
pH		7.6	7.8
Mg	meq/L	5.4	1.7
Ca	meq/L	6.5	2.0
Na	meq/L	2.1	1.2
Cl	meq/L	2.8	1.3
Na	%	17.5	24.0
SAR		0.91	0.87
Salinity EC	dS/m	1.26	0.44

221 Using grey-water for irrigation had no negative impacts on soil properties. The soil at all depths
 222 for the intervals sampled and at all the monitored locations showed a low salinity level within the
 223 range of 0.263–0.627 dS/m and average 0.44 dS/m (Table 2). However, the drop in soil salinity
 224 was not a result of using grey-water for irrigation, but was due to natural salt leaching during a
 225 recent rainy season. There was a relatively high rainfall and the irrigation was continuous
 226 regardless of a rain event or wet soil conditions. This situation enhanced leaching of the soil
 227 salinity in all six monitored locations.

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 229 Chemical analyses of the soil clearly showed that using grey-water, treated either using volcanic
 230 tuff or white gravel, reduced the concentrations of NO3-N, K, Cd, Pb, P, Mg, Ca, Na and Cl.
 231 However, the Na concentration increased in soil irrigated with grey-water treated with volcanic
 232 tuff, without affecting the SAR, but slightly raised the soil pH. The main reason for this rise in soil
 233 pH was probably the leaching of soil salinity (Table 2).

234 The Zn concentration was an exception. Its concentration in soil increased regardless of the
 235 treatment media used. The grey-water was not analyzed for Zn before or after treatment, and
 236 thus it is difficult to explain this increase, particularly as its concentration in the plant leaves
 237 decreased (Table 3).

238
 239 These results are consistent with a research study conducted in Australia that examined the
 240 effects of grey-water irrigation on the growth of silverbeet plants and changes in soil properties.
 241 Their grey-water irrigation had no significant effects on soil total N and total P; however, pH and
 242 EC significantly increased (Maheshwari et al., 2009). Furthermore, an applied research study
 243 conducted at Al-Amer village in Jordan showed quite similar results; whereas salinity, SAR and
 244 organic content of soil increased with time (Al-Hamaiedeh H. &Bino M., 2010).

245 4.3 Quality of Olive Leaves

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 248 Chemical and biological analyses of the leaves of olive trees irrigated with treated grey-water in
 249 the locations of our network of treatment units were performed at two different times: the first
 250 before using grey-water and the second after two years of using treated grey-water for irrigation
 251 (Table 3).

Table3. Chemical analyses of olive tree leaves before and after using treated grey-water for irrigation for two years

Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
N (%)		P (%)		K (%)		Pb (ppm)		Cd (ppm)		Zn (ppm)	
1.54	1.79	0.13	0.10	0.80	0.43	3.21	8.69	0.46	0.95	18.15	7.56

The chemical analysis of the leaves showed clearly that the concentrations of P, K and Zn had decreased; while N, Pb and Cd concentrations increased. The high N values were because leaves were the plant parts analyzed; the values for K and P were determined from leaves collected at two different times of the year. Samples before and after the grey-water use were taken from trees during December and March, respectively. The difference in the sampling times makes it difficult to conclude anything regarding the decreases in K and P concentrations. Both Pb and Cd concentrations increased while their concentrations in the grey-water had not changed, indicating that another source for these metals was responsible for their increased concentrations in leaves.

The grey-water did not have any adverse impacts on plant quality (Table 3). However, further investigation is required to explain the variations in Pb and Zn concentrations. Several studies have been conducted to identify the sources and removal efficiencies of metals in grey-water. Eriksson et al. (2009) investigated the sources, presence and potential fate of Cd, Pb, mercury (Hg) and nickel (Ni) in onsite grey-water treatment systems. Their study showed that onsite treatment could remove a third to a half of Pb, Hg and Ni but showed no significant removal of Cd. Based on geochemical modeling, they concluded that metals should not pose a problem for reuse in toilet flushing and fruit tree irrigation; however, potential health problems were associated with sludge disposal (Eriksson et al., 2009). Results of the present study (Table 3) are also consistent with the findings of a study of the benefits and risks associated with domestic grey-water reuse for the purposes of vegetable garden irrigation, in which heavy metals were within the acceptable ranges in both grey-water and plant leaves (Sara et al., 2009).

5. CONCLUSIONS

The treatment units implemented at the household level in Madaba Governorate in Jordan were evaluated and several important parameters were measured. Overall, the results were satisfactory and were consistent and compatible with Jordanian standards. Interviews with community members and farmers indicated wide community interest in using the treated grey-water, especially after observing the positive growth of the olive trees.

Using treated grey-water from treatment units is a promising strategy for achieving significant local water savings. Research on further economic benefits is underway to determine the real financial returns to farmers and the community as a whole.

The main conclusions from this project were:

- The composition and characteristics of grey-water varied significantly and were very dependent on the practices of the households' inhabitants.
- The quality of the treated grey-water complied with Jordanian standards for reclaimed wastewater reuse in restricted irrigation.
- Knowledge of local people should be recognized and participatory approaches applied when investigating integrated water resources management programs for small communities. However, intensive awareness campaigns and training sessions are required.
- Using constructed wetlands for grey-water treatment in rural and peri-urban communities can be a good option with Both media treatments used (i.e. volcanic tuff and white gravel), performed well in producing treated grey-water conforming within Jordanian standards and without adverse effects on soil or plants.
- Using media-size volcanic tuff as the treatment media was more effective than media-size white gravel in reducing BOD and COD values.

- 308 - Using media-size volcanic tuff as the treatment media caused a greater increase in water
309 salinity than media-size gravel.
310 - Heavy metals were within the acceptable ranges in both grey-water and plant leaves
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