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RE-USE OF GREYWATER FOR IRRIGATION OF VEGETABLE CROPS: PRODUCTION AND HEALTH RISKS

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ABSTRACT

The safe re-use of wastewater for agriculture is a desired goal in many arid zone countries. The potential of greywater as alternative irrigation source for vegetable crops was investigated. Tomato, pea and cantaloupe plants were drip irrigated with both fresh Nile water and greywater to access the impact on yield production and associated environmental and health risks. The biological properties of the two different sources of water clearly indicated that greywater was extremely higher in bacterial content compared with fresh Nile water. Pea plants showed significantly higher yield irrigated with fresh Nile water, however, tomato and cantaloupe plants gave significantly higher yield irrigated with greywater. Generally, the coliform populations in untreated greywater irrigated plants were higher than those irrigated with Nile water in all tested vegetables. The percentages of increasing in total coliform in untreated-irrigated greywater vegetables were 27.95%, 34.55% and 41.4% for pea, tomato and cantaloupe (averaged over outer and inner fruit tissues), respectively. Unexpectedly, central part of fruits for pea and tomato had highest coliform counts when compared to the outer surface using both Nile and untreated greywater. Overall, irrigation with greywater increased soil bacterial content by 15% while fresh Nile water increased it by 13% at the end of the experiment. In addition, greywater elevated the content of soil total coliform by 52% where fresh Nile water increased it by 30%. The results of this study indicated that untreated greywater should not consider as an alternative irrigation source for edible crops such as vegetables. In current investigation, the beneficial effects in tomato through giving significantly higher yield with greywater became worthless after the enormous fecal contamination that was detected in fruits. Several considerations must be adopted to minimize the health and environmental risks associated with greywater reuse in irrigation of vegetable crops.

INTRODUCTION

When fresh water resources become limiting, there is a need for expanding use of marginal quality waters (**Matos et al 2012; Rezvani and Yazdi 2013**). Marginal quality water is those waters having some limiting quality characteristics that may have adverse impacts on soil properties, plant production and quality, surface and ground water quality or pose a threat to human and animal health (**Tanji, 1997**). Greywater is non-industrial wastewater generated from domestic usages including showers, bathroom sinks, dishwashers and washing machines. It is distinguished from blackwater (sewage) which is regarded as heavily polluted wastewater generated from the toilet and contains large concentrations of fecal matter and

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urine. Also, blackwater includes kitchen sinks due to the presence of organic matter from food remnants. It is estimated that greywater constitutes around 60-70% of domestic wastewater (**Friedler 2004**). Greywater is simpler and more space-efficient to treat and/or reuse and mildly less contaminated (**Casanova et al 2001**).

On the other hand, greywater may contain organic and chemical compounds that can pollute the environment and pose a health risk to humans. The most obvious risks associated with greywater irrigation include elevated pH, salinity and boron in greywater and the potential accumulation of pathogenic microorganisms, metals and complex organic chemicals in receiving soils that may be slow to break down in the environment. While the first three factors mainly affect soil properties, the later three can have impacts on human health, especially in the irrigation of edible crops such as vegetables (**Eriksson et al 2002; Jefferson et al 2004**).

Pathogens of concern in greywater include: bacteria as entrotoxigenic *Escherichia coli*, *Salmonella*, *Shigella*; *Protozoan*; and Viruses such as *enteroviruses*, *hetatitis A*. Greywater reuse studies rarely enumerate these pathogens directly. Instead, they test for various pathogen indicators (organisms that are relatively benign, easy to enumerate, and whose presence may infer that a pathogen is present). Examples of commonly used indicators are fecal, total coliform, fecal *streptococc*i and *E. coli* (**Ottoson and Stenstrom 2003**).

