DISSERTATION

INVESTIGATING THE EFFICACY OF GRAYWATER USE AT THE HOUSEHOLD LEVEL

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY RAMADAN ALKHATIB ENTITLED INVESTIGATING THE EFFICACY OF GRAYWATER USE AT THE HOUSEHOLD LEVEL BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

INVESTIGATING THE EFFICACY OF GRAYWATER USE AT THE HOUSEHOLD LEVEL

The use of graywater at the household level is gaining increasing popularity in both the United States and elsewhere. The treatment methods in the market are either too simple or too complicated for a household resident to use. Also, the effects of using graywater in landscape irrigation and the fate of chemicals in graywater are still unclear. The socio-economic aspects of graywater are variable from one place to another and need to be investigated in order to predict whether graywater use will be accepted or not by the people.

This study investigates the use of graywater at the household level. Three areas were investigated: 1) Graywater treatment at the household level, 2) Effects of using graywater in landscape irrigation, 3) Social response of the people in the Gaza Strip, Palestine.

A house was retrofitted with dual plumbing system to collect graywater. Several treatment schemes were evaluated. The schemes were: I) storage only, II) storage with aeration, III) storage with aeration followed by 24-hour settling, IV) storage with aeration followed by 24-hour settling, coarse filtration, and UV disinfection, V) storage with aeration followed by 24-hour settling, coarse filtration, 5-micron filtration, and UV

disinfection, VI) point-of-use treatment using coarse filter and UV disinfection, VII) point-of-use treatment using coarse filter, UV disinfection, and 5-micron filter. The combination of aeration and settling achieved significant reductions in turbidity, COD, and BOD_5 with efficiencies of 83% and 66% for COD and BOD_5 respectively. Significant reductions in levels of indicator organisms were not achieved till after the introduction of UV unit in scheme IV. As a result, 3-log removal was achieved in the case of the total coliforms, while a removal efficiency of 77% was achieved in the case of fecal coliforms. No *E. coli* was detected as a result of implementing scheme IV. Using the combination of 5-micron filtration and UV disinfection was not sufficient in achieving satisfactory results. Only with the aid of biological treatment, significant results were achieved.

Landscape plants (petunias and geraniums) irrigated with graywater did not show observable visual differences as compared to control plants irrigated with tap water. Plant tissue analysis results at the end of 7-month irrigation period demonstrated significant increase in the levels of sodium and total-N in the graywater-irrigated plants. Alternating irrigation using both tap water and graywater was successful in significantly reducing the accumulated amounts of sodium and total-N. Soil analysis results after 16 months of irrigation revealed that sodium and Sodium Adsorption Ratio (SAR) seemed to be the most affected by graywater irrigation.

The results of 511 surveys distributed to residents in the Gaza Strip revealed that about 84% of the interviewed people accepted the idea of using graywater. Knowing that installing a graywater system would cost the family about $500.00 reversed the acceptance rate of 84% to a rejection rate of about 90%. The situation returned back to the 84% acceptance rate when it was known that the cost paid by the resident would only be $50.00, with the rest of the cost to be contributed by an NGO. Surprisingly, the occupation of the interviewee and whether the house is connected or not to the sewer system did not affect the people's decision of whether or not to accept the use of graywater as demonstrated by the Chi-square tests.

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INTRODUCTION

1.1 Background

Water is a precious resource that needs to be utilized in a wise manner in order to optimize its usage. This will also serve the broader goal of meeting future water demands. Many areas of the world are suffering from limited water supplies and severe droughts. Due to the finite nature of water, both water and wastewater should be treated as commodities of economic value. They should never be treated as wastes of no value.

The dominance of the collection-and-disposal paradigm has developed mainly due to convenience and concerns of public health officials. This type of management – which is supply-driven and centralized in nature – is inappropriate to the goal of sustainable water management. According to Al-Jayyousi (2003), such management has led to over-exploitation and depletion of renewable water resources, mining of non-renewable water resources and deterioration of water quality. Centralized systems are known to be water-intensive in large part because of convenience. In such systems, people are distanced from the precious value of water. This attitude contradicts the fact that the first priority or attention in water management should be given to the reduction in water consumption. If this is effectively achieved, then the available water resources can balance the demand.

Many solutions have been proposed to solve the potable water scarcity problem. Some of them have a centralized basis, and some have a decentralized basis (including house or clustered houses level).

Potable water is used for many purposes; such as drinking, toilet flushing, irrigation, car washing, and decorative water features. However, such high water quality is clearly not required for many of these purposes. Therefore, the premise of this study is that potable water should not be used for purposes where it is not needed. However, there is opposition to such an approach primarily from the public health departments who are concerned that non-potable water may be used accidently for potable purposes. As stated in Al-Jayyousi (2003), to ensure sustainable water management, it is crucial to move towards the goal of efficient and appropriate water use. This attitude was also supported by York and Burg (1998) in their statement: "As the population increases and water becomes increasingly scarce, it simply does not make sense to use precious, potable quality water for these activities".

A parallel model for water use may be drawn from the field of solid waste management. The USEPA has set a hierarchy for solid waste management, which from top to bottom is:1) Reduction, 2) Reuse, 3) Transformation, and 4) Disposal. This hierarchy means that the effort should be on reduction, then reuse, ..etc. The same should apply to the water management sector. First and foremost priority should be given to the reduction in water consumption. This should be obvious since reduction is the cheapest and safest way of conserving water resources. This is especially true for countries that have extreme demands for fresh water. The second option is the reuse of wastewater. The increasing interest in the reuse of wastewater in both developed and developing countries is motivated by several factors. One is water shortage due to low amounts of rainfall along with high evaporation rates. This is the case in countries like Australia (Eriksson et. al., 2002). Another reason can be high water demands due to the size of the population. This is the case in countries like Japan (Eriksson et. al., 2002). A third reason can be the environmental and economical considerations behind the reuse process. Living in a remote area where wastewater collection or potable water network are not available can be a fourth reason (this is the case where graywater use becomes of special interest). Reuse is vital to the sustainability of the water supply. Environmental sustainability will always require conservation and increased recycling of natural resources.

Reclaimed wastewater has been successfully used in many places for non-potable purposes. However, reclaimed wastewater is wastewater that has gone through a set of complex and advanced treatment sequence at the city level. Therefore a great deal of effort has been put into the collection, treatment, and distribution of such water. In addition, this treated wastewater will be recycled anyway – even if unintentionally – to streams or to groundwater. Therefore, the fact of the matter is that it is reused in both cases.

An alternative to the centralized reuse of water is to use it at the household level. This type of management can be considered as one type of decentralized systems. Crites and Tchobanoglous (1998) defined decentralized wastewater systems as "systems that collect, treat and reuse or dispose of wastewater at or near its point of generation". A report prepared by the Rocky Mountain Institute (2004) for the USEPA elaborated on this definition by saying that decentralized wastewater systems include single-home onsite systems and cluster systems that may serve several hundred homes (or equivalent flows).

Therefore, wastewater reuse is not only limited to the large scale. Homeowners have the chance to reuse wastewater by using graywater at the household level (most commonly in landscape irrigation and toilet flushing). Graywater comprises the wastewater generated by washbasins, showers, bathtubs, and laundry. This kind of reuse might pose a health hazard to the household residents. Physical contact with graywater and eating fruit or vegetables irrigated with graywater can be two routes of exposure associated with graywater reuse (CSBE, 2003). However, if certain regulations are developed and followed, any hazard possibility can be lowered to a safe level. The most polluted portions of the wastewater stream generated by a household are the toilet wastes and the kitchen sink wastes. If such portions are removed from the waste stream, the remaining portion of wastewater might have a good potential for reuse. This type of wastewater is called graywater (sometimes spelled greywater). It has particularly good potential for reuse in landscape irrigation and toilet flushing. By reusing graywater in landscape irrigation and toilet flushing, there will be a significant reduction in potable water usage. According to a report prepared by the City of Los Angeles on the graywater usage (City of Los Angeles, 1992): "To reduce or eliminate the projected water supply shortfalls, water conservation and water recycling must be available options to citizens and decision makers". The usage of graywater, especially in arid regions, should receive a great deal of public support if it is organized and well introduced to the public. Graywater recycling offers a way in which individual homeowners can save water and reuse the wastewater generated in their own home. In a graywater literature search prepared for the Texas Onsite Wastewater Treatment Research Council (TOWTRC, 2004), it was stated: "graywater has promising potential as a resource that can be used to supplement or replace potable water for the purpose of landscape irrigation". The different water needs can be met with the appropriate quality of water (Al-Jayyousi, 2003). In several places this has been proven to be economically beneficial. Besides, in doing so the high-quality freshwater is preserved and the need for new fresh water supplies is reduced. Sun (1986) stated that graywater use could be an inexpensive way to solve wastewater disposal problem and to lower the demand of municipal water supply. Governments and regulating bodies are trying to develop new ways to conserve depleting water resources. Graywater treatment and reuse is one of the key methods being considered (CRD, 2004).

1.2 Purpose of this Study

This study has three main goals. The first is to compare various methods for treating graywater at the household level. The second is to investigate the impacts of graywater irrigation on soils and landscape plants. The third is to characterize the opinion of the Gaza Strip residents about the use of graywater in irrigating backyard plants.

1.3 Organization of Dissertation

The study was structured around three main issues, which are: 1) Graywater treatment at the household level, 2) Effects of graywater on landscape plants and soils, 3) The acceptability of graywater reuse for landscape irrigation in the Gaza Strip, Palestine.

Chapter 2 of this study discusses the definition of graywater, quantities of graywater generated at the household level, and an overview of the current uses of graywater in the United States and in some other countries as well. Chapter 3 includes the research done in this study on the treatment of graywater generated at a local household in the City of Fort Collins, CO. Literature review of graywater characteristics and treatment methods are also included in chapter 3. The effects of graywater irrigation on soils and plants – literature review, materials and methods, and the results of the greenhouse experiments done in this study – are the topics of chapter 4. Chapter 5 covers the topic of the acceptability of graywater reuse for landscape irrigation in Gaza Strip, Palestine. It gives an overview of the current situation, describes the methodology used in this research, and discusses the results and analyses of the surveys distributed in the Gaza Strip. The conclusions and recommendations of this study are summarized in chapter 6.

Chapter 2

GRAYWATER: DEFINITION, QUANTITY, USES, AND REGULATIONS

2.1 Definition and Quantity of Graywater

In some literature, graywater is defined as "wastewater without any input from toilets" (Eriksson et. al. 2002). This definition implies that graywater would include wastewater generated from bathtubs, showers, hand basins, laundry machines, kitchen sinks, and dishwashers. Ingham (1980) defined graywater as all wastewaters generated in the household, excluding toilet wastes, and therefore including wastewater from bathroom sinks, baths, shower, laundry facilities, dishwashers, and kitchen sinks. The inclusion of kitchen wastes in the graywater definition is the traditional definition of graywater (Ramon et al. 2004). The majority of graywater literature nowadays prefers to exclude the wastewater produced by the kitchen sinks and the dishwashers since the inclusion of such wastewater has a negative impact on the quality of graywater. Wastewater generated from kitchen sinks and dish washing machines introduces things like oils, greases, a considerable load of food wastes, and microbial contamination. Such wastes are hard to accept for a homeowner and can create an environment that supports the growth of microorganisms. Therefore, the newer definition that will be used here and is also used and recommended by many studies is all types of wastewater generated in a household excluding input from both toilets and kitchen sinks. According to the Uniform Plumbing Code, 2000 edition, appendix G, graywater is defined as "untreated household wastewater which has not come into contact with toilet wastes. Graywater includes used water from bathtubs, showers, bathroom, wash basins, and water from clothes washing machines and laundry tubs. It shall not include waste water from kitchen sinks or dishwashers".

Ramon et al. (2004) divided graywater into two types according to the loading types. The first type is high-load graywater, which comprises wastewater generated by kitchen, washing machine, and dishwasher. The second type is low-load graywater, which comprises wastewater generated by bath, shower, and washbasin. In its classification of graywater types, CRD (2004) ranked the washing machine wastewater in the light graywater category. The other category defined by CRD (2004) was the dark graywater, which primarily originates from kitchen sinks. In its information and guidance note, the Water Regulations and Advisory Scheme (WRAS, 1999) referred to treated graywater as reclaimed water. Such reclaimed water can be used for a number of non-potable uses such as toilet flushing (WRAS, 1999).

In the US, this type of water is spelled as "graywater". In Australia and European countries, it is commonly spelled as "greywater". In Australian references, the name "sullage" is also commonly used as a surrogate and synonym to the graywater term.

The amount of graywater generated at the household level varies greatly from one house to another. Therefore, if a graywater system is to be installed in a house it is important that each household owner determines how much graywater is generated.

Significant amounts of the household landscape irrigation needs can be met with graywater generated within the household. In Tucson, Arizona, it has been estimated that the amount of graywater that can be collected is 31 gallons per day per person (Rose et al., 1991). For a family of three, that amounts to 33,945 gallons per year (Rose et al., 1991). A household in Arizona can generate about 30,000 to 40,000 gallons of graywater per year (Watercasa website). Karpiscak et al. (1990) estimated that about 30% of the total household water consumption could be saved by reusing graywater for toilet flushing. The same percentage was reported by Legget et al. (2001), but with the feeling that 20 to 25% is more realistic. A 40% reduction in the wastewater flow is anticipated as a result of applying graywater segregation (Laak, 1977 as reported by Raniga, 1980).

The American Water Works Association published a study investigating how water is utilized in North American Households. The study, in which 14 North-American cities were examined, showed that the graywater generation rate ranged from 33 to 45 gallons.capita^{-1}.d^{-1}, and averaged at about 38 gallons.capita^{-1}.d^{-1}. This constitutes about 56 % of the total indoor use. Table 2.1 shows some results for indoor water consumption. The combination of the indoor and the outdoor water consumptions is shown in Table 2.2. The study revealed that the average household in this study uses about 152,600 gallons of water annually. About 42.1% (62,900 gallons) of this amount is used indoors, while the rest, 58.8% (89,700 gallons), is used outdoors. These numbers mean that graywater (not including kitchen sink wastewater) constitutes about 23% of the total water consumption in a household.

Table 2.1 Average Indoor Consumption for Each Use Category (gal.cap^{-1}.d^{-1})

	Persons per household	Bath	Shower	Faucet	Clothes washer	Availble GW	Toilet	Dish-washing	Other indoor	Total indoor	%GW * (of indoor)
Phoenix, AZ	2.9	1.2	12.5	9.6	16.9	40.2	19.6	0.8	17	77.6	51.8%
Scottsdale & Tempe, AZ	2.3	0.9	12.6	11.2	14.5	39.2	18.4	1.1	22.6	81.3	48.2%
Las Virgenes, CA	3.1	1.3	11.4	11.2	16.8	40.7	15.7	0.9	12.3	69.6	58.5%
Lompoc, CA	2.8	1.2	11.1	9.9	15.3	37.5	16.6	0.8	11	65.9	56.9%
San Diego, CA	2.7	0.5	9	10.8	16.3	36.6	15.8	0.9	4.9	58.2	62.9%
Walnut Valley, CA	3.3	1	11.7	12.3	14.1	39.1	18	0.8	9.9	67.8	57.7%
Boulder, CO	2.4	1.1	11.4	8.7	12	33.2	17.1	1		51.3	64.7%
Denver, CO	2.7	1.6	12.9	10.5	15.6	40.6	21.1	1.2	6.3	69.2	58.7%
Tampa, FL	2.4	1.1	10.2	12	14.2	37.5	16.7	0.6	11.1	65.9	56.9%
Waterloo & Cambridge	3.1	1.9	8.3	11.4	13.7	35.3	20.3	0.8	14.2	70.6	50.0%
Eugene, OR	2.5	1.5	15.1	11.9	17.1	45.6	22.9	1.4	13.7	83.6	54.5%
Seattle, WA	2.8	1.1	11.4	8.7	12	33.2	17.1	1	5.9	57.2	58.0%
Average	2.75	1.2	11.5	10.7	14.9	38.2	18.3	0.9	11.7	68.2	56.1%
% of total indoor		1.8%	16.8%	15.7%	21.8%	56.1%	26.8%	1.4%	17.2%	100.0 %	

Source: Mayer et al. 1999

* Calculated

Table 2.2 Annual Indoor, Outdoor, and Total Water Use

	Outdoor Annual Use (kgal/home)	Indoor Annual Use (kgal/home)	Total Annual Use (kgal/home)
Phoenix, AZ	161.9	70.8	232.7
Scottsdale & Tempe, AZ	156.5	60.1	216.6
Las Virgenes, CA	213.2	70.9	284.1
Lompoc, CA	43.5	62.1	105.6
San Diego, CA	99.3	55.3	154.6
Walnut Valley, CA	114.8	76.3	191.1
Boulder, CO	73.6	54.4	128
Denver, CO	104.7	61.9	166.6
Tampa, FL	30.5	56.1	86.6
Eugene, OR	48.8	65.1	113.9
Seattle, WA	21.7	54.1	75.8
Waterloo & Cambridge	7.8	67.7	75.5
Average	89.7	62.9	152.6
% of total	58.8%	41.2%	100.0%

Source: Mayer et al. 1999

If the total available graywater is used in a household, the amount of water savings may be in the range of 50 percent (City of LA, 1992). This number was estimated from eight graywater sites in which the potential demand for graywater use ranged from 13 to 65 percent. Christova-Boal et al. (1996) estimated the water savings resulting from using a typical graywater system in Melbourne, Australia. The results of their estimation are shown in Table 2.3.

Table 2.3 Estimated water savings resulting from using a graywater system in Melbourne

	Saving (kl/a)*	**% of total water use****	**% of total sewage**
Garden	52	21	32
Toilet	49	20	30
Toilet and garden	77	31	47

* Kl/a = kiloliters/annum
** Based on average consumption of 250 kl/a
Source: Christova-Boal et al. (1996)

Several methods exist for the determination of the graywater generation at a household level. A procedure for estimating the graywater discharge was suggested by California Graywater Standards. The procedures are not limited to the residential rates; they are extended to the estimation of commercial, industrial, and institutional projects. The procedure for estimating the residential use is summarized in the following steps:

1- Estimate the number of occupants: Two occupants for the first bedroom and one occupant for each additional bedroom.

2- Estimate the graywater discharge for each occupant: 25 gal.capita^{-1}.d^{-1} for showers, bathtubs, and wash basins; and 15 gal.capita^{-1}.d^{-1} for laundry.

3- Multiply the estimated number of occupants by the estimated graywater discharge in step 2.

The generation rates mentioned in step 2 are very close to the values found in the 1999 AWWARF Residential End Uses of Water study (Table 2.1).

2.2 Graywater Uses

The main potential uses for the graywater are landscape irrigation and toilet flushing. Other applications exist, but they may require higher level of treatment. Besides, the amounts of graywater generated can be fully utilized by landscape irrigation and toilet flushing. Therefore, there is no need to include other uses.

A report prepared by CDR (2004) in Canada justified the use of light graywater for direct reuse for applications where there is low risk of public contact; e.g. subsurface irrigation and toilet flushing because light graywater typically has low concentrations of organic and inorganic contaminants, and disease-causing microorganisms. However, caution must be exercised when graywater reuse is exercised because of the undefined increase in risk to public health and the environment (Jeppesen, 1996). Despite the fact that fecal waste stream is excluded from the graywater stream, raw graywater still contains relatively large numbers of total and fecal coliforms. Jeppesen and Solley (1994) suggested the occurrence of at least one of two measures for safe reuse of graywater: 1) Graywater must be treated to remove or destroy those microorganisms; 2) Human contact with graywater must be prevented.

2.2.1 Landscape Irrigation

Graywater reuse for irrigation is gaining popularity as communities in the US – especially the in the western states – are now more interested in innovative approaches to water resource sustainability (Criswell et al. 2005). In the United States, landscape irrigation is the most common application of graywater. The western states are considered world leaders in graywater reuse (Jeppesen and Solley, 1994). The practice of using graywater in landscape irrigation has been legalized by several states such as Arizona, California, Idaho, Nevada, New Mexico, South Dakota, Texas, Utah, and Washington (Criswell et al. 2005). Since these states suffer from water scarcity, the motive of using graywater in these states is the water shortage.

Graywater reuse is not allowed in the State of Colorado. An information sheet prepared by the Colorado Division of Water Resources (CDWR, 2003) reported that the use of graywater systems is not viable for most homeowners in Colorado. In terms of the permitting procedures, it has been mentioned in the same sheet that if graywater is discharged below the soil surface and below the root zone similar to a leach field, a permit from the local health department is all that is required (CDWR, 2003). If graywater is used to irrigate below the soil surface, but within the root zone (above frost line), both a local permit and monitoring are required (CDWR, 2003).

However, the use of reclaimed water is allowed under regulation 84 of the Colorado Department of Public Health and Environment. The standards and categories of reclaimed water are shown in Table 2.4. Table 2.5 shows the approved uses of reclaimed water.

Table 2.4 Reclaimed Water Categories and Standards

Category No.	Minimum Treatment Required	Parameters	Limits
1	Secondary treatment with disinfection	*E. coli*	126/100ml monthly geometric mean and 235/100ml single sample maximum
		Total suspended solids	30 mg/L as a daily maximum
2	Secondary treatment with filtration and disinfection	*E. coli*	126/100ml monthly geometric mean and 235/100ml single sample maximum
		Turbidity	3 NTU as a monthly average and not to exceed 5 NTU in more than 5 percent of the individual analytical results during any calendar month
3	Secondary treatment with filtration and disinfection	*E. coli*	Non detected in at least 75% of samples in a calendar month and 126/100ml single sample maximum
		Turbidity	3 NTU as a monthly average and Not to exceed 5 NTU in more than 5 percent of the individual analytical results during any calendar month

Source: CDPHE, 2005

Table 2.5 Approved Uses of Reclaimed Water as Stated by the Colorado Department of Public Health and Environment in Regulation 84

Approved Uses	Category 1	Category 2	Category 3
INDUSTRIAL			
Cooling tower	✓	✓	✓
Concrete mixing & washout	✓	✓	✓
Dust control	✓	✓	✓
Soil compaction	✓	✓	✓
Closed loop cooling system	✓	✓	✓
LANDSCAPE IRRIGATION			
Restricted access	✓	✓	✓
Unrestricted access	×	✓	✓
Resident-controlled	×	×	✓
COMMERCIAL			
Mechanized street cleaning	✓	✓	✓
Zoo operations	✓	✓	✓
FIRE PROTECTION			
Unresidential fire protection	×	✓	✓
Residential fire protection	×	×	✓

Source: CDPHE, 2005

As shown in Table 2.5, landscape irrigation has been divided into three types: 1) Restricted access, 2) Unrestricted access, and 3) Resident controlled. The definition of each type is not clear. It seems that subsurface irrigation lies in the restricted-access category. As illustrated in Table 2.4, the only parameters used to monitor the application of reclaimed water use are *Escherichia coli (E. coli)*, total suspended solids (TSS), and turbidity.

2.2.2 Toilet Flushing

Since toilet flushing uses a significant portion of the water consumed in the house, the collection and use of graywater to replace toilet flushing might result in substantial reductions in water consumption (Sun, 1986). Karpiscak et al. (1990) estimated that about 30% of the total household water consumption could be saved by reusing graywater for toilet flushing. For office buildings, the situation is different. The amount of graywater generated is very little compared to the amount needed for toilet flushing. Therefore, in order to use graywater in toilet flushing, only few toilets in an office building can use graywater.

