Alleviating Water Scarcity in Rural Arid Areas through Grey Water Treatment and Reuse: Palestine as a Case Study

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Abstract: Conventional water sources in Palestine are vulnerable and scarce. Among potential alternative non-conventional water sources is greywater which comprises 50–80% of residential wastewater. In this paper the long and short term impacts assessment of six onsite greywater treatment plants, GWTPs using constructed wetland technology was conducted. The constructed wetland system were constructed by National Agricultural Research Committees, NARC and International Center for Agricultural Research in the Dry Areas, ICARDA in Northern West Bank to disseminate the safe uses of the treated greywater. Performance indicators were used for assessing the quality and efficiency of the execution of six treated greywater reuse stations in Jenin and Tubas governorates. Effluent from the six plants was reused in nine home gardens for fruit tree (citrus and olive) and fodder (sorghum) plantations. A field survey was designed and conducted for reuse beneficiaries. The short term indicator included greywater quality parameter before and after treatment during the period from June and July 2015. pH , TDS, Na+ ,Ca2+ ,Cl- ,BOD ,PO42+ and SO42-fall within the Palestinian standard for treated wastewater (2012). The average water quality was: pH 7.5, TDS 1024.27, Na 128.2, Ca 65.6, Cl 224, Mg 288.3,NO-3 77.8 and COD 400.8, BOD 178,PO4 7.69 and So4 139. The efficiency of total coliform and Ecoli removal efficiency was 33.3% and 37.3% in 2015 compared to 87 % and 55.3% in 2011. The efficiency of BOD was 70.8 in 2015 compared to 75.8 % in 2011. The decrease was 5%. The efficiency of EC was 9.8 % in 2015 compared to 27.3 % in 2011. The decrease in the efficiency with time was due to accumulation of solids in the constructed wetland. Soil pH and EC were 6.67 and 2.65. No heavy metal accumulation in soil was observed. Both grew water and soil analysis after five years of treatment remains within the accepted Palestinian reuse standards.

Keywords: Greywater, Reuse, Palestine, Constructed wetland, Water Scarcity, Arid Areas.

1. INTRODUCTION

Water Scarcity and Degradation in Palestine as Challenges, Vulnerabilities and Risks for Environmental Security are increasing is one of the major problems facing Palestinian society. This partially due to natural hydrological conditions and mainly to the specificity of Palestine as country under military occupation and control [1, 2].

With increased population growth in Palestine [3], the conventional water sources supply are becoming increasingly vulnerable and scarce. This water demand increase, combined with recent years of low rainfall and political turmoil, has resulted in increasing pressures on water supplies. To avoid or reduce this problem, an alternative water resource plan is being promoted. Among these potential alternative sources of supply was greywater reuse [4].

At present, water needs in Palestine exceed the available water supply, the gap between water supply and water needs is steadily growing and is calling for the mobilization of any additional conventional and non-conventional water resources including treated wastewater reuse [5]

Disposal of domestic wastewater in rural areas of Palestine is done through the use of cesspits. This widespread application of cesspits may represent a source of pollution to shallow water resources. These cesspits also form a large burden on the income of the Palestinian families, where some families spend about 20% of their monthly income to manage water and wastewater at house level [6, 7].

A decentralized system employs a combination of onsite and/or cluster systems and is used to treat and dispose of wastewater from dwellings and businesses close to the source. It was found that managed decentralized wastewater systems are viable, long-term alternatives to centralized wastewater treatment facilities, particularly in small and rural communities where they are often most cost-effective. These systems already serve a quarter of the population in the U.S. and half the population in some states. They should be considered in any evaluation of wastewater management options for small and mid-sized communities [8].

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This prevailing practice of on-site sewage disposal in rural areas (the majority of the households in the West Bank villages use septic tanks and cesspits) does not accommodate the increase in generated wastewater flows by the population and there is a high need to introduce and demonstrate suitable wastewater treatment and reuse system.

This paper discusses and assesses how water scarcity in rural arid areas of Palestine could be tackled through greywater treatment and reuse.