Total coliform are a broad bacterial category based on certain biochemical properties. Coliform are not solely enteric bacteria but they can be found naturally in water, plant and soil samples. Because of their ubiquitous presence in nature, total coliform is not an accurate indicator of fecal contamination. On the other hand, fecal coliform are a thermo- tolerant subgroup of total coliform that are found in gastrointestinal tracts of warm-blooded animals. The presence of fecal coliform in water indicates that the water has become contaminate with fecal matter and that enteric pathogens may be present. Because fecal coliform are not indigenous to water and soil, their presence is a better indicator of fecal contamination than total coliform (**Casanova et al 2001; Ottoson and Stenstrom 2003**).

It is well established that the levels of fecal coliform in greywater exceed allowable criteria. But there is controversy regarding whether the indicator organism counts are an accurate indicator of the actual threat posed to the humans who comes into direct contact with greywater because fecal coliform concentrations have been observed to multiply in greywater, whereas pathogens die off rapidly. Therefore a high greywater fecal coliform count may not indicate the same level of pathogen exposure risks.

Landscape and agricultural irrigation are identified as logical uses for recycled greywater and have shown general net benefit terms of water conservation, reduction in strain on wastewater facilities. This is particularly important in arid zones, where water is scarce and reuse of greywater for irrigation could reduce potable water use by up to 50% (**DHWA 2002**).

In many Muslim countries, the use of ablution water from Mosques for irrigating surrounding gardens and nearby orchards is a traditional and unique practice. Several reports from diverse countries have been published which include; Yemen (**Al-Nozaily et al 2008**), Oman (**Prathapar et al 2006**), Jordan (**Faruqui and Al-Jayyousi 2002**), Bangladesh (**Khatun and Amin 2011**), and Senegal (**Faruqui et al 2004**). **Al-Nozaily et al (2008)** reported that in Yemen, ablution water is used for irrigation of vegetables such as leek, radish, onion, garlic, and coriander for daily-based fresh consumption.

Ablution water from Mosques was suggested to be a greywater (**Al-Nozaily et al 2008**) since it fit with **Jackson and Ord (2000)** definition of greywater as water with lower quality than potable water but of higher quality than blackwater. Due its relative cleanliness and absence of impurities or oil and soap traces, this water may considered very suitable for irrigation. **Prathapar et al (2006)** discussed some constrains associated with usage of greywater from Mosques in Sultanate of Oman. High degree of temporal variability in the amount of water produces on a daily basis which makes the supply of greywater an unreliable one (**Prathapar et al 2006**).

While most studies focus exclusively on greywater reuse for landscape irrigation, only few studies examine the effect of greywater irrigation on edible crops and the potential transmission of human pathogens. Field studies conducted using wastewater for vegetable irrigation have found higher bacterial counts on crop portions that mature underground or near the surface of the soil **(Rosas et al 1984)**. On the other hand, **Jackson et al (2006)** found no significant difference in bacterial levels on plant surfaces grown in plots irrigated with greywater and non-greywater. Similar results have been found by **Finley et al (2009)** where no significant difference in contamination levels was detected between crops irrigated with greywater and non-greywater. In the same study, the plant growth and productivity were unaffected by water quality **(Finley et al 2009)**. The same was found by **Misra et al (2010)** and **Rodda et al (2011)**. Conflicting results were achieved by **Salukazana et al (2006)** concerning the growth and yield of vegetables irrigated with greywater comparing with non-grey water.

No heavy metal accumulation neither in the soil nor in tomato plants were detected after irrigation with kitchen, ablution water and a mix between them **(Al-Zubi and Al-Mohamadi 2008)**. Also, there was no significant difference between nutrient contents of leaves and fruits of tomato plants irrigated by different types of greywater treatments **(Al-Zubi and Al-Mohamadi 2008)**. On the other hand, tomato plants irrigated with ablution water gave significant higher yield than those irrigated with other sources of greywater or those irrigated with tap water **(Al-Zubi and Al-Mohamadi 2008)**. Chemical properties of the irrigated olive trees and annual plants (okra, bean, corn, and sunflower) were not affected due to irrigation with treated greywater while the biological quality of some annual crops was adversely affected **(Al-Hamaiedeh and Bino 2010)**. Irrigation with 100% greywater had no significant effects on plant biomass **(Pinto et al 2010)**. Irrigation with potable water and greywater in an alternative pattern had soil pH and EC similar to that of irrigation with 100% potable water which means that irrigation with this mixing system could reduce of the soil adverse effects associated with the reuse of greywater **(Pinto et al 2010)**.