Albrechtsen (2002) discussed four graywater systems and seven rainwater collection systems used for toilet flushing. The graywater sources were the shower and the hand wash basins. Despite the treatment applied to the graywater, graywater brought about several complaints regarding bad smell. Besides, the author reported that very high numbers of *E. coli* (up to 510,000 per 100mL) and *Enterococcus* (up to 570,000 per 100mL) were observed in some toilet bowls supplied with graywater. The author warned about the microbial quality of graywater and raised several concerns: 1) The treatment systems for graywater are much more complicated than those needed for rainwater and have more reliance on maintenance. 2) In apartment buildings, graywater is typically collected from several apartments, mixed, and distributed to all apartments for toilet flushing. If disease-carrying persons reside in an apartment then some pathogenic agents may be excreted from those sick people to the graywater. Theoretically, a significant risk exists in such situations. The use of graywater in toilet flushing poses some health risk associated with splashing when the toilet is used and aerosols when the toilet is flushed (Christova-Boal et al., 1996). Bingley (1996) considered that the current published methods of graywater treatment were too crude to be used for toilet flushing.

Several successful graywater projects were documented for the reuse in toilet flushing. However, they either require a full automation or an extensive manual care in order to be reliable. March et al. (2004) examined a graywater system for an 81-room hotel in Spain. The hotel has been retrofitted with a graywater system that incorporated a treatment train. The treatment train adopted was filtration using a nylon sock (0.3 mm mesh), sedimentation, and disinfection with sodium hypochlorite. The treated graywater is stored in a 4.5m^3 ground tank and then pumped to an elevated tank. The residual chlorine concentration was maintained at values higher than 1mg/L. All samples taken showed a zero level of total coliform bacteria. The analysis of raw graywater showed that the hotel graywater is more dilute than the household graywater. The total amount of graywater generated was 5.2 $m^3.d^{-1}$, which comprises 23% of the total water consumption.

Criteria for using service water or reclaimed wastewater in toilet flushing were set by different agencies/departments. Table 2.6 shows some of these criteria.

Table 2.6 Criteria for Using Service Water or Reclaimed Water in Toilet Flushing

USEPA*	**Berlin Senate Department for Building & Housing***	**Tokyo, Japan***
- Reclaimed water for toilet flushing should undergo eventual filtration and disinfection - No detectable fecal coliform/100 mL - Cl_2 residual of > 1 mg/L - Reclaimed water should be clear and odorless	- $BOD_7 < 5$ mg/L - Total coliforms<100 mL^{-1} - Fecal coliforms<10mL^{-1} - Pseudomonas aeruginosa< 1mL^{-1}	- $BOD_5 < 20$ mg/L - Total coliforms<100 mL^{-1}

* *Source*: Nolde, 1999

In the US, there are no federal regulations directly governing water reuse practices (USEPA, 2004). Instead, each state has its own water reuse regulations and guidelines. Only 10 US states have regulations or guidelines pertaining to the use of reclaimed water in toilet flushing. Those states are: Arizona, California, Florida, Hawaii, Massachusetts, New Jersey, North Carolina, Texas, Utah, and Washington. Table 2.7 shows the unrestricted urban reuse regulations/guidelines in some US states.

Table 2.7 Unrestricted Urban Reuse Regulations/Guidelines in Some US States

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, & disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (Not Specified)	Oxidized, coagulated, filtered, and disinfected
BOD_5	NS	NS	20 mg/L	NS	30 mg/L	5 mg/L	30 mg/L
TSS	NS	NS	5.0 mg/L	NS	NS	NS	30 mg/L
Turb.	2 NTU (Avg) 5 NTU (Max)	2 NTU (Avg) 5 NTU (Max)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg) 5 NTU (Max)
T.Coliform	NS	2.2/100 ml (Avg) 23/100 ml (max in 30 days)	NS	NS	NS	NS	NS
F.Coliform	Non-detect (Avg)		75% of samples below detection	2.2/100 ml (Avg)	2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (max)		25/100 ml (Max)	23/100 ml (max)	23/100 ml (max)	75/100 ml (max)	23/100 ml (max)

Source: USEPA, 2004

2.3 Graywater Use and Regulation in the United States

The water saving potential of using graywater has been recognized by several US states. According to Jeppesen and Solley (1994) the western states of the US and Japan are the world leaders in graywater reuse. About one quarter of housing units in the United States are not connected to publicly owned wastewater collection systems (US Census, 1990). Such places have high potential uses for graywater.

There are no federal regulations concerning the use of reclaimed Water. Every state carries the burden of setting guidelines or regulations for reclaimed water reuse. Some states went beyond those limits by setting guidelines or regulations for graywater use. Jeppesen and Solley (1994) reported that twenty-two states of the USA allow the direct reuse of untreated domestic graywater by sub-surface watering of ornamental gardens and lawns. Subsurface irrigation, a minimum distance to the highest groundwater level, and sealed and vented tank with a label are few regulations commonly encountered in the graywater state regulations. Subsurface irrigation is mandated in most of the states to prevent human contact with untreated graywater. No federal guidelines or regulations exist for the use of graywater. However, the Uniform Plumbing Code (UPC) has addressed graywater systems since its 1994 edition (CSBE, 2003). The official allowance of graywater usage is not a new issue in the United States. During a drought period in the years 1977-1978 and as an incentive to use graywater, the State of California provided tax relief to those who chose to install graywater systems. In 1989, the first graywater regulations in the US were introduced by Santa Barbara, California (CSBE, 2003).

The State of Arizona is not only one of the states that strongly encourages the use of graywater at the household level, but also it allows the direct use of graywater in surface irrigation provided that graywater pooling does not occur and spray irrigation is avoided. This means that methods like surface irrigation – with limitations – and drip irrigation are legal. Many of these rules are based on the results of a graywater study conducted in the Tucson area [ADEQ, website]. The study, which was conducted by the Water Conservation Alliance of Southern Arizona, can be found at the Watercasa website [Watercasa, website]

Box 2-1 shows the graywater regulations issued by the Arizona Department of Environmental Quality for the direct reuse of graywater.

Box 2-1.

Graywater regulations issued by the Arizona Department of Environmental Quality

A. A Type 1 Reclaimed Water General Permit allows private residential direct reuse of gray water for a flow of less than 400 gallons per day if all the following conditions are met:

1.0 Graywater is originating from the residence is used and contained within the property boundary for household gardening, composting, lawn watering, or landscape irrigation;

2.0 Surface application of graywater is not used for irrigation of food plants, except for citrus and nut trees;

3.0 The gray water does not contain hazardous chemicals derived from activities such as cleaning car parts, washing greasy or oily rags, or disposing of waste solutions from home photo labs or similar hobbyist or home occupational activities;

4.0 The application of graywater is managed to minimize standing water on the surface;

5.0 The graywater system is constructed so that if blockage, plugging, or backup of the system occurs, gray water can be directed into the sewage collection system or on-site wastewater treatment and disposal system, as applicable. The gray water system may include a means of filtration to reduce plugging and extend system lifetime;

6.0 Any gray water storage tank is covered to restrict access and to eliminate habitat for mosquitoes or other vectors;

7.0 The graywater system is sited outside of a floodway;

8.0 The graywater system is operated to maintain a minimum vertical separation distance of at least five feet from the point of gray water application to the top of the seasonally high groundwater table;

9.0 For residences using an on-site wastewater treatment facility for black water treatment and disposal, the use of a gray water system does not change the design, capacity, or reserve area requirements for the on-site wastewater treatment facility at the residence, and ensures that the facility can handle the combined black water and gray water flow if the gray water system fails or is not fully used;

10.0 Any pressure piping used in a gray water system that may be susceptible to cross connection with a potable water system clearly indicates that the piping does not carry potable water;

11.0 Gray water applied by surface irrigation does not contain water used to wash diapers or similarly soiled or infectious garments unless the gray water is disinfected before irrigation; and

12.0 Surface irrigation by gray water is only by flood or drip irrigation.

B. Prohibitions. The following are prohibited:

1. *Gray water use for purposes other than irrigation, and*
2. *Spray irrigation.*

C. Towns, cities, or counties may further limit the use of gray water described in this Section by rule or ordinance.

The State of New Mexico also passed some regulations in the year 2003 as amendments to the Water Quality Act allowing the discharge of up to 250 gallons per day of residential graywater without a special permit provided that certain conditions are fulfilled. These conditions are shown in Box 2-2.

Box 2-2

Conditions for Graywater Reuse in the State of New Mexico

A permit is not required to apply less than two hundred fifty gallons per day of private residential gray water for the resident's household gardening, composting or landscape irrigation if the following conditions are met:

- *The gray water distribution system must be constructed so that overflow from the system drains into the sanitary sewer or septic system. In some cases, a liquid waste permit may be necessary if an on site septic system is modified.*
- *A gray water storage tank must be covered to restrict access and to eliminate habitat for mosquitoes or other vectors. Standing water left in place for more than seven days has the potential to allow mosquitoes to breed and hatch.*
- *The gray water system must not be located in a floodway.*
- *Gray water is discharged only in areas where there is vertical separation of at least five feet between the point of discharge and the ground water table to protect ground water resources from possible contamination. Current Liquid Waste Disposal Regulations require that gray water is not applied within 100 feet of a domestic well or within 200 feet of a public water supply.*
- *Gray water pressure piping is clearly identified as carrying non-potable water.*
- *Gray water is used on the site where it is generated and may not run off the property.*
- *Gray water is applied in a manner that minimizes the potential for contact with people or domestic pets. Gray water application methods that reduce contact include drip irrigation, shallow piping systems, or mulch trenches.*
- *Ponding of gray water is prohibited and application of gray water must be managed to minimize standing water and to prevent saturation of the soil.*
- *Gray water must not be sprayed. Low-pressure drip irrigation or bubblers located under mulch help to prevent misting and exposure to gray water.*

...Continue Box 2-2

- *Gray water must not be discharged to a watercourse. Current Liquid Waste Disposal Regulations require that discharges of gray water be at least 100 feet from streams or lakes or 25 feet (plus the depth of the arroyo) from an arroyo.*
- *Gray water use shall comply with all applicable municipal or county ordinances and local building codes.*

Source: NMED, 2003

The use of graywater is not legal in the State of Colorado. However, the use of reclaimed water for different purposes is regulated by Colorado Department of Public Health and Environment, regulation 84 for the year 2005. In regulation 84, three categories of reclaimed water have been identified; category 1, category 2, and category 3 (Table 2.4), with category 3 being the most stringent among the three categories. Each category has its specific standards, treatment requirements, and approved uses. For example, for the landscape irrigation, the only approved use under category 1 is the restricted-access use. Unrestricted-access and resident-controlled uses are not approved under category 1 of reclaimed water. Table 2.5 shows the approved uses of reclaimed water as stated by Colorado Department of Public Health and Environment.

2.4 Graywater Use in other Countries

The literature review carried out indicated more intensive use of graywater in several countries when compared to that found in the United States. In the United States, the use of graywater is mostly limited to landscape irrigation. In other countries, several cases of using graywater in toilet flushing have been encountered. Many of these cases incorporate biological treatment systems to reduce the amount of organic matter in the graywater and disinfection as the final stage.

In a country like Australia where water is scarce, water reuse is very common. Australia appears to be at the forefront of the move to implement graywater reuse as one of the key methods of residential water conservation (CRD, 2004). It is found that each state has its own regulations regarding the use of graywater.

NSW Department of Health realized the interest in the graywater use and issued accreditation guidelines for the domestic graywater treatment systems (DGTS). The guidelines are intended to provide the manufacturers with guidelines about the domestic graywater treatment systems (DGTS) and enable consistent assessment by a third party and final issuance of a certificate of accreditation by NSW health to a DGTS manufacturer. According to these guidelines, a DGTS is defined as a domestic graywater treatment system designed to store, treat, and disinfect graywater or components of graywater to the standards specified in the NSW Health Accreditation Guidelines so that it may be applied to a surface or sub-surface irrigation area, and/or reused for toilet flushing and laundry use in the household. Local authorities cannot approve the installation of a manufactured DGTS unless it is accredited by the NSW Health Department. The system is to be tested by a third party according to these guidelines for a period of 26 weeks. Samples are to be analyzed for BOD_5, suspended solids, thermotolerant coliforms, and free chlorine (if used as disinfectant).

NSW Health Department published a document in 2000 entitled as "Greywater Reuse in Sewered Single Domestic Premises". In this document, the graywater reuse practice was divided into two types:

1) Graywater diversion devices: which simply divert graywater without storage or treatment. The graywater in this practice may not include kitchen wastewater.
2) Domestic graywater treatment systems (DGTS): which collect, store, and treat graywater to a higher standard. The graywater in this practice may include kitchen wastewater. As mentioned earlier, a DGTS has to be tested by a third party to receive an accreditation by the NSW Health Department.

As understood from NSW (2000) and NSW (2005), untreated graywater diversion for subsurface irrigation does not require installation approval from the local authority nor does it require accreditation from NSW Health Department. However, it requires an approval to operate from the local authority. For uses like surface irrigation and toilet flushing, a DGTS has to be used (a mere diversion device cannot be used). The DGTS has to have an accreditation from NSW Health Department for its intended use.

According to CSBE (2003), graywater reuse is not widespread in the UK. A report by Leggett et al. (2001) on the use of graywater and rainwater reported that no legislative barriers to the use of graywater and rainwater exist in the UK. However any design and installation need to comply with to the requirements of the Water Supply (Water Fittings) Regulations 1999 for England and Wales, the Water Quality Regulations (North Ireland) 1994 and the Private Water Supplies Regulations (North Ireland) 1994 for Northern Ireland, and the Water Supply Regulations 1990 and amendment 1991 for Scotland. Leggett et al. (2001) considered compliance with the Water Fittings

Regulations 1999 as the key requirement. These regulations require that mains water and water supplied is protected against backflow or any kind of cross connection by unrestricted air gaps. The same regulations also require that pipes conveying reclaimed water shall be easily distinguished. Guidance published by the Water Regulations Advisory Scheme regarding reclaimed water systems and pipe marking has been considered valid by the Department of Environment, Transport, and Regions.

It has been reported by CSBE (2003) that Cyprus offers a subsidy program for those households that choose to install graywater reuse systems. According to Kambanellas (1998), dual plumbing systems have been introduced in Cyprus to allow the reuse of graywater in toilet flushing.

In Palma Beach, Spain, an 81-room hotel was retrofitted to accommodate an indoor graywater recycling system for the purpose of toilet flushing. The treatment system adopted is based on filtration, sedimentation, and disinfection (March et al. 2004). The system worked for one year without significant problems. March et al. (2004) reported that no complaints have been reported to the hotel administration and the overall customer acceptance was satisfactory.

In Södra Vibyåsen in Stockholm, Sweden; household wastewater is separated into black water and graywater. Södra Vibyåsen is a housing area consisting of 85 row houses inhabited by about 212 people (Ottoson and Stenström, 2003). According to Ottoson and Stenström (2003), graywater is treated locally in settling tanks, by activated sludge, then passed through a biofilter, and finally released into a pond where exposure to humans may occur.

Chapter 3

GRAYWATER CHARACTERISTICS AND TREATMENT METHODS

3.1 Graywater Characteristics

Knowledge of the graywater characteristics is essential in the determination of the best treatment needed and the proper avenues in which graywater may be utilized. Such knowledge is also essential in assessing the risks of graywater use (Casanova et al., 2001a). Usually, the main potential uses of graywater are landscape irrigation and toilet flushing. However, one of the reasons behind the reluctance in using graywater comes from the varying nature of its quality; i.e. the fact that its quality is not the same in both time and location. The quality is different from one location to another and from time to time. When browsing the available literature about the graywater quality, one can notice the wide variations in the critical water quality parameters (e.g. indicator organisms, BOD, suspended solids, etc) among different graywater sources. The wide variations in composition stand as one of the major difficulties encountered in graywater treatment (Al-Jayyousi 2003). The general characteristics of several graywater sources are shown in Table 3.1.

Table 3.1 General Graywater Characteristics by Source

Water Source	Characteristics
Automatic clothes washer	Bleach, Foam, High pH, Hot water, Nitrate, Oil and Grease, Oxygen demand, Phosphate, Salinity, Soaps, Sodium, Suspended solids, and Turbidity
Automatic dish washer	Bacteria, Foam, Food particles, High pH, Hot water, Odor, Oil and grease, Organic matter, Oxygen demand, Salinity, Soaps, Suspended solids, and Turbidity
Bath tub and shower	Bacteria, Hair, Hot water, Odor, Oil and grease, Oxygen demand, Soaps, Suspended solids, and Turbidity
Evaporative cooler	Salinity
Sinks, including kitchen	Bacteria, Food particles, Hot water, Odor, Oil and grease, Organic matter, Oxygen demand, Soaps, Suspended solids, and Turbidity

Source: New Mexico State University's Safe Use of Household Graywater guide, 1994

According to a report prepared by the City of Los Angeles in 1992 (City of Los Angeles, 1992), the quality of graywater can vary according to lifestyles and customs, whether young children exist in the house or not, whether kitchen sink wastewater is included or not, types of detergents used, etc. Other specific factors that seem to affect the quality of graywater are the disposal of medications and some other waste products to the graywater stream, whether water conservation devices are used or not, and the sources connected to the graywater collection system. The later one is of special importance since it determines the general characteristics of a graywater stream. All of these factors can lead to large variations in the graywater quality parameters; including physical parameters, chemical parameters, and microbial parameters. As an example, Casanova et al. (2001a) found that there is a statistically significant difference in levels of fecal coliforms between a household inhabited by two adults only and a household inhabited by two adults and one child. Eriksson et al.(2002) mentioned three factors that significantly affect the graywater composition: water supply quality, the composition of the system that transports both gray and drinking water, and the activities in the house.

From the health perspective, while the biological risks are known to have a relatively immediate outcome in the form of illnesses development in a short period of time, the chemical risks cause time-delayed effects (Lazarova and Bahri, 2004).

The graywater characteristics as reported by several studies indicate that graywater has to be considered as dilute sewage because it has all constituents of raw wastewater (Christova-Boal et al. 1996). A study by Casanova et al. (2001a) suggested that the overall microbial, chemical, and physical quality of untreated residential graywater lies somewhere between raw wastewater and secondary effluent. Table 3.2 shows a comparison between the characteristics of domestic raw wastewater and those of graywater generated at a student residence hall.

Table 3.2 Average pollutant concentration in graywater and wastewater

	Graywater generated at a student residence hall			**Raw Wastewater**
	Bath & shower	**Wash basin**	**Washing machine**	
BOD	216	252	472	300
COD	424	433	725	618
Total coliform (c/100ml)	6×10^6	5×10^4	7×10^5	$10^6 - 10^7$
Fecal coliform (c/100ml)	600	32	728	10^4
Turbidity (NTU)	92	102	108	
Total Carbon	130	60	135	
Inorganic carbon	26	20	25	
TOC	104	40	110	182
Total solids	631	558	658	730
Suspended solids	76	40	68	152
Dissolved solids	559	520	590	578
Volatile solids	318	240	330	375
Ammoniacal-N	1.56	0.53	10.7	42
Nitrate-N	1.56	0.34	1.6	59
Phosphate-P	0.9	45.5	101	11
pH	7.6	8.1	8.1	7.6

Source: Surendran et al. 1998

At the household level, the chemical, physical, and microbial characteristics of graywater generated by a family of two in Tucson, Arizona are summarized in Table 3.3 (As reported by Casanova et al., 2001a).

Table 3.3 Chemical, Physical, and Microbial Characteristics of Graywater Produced by a Family of Two Adults in Tucson, Arizona

Parameter	**Arithmetic mean**	**Geometric mean**
pH	7.47	7.46
Turbidity, NTU	43.00	40.65
BOD (mg/L)	64.85	63.31
TSS (mg/L)	35.09	29.36
EC (mS/cm)	0.43	0.43
SO_4^{2-} (mg/L)	59.59	57.21
Cl^- (mg/L)	20.54	20.03
Total Coliform (CFU/100ml)	8.03×10^7	2.39×10^7
Fecal coliforms (CFU/100ml)	5.63×10^5	6.95×10^4
Fecal streptococci (CFU/100ml)	2.38×10^2	1.21×10^2
S. aureus (CFU/100ml)	<1	<1
P. aeruginosa (CFU/100ml)	1.99×10^4	2.92×10^3
Coliphages (PFU/100ml)	<1	<1

Source: Casanova et al. (2001a)

The major concerns in graywater use appear to be turbidity, microbial concentration, and the potential presence of pathogens (Rose et al., 1991). Raniga (1980) stated that the important contaminants of concern in wastewater are suspended solids, biodegradable organics, pathogens, and nutrients.

3.1.1 Microbial Characteristics

One major problem that prevents graywater use from being more widely used among people and from being considered by many official authorities is the pathogens that might be present. Although toilet wastes are not included in graywater, graywater still contains human fecal indicator bacteria in concentrations high enough to indicate a health risk from the potential presence of pathogenic microorganisms (Jeppesen and Solley, 1994). Table 3.4 shows the microbial characteristics of graywater as reported by several studies.

Table 3.4 Microbial Quality of Untreated Graywater as Reported by other Studies

Reference	Graywater sources	Total coliforms	Fecal coliforms	Total Counts	*E. coli*	Fecal streptococci
Surendran et al. (1998)	Raw wastewater	$10^6 - 10^7$	10^4	–	–	–
Nolde (1999)	Bath, shower, & washing machine w/baby diapers	10^6–10^8	10^6–10^8	10^8-10^9	–	–
Nolde (1999)	Bath & shower	10^4–10^5	10–10^3	10^7-10^8	–	–
Nolde (1999)	Shower	10^3–10^5	10–10^3	10^7-10^8	–	–
Surendran et al. (1998)	Bath & shower (from university residence halls)	6×10^6	600	–	–	–
Surendran et al. (1998)	Wash basin (from university residence halls)	5×10^4	32	–	–	–
Surendran et al. (1998)	Washing machine (from university residence halls)	7×10^5	728	–	–	–
Casanova et al. (2001b)	GrW w/children	–	4.99×10^3	–	61	–
Casanova et al. (2001b)	GrW w/out children	–	4.25×10^3	–	10	–
Casanova et al. (2001b)	GrW w/kitchen sink	–	8.84×10^4	–	95	–
Casanova et al. (2001b)	GrW w/out kitchen sink	–	8.22×10^2	–	8	–
Casanova et al. (2001b)	GrW w/animals in house	–	2.12×10^3	–	36	–
Casanova et al. (2001b)	GrW w/out animals in house	–	3.34×10^4	–	11	–
Casanova et al. (2001a)	Composite	8.03×10^7	5.63×10^5	–	–	8.22×10^2
Rose et al. (1991)	Shower	10^5	6×10^3	–	–	–
Rose et al. (1991)	Laundry wash	199	126	–	–	–
Rose et al. (1991)	Laundry rinse	56	25	–	–	–
Rose et al. (1991)	Composite	2.8×10^7	1.82×10^4 – 7.94×10^6	–	–	–
Raniga (1980)	GrW w/kitchen sink	1.1×10^9	2.0×10^6	–	–	3.4×10^3

Bacterial and other indicators have commonly been used to assess the effectiveness of water and wastewater treatment systems in the inactivation or removal of microorganisms. This has been the traditional way of checking the potential presence of pathogens in water or wastewater (i.e. the effectiveness of treatment is not assessed through the pathogens that actually pose health risks). Also, the regulations are based on the concentration of indicator organisms (besides other parameters like the suspended solids and the turbidity), not on the concentration of the actual pathogens. Normally, total and fecal coliforms are not pathogenic for adult humans (Raniga, 1980). When indicator organisms are detected, other fecal-borne pathogenic bacteria could be present. Based on Albrechtsen (2002), the microbial quality of water can be assessed through different avenues. The total numbers of bacteria, presence of indicator organisms, and specific pathogens are three parameters that can be used for the characterization of the water microbial quality.