2. BACKGROUND ON GREYWATER TREATMENT AND REUSE

2.1. Greywater Definition, Characterization, and Impacts

Greywater is washing water from bathtubs, showers, bathroom wash basins, clothes washing machines and laundry tubs, kitchen sinks and dishwashers [9-13]. Accordingly greywater is wastewater which is not biologically contaminated by faces or urine and has little nutrients to crops.

The most important contaminants in domestic greywater are dissolved powdered laundry detergents. These contain high salt concentration and in many cases still contain phosphorus, and are often very alkaline. Long term garden reuse of laundry water containing high salt and phosphorus concentrations can lead to salt accumulations in the soil and stunting of plants with low phosphorus tolerance. Regions with regular rainfall may not suffer salt build-ups due to leaching of salts from soil after rain.

These contaminants in domestic greywater have and represent potential negative environmental and health impact, such as dissolved salts [14], surfactants [15], oils [16], synthetic chemicals [17] and microbial contaminants [18]. Other potential detrimental effects of greywater reuse include soil aggregate dispersion from sodium accumulation due to long term operation of the plant [19]; and microbial growth risks [20-22].

The use of treated greywater for irrigation in home gardens in Jordan, is becoming increasingly common. The results of greywater reuse in Jordan showed that salinity, sodium adsorption ratio (SAR), and organic content of soil increased as a function of time, therefore leaching of soil with fresh water was highly recommended. The chemical properties of the irrigated olive trees and vegetable crops were not affected, while the biological quality of some vegetable crops was adversely affected [23].

Experiments were conducted worldwide to examine the effects of greywater irrigation on the growth of food crops plants, their water use and changes in soil properties. Results showed that greywater irrigation had no significant effect on soil total N and total P after plant harvest, but there were significant accumulation effects observed on the values of soil pH and EC. Furthermore, there were no significant effects of greywater irrigation on plant dry biomass, water use and number of leaves [24, 25].

It was found that there is no increase in the rate of water borne diseases after greywater reuse for irrigation. The accumulation of heavy metals in the soil was insignificant and the uptake of these metals by the irrigated plants did not occur [26].

The Jordanian Effluent quality of treated wastewater including greywater are listed in Table **1** below. These are widely accepted by the Palestinian ministry of agriculture. Palestine has its own standard "The sixth draft of treated wastewater standard". The main feature of this standard is the classification of treated effluent quality into 4 groups based on a combination of quality characteristics and factors See Table **2** below).

Table 1: Treated Wastewater Effluent Quality

Characteristic	Unit	limits
BOD5	mg/l	300
COD	mg/l	500
TSS	mg/l	150
pH	Unit	6-9
NO3	mg/l	50
T-N	mg/l	70
Turbidity	NTU	25
Phenol	mg/l	0.05
MBAS	mg/l	25
TDS	mg/l	1500
T-P	mg/l	15
Cl	mg/l	350
SO4	mg/l	500
Escherecia coli	cfu/100ml	**
Intestinal Helminthes Eggs	egg/ L	≤1

Source: Water -Reclaimed greywater in rural areas- Jordanian standards [27].

2.2. Greywater Treatment and Reuse

Due to freshwater unavailability and associated environmental pressures and impacts greywater treatment and reuse in rural as well as in arid and semi-arid areas is gaining higher popularity all over the world especially in developing countries [29-47].

Table 2: Reclaimed Wastewater Classification

Class	Water Quality Parameters
	BOD5 TSS Faecal Coliforms
Class A	High quality 20 mg/l, 30 mg/l 200 MPN/100 ml
Class B	Good quality 20 mg/l, 30 mg/l, 1000 MPN/100 ml
Class C	Medium quality 40 mg/l, 50 mg/l, 1000 MPN/100ml
Class D	Low quality 60 mg/l, 90 mg/l, 1000 MPN/100 ml

Source: Palestinian Standards Institute [28]

There is a potential up to half the quantity of domestic water supply could theoretically collected, treated, and reused (up to 40-50 MCM/year in Palestine). However, although it is an adopted Palestinian policy to promote reuse, attempts so far have not been highly convincing [48].