The objective of this study was to evaluate the potential of greywater as an alternative irrigation source. In addition determine the environmental impact and health risks associated with greywater irrigation. The influence of crop type was also determined by the selection of different vegetable crops of varying growth habits.

MATERIALS AND METHODS

Experimental design and treatments

A field experiment was conducted at the Experimental Research Farm of Fac. of Agric., Suez Canal Univ., Ismailia, Egypt during the season 2013/2014. The soil of the experimental site was sandy soil (86.21% sand, 10.5% silt and 3.29% clay) with pH 8.07 and EC_e 0.97 dS m^{-1}. Before planting, the experimental location was prepared three months before transplanting. During preparation, a rate of 300 kg calcium superphosphate (15.5 % P_2O_5) per fadden was supplemented, and then the soil of the site was cleared, ploughed and harrowed.

The experiment was laid-out in a randomized complete block design with three replicates. A drip irrigation system was adopted in this study. The tested plants were irrigated with two irrigation water sources, untreated greywater and Nile water (used as control). Pea plants occupied four drip irrigation lines in each replication with total of 12 lines for greywater and 12 lines for fresh Nile water. Tomato plants occupied two drip irrigation lines in each replication with total of 6 lines for greywater and 6 lines for fresh Nile water. Cantaloupe plants occupied six drip irrigation lines in each replication with total of 18 lines for greywater and 18 lines for fresh Nile water. The experimental unit represented by a single line of 10 m length and 1 m width.

Plant materials and growth conditions

Pea (*Pisum sativum* cv. Little Marvel) was direct-seeded 30 cm apart and 100 cm between rows in the soil of the experimental site on mid-October while tomato and cantaloupe were transplanted after a germination and growth period in the greenhouse. Seeds of tomato (*Solanum lycopersicum* cv GS12 F_1; Syngenta) were sown in 209-cell styropham trays under greenhouse conditions in med-September 2013. The trays were filled with a soil mixture (peat and vermiculite mixes in 1:1 v/v, enriched with different nutrients). After emerging, they were watered with a commercial nutrient solution (19-19-19 N-P-K with micronutrient) at a dilution of 1:200. The seedlings were maintained under high humidity and with day/night temperature of 35/25 °C for four weeks. Tomato seedlings, four weeks old, were hand transplanted (0.6 m apart) on the field on mid-October 2013 and remain yielding till early March 2014. Cantaloupe transplants (*Cucumis melo* cv. Galia F_1; Holland AgriSeeds) were obtained from commercial nursery and hand transplanted (0.9 m apart) on the field on April 2014 and remain yielding till end of June 2014. Recommended practices for fertilization, disease and insect control were followed for each crop.

Untreated greywater origin

Plumbing system of the Mosque that located in the Experimental Research Farm of Fac. of Agric. was adjusted to allow the ablution water (greywater) to be separated from blackwater (toilet flush that contain urine and fecal matter). Ablution water was allowed to accumulate in special tank that was placed underground. Electrical pump was used to flush the ablution water from the tank to the irrigation system. Ablution water is mainly used to wash body parts (mouth, nose, face, hands, hair, ears, and feet). Therefore, saliva and mucus may be expected to exist in ablution water. Occasional use of soap and detergents may be expected. Samples from water sources (greywater and Nile water) were collected to analyze its physical, chemical, and microbial properties **(Table 1)**.

Plant and soil sampling

Fruits of pea, tomato, and cantaloupe were collected at maturity stage, counted and weighted to obtain the total yield. Additionally, samples from the experimental rhizosphere soil were collected before the start of the experiment and after irrigation with different water sources from different locations to test the effect of irrigation source on soil microbial, *i.e.* coliform group, in relation to different crop species.