One factor that makes the graywater of special interest is that it does not include toilet waste, which is the major source of fecal contamination. Fecal contamination in graywater should be minimal since activities like childcare, washing clothes having fecal contamination, and showering may add only minor amounts of fecal contamination (Ottoson and Stenström 2003). Despite the fact that graywater should contain only a minimal amount of fecal contamination, high numbers of fecal indicators were reported in several studies. In some graywater studies, the numbers of fecal indicators reported were in the range found in raw wastewater. In their study about using rainwater and graywater in large institutions, Surendran et al. (1998) showed that the organic and microbial quality of graywater collected from one of the residence halls at the

Loughborough University are comparable with domestic wastewater. The results of their graywater characterization are shown in Table 3.2. They mentioned that this was unexpected but is corroborated by several references.

Given the fact that graywater contains only a minimal amount of fecal contamination, the high numbers of fecal indicators reported in several studies might be misleading. The high numbers of indicator organisms reported can be attributed to the fact that graywater may have a load of easily degradable organic material. According to Ottoson and Stenström (2003), the presence of such organic material may favor the growth of enteric bacteria such as fecal indicators. They concluded that if actual risks should be assessed in the usage of graywater, then there should be a differentiation between the actual fecal loads and potential regrowth of indicators. They found that bacterial indicator densities overestimated the fecal load by 100-1000 fold when compared to chemical parameters. Based on the measured levels of *E. coli*, fecal enterococci, Coprostanol, and Cholesterol; the fecal loads were 65, 5.4, 0.04, and 0.22 $g.person^{-1}.day^{-1}$ respectively. They suggested that guidelines for graywater should not be based on thermotolerant coliforms because of the large contribution of non-fecal coliforms and/or growth of coliforms. They recommended that if guidelines should be based on bacterial densities, fecal enterococci are preferred. This conclusion was based on two findings from their work. The first was that the overestimation of the fecal load by fecal enterococci was not as high as that predicted using coliform bacteria. The second was that the risk model based on fecal enterococci densities correlated well to the risk from viruses, which is supposed to be the most prominent.

Several studies exist regarding the detection of pathogens in graywater. In a study carried out by the City of Los Angeles (1992) and over a testing period of one year, three types of pathogens; *Salmonella*, *Shigella*, and *Entamoeba histolytica* were not detected in neither stored graywater nor soil irrigated with graywater. The authors of the report considered this point encouraging for the possibility of safe use of graywater. Not detecting these pathogens – while total adherence to hygienic handling of graywater is not assured – may indicate either a totally healthy test population (highly remote possibility according to the report) or a mechanism by which pathogens were deactivated such as by the action of detergents (City of Los Angeles, 1992). Christova-Boal et al. (1996) investigated the presence of *Salmonella* spp., *Campylobacter* spp., *Giardia* and *Cryptosporidia* in graywater. None of these microorganisms were detected in graywater samples. Rose et al. (1991) investigated the persistence of several pathogens in graywater by seeding three types of pathogens in graywater; *Salmonella*, *atyphimurium* and *Shigella dysenteriae*. It was found that these pathogens were able to persist for several days. Regrowth of *Salmonella* and *Shigella* was not observed, unlike the coliform bacteria which grew in the first 48 hours. Poliovirus type 1 was also added and found to decrease 99 and 90% at 25 and 17°C after 6 days. The pathogen persistence data indicate that there may be a risk in using graywater if these pathogens are being excreted by a person residing the house.

3.1.2 Chemical Characteristics

Chemical compounds in the graywater originate from household chemicals, cooking, and washing pipes (Eriksson et. al. 2002). Shampoos, detergents, personal care products, and pharmaceuticals are sources of many chemicals. Some of the chemical quality parameters of graywater are listed in Table 3.5.

Table 3.5 Chemical Quality of Untreated Graywater as Reported by other Studies

Reference	**Graywater sources**	**COD** mg/L	**BOD_5** mg/L	**TOC**	**N_{total}** mg/L	**P_{total}** mg/L	**SO_4** mg/L	**Cl** mg/L
Nolde (1999)	Bath, shower, & washing machine w/baby diapers	250–430	BOD_7 150–250	–	–	–	–	–
Nolde (1999)	Bath & shower	100–200	BOD_7 50–100	–	5–10	0.2–0.6	–	–
Nolde (1999)	Shower	113–633	BOD_7 70–300	–	–	–	–	–
Almeida et al. (1999)	Shower	501	–	–	NH_3-N 1.2 NO_3-N 6.3	PO_4-P 19.2		
Almeida et al. (1999)	Wash basin	298	–	–	NH_3-N 0.3 NO_3-N 0.6	PO_4-P 13.3		
Almeida et al. (1999)	Bath	184	–	–	NH_3-N 1.1 NO_3-N 4.2	PO_4-P 5.3		
Almeida et al. (1999)	Laundry wash	1815	–	–	NH_3-N 2.0 NO_3-N 2.0	PO_4-P 21.0		
Surendran et al. (1998)	Bath & shower (from university residence halls)	424	216	104	Ammoniacal-N 1.56	Phosphate-P 0.9	–	–
Surendran et al. (1998)	Wash basin (from university residence halls)	433	252	40	Ammoniacal-N 0.53	Phosphate-P 45.5	–	–
Surendran et al. (1998)	Washing machine (from university residence halls)	725	472	110	Ammoniacal-N 10.7	Phosphate-P 101	–	–
Casanova et al. (2001a)	Composite	–	64.85	–	–	–	59.59	20.54
Rose et al. (1991)	Composite	–	–	–	0.6–5.2	4–35	22.9	3.1–12
Sun (1986)	Composite (includes grw from one side of the kitchen sink)	–	–	–	1.94	8.2	28.9	9.0
Raniga (1980)	GrW w/kitchen sink	–	–	142	NH3-N 0.04 TKN 7.18	2.08	–	–

High levels of sodium, phosphorous, aluminum, zinc, and copper have been found in graywater (Christova-Boal et al. 1996). Detergents and shampoos are the main sources of sodium, phosphorous, and aluminum. The high levels of zinc and copper were caused by the galvanized steel collection tanks and from the household plumbing. Nolde (1999) reported that untreated graywater contains low nutrient concentrations that are below the German regulatory requirements for effluents of modern large sewage treatment plants (N_{total} = 18 $mg.L^{-1}$ and P_{total} = 1 $mg.L^{-1}$).

Al-Jayyousi (2003) mentioned two things that might make the biological treatment of graywater questionable. They are the high COD:BOD ratio (as high as 4:1) and a deficiency of macro-nutrients such as nitrogen and phosphorous. This results in a COD:NH_3:P of 1030:2.7:1 for the graywater compared to 100:5:1 for domestic wastewater (Al-Jayyousi, 2003).

The reported Biochemical Oxygen Demands (BOD) for residential graywater in Table 3.5 ranged from 50 mg/L to 300 mg/L, which is indeed a wide range. Even wider range and much higher values were reported by Faruqui and Al-Jayyousi (2002). In a Jordanian village where the water consumption was about 28 liters per capita per day, Faruqui and Al-Jayyousi (2003) reported a BOD_5 range from 275 mg/L to 2,287 mg/L. The authors attributed the high BOD_5 values to the very low water consumption rate (28 $liter.capita^{-1}.d^{-1}$) and to the inclusion of kitchen wastes.

3.1.3 Physical Characteristics

Physical parameters are of great importance to graywater users. Parameters like odor, temperature, color, turbidity, and suspended solids are also important to water quality and should be investigated. High temperatures will not be desirable since it may encourage the growth of microbes. Turbidity measurement is also important since it exists in the reclaimed water guidelines and it is important if UV disinfection will be used. Suspended solids measurement is also important since it exists in the reclaimed water guidelines and can give some information about the amount of solid particles that may cause clogging problems in pipes or irrigation system. Table 3.6 shows some physical graywater characteristics as reported by other studies.

According to Al-Jayyousi (2003), graywater is relatively low in suspended solids and turbidity, indicating that a greater proportion of the contaminants are dissolved.

Table 3.6 Physical Quality of Untreated Graywater as Reported by other Studies

Reference	Graywater sources	Turbidity	pH	DO	TSS (mg/L)	Dissolved solids (mg/L)	EC (mS/cm)*
Surendran et al. (1998)	Bath & shower (from university residence halls)	92	7.6	–	76	559	–
Surendran et al. (1998)	Wash basin (from university residence halls)	102	8.1	–	40	520	–
Surendran et al. (1998)	Washing machine (from university residence halls)	108	8.1	–	68	590	–
Casanova et al. (2001a)	Composite	43.0	7.47	–	35.09	–	0.43
Rose et al. (1991)	Composite	76.3	6.54	–	–	–	–
Sun (1986)	Composite (includes grw from one side of the kitchen sink)	67.5	6.6	–	–	–	–

mS/cm: MilliSiemens per cm

3.2 Effect of Storage on Graywater Quality

To be efficient in graywater reuse, the system has to be able to balance the supply and demand. In other words, the graywater disposal should be minimized. This cannot be achieved effectively unless graywater is stored. The storage will allow the user to use graywater when it is needed, not merely when it is available. However, significant changes in graywater quality occur as a result of storage. The characteristics of fresh graywater and those of stored can differ substantially (Eriksson et al. 2002). Important parameters like dissolved oxygen, COD, BOD, suspended solids, turbidity, and coliform counts will experience significant changes with time. The most disturbing sign of storage is the noxious odors that will be generated if graywater is left untreated because stored graywater will quickly become septic. According to Dixon et al. (1999), during the first three days of storage, the DO concentration drops rapidly to some value between a quarter and a third of the initial value. After that decrease, DO values fluctuated between 0.2 to 3.0 mg/L according to the ambient temperature (Dixon et al. 1999). They also reported a drop in TSS concentrations in heavily polluted samples. However, that decrease was not obvious in the weakly polluted samples (bath samples). A similar trend occurred with turbidity. Al-Jayyousi (2003) reported that counts of total coliforms and fecal coliforms increased from 10^0–10^5/100ml to above 10^5/100ml within 48 h. In Dixon et al. (1999) experiments, the total coliform count never fell below 10^5/100ml after the third day of storage.

Four main processes were hypothesized by Dixon et al. (1999) to govern the changes in graywater quality as a result of storage. The processes are settling of suspended particulate matter, depletion of dissolved oxygen, reaeration of dissolved oxygen through the water surface, and the release of soluble COD from anaerobically degraded settled organic matter. Four factors were identified as the main factors influencing graywater quality during the storage (Dixon et al., 1999). These factors are: settling of suspended solids, aerobic degradation of organic matter, anaerobic degradation of organic matter, and the transfer of oxygen through the water surface according to changes in temperature.

In several references, it was documented that the first 24 hours of storage are beneficial to the graywater quality. Dixon et al. (1999) attributed that to the substantial reductions in COD and TSS that occur in the settling phase. In terms of coliform counts, the first 24-hr period is almost neutral. One of the recommendations suggested by Mustow et al. (1997) is not to store graywater for more than 48 hours. This recommendation was also supported by the experiments and simulation model developed by Dixon et al. (1999), in which they decided that storing graywater beyond 48 hours leads to depletion of DO and potential aesthetic problems. Legget et al. (2001) were more conservative and suggested not to store untreated graywater for more than 24 hours and that any graywater stored for more than 24 hours should be discharged to the sewer. For treated graywater, Legget (2001) suggested a maximum storage time of three days.

3.3 Graywater Collection and Treatment Systems

3.3.1 General

As mentioned previously, the use of graywater is becoming more and more common. Some people are utilizing graywater without having any formal collection or treatment systems. They merely have their washing-machine water drained directly into their backyard for reasons like reducing the emptying frequency of their septic tank and reducing the amount of potable water needed for irrigation. In order to make a graywater reuse system practical and acceptable, treatment prior to reuse would be necessary (Rose et al., 1991). Rose et al. (1991) mentioned that the major concerns appear to be turbidity, microbial concentration, and the potential presence of pathogens. Different treatments are available including storage, aeration, sedimentation, filtration, biological treatment, and disinfection. Raniga (1980) mentioned that for ultimate surface disposal purpose, graywater is more amenable to treatment because some of the soil clogging material (such as toilet paper and feces) has been eliminated. Based on the graywater characteristics, Raniga (1980) concluded that graywater carries too much pollutional load to be discharged to environment without special treatment.

Currently, the market recognized this trend of using graywater and engineered graywater collection/treatment systems. The majority of the systems encountered in this study uses graywater solely for irrigation. Normally, the other less common use is the use in toilet flushing. This trend of using graywater is not limited to the United States. In fact, other countries are making a good progress towards the use of graywater; e.g. Germany, Australia, Japan, and the UK.

Nowadays, the use of graywater is legal in some states and in some other countries as well. For States like Arizona, California, and New Mexico; the use of graywater is legal. However, there are some guidelines that restrict its use including the need for a permit, limiting surface irrigation, prohibiting spray irrigation, and not allowing other graywater uses. Most of the graywater systems (collection and treatment) were designed in light of those guidelines, which are different from state to state and from country to country.

The extent of treatment is different from each manufacturer. Up to this point, the systems surveyed ranged from simple collection of graywater without treatment to more complex systems that simulate the real treatment plants but on a miniature scale. The more complex systems are normally utilized for uses other than irrigation (e.g. toilet flushing). Typically, the minimum treatment is to use coarse filtration or mesh screens to remove large objects like hair, threads, and lint.

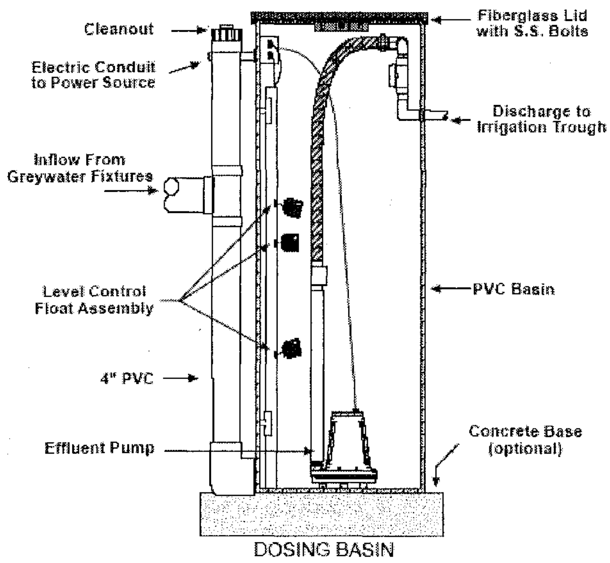
Some systems have surge tanks. The volume of such tanks should be small to minimize the residence time and the space required. Most graywater regulations state that the maximum residence time allowed for graywater is 24 hours. If it stays for more than 24 hours, the oxygen will be depleted and the water will go into septic conditions.

In order for the treatment system to be successful, it has to satisfy the needs of two parties; the homeowner and the regulatory agency. Criswell et al. (2005) summarized the viewpoint of each party. From the homeowner point of view, the system has to be easy to maintain and cost effective. On the other hand, the regulatory agencies want effective and reliable treatment. Therefore, according to Criswell et al. (2005), the research goal should be to finally find a scientifically tested treatment method fulfilling the needs of homeowners and the requirements of regulatory agencies.

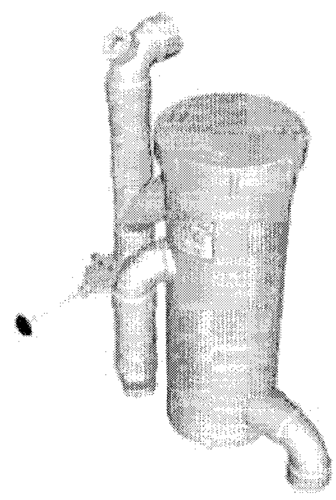
Five systems have been selected as examples. However, other systems do exist. The example systems were selected on the basis of their diversity. They were chosen to show the big picture and the big variations in the existing systems along with the different treatment methods that have been adopted. Four of the five systems are portrayed in Figure 3.1.

Earthstar Graywater System is a graywater system marketed by Gaiam Real Goods. The system main components are a 55-gallon tank, sand filter, automatic float switch, and a pump. When the water reaches the desired level in the tank, the automatic float switch triggers the operation of the pump to start evacuating the tank to the yard. The system is intended for irrigation use. According to the manufacturer, in order to clean the sand filter, an automatic backwash is applied every two months.

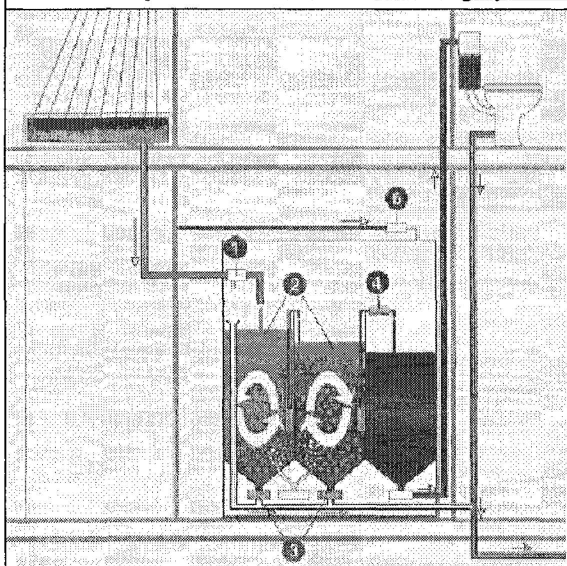
Clivus Multrum developed a system which looks like a wet well in the pumping station. The main components are the dosing basin, a submersible pump, and level control float. No treatment is included. The system is intended for irrigation use. The irrigation system adopted in this system is an underground irrigation using either an irrigation chamber (a half-round pipe 8-12" diameter) or wood made irrigation trough. The pump starts working when the amount of water in the dosing basin is enough to create a 1-1/2 inches of water depth in the irrigation chamber. This minimum 1-1/2 inches is set to insure a constant depth overall the irrigation chamber.



Clivus Multrum System
Source: http://www.clivusmultrum.com/greywater.html

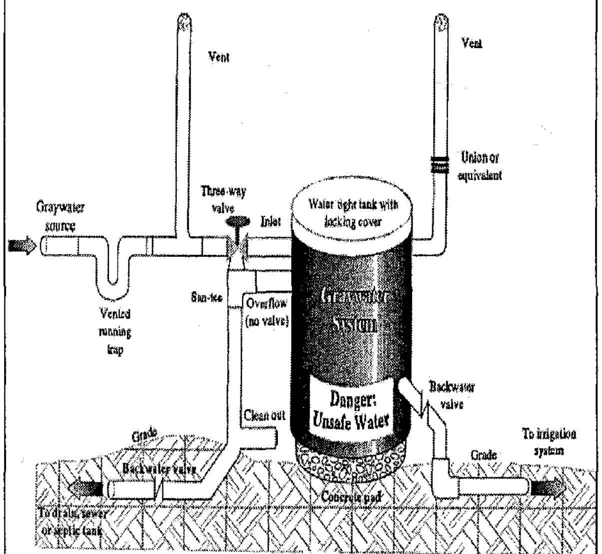


Graywater Saver
Source: http://www.greywatersaver.com/index.htm



1) Filteration
2) Primary & secondary cleansing chambers
3) Sludge extraction
4) UV disinfection unit
5) Tap water backfeed

Graywater System for Toilet Flushing, Germany
http://www.umweltbundesamt.org/wsektor/wasserdoku/english/frameset_e.html



California Graywater System
Source: California Revised Graywater Standards (website)

Figure 3.1 Graywater Treatment Systems Discussed in this Section

A graywater system for toilet flushing should have some kind of treatment. Most likely the treatment required would be too complex to be handled by a household owner. This is what was noticed in a graywater system in Germany. That system was found in the German Water Sector Report. It utilizes graywater for toilet flushing. The system looks like a real treatment plant but in a miniature scale. It includes coarse filter, two chambers, UV disinfection unit, storage tank, and backup potable water feed if the graywater is not enough to feed the toilets. Comparing it to the real wastewater treatment plants, one can see that the coarse filter functions as the bar screen in a WWTP. The two chambers act as primary and secondary treatment tanks. Aeration is also included in the tanks. The system also has a small-scale UV disinfection unit. Finally, there is a third tank that works as a storage reservoir to feed the toilets. The following treatment sequence exists in the system:

1) *Filtration*: to remove coarse items such as hair, threads, and lint. Backwashing is applied by a jet pump. Residues drain off into the sewer line.

2) *Biological cleansing*: Two chambers are used; primary and secondary.

3) *Sludge extraction*: Sludge accumulated in the biological cleansing process is fed into the sewer line.

4) *Disinfection*: After leaving the secondary tank, the graywater goes into a UV disinfection unit.

5) *Water storage reservoir*: A third tank exists after the UV unit to store water. The toilet takes water from this tank.

6) *Drinking water backfeed*: In the case that graywater quantity- is not enough for toilet flushing, drinking water is fed into the third tank.

An Australian owned and patented graywater reuse system was also investigated. The system is called "Greywater Saver". In this system, graywater is collected for use in irrigation (irrigation trenches). The system is one of the simplest in operation and construction. The only treatment used is a mesh basket filter and no graywater storage is provided. The system is also so flexible in diverting the graywater to the sewer system by the use of Push-Pull valve. The fact that the system has no storage makes it one of the systems that lean towards the disposal practice.

Table 3.7 summarizes the main characteristics of the above-mentioned systems

Table 3.7 Characteristic of Several Graywater Systems Discussed Earlier

System	Components	Use	Storage	Aeration	Filtration	Pumping	Disinfection
1†	Tank, sand filter, UV.	Irrigation	300 gallon tank	Yes	Sand filter	Yes	UV
Earthstar	Tank, sand filter, automatic float switch, and a pump.	Irrigation	55-gallon tank	No	Sand filter	Yes	No
Clivus Multrum	Dosing basin, level control float, and submersible pump.	Irrigation	Dosing basin Approx. 250 gal	No	No	Yes (submersible pump)	No
2‡	Coarse filter, two sedimentation chambers, UV, pump, and a storage tank	Toilet flushing	Yes	Yes	Coarse filtration	Yes	UV
Greywater Saver	Small collector, strainer, pull-push valve.	Irrigation	No	No	Coarse filtration through mesh basket filter (strainer)	No	No

† System used by Marjoram (2007) in the City of Fort Collins, CO

‡ A German system found at: http://www.umweltbundesamt.org/wsektor/wasserdoku/english/frameset_e.html

3.3.2 Treatment Alternatives and their Effectiveness

Currently, there are many on-site wastewater treatment units that are in operation. Several studies indicated that the majority of these systems are not functioning well due to lack of adequate maintenance. Sextone et al. (2000) indicated that 92% of 419 on-site aerobic treatment units did not perform as well as expected due to lack of frequent and adequate maintenance. Out of 12 on-site aerobic treatment systems inspected by Asbury and Hendrickson (1982), only four were found to operate properly. Therefore, regular and adequate maintenance is essential for the success of any on-site wastewater treatment system. The word "success" means satisfying the treatment objectives set for the system under consideration.

The treatment systems for graywater are not only limited to the commercial sector. Several researchers investigated different treatment options including sand filtration, microfiltration, rotating biological contactors, etc.