As in many developing countries, sanitation needs and development tends to receive less attention and financial resources support by governments than water supply. This leads to a lack of proper operation and maintenance even of existing wastewater treatment plants (WWTP), as is the case, for example, in Morocco and Algeria more than half of the WWTP are not functioning properly [49].

Treated waste water and greywater reuse for agricultural purposes in Palestine is being slowly introduced for a number of reasons [50].

Experiences in greywater reuse in Cyprus indicates a 36% reduction in water bills when household greywater is reused. It was indicated in the same study that most system failures are caused by inappropriate operation and maintenance, sometimes also resulting from a lack of system understanding by the owners [51]. Examples of well-planned wastewater reuse experiences can be found in Tunisia and indirect reuse can also be also found in Jordan and Morocco, where treated wastewater is discharged into open watercourses [52].

3. METHODS AND MATERIALS

Performance indicators for greywater reuse are qualitative and quantitative indicators for assessing the quality and efficiency of the execution of treated greywater reuse projects in the North West Bank. The Performance indicators are divided into social, economic, and environmental indicators:

- Social indicators: include employment, training, quality of life, society awareness of water resources.
- Economic indicators: include supply, saving, process/service saving, infrastructure needs, economic development, and increased crop productivity.
- Environmental indicators: include changes in water composition (physical–chemical), ecological quality, and change in soil composition.

3.1. Socioeconomic Indicators

A field survey will cover the main groups of interest for reuse of treated greywater. Questionnaires were designed for the target group and distributed to the direct and indirect beneficiaries. Questionnaires consist of 88 questions in three domains: basic data, environmental awareness, and water. The three domains questions gave answers the following topics:

- Social information on farmer’s household.
- Irrigation quantities, cost, quality, irrigation methods, and irrigation scheduling.
- Previous experiences with greywater reuse.
- Level of awareness on safe reuse of greywater.
- Impacts of greywater station on the environment, labors, and consumers
- Valuation of the total saving in freshwater use.
- Valuation of the farming methods, crop patterns, and fertilizer use and application.
- Identification of farmers’ ability and willingness to pay;
- Economic analyses to compare between previous farming practices and farm greywater reuse scheme.

A sample of 71 households from the two governorates Jenin 33 and Tubas 38 was selected and personally interviewed for questionnaire completion. Table **1** include sample distribution among the villages where the six greywater treatment plants were installed and operated.

Table 3: Sample Distribution by Governorate

Percent	Village	Percent	Governorate
16.9	Jalbon	46.5	Jenin (33)
15.5	Der Abod		
14.1	Faqu'a		
25.4	Tayaseer	53.5	Tubas (38)
28.2	Aqaba		
100.0	Total	100.0	Total

After distribution and completion, questionnaire data were sorted into excel file, and later analyzed using SPSS.

3.2. Greywater Sampling and Chemical Analysis

Field visits were carried out to determine greywater sampling, and greywater treatment unit locations in Jenin and Tubas six unites were chosen. These locations were chosen according to the following criteria:

1. Greywater treatment unit age.
2. Long term reuse period.
3. Planted home garden.
4. Family size, which used the greywater treatment unit

Analysis of the greywater before and after the treatment were performed acquiring several samples and analyzing the parameters. These include analysis of Cations including: K^+, Na^+, Mg^{2+}, Ca^{2+} and Anions such: Cl^-, CO_3^{2-}, NO^{3-}, $PO4^3$. Other important parameters include biological oxygen demand (BOD), chemical oxygen demand (COD), Conductivity, Total Coliforms (TC), and the Total Dissolved Solids (TDS). Some of the most important parameters that would reflect the efficiency of the treatment can be evaluated by looking at the BOD, Total Coliforms.

3.3. Soil Sampling

Soil samples were collected from Tubas and Jenin village, three locations were targeted, and three home gardens irrigated by treated greywater. Samples were from 2 depth 0-30 and 30-60. Samples were placed in plastic bags and sealed for transport and storage. The samples were then air- dried and sieved with 2 mm stainless steel sieving. Samples were stored in the refrigerator at 2-4. The soil quality was tested for both physical and chemical properties. Analysis of the irrigated soil with treated greywater will be performed acquiring several soil samples and analyzing the parameters. These include analysis of Cations such as: K^+, Na^+, Mg^{2+}, Ca^{2+} and Anions such: Cl^-, CO_3^{2-}, NO^{3-}, $PO4^{3-}$. Other important parameters include biological oxygen demand, and the Total Dissolved Solids (TDS Several analytical methods for treated greywater parameters, namely chemical, physical and microbiological were analyzed.