Leave samples from upper (away from contact with irrigation water and soil) and lower (in contact with irrigation water and soil) of pea and tomato were collected. Additionally, fruits of pea, tomato and cantaloupe also collected for bacteriological analyses. All fruits were scarped aseptically with sterile knives and the outer surface and the central part (inner) of fruits were collected to test the possible contamination with coliform microbes due to the irrigation.

Enumeration of heterotrophic bacteria and coliforms

Soil aerobic heterotrophic bacteria was enumerated using classical methodologies, with the results being expressed as colony forming units (CFU/g). However, soil total and fecal coliforms as well as plant total coliforms were enumerated using most probable number (MPN) method (APHA 1998). The inoculated dishes (Sugar peptone agar medium) and tubes (Lactose broth medium) were incubated at 48 hours at 37 ± 0.5 ˚C for heterotrophic bacteria and total coliform and at 44.5 ± 0.25°C for fecal coliform. The MPN index is determined by comparing the pattern of positive results (the number of tubes showing growth at each dilution) with statistical tables. The counts were reported per gram of dry soil.

Data analysis

Data were statistically analyzed using ANOVA/MANOVA of Statistica 6 software **(Statsoft, 2001, Tulsa, OK, USA)** with mean values compared using Duncan's multiple range with a significance level of at least p≤ 0.001, 0.01 and 0.05.

RESULTS

Characterization of untreated greywater in comparison with Nile water

Table (1) represents some chemical and microbiological properties of both Nile water and untreated greywater used in this study. The data showed that EC was not that different between both kinds of water sources. Untreated greywater was lower in pH than Nile water by 12%. Nile water tended to be more alkaline than greywater. Total solids were almost 2-fold higher in Nile water than greywater. In addition, both total hardness and sodium adsorption ratio were higher in Nile water than greywater. These properties of Nile water were associated with higher content of calcium and chloride ions than greywater but sodium and potassium ions are almost similar. Only magnesium was higher in greywater than Nile water **(Table 1)**. The microbiological properties of the two different sources of water clearly indicated that greywater was enormously higher in bacterial content. The total heterotrophic bacterial count was approx. 1.60-fold higher in greywater compared to Nile water. The total coliform and fecal coliform counts were higher in greywater by approx. 1.21- and 1.25- fold comparing to Nile water.

Yield components of tested vegetable crops

Table (2) summarizing the effects of irrigation water source on yield of vegetable crops in current study. Different crops responded in different manners to water sources. Whereas pea plants showed significantly higher yield (both in number of pods per plant and yield as ton/fadden) with Nile water. In pea plants, Nile water gave 5% higher number of pods per plant and 27% in yield as ton/fadden. On the contrary, tomato plants gave

Table 1. Chemical and microbiological properties of irrigation water under this study.

Parameters	Unit	Nile water	Untreated greywater
Chemical			
EC	dS m^{-1}	0.36	0.38
EC	ppm	230.4	243.2
pH	-	7.95	7.11
Ca^{2+}	meq l^{-1}	0.97	0.89
Mg^{2+}	meq l^{-1}	0.50	0.78
Na^{+}	meq l^{-1}	1.73	1.72
K^{+}	meq l^{-1}	0.40	0.41
Cl^{-}	meq l^{-1}	2.0	1.80
Total alkalinity	meq l^{-1}	3.60	3.18
Total solids	ppm	120	64
Total hardness	ppm	100.0	80.0
SAR	-	2.02	1.88
Microbiological			
Total heterotrophic bacteria	log_{10} CFU ml^{-1}	3.64	5.85
Total coliform	log_{10} ml^{-1}	2.90	3.52
Fecal coliform	log_{10} ml^{-1}	1.57	1.96

EC: electrical conductivity, CFU: colony forming unit, SAR: sodium adsorption ratio.

Table 2. Effect of water irrigation source on crop of fruit yield.