Friedler et al. (2005) investigated treating light graywater (originating from bath, shower, and washbasin) using a combination of biological and physiochemical treatment. The treatment started with a fine screen followed by an equalization basin. The effluent from the equalization basin passes through the biological treatment unit, which consists of two rotating biological contactor basins in series. A sedimentation basin and pre-filtration storage tank follow. Disinfection, which is the final treatment stage, is preceded by a gravity sand filter that has a diameter of 10cm. Disinfection is carried out by chlorination using hypochlorite 0.2 – 0.25% to finally maintain 1-mg/L chlorine residual after 30 minutes of contact time. As stated by the authors (Friedler et al., 2005), the pilot plant was able to produce effluent of very high quality. For example, the treatment system reduced the turbidity from an average of 33 NTU to an average of 0.61 NTU. The BOD was reduced from an average of 59 mg/L to an average of 2.3 mg/L. Microbially, the system was able to achieve a 100% reduction in terms of the fecal coliform.

Babcock et al. (2004) evaluated the performance of a wastewater treatment package unit (400 gallons/day) consisting of anaerobic, aerobic, sedimentation, and disinfection processes. The effluent from this treatment package is equivalent to the effluent from secondary wastewater treatment plants (Average values of BOD_5 and TSS were 13.9 and 13.1 mg/L). In order to produce an effluent of recycled water quality, a sand filter and a tabular UV disinfection unit were added to the package unit. According to the authors, the new additions (sand filter and UV unit) were able to produce high quality recycled water equivalent to R-1 recycled water category, which is the highest quality of recycled water requested by the Department of Health in the State of Hawaii (equivalent to California unrestricted reuse category, according to Babcock et al., 2004).

Due to the high number of indicator organisms found in graywater, it is essential to have some kind of disinfection to inactivate pathogens and reduce the number of indicator organisms. Traditionally, disinfection has been done using chemicals such as chlorine. The application of chemicals is being highly discouraged due to the toxicity of chemicals, the formation of carcinogenic by-products, large contact time needed, and dangers associated with shipping and handling. In addition to the previous dangers, using chemical disinfectants might be a burden on the household owner because of the need to check the level of the disinfectant and to add more chemical. Some commercial graywater systems use chlorine or bromine based chemicals to disinfect graywater. According to Howarth (1998), such systems can prove unreliable and rely on user support to add chemicals. Babcock et al. (2004) examined the performance of a wastewater treatment package that uses a built-in chlorine tablet disinfection system. They stated that the built-in chlorine tablet disinfection system did not work well due to inadequate retention time or poor dissolution of chlorine tablets.

It seems that the most appropriate disinfection method is to use ultraviolet (UV) light. Small UV disinfection units are commercially available to household owners. Fenner and Komvuschara (2005) listed several advantages of using UV light in graywater disinfection such as the elimination of the need to use chemicals, greater effectiveness on wide range of pathogens, small contact times (6 to 40 seconds, according to CEWRE 2006), low capital and operation costs, low maintenance, and simple and safe operation.

The main widely known disadvantage of UV light disinfection is that it is greatly influenced by the quality of the water being treated (MWH, 2005). For the case of graywater, turbidity is an important factor that would question the effectiveness of the UV disinfection. Turbidity values ranging from 40 to 90 NTU have been commonly encountered in the graywater literature research carried out in this study. The total suspended solids (TSS) is another important concern since it can scatter and absorb the light (Fenner and Komvuschara, 2005); and therefore shield the microorganisms from the UV light. Therefore, in order to reduce the concentration of the microbiological indicators to acceptable levels, the TSS and turbidity values of graywater should be reduced to levels that can no longer affect the UV effectiveness or at least have minimal effects on the UV effectiveness. Unlike chemical disinfectants, UV disinfection does not leave a residual in the treated water; an issue that raises concerns about the re-growth of microorganisms after UV disinfection and during the storage process. On the other side, not having a disinfectant residual might be considered an advantage in case graywater will be considered for landscape irrigation.

Based on the previous discussion, it seems that the UV disinfection will not be successful unless the turbidity and the total suspended solids are reduced to levels below which the UV light can effectively penetrate the water and reach the microorganisms without being scattered by the particulate matter.

3.3.3 Cost Associated with Graywater Reuse

The cost of a graywater system varies greatly with its complexity and capabilities (City of LA, 1992). Three price ranges were listed by City of LA (1992):

a. **$400 – $800**: Systems utilizing only the washing machine and connected to low-tech system.

b. **$1,000 – $1,500**: All graywater tributaries are usually connected, but the graywater collection and distribution system is still simple and low-tech system.

c. **$2,500 – $5,000**: Nearly all sources of graywater are connected to the system and the system is fully automated.

CRD (2004) mentioned that costs for individual graywater treatment systems vary greatly from $64 for a simple sink diversion system (with no treatment) to $15,000 for a complex treatment system to provide full graywater reuse capabilities.

March et al. (2004) examined the water savings and the payback period that have been achieved by retrofitting a hotel of 81 rooms with a graywater system to be used for toilet flushing. Compared to the old traditional system, the graywater system was able to save 1.09 €/m^3 with a simple payback period of 14 years. It is worth noting that this payback period was based on seven months of operation and 85% occupancy. Therefore, this payback period would be much favorable if the calculations were made on a year round of operation (March, et al. 2004). Table 3.8 shows the individual costs of system components. The Table shows that changing the existing piping system to dual piping system cost about €12,000. A large portion of this amount could be saved if the dual piping system was implemented during the construction of the building. Implementing a dual piping system during the construction of a building could represent an additional cost of 5% on the plumbing budget (March, et al. 2004). However, CRD (2004) had a much higher estimate of the cost of implementing a dual piping system. They stated that the cost of dual plumbing ranges from $10,000 for new construction to as much as $25,000 for retrofit plumbing. Neither the size nor the type of building was mentioned for the estimates.

Table 3.8 Cost of Recycling System Installed in the Hotel

A) Acquisition and installation, €:	
Storage tanks	3,000
Pump & Flow Control	2,000
Plumbing (dual piping)	12,000
Total acquisition	**17,000**
B) Operation & Maintenance, €/m^3:	
Energy & chemicals	0.33
Labour	0.42
Total operation	0.75
C) Savings, €/m^3:	**1.09**

Source: March et al. (2004)

The use of graywater at the single-household level is likely to be less economic than larger systems (Leggett et al., 2001). However, the use of graywater in a multi-family housing will require higher level of treatment to make sure that the water quality is high enough to be used by different families. Leggett et al. (2001) considered economics as a major problem for graywater systems. They expected payback periods of 20 years or more in the UK situation. Using five identical residential graywater systems, it has been shown by Environment Agency (2000) that the number of occupants had a high influence on the payback periods of graywater systems; ranging from 92 years for the 1-occupant household to 18 years for the 5-occupant household.

The cost of replacing components in the system seems to be an important issue that should be taken into account when considering a graywater system. Leggett et al (2001) summarized the main problems associated with graywater systems as reliability, loss of water savings during downtime of the system, and cost of replacing components of the graywater system. All of those issues affect the cost/benefit of using graywater.

In several references, it has been mentioned that the water savings potential of a household graywater system is significant (about 50% of all the water used in the household). According to City of LA (1992), despite the fact that significant water savings will be achieved, it is highly unlikely that graywater systems will be installed by a large enough number of people in the United States. The authors of this report based their conclusions on three factors: 1) Maintenance requirements, 2) Complications with permitting, 3) Cost. At the time of writing that report (1992), the authors finally reached the conclusion that graywater cannot be expected to play a significant role in a community's water supply reliability. However, they mentioned that on individual basis, "a gray water system can spell the difference between a lush landscape and a dry one under drought conditions". They also added that the use of graywater at the household level might mean avoiding fines and achieving considerable savings in water costs.

3.3.4 Summary and Needs for Study

The literature review conducted for this study revealed that there are significant findings that need to be summarized and gaps that need to be addressed:

- There is a general consensus that kitchen wastes should be excluded from the graywater stream. Other researchers preferred to exclude both kitchen wastes and laundry wastes and referred to the remaining portion as light graywater.
- About 15% to 40% of the total household water consumption could be saved by the reuse of graywater, with 20 to 30% being the most common range of water savings. In terms of the indoor water consumption, graywater constitutes about 50 to 60% of the indoor water use. In residential houses, the amounts of graywater generated match well with the water amounts needed for toilet flushing. However, for office buildings, the amount of graywater generated is very little compared to the amount needed for toilet flushing.
- The main potential uses for the graywater are landscape irrigation and toilet flushing. In the United States, landscape irrigation is the most common application of graywater. Toilet flushing is more common in European countries. At this point, it seems that the water quality regulations pertaining to the use of graywater in either landscape irrigation or toilet flushing are not clear. The existing regulations for wastewater should be modified so that graywater can have

its own regulations. Several researchers supported the attitude of moving towards the appropriate use of water; which means matching the water quality with the intended use.

- The major problems associated with graywater seem to be turbidity, microbial concentration, and organic matter (relatively high BOD values). Odor seems to play a major role in people's decision to use graywater water especially when toilet flushing is considered.
- In order to use graywater safely, either proper treatment or a minimum contact policy should be adopted. In the US, it is a common practice among the graywater users to apply graywater without treatment unlike some other countries in which graywater treatment seems to be more common. The existing collection and treatment systems are either very simple or too complicated for a homeowner to install.
- It has been found that there is a wide gap between the public and scientific background. A homeowner seeks criteria like simplicity, flexibility, effectiveness, reliability, and cost.
- The complex treatment systems involved the use of biological treatment and disinfection in addition to other techniques like settling and filtration. Several studies revealed that biological treatment of graywater worked well in spite of the higher COD/BOD ratio and the imbalance of nutrients.
- The large number of indicator organisms found in graywater indicates that disinfection should be included in the treatment process. Effectiveness of chemicals disinfection was questionable in terms of both effectiveness and effects

on soils and plants. The use of UV disinfection seems to be an easier and more effective option for disinfection. However, the high turbidity values of graywater would certainly impede the effectivemess of the UV disinfection.

- Storage leads to deterioration in the graywater quality, but it is essential to maximize the advantage of graywater.
- Regular and adequate maintenance is essential for the success of any on-site wastewater treatment system. Most of the failures encountered in treatment systems were caused by lack of regular and adequate maintenance.
- Finally, there is a general perception that graywater reuse is not feasible – at least with the current treatment technologies and the existing regulations.

3.4 Research on Graywater Treatment

3.4.1 General Approach

After investigating the existing graywater treatment systems, it is apparent that the existing systems are either too complex and expensive for household residents to handle or too simple with minimal treatment. Therefore, there is a need to have a system that the normal household resident can handle, understand, and trust; a system that does not act as black box. Besides the common goal of reducing the levels of the common wastewater contaminants to acceptable levels, another important goal was set, which is to apply treatment techniques that can be purchased, built, and managed by the average household owners. This goal has been achieved through a combination of different treatment schemes comprised of different treatment units. This criterion has been set as one of the criteria for the design of the graywater treatment options.

A single-family house occupied by two adults was retrofitted with dual plumbing system; one collecting the black wastewater, and the other collecting the graywater. The graywater generated in this house averaged at about 26 gallons per day. The graywater system collected wastewater from the washing machine, bath sinks, showers, and bathtubs. It does not include the wastewater generated from kitchen sinks or dishwashers. An experimental program has been designed to address the question of graywater treatability at the household level. One of the goals behind the treatment was to reduce the common wastewater characteristics to acceptable levels. The parameters of concern were total colifroms, fecal coloforms, *E. coli*, turbidity, total suspended solids, total dissolved solids, BOD, and COD. As mentioned earlier, another goal behind the treatment is to apply treatment techniques that can be used by the average household owners. This has been implemented through a combination of different treatment units and different treatment schemes.

3.4.2 Materials and Methods

Graywater was collected into a 300-gallon tank and stored for seven days. During and/or at the end of the seven-day storage period, several treatment schemes were implemented. At the end of the storage period, two graywater samples were collected in two 1-liter bottles to assess the treatment effectiveness. The samples were analyzed for the following physical and chemical parameters: turbidity, total suspended solids, total dissolved solids, BOD, and COD. In addition to the two 1-liter samples, one sample was collected in a 250-ml autoclaved bottle to be tested for some microbiological parameters, which were total coliforms, fecal coliforms, *E. coli*, and heterotrophic plate counts. Methods and aparatus of measurements are summarized in Table 3.9.

Seven schemes were implemented and investigated. The effectiveness of each treatment scheme was assessed by measuring the parameters mentioned previously (also mentioned in Table 3.9). The seven schemes were:

I- Storage only

II- Storage with aeration

III- Storage with aeration followed by 24-hour settling

IV- Storage with aeration followed by 24-hour settling, coarse filtration, and UV disinfection

V- Storage with aeration followed by 24-hour settling, coarse filtration, 5-micron filter, and UV disinfection

VI- Point of use treatment using coarse filter and UV disinfection (No aeration)

VII- Point of use treatment using coarse filter, UV disinfection, and 5-micron filter (No aeration)

Table 3.9 Methods and Devices Used in Measuring Graywater Parameters

Parameter	Device/s used	Method or/and reference
Turbidity	2100P Portable Turbidimeter from Hach company	
Total Suspended Solids		Method 2540-D described in Standard Methods for the Examination of Water and Wastewater, 20th edition
Total Dissolved Solids		Method 2540-C described in Standard Methods for the Examination of Water and Wastewater, 20th edition
Chemical Oxygen Demand	COD Reactor and DR4000 Hach spectrophotometer	Method 8000 from the HACH company Water Analysis Handbook
Biochemical Oxygen Demand		Method 8043 from HACH company Water Analysis Handbook
Total Coliform	Environmental Quality Lab at Colorado State University	Method 9222-B described in Standard Methods for the Examination of Water and Wastewater, 20th edition
Fecal Colifrom	Environmental Quality Lab at Colorado State University	Methods 9222-D and 9222-G described in Standard Methods for the Examination of Water and Wastewater, 20th edition
E. coli	Environmental Quality Lab at Colorado State University	Standard Methods 9222-D and 9222-G described in Standard Methods for the Examination of Water and Wastewater, 20th edition
Heterotrophic plate count	Environmental Quality Lab at Colorado State University	Standard Method 9215-D, 20th edition

The goal of these experiments is to find out the best treatment combinations that household owners can adopt and install by themselves with minimal help from outside manufacturers or experts.

I) Storage only:

In this scheme, graywater was stored for seven days in the 300-gallon tank (Figure 3.2). At the end of the 7-day storage period, samples were collected from a sampling location distanced at about 10 inches above the bottom of the tank in the same manner mentioned at the beginning of Section 3.4.2. Samples were analyzed for the parameters mentioned earlier in Table 3.9. This process was repeated for four weeks. In this scheme, storage was the only action taking place (No aeration or passage through filter or UV unit).

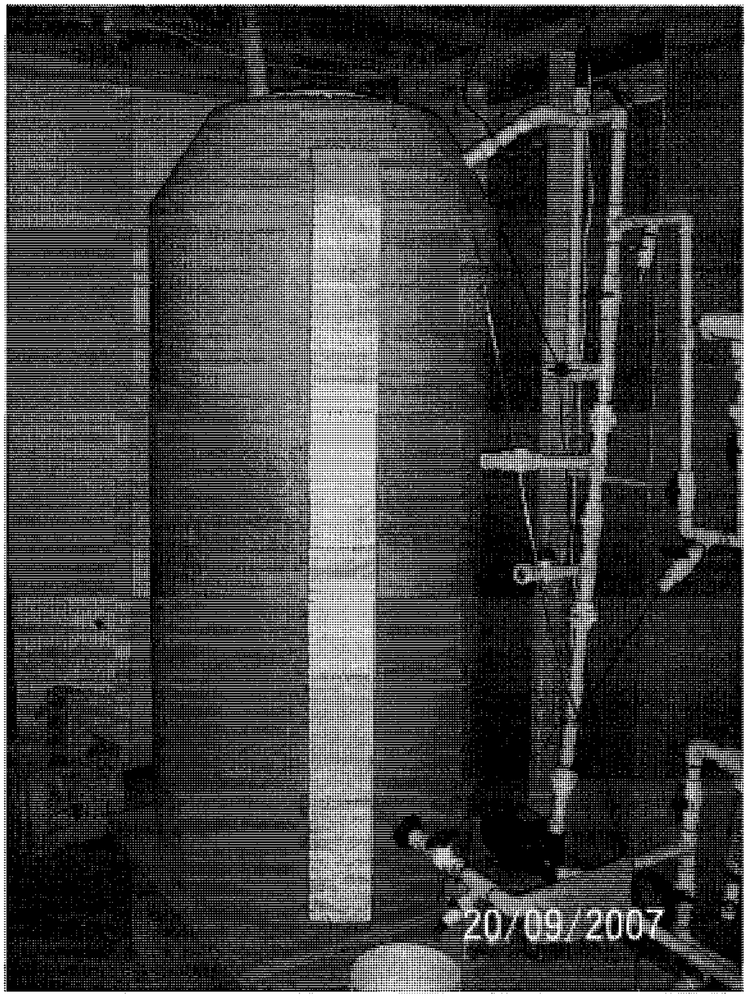


Figure 3.2 Graywater tank used in the graywater treatment schemes

II) Storage with Aeration

Several researchers indicated that the quality of the fresh graywater is relatively good compared to that of wastewater. However, the quality will deteriorate with time if no measures are taken. Another problem associated with graywater storage is the bad odor generated as a result of the graywater becoming anaerobic. To solve these problems and to minimize the organic matter in graywater, aeration was applied inside the storage tank for six days. An air compressor producing 88 liters/minute of air was used. The air was distributed into the tank using a diffuser hanged inside the tank in a position very close to the bottom of the tank (Figure 3.3). Aeration was thought to have the effect of aerobic treatment on graywater and therefore reducing the levels of both BOD and COD. However, it might adversely affect the settleability of suspended matter, which is believed to enhance the graywater quality as mentioned previously in the literature review section.

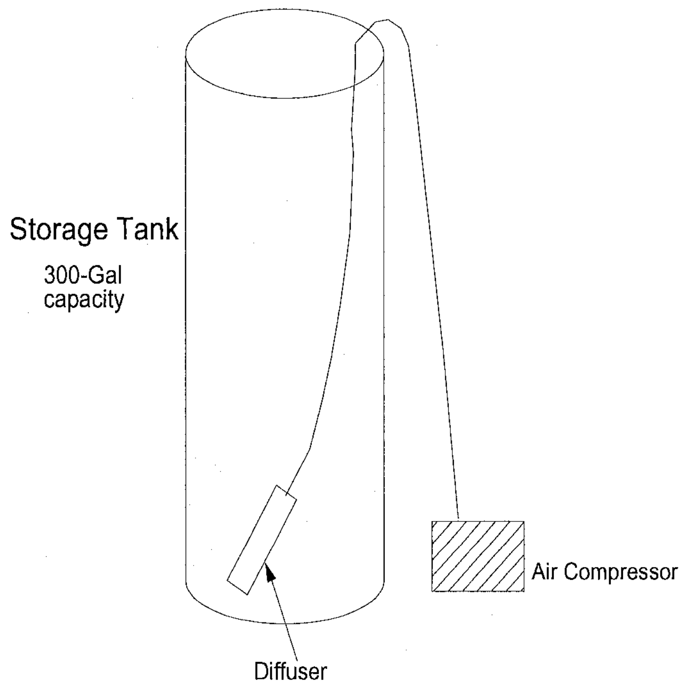


Figure 3.3 Air compressor and diffuser used in scheme 2

At the end of the 6-day aeration period, graywater samples were collected in the same manner mentioned in the storage scheme and while aeration is taking place. The samples were tested for the same parameters mentioned in Table 3.9. This process was repeated for three weeks.

III) Storage with aeration followed by 24-hour settling

In this scheme, the 6-day aerated graywater was settled for 24 hours by switching off the air compressor and leaving the tank in quiescent conditions for 24 hours. The idea behind this scheme is to settle the flocs which have formed in the aeration step and then monitor the effect on graywater inside the tank. At the end of the 24-hour settling period, graywater samples were taken in the same manner mentioned in the storage scheme. The number of samples taken for this scheme along with the days on which samples were taken is summarized in appendix 1.

IV) Storage with aeration followed by 24-hour settling, coarse filtration, and UV disinfection

In this treatment scheme, aeration was applied for six days, and then stopped to allow graywater to settle for 24 hours; i.e. the same procedure implemented in scheme 3. The addition to scheme number 3 is the recycling line that comprised both a coarse filter and a UV disinfection unit (Figure 3.4). After the end of the 24-hr settling period, the graywater in the tank was pumped into a recycle line (3/4" pipe diameter) comprising a coarse filter of 254-micron opening size (Figure 3.5) and a 15-W UV disinfection unit (Figure 3.6) that accepts a maximum flow of seven gallons per minute (according to manufacturer instructions). The graywater was recycled at the rate of four gallons per minute. The recycling time was three hours. The 3-hour recycling time was chosen so that graywater volume existing in the tank passes through the recycle line five times. The recycling process will also have the effect of increasing the dissolved oxygen concentration in graywater, which is recommended for the health of plants and soils. The graywater samples were taken from port 2, which is a location after the UV unit (Figure 3.4) to to ensure that a minimum of one passage through the treatment train is achieved. The samples were taken in the same manner described in the storage scheme. The only difference was the sampling location, which was after the UV unit in the case of this scheme.