3.4. Analytical Methods of Treated Greywater and Soil

All analysis of greywater (treated or untreated) were conducted in accordance with standard methods for the examination of water and wastewater [53] and soil [54].

3.5. Sites Selections for Greywater Treatment Plants

Jenin, Tubas governorates located in Northern West Bank were selected to install greywater treatment plants due to that they represent a major agricultural area with limited water resources. They mainly cultivated rain-fed crops, such as wheat, barley and some forages. Eastern parts of these areas are considered a marginal region with limited rainfall that do not exceed 300 mm, which make it suitable for the project.

3.6. Description of Treatment Plants

The treatment system adopted was constructed wetland system was developed by ICARDA and adopted by NARC. The design of the treatment unit of the “wetland system” as illustrated and shown in Figure **1** consisted of the followings:

Inlet Stage

The greywater from the house is transferred to the manhole through a PVC pipe (diameter = 4 inches). The manhole contains two valves for maintenance and controlling overflow to cesspits, and is covered with a concrete lid (diameter 50cm, depth 50cm).

Treatment Phase

A 100 L tank which separates greywater into three layers: solids in the bottom, the upper layer for grease and oils removal, and a middle layer consisting of greywater. There is a filter connected to the end of the line to take the water to the next part. The other end is connected to a pierced horizontal 3˝tube. The upper end of the U-tube is connected to a 50cm tube for

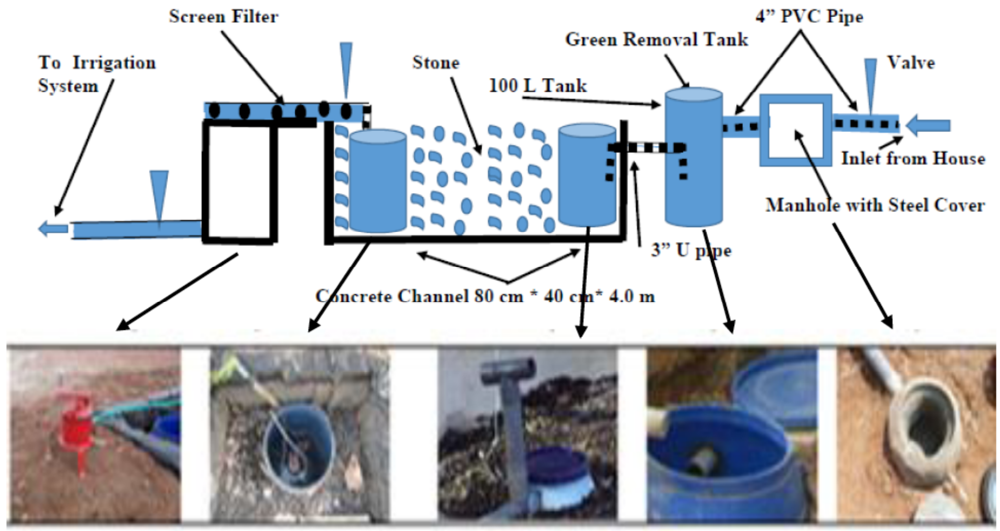

Figure 1: Schematic of treatment plant.

sampling. The 3˝ U – pipe tube were used to transfer the middle layer (greywater) to the next part.

The third compartment is used as up flow Tuff. This part has been constructed from concrete and cinder-blocks (Dimensions W=80cm, H=80cm, L= 4m). The compartment has a slight ground slope of 1%. There is a layer of soft sand to adjust the slope and to protect internal black-plastic cover (thickness 600 micron). An insulating sheet of polystyrene (thickness 2cm) is placed between the walls of the compartment and the black-plastic cover. Finally, the volcanic Tuff (diameter ~20 mm) was placed in the compartment.