Water source	**Crop**					
	Pea		**Tomato**		**Cantaloupe**	
	Fruit No./plant	**Fruit yield (ton fad.$^{-1}$)**	**Fruit No./plant**	**Fruit yield (ton fad.$^{-1}$)**	**Fruit No./plant**	**Fruit yield (ton fad.$^{-1}$)**
Untreated greywater	51.29 b[#]	2.86 b	43.27 a	20.91 a	0.989 a	2.51 a
Nile water	53.91 a	3.63 a	29.20 b	12.89 b	0.871 a	2.15 b
Significance (*P* value)						
Water source	ns	0.000***	0.003**	0.000***	ns	0.011*

#For each trait, means followed by the same letter in each column are not significantly different at (p≤5%). ns= non-significant

significantly higher yield in both yield traits with greywater. In tomato plants, greywater gave higher number of fruits per plant by 48% and 62% increase in fruit yield as ton/fadden. Cantaloupe plants showed varied results. Greywater was not significantly different than Nile water in number of fruits per plant although the slight higher yield by approx. 14%. The difference between greywater and Nile water was significant concerning fruit yield as ton/fadden. Greywater gave 17% higher yield in contrast to Nile water.

Effect of type of used water

Table (3) shows that the effect of untreated greywater on the population of total coliform on different parts of vegetable crops. The whole test-

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ed vegetables had mean coliform counts ranging from 3.79 to 5.23 ($\log_{10}$) g^{-1} and from 4.42 to 8.04 $\log_{10}$ g^{-1} in irrigated plants with Nile water and untreated greywater, respectively. Generally, the coliform populations in untreated greywater irrigated plants were higher than those irrigated with Nile water in all tested vegetables. The highest mean coliform counts were obtained in the outer fruits of cantaloupe (8.04) which irrigated with greywater. The populations were higher in the lower leaves than the upper leaves of pea and tomato. For leaves of cantaloupe, the total coliform was recorded as 5.23 $\log_{10}$ g^{-1} and 7.96 $\log_{10}$ g^{-1} in Nile water and greywater irrigated plants, respectively. On the other hand, the populations of total coliform were higher in outer surface than those in the inner (the central part of fruits) of cantaloupe fruits. In contrary, the central part of (inner) fruits for pea and tomato had highest coliform counts when compared to the outer surface using both Nile and untreated greywater. From the previous results, the highest contamination was observed in vegetables irrigated with untreated greywater compared to Nile water.

Table 3. Effect of water irrigation sources on total coliform contaminated leaves and fruits of crops

Plant	Tissue	Location	Total coliform ($\log_{10}$) g^{-1} plant	
			Nile water	Greywater
Pea	Leaf	Top	3.79	4.73
		Bottom	4.15	5.73
	Fruit	Outer	3.83	4.42
		Inner	4.15	5.83
Tomato	Leaf	Top	4.79	7.73
		Bottom	4.15	6.73
	Fruit	Outer	3.83	4.42
		Inner	4.15	6.38
Cantaloupe	Leaf	-	5.23	7.96
	Fruit	Outer	5.15	8.04
		Inner	4.42	5.60

Soil Microbiology

Table (4) illustrates the effect of irrigation source on bacterial count in soil before and at the end of each tested crop under this study. Nile water irrigated soil showed an increase in total viable bacterial count by 11%, 12%, and 16% in pea, tomato, and cantaloupe plants respectively. In the same direction, total viable bacterial count increased by 14%, 14%, and 17% in soil cultivated with pea, tomato, and cantaloupe plants at the end of each cultivation, respectively **(Table 4)**. Concerning total coliform, Nile water increased the soil count by 23%, 23%, and 45% while greywater increased the soil total coliform by 41%, 49%, and 66% in pea, tomato, and cantaloupe plants respectively. For fecal coliform Nile water increased its soil content by 27% and 48% when cultivated with pea and tomato plants respectively while greywater increased the same content by 42% and 55% in pea and tomato plants respectively.

Overall, irrigation with untreated greywater increased soil bacterial content by 15% while Nile water increased it by 13% at the end of the experiment. In addition, untreated greywater elevated the content of total coliform by 52% where Nile water increased it by only 30%. For fecal coliform, irrigation with greywater increased soil content by 49%, which is less than the effect of Nile water that increased it by 38%.