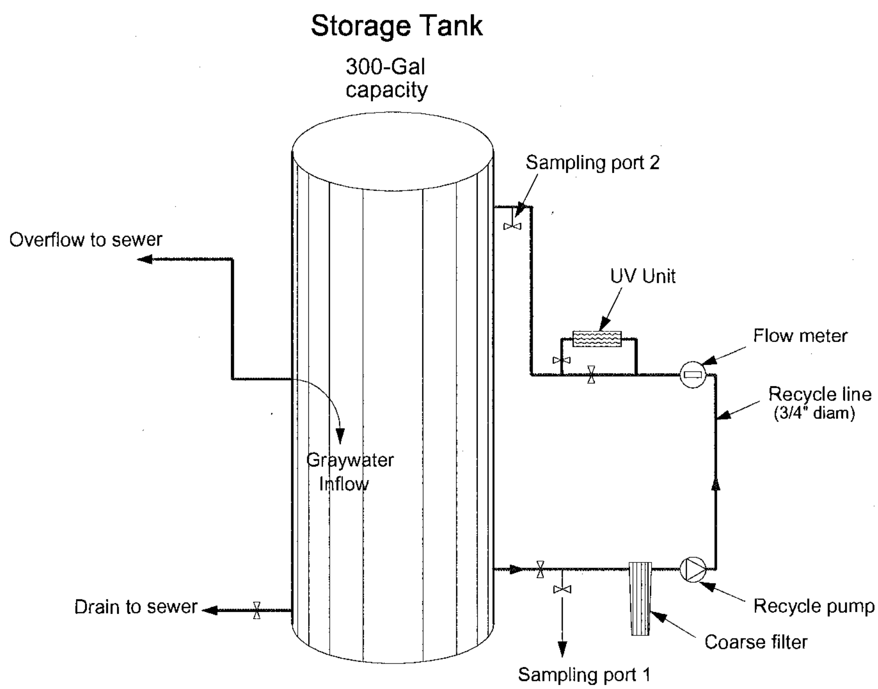


Figure 3.4 Schematic drawing of the graywater treatment system used in scheme IV

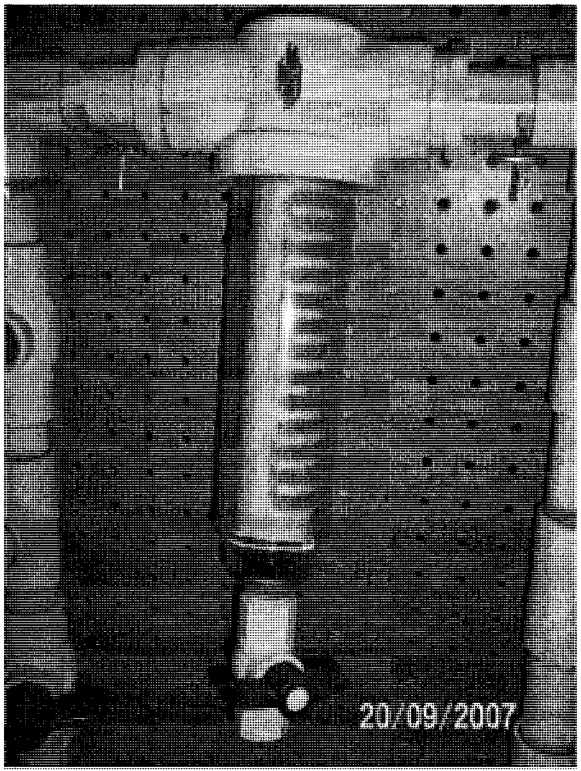


Figure 3.5 Coarse filter used in the treatment
(*Manufactured by*: Water Whiz Irrigation, FL)

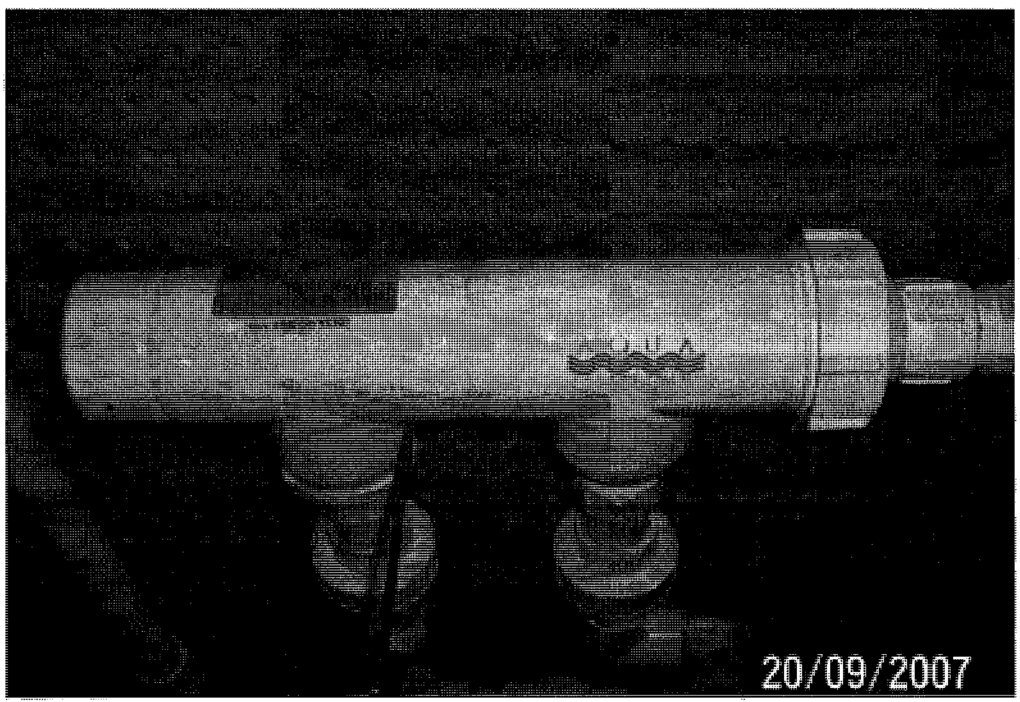


Figure 3.6 UV unit used in the disinfection (Manufactured by Aqua Ultraviolet, CA)
(*Manufactured by*: Aqua Ultraviolet, CA)

V) Storage with aeration, followed by 24-hour settling, coarse filtration, 5-micron filtration, and UV disinfection

One of the biggest problems associated with graywater is its relatively high turbidity, which may impede the effectiveness of the UV disinfection. To overcome or at least reduce this problem, a 5-micron filter was introduced in the recycle line after the coarse filter and before the UV unit (Figure 3.7). The 5-micron filter used in this treatment scheme was a pleated filter that causes much less pressure drop compared to thicker of 5-micron filters. Graywater samples were taken in the same manner described in scheme IV.

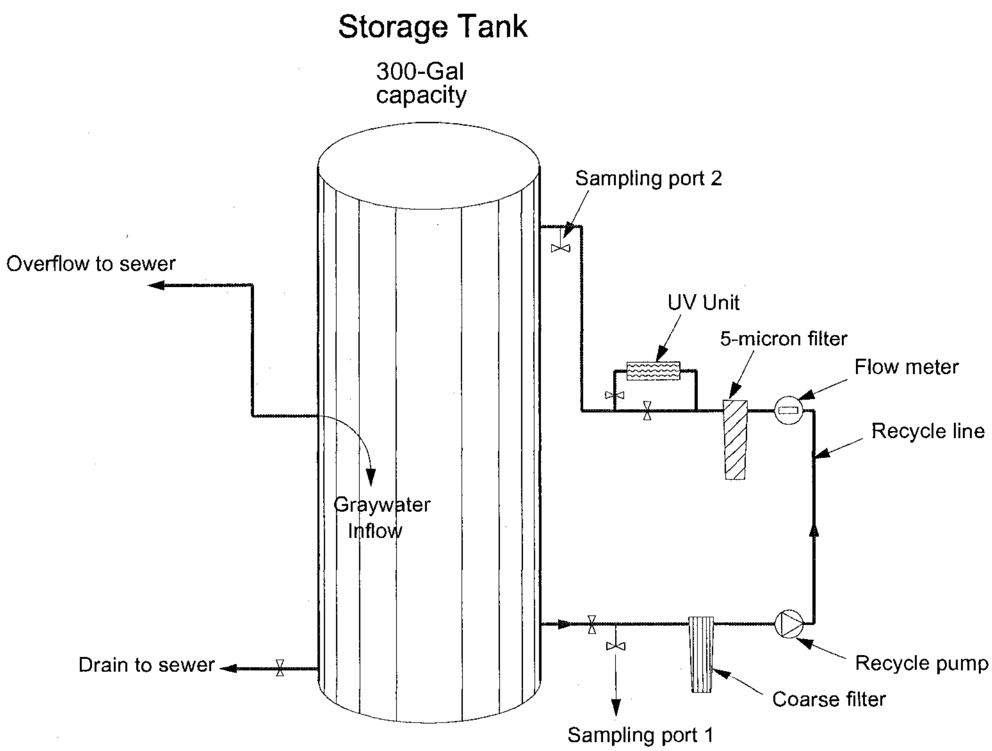


Figure 3.7 Schematic drawing of graywater treatment system used in scheme V

VI) Point of use treatment using coarse filter and UV disinfection unit following a 7-day storage period (No recycling or aeration included)

The effect of point of use treatment using a coarse filter and the UV disinfection unit – without aeration – was investigated in this scheme. This is of special importance since it will answer the question of whether biological treatment is necessary or not and if the UV unit would decrease the microbial load significantly without the aid of biological treatment. In this scheme, graywater was stored for seven days without aeration, i.e. same as scheme I. At the end of the 7-day storage period, graywater was passed through the coarse filter and the UV disinfection unit, with no recycling of graywater to the tank. Graywater samples were taken in the same manner described in scheme IV and from the same sampling location; i.e. after the UV unit. In this scheme, the sampling location resembles the point of use.

VII) Point of use treatment using coarse filter, UV disinfection, and 5-micron filter following a 7-day storage period (No recycling or aeration included)

This scheme only adds a 5-micron filter to scheme VI between the coarse filter and the UV unit. The same procedure followed in scheme VI was followed in this scheme. The 5-micron filter was inserted before the UV unit in order to enhance the UV disinfection effectiveness by reducing the turbidity and the suspended solids concentration.

3.4.3 Results of the Graywater Treatment Experiments

The results of the graywater treatment schemes are summarized in Table 3.10 and Figures 3.8 to 3.16.

Table 3.10 Results of the Graywater Treatment Schemes

		I	II	III	IV	V	VI	VII
TSS	**Mean**	**18.6**	**92.2**	**11.8**	**11.1**	**26.8**	**24.7**	**23.0**
	Max	31.5	93.5	16.7	17.5	50.0	25.0	23.8
	Min	5.5	91.0	7.2	0.3	14.0	24.3	22.3
TDS	**Mean**	**118.1**	**131.3**	**150.6**	**127.4**	**103.0**		
	Max	146.7	139.7	155.3	176.6	110.3		
	Min	93.0	123.0	142.0	90.7	93.7		
Turbidity	**Mean**	**88.9**	**138.7**	**22.9**	**22.1**	**9.3**	**60.8**	**64.2**
	Max	124.0	181.0	40.8	37.5	13.6	61.9	64.6
	Min	61.7	101.5	14.1	9.4	5.0	59.7	63.7
COD	**Mean**	**290.6**	**266.9**	**96.5**	**90.9**	**52.0**	**254.5**	**244.0**
	Max	354.0	327.5	126.0	116.5	60.0	255.0	247.0
	Min	253.5	226.5	52.0	66.0	44.0	254.0	241.0
BOD	**Mean**	**102.6**	**53.2**	**17.3**	**11.2**	**12.2**		
	Max	139.7	74.9	24.4	18.1	18.2		
	Min	85.9	40.9	8.9	7.4	5.8		
COD/BOD	**Mean**	**2.97**	**7.59**	**7.27**	**7.99**	**5.85**		
	Max	3.74	8.01	11.46	11.16	8.79		
	Min	2.50	7.18	4.53	5.72	3.11		
TC (CFU/100ml)	**Mean**	$\mathbf{2.03\times10^{07}}$	$\mathbf{7.27\times10^{07}}$	$\mathbf{5.45\times10^{05}}$	**464**	**89**	**25050**	**2545**
	Max	2.80×10^{07}	2.60×10^{08}	1.00×10^{06}	870	113	31000	4600
	Min	6.40×10^{06}	3.40×10^{05}	9.00×10^{04}	172	64	19100	490
FC (CFU/100ml)	**Mean**	$\mathbf{5.30\times10^{05}}$	$\mathbf{4.27\times10^{05}}$	**210**	**48**	**16**	**2745**	**81**
	Max	8.90×10^{05}	1.60×10^{06}	340	156	19	5100	131
	Min	1.70×10^{05}	3.20×10^{03}	80	2	13	390	30
***E. coli* (CFU/100ml)**	**Mean**	$\mathbf{1.00\times10^{04}}$	$\mathbf{8.04\times10^{03}}$	**10**	**0**	**0**	**7**	**7**
	Max	1.00×10^{04}	1.00×10^{04}	10	0	0	10	10
	Min	1.00×10^{04}	3.00×10^{02}	10	0	0	3	4
HPC (CFU/ml)	**Mean**	$\mathbf{7.48\times10^{07}}$	$\mathbf{1.46\times10^{08}}$	$\mathbf{1.67\times10^{06}}$	$\mathbf{1.39\times10^{04}}$	**4510**		
	Max	1.47×10^{08}	3.20×10^{08}	2.73×10^{06}	3.30×10^{04}	4510		
	Min	2.60×10^{06}	1.00×10^{05}	6.00×10^{05}	5.00×10^{02}	4510		

I. Storage only
II. Storage with aeration (no settling)
III. Storage with aeration followed by 24-hour settling
IV. Storage with aeration followed by 24-hour settling, coarse filter, and UV disinfection unit
V. Storage with aeration followed by 24-hour settling, coarse filter, 5-micron filter, and UV disinfection unit
VI. Point of use treatment using coarse filter and UV disinfection
VII. Point of use treatment using coarse filter, UV disinfection, and 5-micron filter

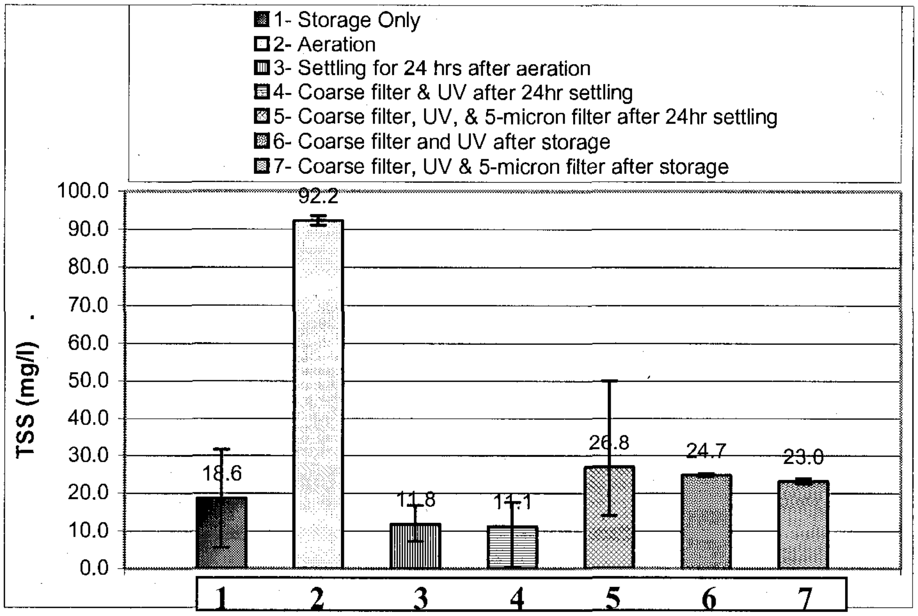


Figure 3.8 Total suspended solids concentration for each treatment scheme (Average, min, and max)

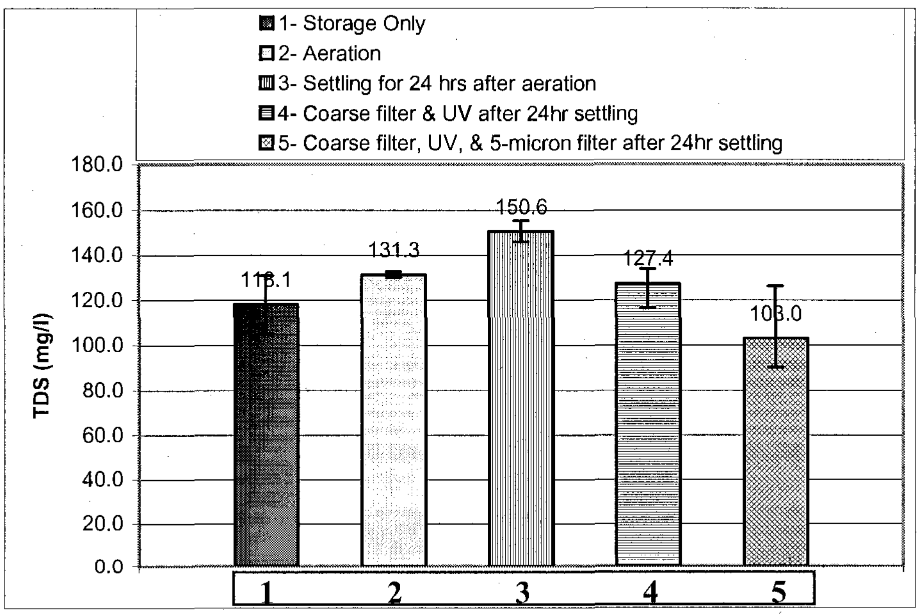


Figure 3.9 Total dissolved solids concentration for each treatment scheme (Average, min, and max)

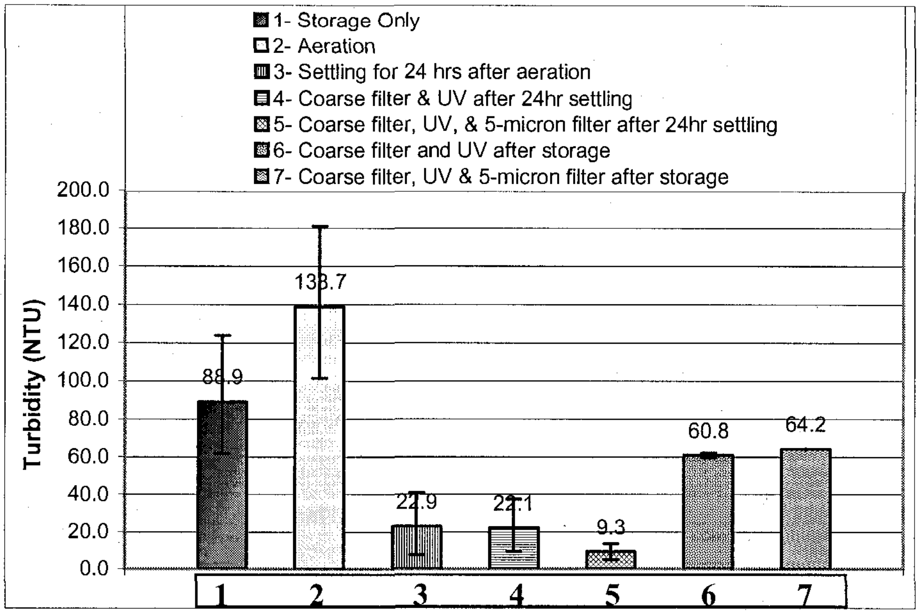


Figure 3.10 Turbidity level for each treatment scheme (Average, min, and max)

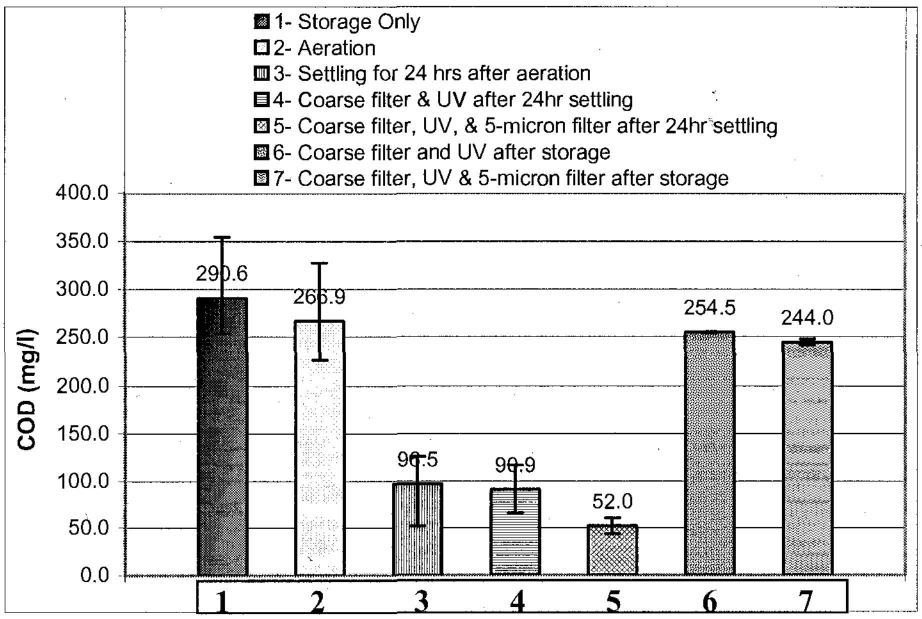


Figure 3.11 Chemical oxygen demand for each treatment scheme, (Average, min, and max)

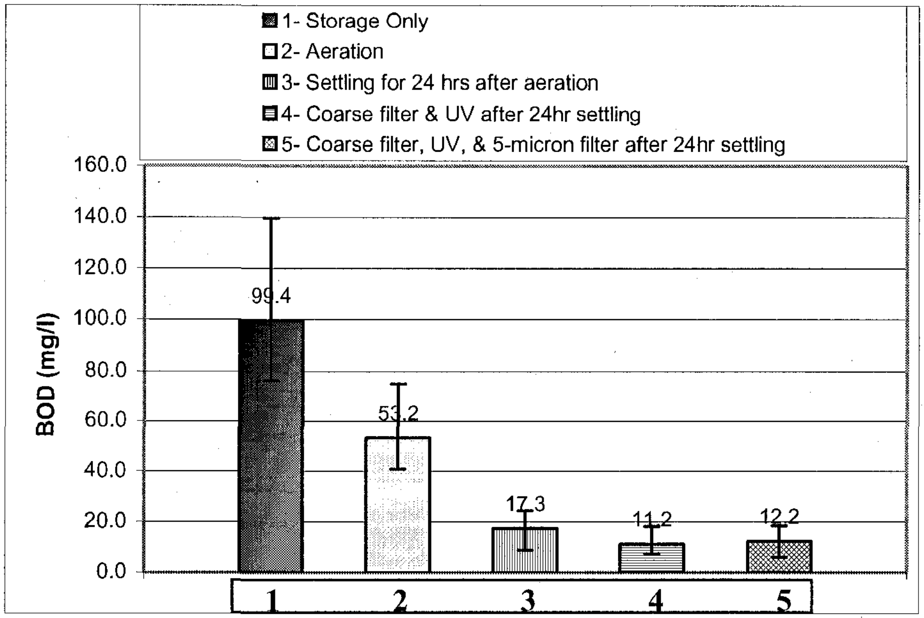


Figure 3.12 Biochemical oxygen demand for each treatment scheme, (Average, min, and max)

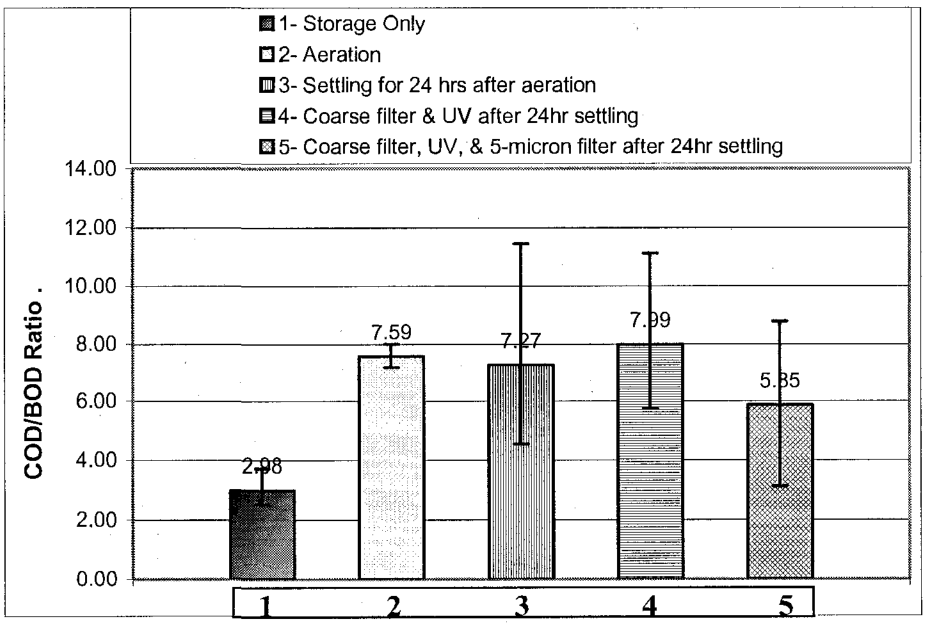


Figure 3.13 COD/BOD ratios for each treatment scheme, (Average, min, and max)