Effluent Stage

The fourth compartment (barrel = 100 liter) is a collection and a pumping stage. This drum is placed below the ground level by a 25 cm. A concrete slab is poured into the barrel to hold it in place. Holes of 0.5 cm are then drilled through the sides of the barrel to a

Table 4: Average Raw and Treated Water Quality for the Six Treatment Systems

Removal Efficiency 2015 [%]	Removal Efficiency 2011 [%]	Raw Greywater	Parameter (unit)
23.5	18.0	5.76	pH
9.8	27.3	1.77	Ec (mmohes)
23.5	40.5	361.93	HCO_3 (ppm)
8.0	10.0	326.06	Hardness (ppm)
13.5	63.0	111.55	Na+ (ppm)
4.5	2.5	62.58	Ca^{2+} (ppm)
10.0	15.0	258.65	Mg^{2+} (ppm)
5.0	31.5	326.37	Cl^- (ppm)
9.8	19	31.47	K + (ppm)
87.5	83.1	453.58	NO_3^- (ppm)
70.8	75.8	710.42	BOD (ppm)
7.69	46.0	15.64	PO_4
49.9	63.5	274.50	SO_4
82.4	87.3	2277	COD
37.8	53.3	1882.5	E-coli (cfu/100ml)
33.0	87.0	145506.	T. Coliform (cfu/100ml)

height of up to 50 cm. Then, a submersible pump is installed within the barrel and an electric aeration unit is installed to pump the air from the bottom of the barrel to the top (bubbling air). A drip irrigation system is connected with the setup to efficiently distribute the water to the garden trees.

4. RESULTS AND DISCUSSION

4.1. Treatment Plants Performance

The long term performance of the greywater treatment system was conducted in 2015 after five years of operation of the six treatment plants, *i.e.*, in 2011. The performance included average greywater quality before and after treatment for the six plants monitored during the experimental period. Results indicated that chemical content of treated greywater is suitable for reuse and still within accepted Palestinian standard for treated wastewater while the biological content is not suitable and is higher than Palestinian standard for treated wastewater of 1000 cfu/100 ml for irrigated trees. This is due to solids accumulation within the bed over five years of operation and indicate the need for media chemical cleanup or media replacement in the constructed wetland. To illustrate the variation in influent and effluent greywater quality between the six treatment plants, COD data was used as an example (see Figure **2**). The overall COD

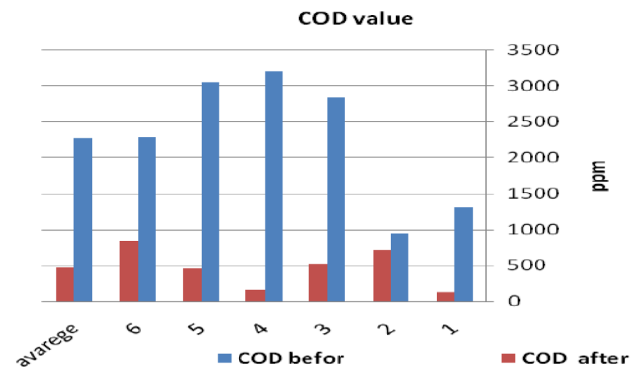

Figure 2: COD values in treated greywater from the six targeted treatment plants [64].

average was 2277 ppm in raw greywater and 400.83 ppm in treated water. All of the measured COD values indicate that treated greywater can be used for fruit tree irrigation purposes. This observed effluent COD results agreed with the Jordanian standard for treated effluent reuse of 500 mg/l COD and higher than draft Palestinian standard of 200 mg/l COD for fruit tree irrigation [56] and within numerous published data for reuse of treated greywater [57-63]. The noted draft Palestinian standard for greywater reuse for tree irrigation, PS 742 of 2003, is not final and going under revision and expected to be modified to follow the Jordanian reuse standards.