DISCUSSION

Agricultural irrigation is the primary water consumer sector where it consumes about 70% of the available resources **(FAO, 2002)**. However it is expected that the amount of fresh water allocation to irrigation will drop to accommodate for the increase in water demand for municipal and industrial purposes **(FAO, 2002)**. The use of greywater for irrigation is one of the methods which are currently widely used. This is particularly important in arid regions, where water is scarce.

Greywater may be beneficial for plants because it contains nutrients, mainly nitrogen and phosphorus, but it may also contain sodium and chloride which can be harmful to some plant species. The sodium adsorption ratio (SAR) is the parameter that measures the effects on the soil structure of sodium compounds and a measure of the suitability of water for use in agricultural irrigation. **Table (1)** showed that greywater used in this study has lower SAR value compared to Nile water which may contribute to the advantages of the greywater on plant growth and yield.

Greywater quality depends on the water source, plumbing system, living habits, personal hygiene of the users **(Prathapar et al 2006)**. The high unexpected count of contamination detected in greywater source from Mosque that was used in this study may be due to the nature of people using this specific Mosque as agricultural workers with known low hygiene level. Number of household occupants was shown to affect the microbial quality of greywater and soil irrigated with greywater **(Casanova et al 2001)**. Hundreds of workers whom using this Mosque might contribute to the higher content of microbes associated with greywater used in current study. **Prathapar et al (2006)** analyzed ablution water samples from Mosques and showed that the pH, EC, and TDS (Total Dissolved Solids) are within limits of water suitable for irrigation. On the other hand, coliform and *E. coli* levels exceeded permissible concentration, requiring treatment before reuse.

During storage of untreated greywater (as in present study) suspended solids settle, aerobic microbial activity increases, anaerobic release of soluble COD (Chemical Oxygen Demand) increases and atmospheric-re-aeration occurs **(Dixon et al 2000)**. This may be responsible for the high level of microbial contamination in present study since greywater was collected and stored until the need for irrigation. **Casanova et al (2001)** proved that storage makes statistically significant differences in fecal coliform and *E. Coli* levels in greywater with higher levels when using underground (as in our study) than those using aboveground tanks. When greywater is stored, it will turn septic providing suitable conditions for microorganisms to multiply **(WHO, 2006)**. Thermo-tolerant coliforms have been found to be multiplied by between 10 and 100 times during the first 24 to 48 hours of storage. Therefore, greywater must only be stored temporary in a surge tank, unless it is adequately treated **(Jefferson et al 1999)**.

Our results indicated that the irrigation with greywater significantly increased fruit yield of tomato and cantaloupe and significantly decreased fruit yield of pea relative to vegetables irrigated with Nile water **(Table 2)**. The conflicting yield response of different vegetables used in current study was reported earlier by **Salukazana et al (2006)** where their first trial showed that nutrient irrigated plants gave a significantly greater increase in plant growth of spinach and pepper compared to greywater irrigated plants. In the second trial, irrigation with greywater produced significantly greater yield and overall plant growth than what was achieved with nutrient solution **(Salukazana et al 2006)**. Similarly, various components of plant biomass and leaf area of greywater irrigated plants were found to be similar or significantly higher than the tap water irrigated plants **(Misra et al 2010; Travis et al 2010)**. **Rodda et al (2011)** indicated that the irrigation with greywater increased plant growth, yield and improved plant nutrient relative to crops irrigated with tap water only, although crops irrigated with hydroponic nutrient solution yielded the highest growth and yield. In addition, they and **Pandey et al (2014)** found that soil irrigated with greywater showed increased electrical conductivity and increased concentrations of metals over time, coupled with an increase in sodium and metal concentrations in crops. Thus, provided precautions are taken with regard to salt and metal accumulation, greywater offers a potential source of water for household crop irrigation which additionally shows some fertilizer properties.