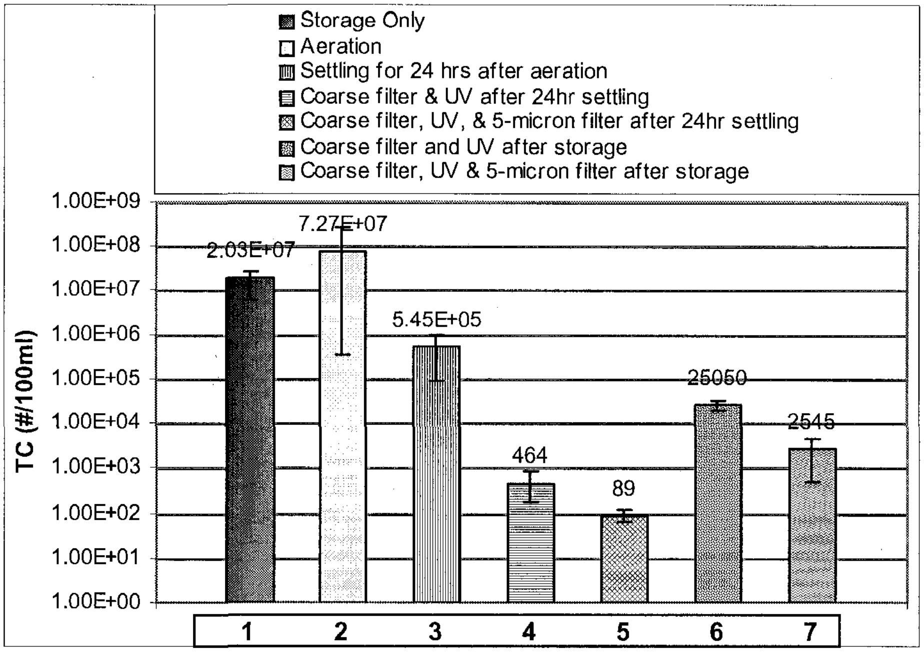


Figure 3.14 Total coliform levels for each treatment scheme, (Average, min, and max)

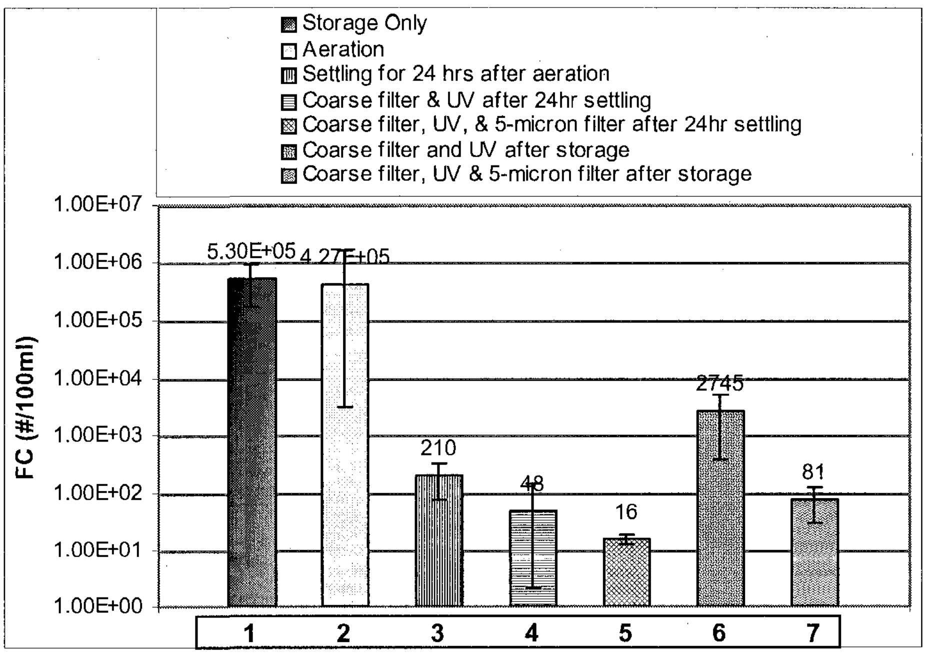


Figure 3.15 Fecal coliform levels for each treatment scheme (Average, min, and max)

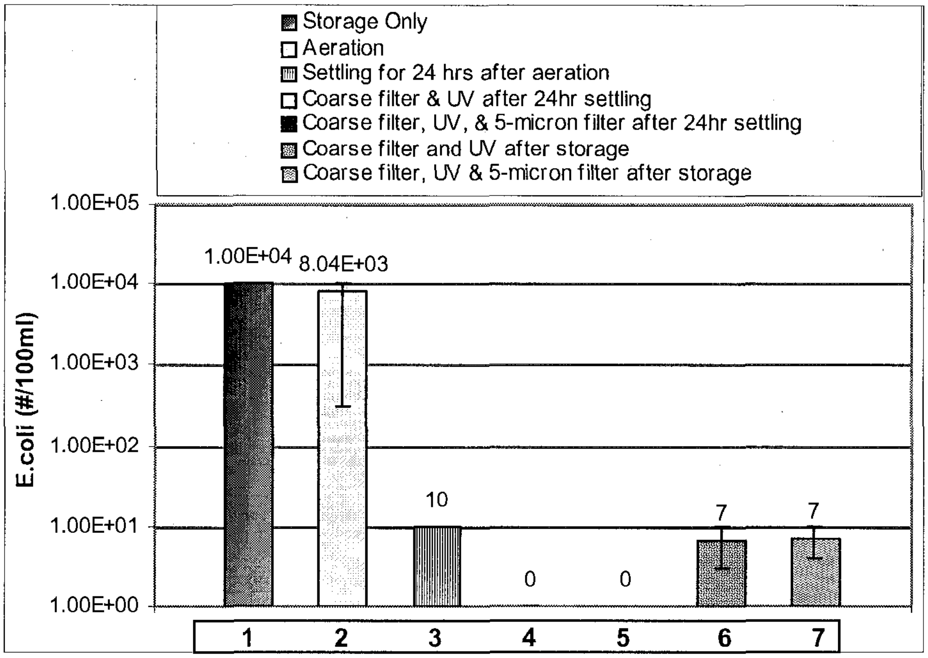


Figure 3.16 *E. coli* levels for each treatment scheme, (Average, min, and max)

The analysis of graywater after seven days of storage revealed that the graywater characteristics resemble those of low-strength untreated domestic wastewater (Table 3.11). The only exception was the suspended solids concentration. The total suspended solids (TSS) concentration of stored graywater averaged at 18.6 mg/L, which is a low concentration when compared to the high values of the other graywater characteristics (e.g. turbidity, BOD, COD, etc). This may be attributed to the fact that stored graywater was stored in the tank for few days, which apparently lead to settling of solids. The average COD/BOD ratio of stored graywater ranged from 2.50 to 3.74; with an average of 2.97, which is higher than that of a typical raw domestic wastewater. This is an indication that graywater has higher proportion of slowly biodegradable organic matter. Another important thing that can be noticed is the low TSS/BOD ratio, indicating that the BOD in graywater is of soluble nature.

The worst of all the measured parameters were the microbiological indicators. The high levels of indicator microorganisms encountered in the stored graywater are comparable to the levels found in other studies. However, such levels may not be indicative of the true population in the generated graywater since such indicator organisms grow during the storage process, and therefore overestimating the actual fecal loads (Ottoson and Stenström, 2003). Also, Rose et al. (1991) had a similar conclusion when they mentioned that the fecal coliform grew in the first 48 hours of storage.

In terms of odor, the household residents did not experience problems related to odor or operation of the system. Maybe this was due to the air-tight nature of the tank and the other plumbing accessories. The only odor problems occurred while irrigating the lawn outside of the house.

Table 3.11 Characteristics of Stored Graywater as Compared to those of Raw Wastewater

Parameter	Stored Graywater†	Low-Strength Untreated Domestic Wastewater‡
Turbidity (NTU)	88.9	-
Suspended solids (mg/L)	18.6	100
Total dissolved solids (mg/L)	118.1	200
COD (mg/L)	291	250
BOD_5 (mg/L)	103	100
COD/BOD ratio	2.97	2.5
Total coliform (CFU/100ml)	2.03×10^7	$10^7 - 10^8$ □
Fecal coliform (CFU/100ml)	5.30×10^5	-
E. coli (#/100ml)	1.00×10^4	-
HPC (#/1ml)	7.48×10^7	-

†Graywater generated by a two-adult household and stored for 7 days
‡ From Davis and Masten, 2004
□ From Metcalf and Eddy, 1991 (for medium strength wastewater)

Scheme II: In scheme II, the tank was put under aeration for seven days. The result was very turbid water with an average turbidity of 139 NTU and an average TSS of 92.2 mg/L. As a result of aeration, large flocs formed, which is an indication of a biological treatment. The large flocs were very visible in the samples collected in this scheme. All microbial indicator measurements; i.e. total coliform, fecal coliform, *E. coli*, and HPC; were at similar levels as those of stored graywater tested in scheme I.

Scheme III: In this scheme, the aerated graywater was settled for 24 hours. As mentioned in scheme II, aeration resulted in the formation of large flocs, which is an indication that biological treatment took place. The 24-hour settling period produced relatively clear water with an average turbidity of 22.9 NTU (a drop from 89 to 22.9 NTU). As a result of aeration and consequent settling, the BOD dropped from an average of 99.4 mg/L to an average of 17.3 mg/L (83% removal efficiency). This is a clear indication that biological treatment took place as a result of aeration. The COD dropped from an average of 291 mg/L to 96.5 mg/L; i.e. about 66% removal efficiency. The new COD/BOD ratio as a result of implementing scheme III (aeration and settling) was 7.27. This ratio, along with the lower COD removal efficiency, indicates the presence of slowly biodegradable organic matter. Microbially, scheme III was able to reduce the levels of total coliforms, fecal coliforms, and *E.coli* to 5.45×10^{5}, 2.10×10^{2}, and 10 CFU/100ml, respectively. These values are still high, and therefore graywater needs some kind of disinfection to achieve a more significant reduction in the level of such indicator organisms.

Scheme IV: As seen in the results of scheme III, letting graywater settle under quiescent conditions, following aeration, was able to achieve remarkable reduction in the levels of indicator organisms, however not acceptable yet. In scheme IV, a coarse filter and an ultraviolet unit (UV) were added in order to recycle the settled graywater through this treatment train . Microbially, scheme IV reduced the total coliform level from an average of 5.45×10^5 to an average of 464 CFU/100ml; i.e. 3-log removal was achieved (99.9%). The fecal coliform reduction was less significant, achieving only 77.1% removal efficiency (from 2.10×10^2 to 48 CFU/100ml). No *E. coli* bacteria were detected as a result of implementing scheme IV. The average COD and BOD values produced by scheme IV were 90.9 mg/L and 11.2 mg/L, respectively.

It was noticed that the coarse filter held significant amounts of hair and similar objects while recycling graywater. Also, in one of the weeks, the household residents cleaned some painting brushes in the bathroom washing basin. The coarse filter was quickly clogged because of the paint in the graywater stream.

Scheme V: In an attempt to reduce the turbidity so that a better microbial reduction is accomplished, scheme V was implemented in which a 5-micron filter was added to the treatment train used in scheme IV. The 5-micron filter was inserted in the recycle line after the coarse filter and before the UV unit. Compared to the turbidity in scheme IV, the introduction of the 5-micron filter, i.e. scheme V, dropped the turbidity from 22.1 NTU to 9.3 NTU. Apparently, this reduction looks significant. However, in order to check this hypothesis, the comparison should be performed between the turbidity values before passing graywater through the treatment train (i.e. aerated-and-settled graywater) and the turbidity values after passing the graywater through the treatment train (coarse filter, 5-micron filter, and UV unit), which are shown in Table 3.12.

Table 3.12 Turbidity Values After Passing through Scheme V compared to those before

Turbidity before†	**Turbidity After‡**	**Significant or not at the 95% CL using student t-test for paired data?**
14.4	12.1	Not significant at the 95% CL
15.1	12.0	
14.1	13.6	
14.3	13.6	
Average 14.5	**Average 12.8**	

† Turbidity values of settled graywater before entering the treatment train of scheme V
‡ Turbidity values after passing scheme V treatment train (coarse filter, 5-micron filter, and UV unit.

The values in Table 3.12 combined with the result of the student paired t-test show that the 5-micron filter did not reduce turbidity. Therefore, the huge difference noticed in Table 3.10 (from 22.1 to 9.3 NTU) cannot be attributed to the use of the 5-micron filter.

Surprisingly, the TSS concentration in the effluent increased after the implementation of scheme V, in which the 5-micron filter was inserted. Probably more samples should have been taken to confirm what happened. The remarkable achievement of scheme V was in the microbial side. The levels of total coliforms and fecal coliforms were significantly lower than those reported in scheme IV, which should be an indication of the effectiveness of the 5-micron filter. However, such reduction in indicator organisms is most likely due to reduction in flow caused by the introduction of the 5-micron filter combined with the lower turbidity values that happened to occur in those sampling times. Such flow reduction increased the effectiveness of the UV disinfection and therefore lowered the level of indicator organisms.

Scheme VI: The turbidity of stored graywater after passage through the UV unit (no aeration or recycling were involved) averaged at 60.8 NTU, which is high enough to impede the effectiveness of the UV disinfection and produce high levels of indicator organisms. Since the turbidity values are still high, the concentration of the microbial indicators is still high. The resulting concentrations of the total coliform, fecal coliform, and *E. coli* bacteria were 2.50×10^4, 2.75×10^3, and 7 units/100ml. Since aeration did not take place, the COD values were still high and averaged at 255 mg/L. The results of this scheme clearly indicate that UV disinfection cannot be used by itself to disinfect graywater. UV unit must be preceded by other treatment units to reduce the turbidity of graywater.

Samples were not tested for BOD because there was no biological treatment occurring in this scheme. Also samples were not run for TDS because such treatment is not expected to achieve any enhancement to the level of TDS.

Scheme VII: The introduction of the 5-micron filter ahead of the UV unit did not result in any decrease in the levels of turbidity, as compared to scheme VI. This treatment scheme resulted in an average turbidity of 64.2 NTU. Obviously, the use of the 5-micron filter did not reduce the turbidity of graywater. In spite of having almost the same turbidity as graywater in scheme VI, a significant reduction in the levels of microbial indicators was noticed. The resulting concentrations of the total coliform, fecal coliform, and *E.coli* bacteria were 2545, 81, and 7 units/100ml. Most likely such reduction is attributed to a reduction in the flow caused by the 5-micron filter, which apparently resulted in a better UV disinfection. Results of schemes VI and VII indicate that biological treatment is necessary to achieve significant treatment levels. The results of this scheme also indicate that the 5-micron filter did not result in any reduction in the levels of both turbidity and suspended solids, which is an indication that the existing solids have sizes less than the five-micron openings of the filter.

Samples were not tested for BOD because there was no biological treatment occurring in this scheme. Also samples were not run for TDS because such treatment is not expected to achieve any enhancement to the level of TDS.

3.4.4 Summary of Graywater Treatment Experiments

The stored graywater in the house under consideration had a relatively low level of TSS. Other measured water quality parameters were at levels comparable to those encountered in low-strength untreated domestic wastewater (e.g. 89 NTU, 291 mg/L, 103 mg/L for turbidity, COD, and BOD). The worst of all measured parameters were the indicator organisms, which were at levels similar to those of medium-strength untreated domestic wastewater. The stored graywater had higher COD/BOD ratio, which is an indication of higher amounts of slowly biodegradable organic matter. Aeration of the tank led to the formation of flocs, which is an indication of the occurrence of biological treatment. An increased turbidity was noticed as a result of aeration. Settling of the aerated graywater for 24 hours lead to settling of the flocs that formed in the aeration stage. Significantly lower levels of turbidity, COD, and BOD were achieved as a result of settling. The settling process did not result in significant reduction in the levels of the microbial indicators.

The introduction of a recycling line comprising a coarse filter and a UV disinfection unit lead to significant reduction in the microbiological parameters. The mean levels of total coliform, fecal coliform, and *E.coli* were 464, 48, and zero CFU/100ml. Knowing that the original levels in stored graywater were 2.03×10^7, 5.30×10^5, and 8.03×10^7 CFU/100ml that simply means a 5-log removal for the case of total coliforms, 4-log removal for the case of fecal coliforms, and a 100% removal for the case of *E. coli*.

A further reduction was achieved when the 5-micron filter was introduced before the UV unit. However, statistical analysis showed that this further reduction was not due to the introduction of the 5-micron filter. In fact, increased levels of TSS were noticed as a result of the 5-micron filter use. Therefore such reduction in the microbial parameters was attributed to the flow reduction caused by the introduction of the 5-micron filter; i.e. not by the filtering action of the 5-micron filter.

Passing the stored graywater into the coarse filter and the UV disinfection unit without any previous aeration, which is the treatment of scheme VI, resulted in levels of indicator organisms that are still high; 2.50×10^4, 2.75×10^3, and 7 units/100ml for the total coliforms, fecal coliforms, and *E. coli* respectively. The introduction of the 5-micron filter before the UV unit (scheme VII) resulted in lower levels of microbiological indicators as compared to those obtained in scheme VI. The levels obtained in scheme VII for total coliforms, total coliforms, and *E. coli* were 2545, 81, and 7 units/100ml respectively. The introduction of the 5-micron filter did not result in any turbidity or TSS reduction. Again, the higher effectiveness of the UV disinfection noticed in scheme VII compared to scheme VI was attributed to the reduction in flow caused by the 5-micron filter.

Chapter 4

EFFECTS OF GRAYWATER IRRIGATION ON PLANTS AND SOILS

4.1 Literature Review

The average U.S. household generates significant amounts of graywater. Results from an AWWA study (Mayer et al., 1999) indicated that the average household in the US, 2.6-person household (US Census 2000/2003), generates about 180 gallons per day. Some calculations from the same study (AWWA study) lead to the conclusion that 50% of this amount; i.e. 90 gallons per day is graywater available for use in landscape irrigation. Depending on the size of yard, the types of plants landscaped, and the amount of rain; this graywater amount may or may not be enough for the landscaped area.

In water reuse systems, water quality is the most important issue (Lazarova and Bahri, 2004). The quality of water determines the safety and acceptability of using graywater in irrigation. It also determines the types of plants that can be grown for the recycled water under consideration. The appropriate treatment technology is determined by the guidelines and regulations for irrigation. The same rules may apply to the use of graywater in landscape irrigation. Lazarova et al. (2004) listed several water quality criteria for water reuse in irrigation. Since the final destination is irrigation, similar criteria can be used when considering graywater for irrigation. Those criteria are shown in Figure 4.1.

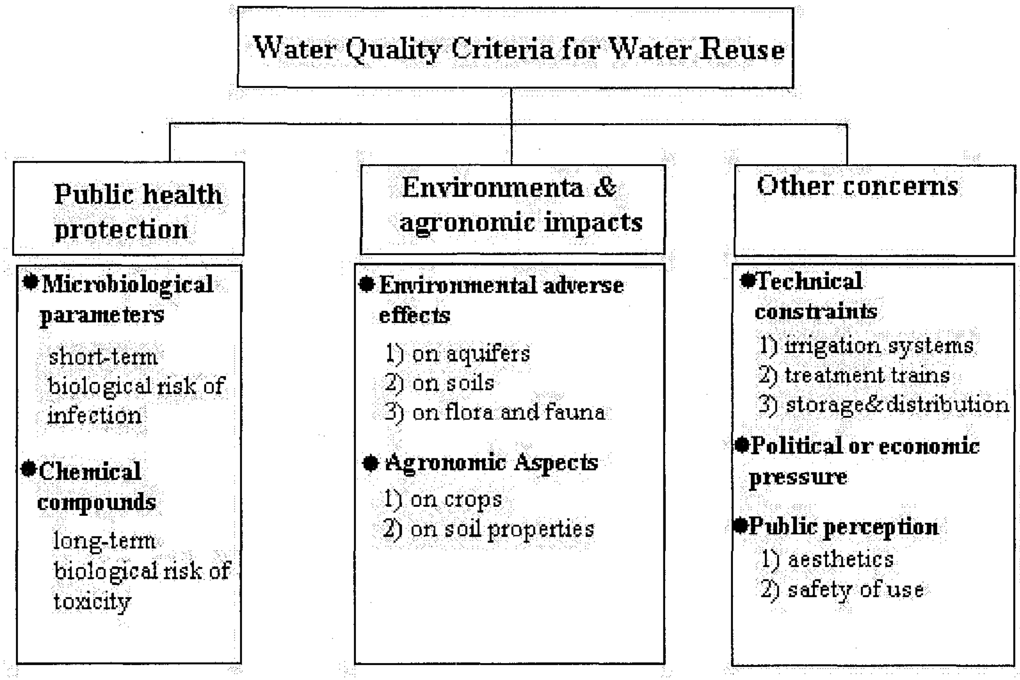


Figure 4.1. Main water quality criteria in reuse systems for irrigation
Source: Lazarova et al., 2004

Graywater quality becomes of utmost importance when graywater is considered for landscape irrigation. The graywater characteristics (physical, chemical, and biological) vary widely with time and location. Such quality seems to be a function of many factors; e.g. habits of household inhabitants, ages and number of household inhabitants, household chemicals used by the residents for cleaning and personal care, the sources connected to the collection system, whether water conservation devices are used or not, medications and waste products disposed in the collection system, etc.

The main interest of this chapter is to investigate the effect of using graywater for landscape irrigation on both plants and soil.

4.1.1 Chemicals in Graywater and their Fate after Irrigation

Graywater contains many chemicals that can be harmful to plants. A study by the National Institute of Health (2004) revealed that over 2,500 chemical names were found in 5,000 products used in households. Many of these chemicals are known to have detrimental effects on plants and soils. The accumulation of such chemicals in the soil root zone and in plant tissues is a major concern that needs to be addressed. Tables 3.1 and 3.2 show the difference in graywater characteristics as a function of the graywater source.

Different chemicals are added in household products for different purposes; e.g. detergents, surfactants, bleaches, fragrances, dyes, enzymes, builders, flavors, preservatives, pharmaceuticals, etc. When considering graywater for irrigation, the accumulation of chemicals in soil is of utmost concern. Graywater application adds metals, salts, and organic compounds to the soil. The addition of such elements and compounds may change many of the soil characteristics. Changes can be direct such as changes in salinity, pH, and concentration of chemicals in soil. Such changes along with any physical changes may have effects on the soil microorganisms and their functions, which may ultimately lead to changes in other surrounding chemical conditions.

For the pH, several studies indicated that the pH of graywater tends to be slightly higher than that of fresh water source. The introduction of laundry water is thought to have the effect of increasing the water pH since laundry water usually have relatively high pH values (as high as 10 and alkalinity as high as 200 mg/L as $CaCO_3$, Christova-Boal et al.1996).

Since graywater contains many chemicals that don't usually exist in irrigation water, the effects of such chemicals may be predicted by knowing the degradability of these chemicals as they come into soil. Factors like the soil type, the chemical concentration, the application rate, whether fresh water is used along with graywater, the degradability of chemicals, sorption, leaching, and plant uptake are important factors that are expected to affect the final impacts on soils and plants.

Metals are not biodegradable and tend to sorb to solid particles and accumulate in the soil. Their accumulation depends on several factors including soil pH, mineralogy, concentrations of complexing ligands and ions, and redox conditions (Adriano, 1986).

Organic chemicals are different from metals in the sense they may be degradable under certain conditions. The new chemicals resulting from degradation might be less or more mobile or degradable than the original organic chemical. The rate of degradation of an organic chemical depends on the chemical itself and on the environmental conditions such as the type and concentration of the electron acceptor, temperature, soil moisture, complexation of chemical with organic matter (Knaebel et al., 1994), and acclimation of microbes (Doi et al., 2002).

By examining the main chemicals that may exist in the graywater stream, it has been found that many of these chemicals are degradable (e.g. soaps, builders, enzymes, surfactant, fabric whiteners, etc). According to Steber and Berger (1995) soaps are readily biodegradable. They are almost completely degradable in 4 weeks both in aerobic and anaerobic digesters.

A typical detergent may contain surfactants, builders, enzymes, fabric whiteners, and bleaches. Table 4.1 shows the main ingredients of a laundry detergent along with their weight percent. The degradability of each constituent can be examined individually.