Table 5: Soil Extract Analysis Results

	Soil irrigated with Treated Greywater						Control
Parameter	Unit	Unit A -30 cm	Unit B -60 cm	Unit C -90 cm	Average	Sd	(Soil irrigated with fresh water)
PH		6.75	6.64	6.62	6.67	0.07	7.37
Ec	Ms	4.2	1.25	2.5	2.65	1.48	0.8
Cu	ppm	0.39	0.52	0.43	0.45	0.07	0.214
Mn	ppm	4.56	5.84	5.1	5.17	0.64	2.236667
Zn	ppm	3.66	3.07	3.21	3.31	0.31	1.686667
Cr	ppm	0.61	0.77	0.7	0.69	0.08	0.311
$N-NO_3$	ppm	2.72	2.81	2.5	2.68	0.16	1.173333
PO4	ppm	26.1	25.3	25.6	25.67	0.40	16.62
K_2O	ppm	12.5	13	12.6	12.7	0.27	2.34
Na	ppm	7.5	6.8	7.2	7.17	0.35	2.146667
Ca	ppm	145	180	155	160	18.03	83
Mg	ppm	73	77.8	74.6	75.13	2.44	41.3
Cl	ppm	465	216	290	323.67	127.8	181
SAR	ppm	1.02	0.8	1.13	0.99	0.16	0.29

4.2. The Impact of Irrigation with Treated Greywater on Soil

The impact of treated greywater irrigation on soil was assessed by testing three soil samples irrigated by treated greywater (see Table **5**).

It is clear from Ec and Cl data listed in Table **2** that salts accumulation in the first 30 cm is higher than deeper layers. This accumulation is expected to increase with time leading to soil hardening and eventually wetland bed replacement. Metals did not show noticeable accumulation in the three soil layers monitored. Also soil pH stayed almost constant at 6.65.

4.3. Socioeconomic Indicator

Field survey results analysis indicated the following main observations:

- The average number of family members in the study area was 6.4 and the average of the income is 2194 NIS. The average number of males is 3.3 and the average number of females is three. The basic education has 63.4 % of the sample and 29.6 % has a higher education degrees (see Table **4.4**).
- In total, 15.5 % of the families had environmental training course. However, the acquired knowledge on greywater was 16.7% and the acceptance to purchase crops irrigated with greywater by the people was 59 %. The results of the analysis indicated that 50% of the surveyed farmers were satisfied with the extension services,
- About 16.7% of the individual received information on the indicative greywater and 83.3% had no information.
- In total 19 m^3 of freshwater per month is the consumption of householders. About 48% of the farmers get irrigation water from wells, 27% from purchased tankers and 2.8 from the networks and this constitutes a major problem facing farmers.
- Water services analysis shows that nearly 76% of the respondents face a water shortage and the same percent reported that water prices being a major constraint they have to deal with.
- About 61% of the farmers indicated that they have no knowledge on the reuse of greywater.
- The average number of seepage times is 4.6 and the average cost is 95 NIS per each time. This reflects the high cost of the seepage.
- 33% of treatment unit owners stated that the units need regular maintenance. About 71 % of unit's owners stated that the units increase crop production in the home garden. In addition, 89 % of them indicated the decrease in treatment unit's efficiency by the time.

Table 6: Personal Information for the Studied Communities

Percent	Item
71	Number of families surveyed
6.38	The average number of family members
2194	Average income
3.3	The average number of males in the family
3	The average number of females in the family
1.38	The average number of households owning garden
257.6	Rate area of the garden
62	No of family own cesspit
9	No of family own GWTP
100%	Who possess electricity network ratio
100%	Who owns the water rate system
0	Who possess a sewage network rate
63.4	The proportion of those with basic education
29.6	The proportion of those with a university education

CONCLUDING REMARKS

Based on the results obtained in this study the following concluding remarks were reached:

- Constructed wetland treatment of greywater proved to be simple with low operation and maintenance needs, inexpensive, efficient, and accordingly suitable for use in rural homes in Palestine.
- Most greywater and soil analysis after five year treatment in the constructed wetland still within accepted Palestinian reuse standards.
- Public awareness on greywater treatment and reuse is modest and need to be enhanced.

- Constructed wetland treatment of greywater resulted in substantial reduction in greywater content of fecal coliforms and e coli, and consequently reduction in public health risks.
- Treated greywater reuse in rural Palestine helped in reducing water shortages at reuse sites.
- Women represent a key element in the operation and maintenance and sustainability of the treatment and reuse system.

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