Coliform bacteria are the most widely used fecal indicators and play an important role in water management. In this study, irrigation of vegetables with untreated greywater increased the coliform counts on leaves and fruits tissue when compared to irrigation with Nile water. This may be due to the increased the microbial load of untreated greywater **(Table 1)**, which consequently resulted in the contamination of edible parts of the plants with pathogenic microorganisms. Results are in agreement with a study of **Gross et al (2007)** showing that the greywater contains significant microbial

Table 4. Effect of water irrigation source on total heterotrophic bacteria ($\log_{10}$ CFU g^{-1}), total and fecal coliform ($\log_{10}$ g^{-1}) in the soil cultivated with pea, tomato and cantaloupe before and at the end of this study.

Parameters	Initial soil	Nile water			Untreated greywater		
		Pea	Tomato	Cantaloupe	Pea	Tomato	Cantaloupe
Total heterotrophic bacteria	5.78	6.40	6.49	6.68	6.58	6.60	6.75
Total coliform	2.87	3.52	3.52	4.15	4.04	4.28	4.76
Fecal coliform	1.32	1.68	1.95	nd	1.87	2.04	nd

nd= not detected

contaminants that had potential negative environmental and health impact.

In this study, the irrigation with untreated greywater or Nile water increased the coliform counts in the lower leaves compared to upper leaves of pea and tomato. This could be due to the direction of lower leaves that allowed them to directly contact with contaminated irrigation water and soil surface. On the other hand, the position of upper leaves away from contact with irrigation water and the soil surface, consequently they had less coliform counts. In this regard, **Ackers et al (1998)** reported that fecal coliform may be introduced is flood irrigation with water contaminated with cattle feces or contact with contaminated surface runoff. A number of recent *E. coli* O157:H7 outbreaks have been linked to contaminated water; furthermore, studies have demonstrated the ability of the pathogen to survive for extended periods in water. In contrary, **Solomon et al (2002)** found that direct contact between the leaves and a contamination source is not required for the organism to become integrated into edible lettuce tissue.

Our results indicated that the outer surface of cantaloupe fruits had more coliform counts than the inner (the central part) of fruits. In contrary, the inner part of pea and tomato fruits had highest coliform counts compared to the outer surface for Nile water and untreated greywater treatments. This may be explained with the coliform organisms is capable of entering the roots of pea and tomato plants and can be transported upward to locations within the edible portions of the plant (fruits). These results are similar to those of **Ackers et al (1998) and Solomon et al (2002)**, who demonstrated that lettuce grown in soil containing contaminated manure or irrigated with contaminated water results in contamination of the edible portion of the lettuce plant. Moreover, the results suggest that edible portions of a plant can become contaminated without direct exposure to a pathogen but rather through transport of the pathogen into the plant by the root system.

Since the vascular systems of plants are sterile, direct contact of water with edible portions is the principal transmission route of pathogens from water to crop **(Gerba and Smith 2005, Mills et al 1925)**. Microbial contamination was found to persist in the irrigation pipes and in the soil for at least 8 and 18 days respectively **(Sadovski et al 1978a)**. This sustained the infection in the field. The persistence of pathogenic bacteria and viruses in the soil is an important cause for concern since contaminated soil may serve as a reservoir for numerous-contaminations of crops and agricultural machinery. Although, microbial contamination of greywater poses a potential risk to human health, however, there are no recorded incidents of serious effects on human health from the use of greywater **(WHO, 2006)**. The microbiological assessment of vegetables (carrot, spinach, taro, peppers, beet and onion) irrigated with domestic greywater was addressed and it was found that there was no significant difference between vegetables irrigated with tap water, hydroponic, and greywater **(Jackson et al 2006)**. The crops produced using greywater appeared to be excellent which highlight that the use of the greywater irrigated vegetables would not likely to cause any additional disease within the local communities where the trial was conducted **(Jackson et al 2006)**. Similar conclusion was achieved by **Finley et al (2009)** when they suggested that the use of household greywater for irrigation does not necessarily correlate to higher levels of bacterial contamination of food crops.