Table 4.1 Main Ingredients in Laundry Detergents

Group	Component	Weight Percent in Liquid Detergents	Weight Percent in Powdered Detergents
Surfactants	Anionic (LAS, AS, AES)	15 – 30	15 – 25
	Nonionic (AE)	0 – 15	0 – 5
Builders	Zeolite	–	20 – 30
	Citrate	0 – 10	0 – 5
	Polycarboxylate polymers	–	0 – 3
	Carbonate	–	8 – 25
	Sodium Silicate	–	1 – 3
Sodium Sulfate		–	10 – 25
Enzymes		0 – 1.5	0 – 3
Fabric Whiteners		0 – 0.5	0.1 – 0.5
Dye binders		–	–
Bleach	Percarborate	–	0 – 5
	Activator	–	0 – 5

Source: Roesner et al. 2006

Surfactants, whether anionic or nonionic, are biodegradable compounds. LAS (linear alkyle benzene sulfonates), have become the most widely used anionic surfactants in detergents. They usually contain between 10 and 13 carbon atoms in the alkyl chain. LAS are biodegradable compounds that have half-lives in the order of weeks under aerobic conditions (Schoberl., 1997 as cited by Roesner et al. 2006). The anionic surfactants AS (alkyl sulfates) and AES (alkyl ethoxy sulfates) are almost completely biodegradable within days. Alcohol ethoxylates (AE) are nonionic surfactants containing 9 to 15 carbons. Biodegradation is almost complete within a month for the linear alkyl chain. (Kravetz et al., 1991). In addition to their use in detergents, surfactants are widely used as an adjuvant to leach chemicals from contaminated soil. Therefore, surfactants in graywater stream may help in solubilizing the chemicals and leaching them below the root level (provided that the surfactant concentration exceeds the critical micelle concentration or CMC, which is not clear). Anionic surfactants are better than both neutral and cationic surfactants in desorbing chemicals (Lee et al., 2004)

Builders are compounds added in detergents to bind hardness cations (mainly calcium and magnesium) resulting in water softening and less interference with the surfactants. They are also added to raise the pH of the wash solution. Examples of builders are zeolites, sodium carbonate salts, and silicate salts. Zeolites are readily hydrolyzable when placed in water.

Enzymes are used in cleaning products in small amounts. Their main task is to breakdown large, water-insoluble molecules into smaller, water-soluble molecules. Enzymes are known to be fully degradable in soil, releasing nitrogen into the soil. Each enzyme has its own very well known and defined task; e.g. some are used in removing starch-based stains (amylase), some are used in removing oil and grease (lipase), etc.

Whitening agents are used to enhance the brightness of light colored fabrics. They tend to sorb to fabrics, and therefore their concentration in the effluent is very low.

Triclosan (TCS) is used as an anti-bacterial in aqueous liquid detergents. According to McAvoy et al. (2002), TCS is readily biodegradable under aerobic conditions, unlike what was thought in the past that TCS is resistant to biodegradation.

4.1.2 Possible Graywater Effects on Residential Landscaping

On one side, the use of recycled wastewater for the irrigation of landscape plants is viewed as one way to maximize the existing water resources and stretch current urban water supplies (USEPA, 1992). It is a powerful means of water conservation. Besides the benefit of freeing potable water for human needs, several other benefits were mentioned by Sheikh (2004). Among the benefits mentioned by Sheikh (2004) are the reliability of recycled water (especially in times of droughts when some restrictions may apply to the use of fresh water for landscape irrigation) and reducing the need for fertilization to a significant degree. On the other side, there are problems associated with using recycled wastewater in irrigation. Speaking about recycled wastewater, the most common problems are salinity buildup, relatively high sodium (Na), boron (B), and sodium adsorption ratio (SAR) values in the soil. The parameters of concern to plants and soils are different from the parameters usually monitored in wastewater treatment plants. In wastewater treatment plants, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids (SS) are the most common parameters routinely measured and reported since they are of a particular interest in pollution control in receiving water bodies. BOD and COD are not directly used in irrigation project planning (Lazarova et al., 2004). SS might be useful in predicting potential clogging problems in irrigation systems (Lazarova et al., 2004). From soil and plants point of view, parameters like salinity, pH, toxic ions (e.g. boron, chloride, and sodium), trace elements, and nutrients are the most important.

Salinity and the accumulation of salts are the first to consider. It is common to find high concentrations of sodium and chloride in recycled water (Westcot and Ayers, 1984). While salinity levels below 1.5 dS/m (about 960 mg/L) would not appreciably affect most landscape plants, higher salinity levels may require special management efforts and avoidance of the most salt-sensitive plants (Sheikh, 2004, Ch6 of Lazarova and Bahri). What is encouraging here is that most recycled waters contain salt concentration less than 500 $mg.l^{-1}$ (Wu et al., 1999).

Dissolved salts in soil are absorbed by roots and carried through the sap stream to leaves, where accumulation to toxic levels may occur. This actually explains why most deciduous trees, which lose their leaves each fall, are more tolerant to salt than evergreens (Roesner et al. 2006). For the long-term success of applying graywater in irrigation, salinity-sensitive plants should be avoided and therefore a synthesis of existing information on the salinity tolerance of landscape plants needs to be available to graywater users. Tables 4.2 and 4.3 show plants commonly used in residential landscaping in the USA with their level of salinity tolerance. The Tables show that some plants are quite sensitive to salinity while others are relatively tolerant to salinity. Since the existing information about the effect of graywater on plants is very limited, the information in Tables 4.2 and 4.3 is based on irrigation with some type of water other than graywater.

Table 4.2 Level of Salinity Tolerance of Some Common Landscape Plants

	Low Tolerance	**Moderate Tolerance**	**High Tolerance**
Bedding Plants	Petunia		Geranium
Turf	Kentucky bluegrass Buffalograss Centipedegrass	Tall fescues Perennial ryegrass	Bermudagrass St. Augustinegrass Zoysiagrass
Deciduous Woody Plants	Crabapple Littleleaf Linden Hachberry Red Mapple Amur Maple Crape Mytle	Siberian Elm American Elm Green Ash Chinese Lilac Crabapple	Quaking Aspen Cottonwood Norway Maple Honeylocust Callery Pear Valley Oak Laurel Oak Live Oak
Evergreen Woody Plants	Colorado Spruce Bird of Paradise	Scotch Pine Chinese Juniper Creeping Juniper Arborvitae Sabin	Austrian Pine Norfolk Island Pine Sabin Juniper Plumbago Oleander Queen Palm Date Palm Sago Palm

Source: Roesner et al. 2006

Table 4.3 Salinity Sensitivity/Tolerance of Typical Landscape Plants

Sensitive (EC 1-2 dS/m)	**Moderately Sensitive**	**Moderately Tolerant**	**Tolerant (EC > 10 dS/m)**
Star Jasmine Pyrenees Cotoneaster Oregon grape Photinia Tulip Tree Crape myrtle	Yellow sage Orchid tree Southern Magnolia Japanese boxwood Xylosma Chery plum	Weeping bottlebrush Oleander European fan palm Blue decaena Rosemary Aleppo pine Sweet gum	Brush cherry Evergreen pear Bougainvillea White/Purple iceplant Croceum iceplant

Source: Maas, 1990 (as cited by Sheikh, 2004 in Lazarova and Bahri)

Irrigation water containing high levels of sodium can lead to a significant increase in the SAR index, which would imply a lower soil permeability and water flow restriction within the soil profile. (Sheikh, 2004, Ch6 of Lazarova and Bahri). Sodium becomes of special importance in turf irrigation especially on golf courses since the turf is cut to very low levels (Sheikh, 2004). Ayers and Westcot (1985) reported that when subsurface irrigation is used sodium concentration higher than 100 mg/L, might cause toxic effects to salt sensitive plants. In the City of Los Angeles study (City of Los Angeles, 1992), the sodium concentration in graywater exceeded the 100 mg/L level in 26 samples out of the 94 samples taken. The average sodium concentration in that study (study of City of Los Angeles, 1992) was calculated to be 118 mg/L (Roesner et al., 2006). Since a sodium concentration of 100 mg/L might cause toxic effects to salt-sensitive plants, that average of 118 mg/L emphasizes the extreme need of a comprehensive list that provides the homeowners with information about the tolerance level of landscape plants. In another study, Ponderosa pines irrigated with recycled wastewater exhibited much higher needle burn symptoms than those irrigated with surface water (Qian et al., 2006). This burn was attributed to high sodium concentration in leaf tissues.

Boron is one of the major concerns since it is one of the toxic ions that can harm plants if its level exceeds specific values in irrigation water. Van der Leenden et al. (1990) mentioned that the boron concentration in graywater could reach 0.4-1.5 mg/L (especially if groundwater was the source), which is an extremely dangerous range; given that Boron concentration higher than 1.0 mg/L can cause severe leaf burn to some sensitive landscape plants (Wu and Dodge, 2005). Wu and Dodge (2005) indicated the encouraging point that most recycled waters have boron concentrations not exceeding 1.0 mg/L.

The long-term effects of recycled wastewater irrigation on golf courses have been examined by Qian and Mecham (2005). The study found out that golf courses irrigated with recycled wastewater (for 4, 13, 14, 19, and 33 years) exhibited 200%, 40%, and 30% higher concentrations of Na, B, and, P. Also, the recycled wastewater irrigated golf courses exhibited 187% higher EC and 481% higher sodium adsorption ratio (SAR). Such increase in the SAR values raises concerns about the possible long-term reductions in parameters like the soil hydraulic conductivity and infiltration rate, especially in soil with high clay content (Qian and Mecham, 2005). According to Bahri et al. (2000), golf courses irrigated with secondary effluent for 20 years in Tunisia did not show any adverse effects, with the golf course producing turfgrass of high quality.

The constituents of great concern in recycled wastewater are summarized in Table 4.4. The same concerns may apply to the use of graywater in landscape irrigation.

Table 4.4 Impacts of Several Water Constituents on Plants, Soils, and Groundwater

Constituent	Impact on plants	Impact on soils	Impact on groundwater
High salinity	Lower yield	Salinization	Degradation of water quality
High sodium (SAR)	Toxicity, leaf burn	Lower permeability	–
High chloride	Toxicity	–	–
High boron	Toxicity	–	–
High levels of microorganims	Farm worker & consumer health	–	Public health
Nitrogen	Better yield	–	Pollution

Source: Maas, 1990 (cited by Sheikh, 2004 in Lazarova and Bahri)

The same principles may apply to the irrigation with graywater. Since the study of the graywater irrigation effects on plants and soils is relatively a new issue, studies examining the effects of using recycled wastewater on landscapes and soils have been used as a starting point. However, there are still some graywater studies that investigated the effects on plants and soils. Jeppesen and Solley (1994) reported that existing graywater systems and limited trials suggested that there is no adverse effect on lawns and ornamental gardens from chemicals in graywater. They mentioned that the concern is over clayey soils and increased level of nutrients in groundwater. While a sandy and well-drained soil will be less affected by graywater, a poorly drained clay soil might be in danger from the application of graywater (CSBE, 2003). According to CSBE (2003), the main effects of graywater on soils are: 1) A tendency to raise soil alkalinity and salinity, 2) A reduction in the ability of soil to absorb and retain water.

In a report prepared for the City of Los Angeles (City of Los Angeles, 1992), the researchers were not able to observe any important horticultural effects after a whole year of graywater irrigation in eight graywater sites, where drip irrigation was the application method in six of the sites. The comparison was made between areas irrigated with graywater and areas irrigated with fresh water (control areas). The authors of this report mentioned that any harmful effects would take a number of years to show effect on plant growth. In spite of the use of regular detergents, no harmful plant symptoms were observed. In the same report (City of Los Angeles, 1992), several parameters were measured in the irrigated soil at the end of the one-year irrigation period; e.g. total coliform, fecal coliform, enterococci, pH, sodium, chloride, calcium, magnesium, and specific conductance. Sodium Adsorption Ratio was also calculated. The only parameters showing significant difference at the 95% confidence level were the total coliform, sodium, and sodium adsorption ratio. None of the other parameters exhibited a statistically significant difference at the 95% confidence level.

A two-year study in Arizona used graywater in underground drip irrigation. The study revealed that no salts had accumulated in either the soil or the plants (NSFC, 2002). A slight increase of Boron was detected, but within acceptable levels. The results of this study are encouraging because the drip irrigation is known to concentrate the salts in the soil, irrespective of the source.

For a 12-week period, Wu et al. (1995) investigated the effect of simulated graywater (high concentrations of Cl^-, Mg^{2+}, Ca^{2+}, and K^+) on the growth and uptake of nine plant species. Five species were not affected by irrigation with simulated graywater (Azalea, Japanese boxwood, Hydrangea, Raphiolepsis, and Jasmine). The authors mentioned that a greater reduction of growth was noticed in those species that accumulated more Cl. It was also noticed that the species with higher concentration of calcium showed more tolerance to Cl levels. This means that calcium concentration in tissues plays a role in tolerance to Cl.

The concerns are not limited to salts. Household cleaning products contain surfactants. Therefore, the effect of surfactants on plants needs to be investigated. Rinallo et al. (1988) noticed that the use of anionic surfactant (ABS) and a non-ionic surfactant on wheat plantlets resulted in growth stimulation at low surfactant concentration and short periods (less than eight days). A long exposure and/or high concentration led to phytotoxic effects.

4.1.3 Effects on Soil Microbiology and Soil Microbial Function

Microorganisms in graywater can be pathogenic or non-pathogenic. Health departments are strong opponents to the use of graywater. Their main concern is the presence of pathogens in graywater. Pathogens can find their way to the graywater stream through several ways; e.g. during showering, laundering, food handling in the kitchen, washing hands, etc.

Soil is known to be a complex medium consisting of a solid phase that includes mineral particles and organic material, a liquid phase that includes water or the soil solution, gases that are in equilibrium with the atmosphere, and a variety of microorganisms (Hopkins and Huner, 2004). Besides the health concern, the effect of graywater on indigenous soil microorganisms and soil microbial function is a concern that needs to be addressed. Since graywater contains many chemicals, which are also variable by location and in time, it becomes difficult to predict the effect of graywater on soil microbiology. Graywater contains organic matter, nitrogen, and phosphorous, all of which will stimulate soil microorganisms' activity and growth. On the other hand, Graywater also contains salts and chlorides, which are known to have detrimental effects on the soil microbiology (e.g. osmotic stress, a noticeable pH change). As a result, some important biological functions in the soil ecosystem might be affected.

A real lack of information exists on the effects of graywater on soil microbiology. Therefore, relevant information may be extracted from the studies that used wastewater as the irrigation water. Most of these studies found that the application of wastewater benefits the soil microbial community and the microbial function (due to inputs of organic matter and nutrients). Several field studies were found supporting the hypothesis that irrigation with wastewater benefits the soil microbial community. Filip et al. (1999) reported that an over-100-year irrigation "long-term" with wastewater significantly increased the active microbial biomass, the counts of actinomycetes and fungi, and the activities of microbial enzymes. The comparison has been made to soil that has never been irrigated. The results of this study are important in showing that microorganisms and their activities benefit from long-term wastewater irrigation. Compared to control soils, a large increase in soil bacterial growth was reported by Tam (1998) as a result of applying artificial wastewater. The study also reported that the activities of several microbial enzymes were not impacted by wastewater irrigation. Citrus orchard soil irrigated with treated wastewater (lagoon treatment) had significantly higher amounts of microbial biomass carbon, soluble carbon, and microbial respiration and enzymatic activities (Meli et al., 2002). The same study reported a lower ratio of CO_2 respired per microbial biomass carbon, indicating better microbial metabolic efficiency as a result of wastewater application.

The previous examples are field studies showing a positive effect on the soil microbial community as a result of wastewater application. This is an encouraging indicator given that wastewater may contain heavy metals that are detrimental to soil microbes, while graywater would not contain such heavy metals. Therefore there is a good potential that graywater application will result in better soil microbial functioning as a result of introducing organic matter and nutrients to the irrigated soil. Even in the case of wastewater, it seems that the benefits of organic matter and nutrients outweigh the detrimental effects of heavy metals.

On the other hand, Friedel et al. (1999) conducted a laboratory study to show the effect of applying untreated wastewater containing branched alkylebenzene sulfonate surfactants (ABS) on soil microbial biomass. Less microbial biomass, stimulated denitrification, production of the greenhouse gas N_2O, and more respiratory activity (i.e. less efficient metabolism) were some results of increased ABS concentration.

The long-term impacts of graywater – especially that related to the buildup of salts and toxins – on indigenous soil microorganisms and their ecosystem functions are still unknown and need more investigation.

Another point that would mean a lot to graywater users is information on the potential clogging of the graywater distribution system and/or the soil pores by the microbial biofilm communities, which is another complication that should be investigated.

4.2 Main Findings of the Plants and Soil Literature Review

Besides the health risks associated with the reuse of graywater in landscape irrigation, three main categories need to be properly investigated in order to reach a final decision on the reuse of graywater in landscape irrigation. The three categories are: 1) chemicals in graywater and their fate, 2) possible graywater effects on residential landscaping, 3) effects on soil microbiology and soil microbial function.

The category of chemicals in graywater and their fate includes several issues such as the accumulation of chemicals in soil root zone, change of soil structure, amendments required in case that change in soil structure occurred, biodegradability of graywater chemicals in the soil matrix, and impacts on groundwater quality. Little information exists about the fate of graywater chemicals after irrigation and the effect on irrigated soil. Previous studies revealed that over 2,500 chemical names were found in 5,000 products used in households. Several studies revealed that a lot of the chemicals in graywater are biodegradable in the soil root zone. Therefore, efforts should be made to manufacture environmentally friendly soaps and detergents that are biodegradable in the soil root zone and that are not harmful to the soil microbes and the soil structure.

The literature review revealed that the accumulation of chloride, sodium, and boron is a main issue. Therefore, producing soaps and detergents having lower amounts of those elements is expected to reduce the impacts of graywater on plants and soils. Several studies showed significant increase in the levels of sodium and sodium adsorption ratio (SAR) in the irrigated soil. Studies examining the long-term impacts of graywater irrigation on soils almost do not exist.

The second category of concern is the possible effects on residential landscaping. Dissolved salts in soil are absorbed by roots and carried through the sap stream to leaves, where accumulation to toxic levels may occur. Knowing this mechanism leads to the conclusion that deciduous trees, which lose their leaves each fall, are more tolerant to salt than evergreens, which is a conclusion reached by a study mentioned earlier in the literature review (see section 4.1.2). Using the same logic leads to the conclusion that using graywater in irrigating annuals has promising potential since annual plants last only for one season, which make them strong candidates for the utilization of graywater. Most of the studies examining the effects of graywater on landscape plants suggested that there is minimal adverse effect on the quality of plants from chemicals in graywater. However, reduction in growth was noticed. The accumulation of Cl, B, and Na in plant tissues is a major concern. The literature review showed that there is a strong need for classifying landscape plants according to salt tolerance level so that homeowners can decide what to choose for graywater irrigation. Another point of special importance is the clogging of the irrigation system. Clogging of the irrigation system due to drying of salts, suspended solids, and/or microbial biofilm communities need to be investigated using field studies.

Studies examining the long-term effects of graywater on landscape plants almost do not exist. Therefore, the long-term effects of graywater irrigation on landscape plants should be further investigated. As a starting point, other types of irrigation water have been used (e.g. reclaimed wastewater).

The third category of concern is the effects on soil microbiology and soil microbial function. The fact that hundreds of chemicals may find its way to the graywater stream makes it extremely difficult to predict the effects of graywater on soil microbiology. Some chemicals are known to be detrimental such as salts and chlorides, while some are beneficial. A real lack of information exists on the effects of graywater on soil microbiology. Therefore, relevant information has been extracted from the studies that used wastewater as the irrigation water. Most of these studies found that the application of wastewater benefits the soil microbial community and the microbial function – most likely due to inputs of organic matter and nutrients.

4.3 Plants and Soil Experiments

The goal of this part is to assess the effect of graywater application on landscape plants and soil. The main research question can be stated as: Would the use of graywater for irrigating typical landscape plants have observable impacts on the irrigated plants and soils?

4.3.1 General Approach

Graywater from a residential house was collected and used in irrigating a set of landscape plants. A second set was irrigated with tap water and was considered to be the control. A third set of plants was irrigated with both tap water and graywater in alternating way in order to investigate the effect of tap water irrigation on flushing the salts accumulating in the soil matrix. The three sets of plants were in a greenhouse to make sure that surrounding conditions are controlled. Finally, comparison was made among the three sets based on visual appearance, tissue analysis, plant mass above ground, and soil analysis.

4.3.2 Materials and Methods

The research question under consideration in this section is: Would the use of graywater for irrigating typical landscape plants have observable impacts on the irrigated plants and soils?

In order to answer that question, three benches filled with the same type of soil were planted with different kinds of landscape plants. The soil used in the benches was a local loamy soil. The soil analysis run by the Soil, Water and Plant Testing Laboratory at

Colorado State University showed that the soil in the benches was a loamy soil consisting of 45% sand, 35% silt, and 20% clay. Figure 4.2 shows the three benches along with the plants in each bench.

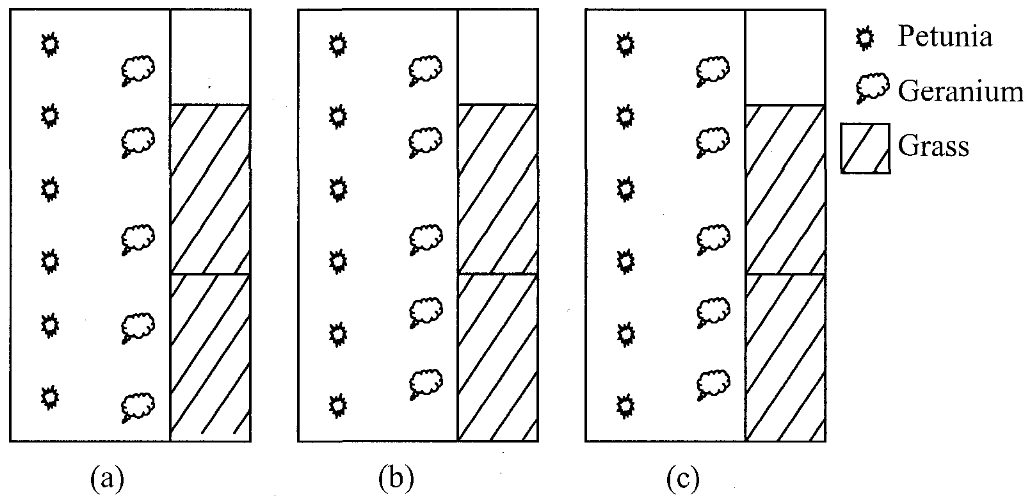


Figure 4.2. The three benches along with plants used in the experiments

Each bench is 6 feet by 3 feet filled with about 7 inches deep of local loamy soil. Bench (c) was irrigated with tap water only and was considered the control. Bench (b) was irrigated only with graywater. Bench (a) was irrigated in an alternating way with both graywater and tap water to investigate the effect of tap water irrigation on flushing the salts and chemicals accumulating in the soil matrix. Each bench has been planted with four types of plants; geranium, petunia, Kentucky blue grass, and fescue grass. The plants were irrigated at the rate of one-and-a-half inch of water per week. For the first month, irrigation was applied on a daily basis. Later, the irrigation was applied every other day at the rate of one inch per week. For the bench irrigated with both tap water and graywater, tap water was applied only one third of the times; i.e. two events of graywater irrigation was followed by one event of tap water irrigation. This cycle of irrigation continued for the whole period of experiments. The graywater used in irrigation was generated in a 2-adult household in the City of Fort Collins, CO. It was collected after seven days of storage in a 300-gallon tank. Kitchen wastewater was not included in the graywater stream. The graywater used in irrigation was the wastewater generated from laundry, bath sinks, shower, and bath tub.