Our study detected that cantaloupe plants were associated with higher levels of bacterial contamination and this can be expected due to the trailing growth habit of the plant that grow in direct contact with soil and irrigation water. This was not the case in tomato and pea plants with the bush growth habit. Cantaloupe plants were cultivated in the same experimental site after the growth period of tomato and pea plants and thus the elevated levels of contamination in plant and soil can be expected due to the higher amount of greywater that was received by the soil.

Hazard Analysis and Critical Control Points – Total Quality management (HACCP-TQM) Technical Guidelines lay down the microbial quality for raw foods. Food containing < 4 log CFU g^{-1}, 4 – 6.70, 6.70 -7.7 and > 7.7 log CFU g^{-1} (aerobic plate counts) are rated as good, average, poor and spoiled food, respectively **(Anonymous 1999)**. In our study, the quality of pea and tomato fruits was regards as average food whereas only fruits of cantaloupe were poor food (as mean of outer and inner part of fruit).

The microbiology of soils is an important consideration for wastewater or greywater reuse. Soil properties are often affected by microbes as they may cause changes in soil pH, mineralization of organic matter and flow and transport of liquids through the soil **(Reichman and Wightwick 2013)**. Additionally, waterborne pathogens may be surviving in the soil and potentially compromise public health. Fecal coliforms are measured as a surrogate of pathogen persistence in the soil. Our results indicated that the soil irrigated with untreated greywater had higher total and fecal coliform than soil irrigated with Nile water **(Table 4)**. This could be due to the microbial load of untreated greywater is higher than those of Nile water. Survival of fecal coliform in the soil affected by several factors such as soil moisture content, soil texture, organic matter, temperature, pH, source application rate and properties and the availability of nutrients **(Jamieson et al 2002)**. A high greywater fecal coliform count may not indicate the same level of pathogens exposure risk as the same fecal coliform count found in wastewater. This may apply to the greywater used in current study. Although the high total coliform detected in water and planted irrigated with greywater, no record of serious health problems have been observed between people worked with water and plants. In addition, no such record was observed between people consumed these vegetables. Our results are in accordance with **Al-Hamaiedeh and Bino (2010)** who reported that there is no increase in rate of water born disease in the study area after greywater reuse for irrigation. Results of questioner analysis among the inhabitants at the study area showed that about 74% of the respondents are suffering only from odor and flies problems **(Al-Hamaiedeh and Bino 2010)**. Climatic conditions and soil type are important factors affecting the survival of microbial contamination in the field. Light-textured soil encourages the viability of pathogenic microorganisms in the upper soil layers due to its restricted water infiltration. Moderate climatic conditions also encourage the viability of pathogenic microorganisms in the soil, while higher solar radiation restricting the viability **(Sadovski et al 1978a)**.

Conclusion and Recommendations

Several considerations might be suggested to minimize the adverse effects of greywater on plant health and environment due to the irrigation with greywater. Greywater should be used in quantities that can be taken by the plants and the soil since excess greywater will flow to the groundwater and may cause contamination. Therefore, sub-surface and drip irrigation seem to be the best irrigation methods for greywater reuse. While surface irrigation makes contact between greywater with plant parts and should be avoided. Also, applying greywater directly to foliage or stems must be avoided. It is recommended to use mulch layer to help prevent the direct contact with greywater. Greywater recommended to be rotated with fresh water to leach out any harmful build up. Greywater storage should be restricted unless proper treatment is applied **(Al-Jayyousi 2003)**.

Plants irrigated with greywater must be monitored regularly for symptoms of damage and if signs of plant injuries appear, greywater use must be discontinued or reduced. To reduce and/or eliminate the microbiological contamination of vegetables after harvest, some recommendations can be suggested such as the use of contaminated water for the bulk-soil removal and for the first wash of fruits should be avoided; instead, potable tap water should be used for such soil removal and cleaning. Removal of roots and non-edible parts of the vegetables before storing is recommended so as to avoid the proliferation of microorganisms. The vegetables should be carefully rinsed for at least 30 seconds and rinsed vegetables should be soaked in disinfectant solution before consumption **(Rosas et al 1984)**.

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