The graywater quality produced by the house was tested for some parameters that are of special importance to plants and soil. Those parameters are: TDS, NO_3, NH_4, total P, ortho-P, Na, Cl, B, SO_4, and total N. One graywater sample was collected from the graywater tank (stored graywater). The sample was tested by the Soil, Water and Plant Testing Laboratory at Colorado State University. The testing results are shown in Table 4.5.

Table 4.5 Quality of Stored Graywater Used in this Study

Parameter	Unit	Concentration
pH		6.9
E.C.	μmhos/cm	174
Ca	mg/L	15.6
Mg	mg/L	2.6
Na	mg/L	16.8
K	mg/L	3.4
B	mg/L	0.02
CO_3	mg/L	<0.1
HCO_3	mg/L	68.3
Cl	mg/L	11.6
SO_4	mg/L	17.1
NO_3	mg/L	<0.1
NO_3-N	mg/L	<0.1
Hardness as $CaCO_3$	mg/L	50
Alkalinity as $CaCO_3$	mg/L	56
TDS	mg/L	135
NH_4	mg/L	<0.01
NH_4-N	mg/L	<0.01
Ortho-P	mg/L	0.005
Total P	mg/L	0.043

Another researcher (Marjoram, 2007) collected some graywater samples from the same graywater tank and tested them using a colormetric field-testing kit manufactured by Hach Company (Table 4.6).

Table 4.6 Quality of Stored Graywater used in this Study as tested by Marjoram (2007)

Parameter	Unit	Concentration
pH		6.5 – 7.8
Free Chlorine	mg/L	0.0
Nitrate	mg/L	0.5 – 4.0
Ammonia-N	mg/L	0.28 – 1.64
Phosphate	mg/L	0.08 – 1.67
Dissolved Oxygen	mg/L	0.0 – 0.8

The following tests/analyses were performed:

1- **Plant tissue analysis** (Final Conditions only since a control bench exists).

Geranium and petunia plants were planted on July 7th, 2005. After a 7-month period of irrigation, the geranium and petunia plants were taken to the Soil, Water and Plant Testing Laboratory at Colorado State University to be analyzed for several parameters. The tissue analysis included nitrogen, calcium, magnesium, sodium, potassium, phosphorus, iron, manganese, copper, zinc, boron, nitrate nitrogen, and sulfur. Through the uptake of those elements by plants, one can gain insight into why plants differed in response – if there is any difference. Statistical analysis was performed to check if the differences were statistically significant or not. The differences among elements/compounds concentration were compared using analysis of variance (ANOVA) at the 0.05 significance level. ANOVA test measures the amount of the total variability of the dependent variable that can be attributed to the differences among the categories of the independent variable. The null hypothesis for ANOVA states that the mean is the same for all groups.

2- Plant mass above ground (final conditions)

At the end of a 7-months irrigation period, the plants were cut at the surface of soil and taken to the Soil, Water and Plant Testing Laboratory at Colorado State University in order to determine the final dry weight of each plant. This is one of the ways to evaluate the plant growth.

3- Soil Analysis : One of the main concerns that need to be addressed is the effect of graywater irrigation on soil and the accumulation of chemicals in the soil. To answer some of the questions related to this issue, two 1-lb soil samples were taken from each of the three benches (tap-water irrigated bench, graywater irrigated bench, alternate irrigation bench). Each sample was collected from the surface down to a depth of 6 inches. The samples were taken at the end of a 16-month irrigation period and analyzed at the Soil, Water and Plant Testing Laboratory at Colorado State University. The soil samples were analyzed for the following parameters: pH, EC, organic matter, NO_3-N, P, K, Zn, Cu, hydraulic conductivity, Boron, NH_4-N, N, P, Ca, Mg, Na, and K. The differences among the three benches were analyzed by analysis of variance (ANOVA) with $p<0.05$ for significance.

4.3.3 Results of Plants and Soil Experiments

The results in this section are divided into two main parts. The first part, part A, shows and discusses the results related to plant experiments. The second part, part B, shows and discusses the results related to the soil in which plants were planted.

A) ***Results of Plant Experiments***

Plant tissue analysis was performed for the geranium and petunia plants. The analysis results of the geranium plants are illustrated in Table 4.7. The difference in the concentration of each parameter among the three groups was examined for significance using the Analysis of Variance (ANOVA) procedure at the 5% and 10% significance levels. Table 4.7 shows that sodium and potassium were the only parameters showing a statistically significant difference with a 95% confidence level. At the 90% confidence level, four parameters – total N, Na, K, and Cu – showed significant difference.

Table 4.7 Plant Tissue Analysis Average Results for the Geranium Plants

	Mean Concentration in Geranium			**No. of Samples**	**Significant or not using ANOVA**			**Significant or not using Student t-test* Between (--) & (--)**	
	Tap water irrigation (T)	**Graywater irrigation (G)**	**Alternating irrigation (A)**		**F_{calc}**	**90% CL** F_{crit}= 3.463	**95% CL** F_{crit}=5.143	**(T) & (G) 90% CL**	**(G) & (A) 90% CL**
N (%)	1.798	2.380	2.244	3	3.545	**Yes**	No	**Yes**	No
Ca (%)	1.825	1.818	1.733	3	0.203	No	No	No	
Mg (%)	0.346	0.350	0.327	3	0.937	No	No	No	
Na (%)	0.038	0.107	0.074	3	32.52	**Yes**	**Yes**	**Yes**	**Yes**
K (%)	1.803	1.558	1.568	3	6.447	**Yes****	**Yes****	**Yes****	
P (%)	0.225	0.237	0.227	3	0.086	No	No	No	
Fe (mg/kg)	124	116	196	3	1.940	No	No	No	
Mn (mg/kg)	25.3	29.4	32.0	3	1.723	No	No	**Yes**	
Cu (mg/kg)	9.7	22.8	17.2	3	4.348	**Yes**	No	**Yes**	**Yes**
Zn (mg/kg)	6.20	7.81	7.77	3	1.728	No	No	**Yes**	No
B (mg/kg)	39.2	39.4	40.9	3	0.04	No	No	No	
NO_3-N (mg/kg)	425	987	674	3	1.149	No	No	No	
S (mg/kg)	1529	1907	1814	3	2.764	No	No	**Yes**	No

* One tail test
** Higher concentration in graywater irrigated plants
T = Tap water irrigated, G = Graywater-irrigated, A = Alternating irrigation (Both gray and tap water)

The increase in the copper (Cu) mean concentration in the graywater-irrigated plants was mostly attributed to the fact that the pipe connecting the graywater tank to the backyard graywater hose is made of copper (about 25-ft long pipe). Later, it has been found out that the water plumbing system of the house was made of copper. Although the alternating irrigation reduced the copper mean concentration in plants from 22.8 mg/kg to 17.2 mg/kg, that reduction was not significant at both the 90% and the 95% confidence levels (using the student-t test).

At the 95% confidence level, the potassium concentration was higher in plants irrigated with tap water. Also alternating irrigation did not reduce the potassium concentration in the plants.

Therefore, the most significant and noticeable difference is encountered in the sodium concentration. ANOVA results revealed that the difference is significant at the 95% confidence level. The alternating irrigation succeeded in reducing the sodium mean concentration from 0.107% (in graywater irrigated plants) to 0.074%, which is also significant at the 95% confidence level using the student t-test.

The tissue analysis results of the Petunia Plants are shown in Table 4.8. The same analysis applied to the geranium testing results was applied to the petunia testing results.

The results of petunia plants tissue analysis in Table 4.8 show that sodium and total N were the only parameters showing a statistically significant difference with a 95% confidence level, indicating that the difference is genuine and is not due to sampling error. At the 90% confidence level, three parameters – total N, Na, and NO_3-N – showed significant difference.

Table 4.8 Plant Tissue Analysis Average Results for the Petunia Plants

	Mean Concentration in Petunia			No. of Samples	Significant or not using ANOVA			Significant or not using Student t-test* Between (--) & (--)	
	Tap water irrigation	Graywater irrigation	Alternative irrigation		F_{calc}	90% CL F_{crit}=3.463	95% CL F_{crit}=5.143	(T) & (G) 90% CL	(G) & (A) 90% CL
N (%)	1.662	2.127	2.497	3	11.60	**Yes**	**Yes**	**Yes**	No
Ca (%)	1.886	1.814	1.778	3	0.460	No	No	No	
Mg (%)	0.300	0.314	0.356	3	2.870	No	No	No	
Na (%)	0.072	0.194	0.157	3	62.38	**Yes**	**Yes**	**Yes**	**Yes**
K (%)	1.482	1.510	1.744	3	2.801	No	No	No	
P (%)	0.333	0.287	0.328	3	2.158	No	No	No	
Fe (mg/kg)	266.8	191.0	178	3	0.849	No	No	No	
Mn (mg/kg)	63.89	67.92	79.1	3	3.145	No	No	No	
Cu (mg/kg)	12.04	14.12	20.7	3	2.784	No	No	No	
Zn (mg/kg)	10.45	9.69	13.41	3	1.071	No	No	No	
B (mg/kg)	16.10	17.55	15.2	3	1.176	No	No	No	
NO_3-N (mg/kg)	843.7	3363	5172	3	4.025	**Yes**	No	No	
S (mg/kg)	6003	5525	5806	3	0.331	No	No	No	

Due to the low number of samples, the standard deviation values were high for some parameters. This led to a relatively wide 95% confidence interval for some parameters. The mean tissue analysis results of the geranium and petunia plants along with the 95% confidence intervals are shown in Figures 4.3 and 4.4.

Comparing the tissue analysis results of geraniums to those of petunias, one can find that the most apparent and common factors in both plants are the sodium and the total-N results. Both the sodium and the total-N showed significant differences at the 90% confidence level using the ANOVA procedure (differences among plants irrigated with tap water, plants irrigated with graywater, and plants irrigated with both graywater and tap water). Table 4.9 shows the increase of sodium and total-N concentrations in both petunia plants and geranium plants as a result of graywater application. In both plants, the student t-test demonstrated that the alternating irrigation significantly reduced the sodium and the total N concentrations (at the 95% confidence level).

Table 4.9 Increase of Sodium and Total-N Concentrations in Plants

		Average Concentration in Tap-Water-Irrigated Plants	**Average Concentration in Graywater-Irrigated Plants**	**Increase**
Sodium (%)	**Geranium**	0.038	0.107	0.069
	Petunia	0.0719	0.1936	0.1217
Total N (%)	**Geranium**	1.798	2.380	0.582
	Petunia	1.6623	2.1267	0.4644

There is another important difference that can be noticed when comparing the results of petunia plants to those of the geranium plants. Both the average sodium concentration in petunia plants and the average increase of sodium were higher than those of the geranium plants. This indicates that geraniums, which are known to be more salt tolerant than petunias, have some kind of salt exclusion mechanism allowing them to be more salt tolerant. Therefore and apparently, when considering graywater for irrigation, the user should look for the plants that are more salt tolerant. This conclusion is completely true when considering the perspective of plant health. However, when the soil perspective is considered, plants like petunias would be preferred since they would mine the accumulated salts in soils and then get removed at the end of their season, which is one benefit of planting annuals when considering graywater for irrigation. This conclusion is of special importance in the case of drip irrigation because drip irrigation concentrates the salts in the soil zone around the plant.

Boron is a parameter commonly mentioned in the graywater literature as one of the expected problems since it is only needed in small amounts. Higher concentrations are toxic to plants. The results of the experiments carried out in this research revealed that graywater irrigation did not result in a significant increase in the boron concentration (Tables 4.7 and 4.8; and Figures 4.3 and 4.4). Also, alternating irrigation did not result in a reduction in the boron concentration. The reason behind not seeing any increase in the boron concentration in the tissues of graywater-irrigated plants was the low boron concentration found in the graywater used in this study, which was 0.02 mg/L as shown in Table 4.5. Therefore, the study would not be able to reach a conclusion about the effect of boron or boron accumulation in the plant tissues.

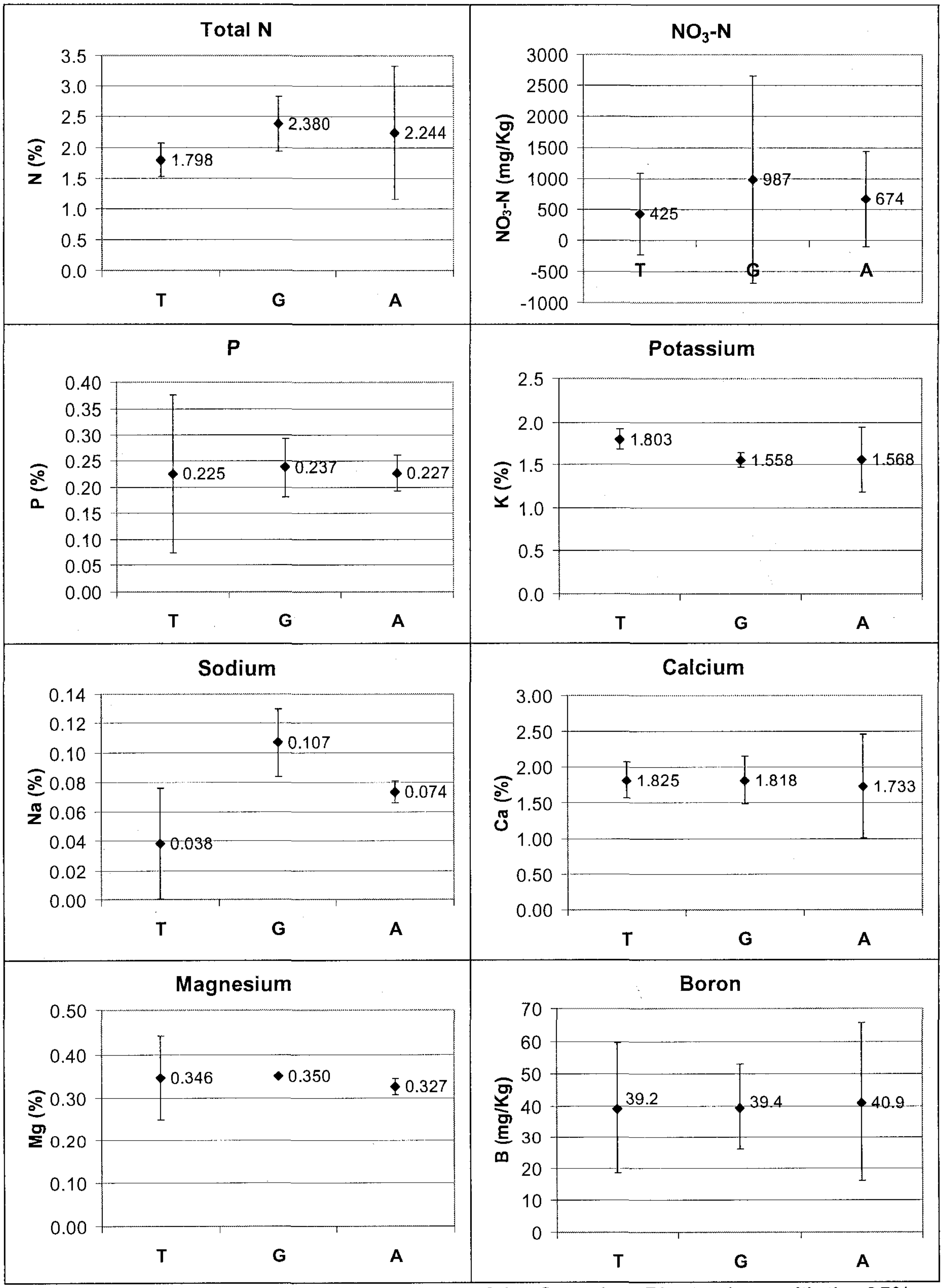
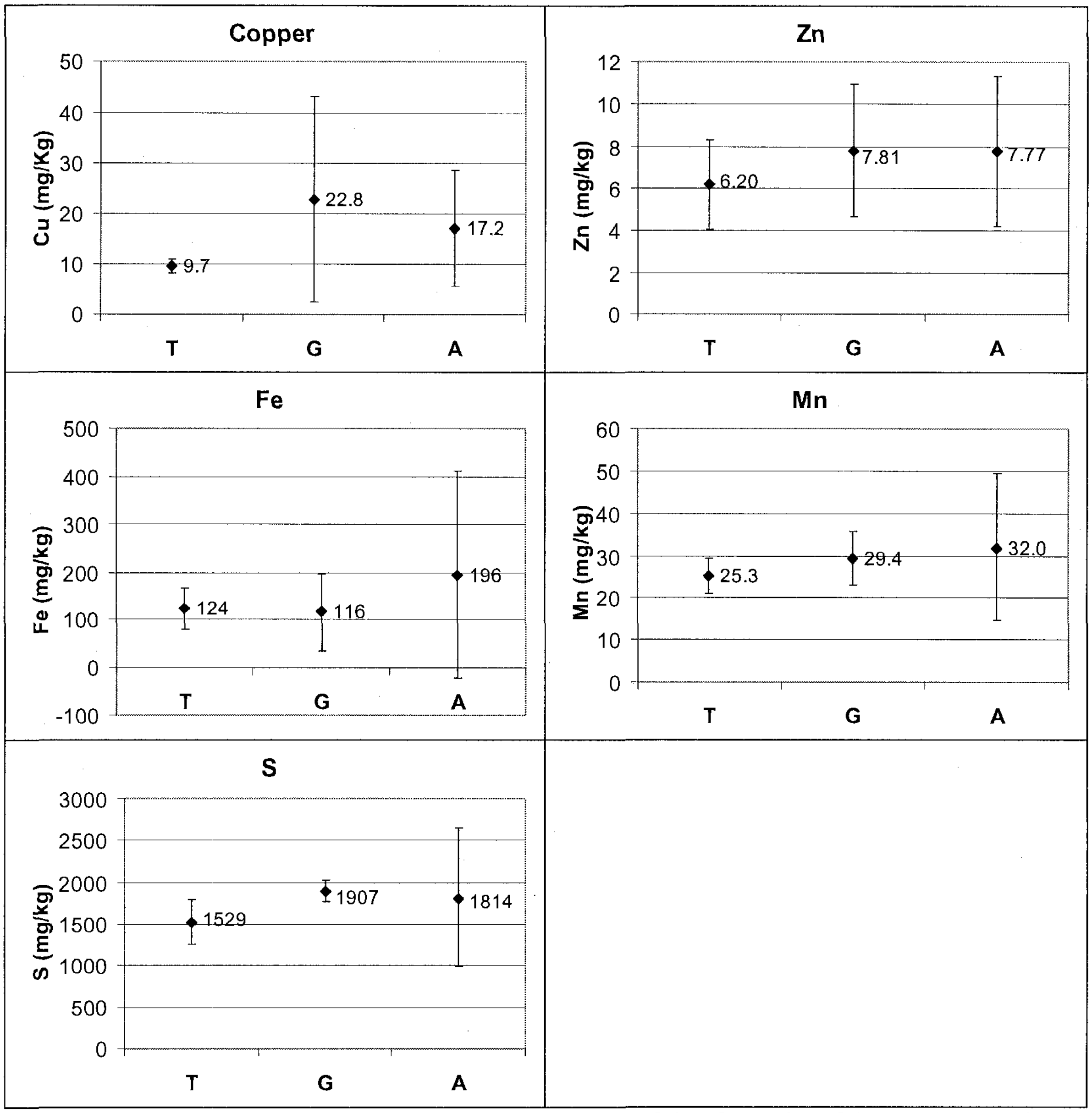


Figure 4.3 Mean Tissue Analysis Results of the Geranium Plants along with the 95% Confidence Intervals

(N = 3 samples). T=Tap water, G=Graywater, A=Alternating



Cont. ... Figure 4.3 Mean Tissue Analysis Results of the Geranium Plants along with the 95% Confidence Intervals (N = 3 samples)

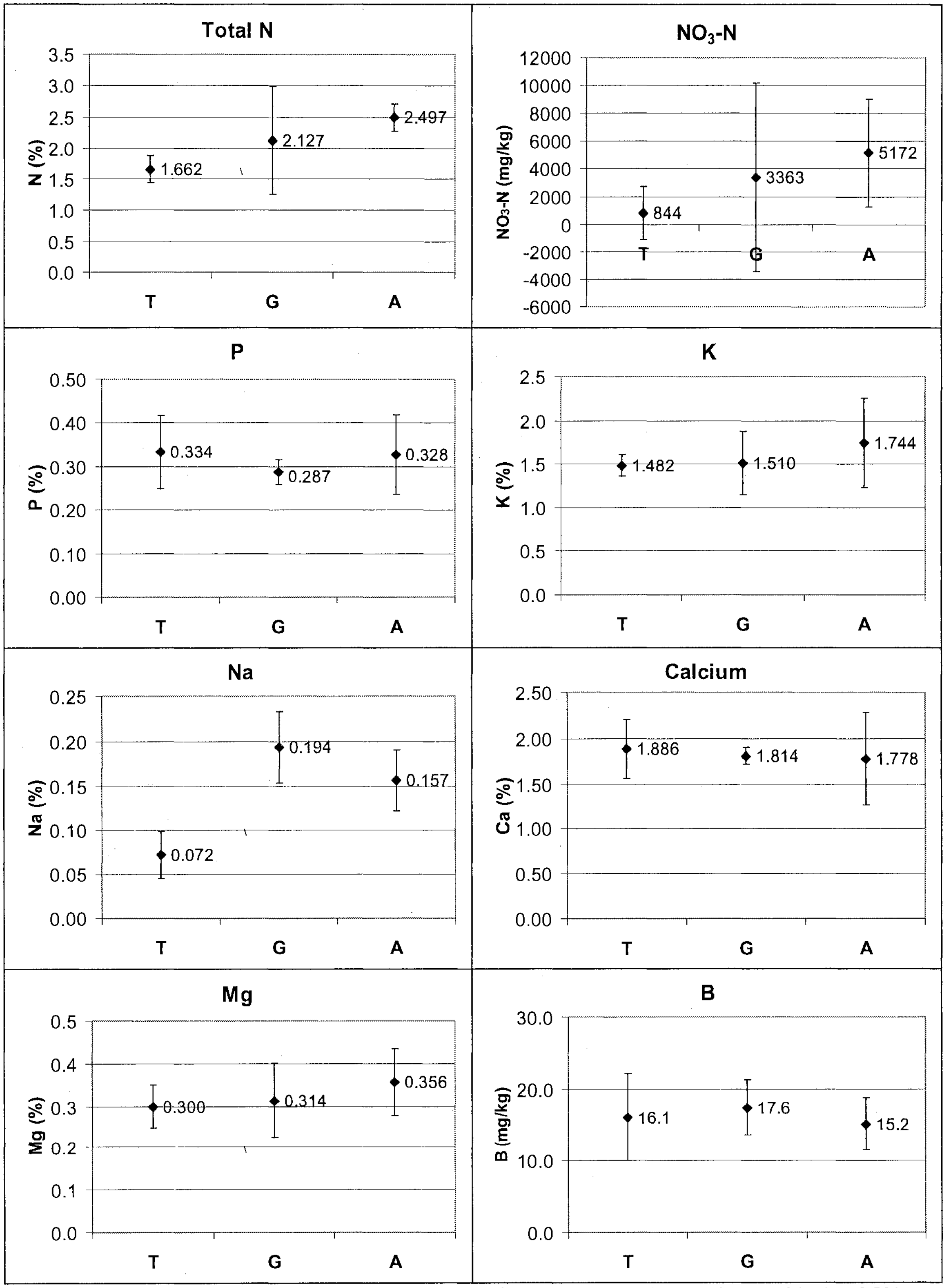
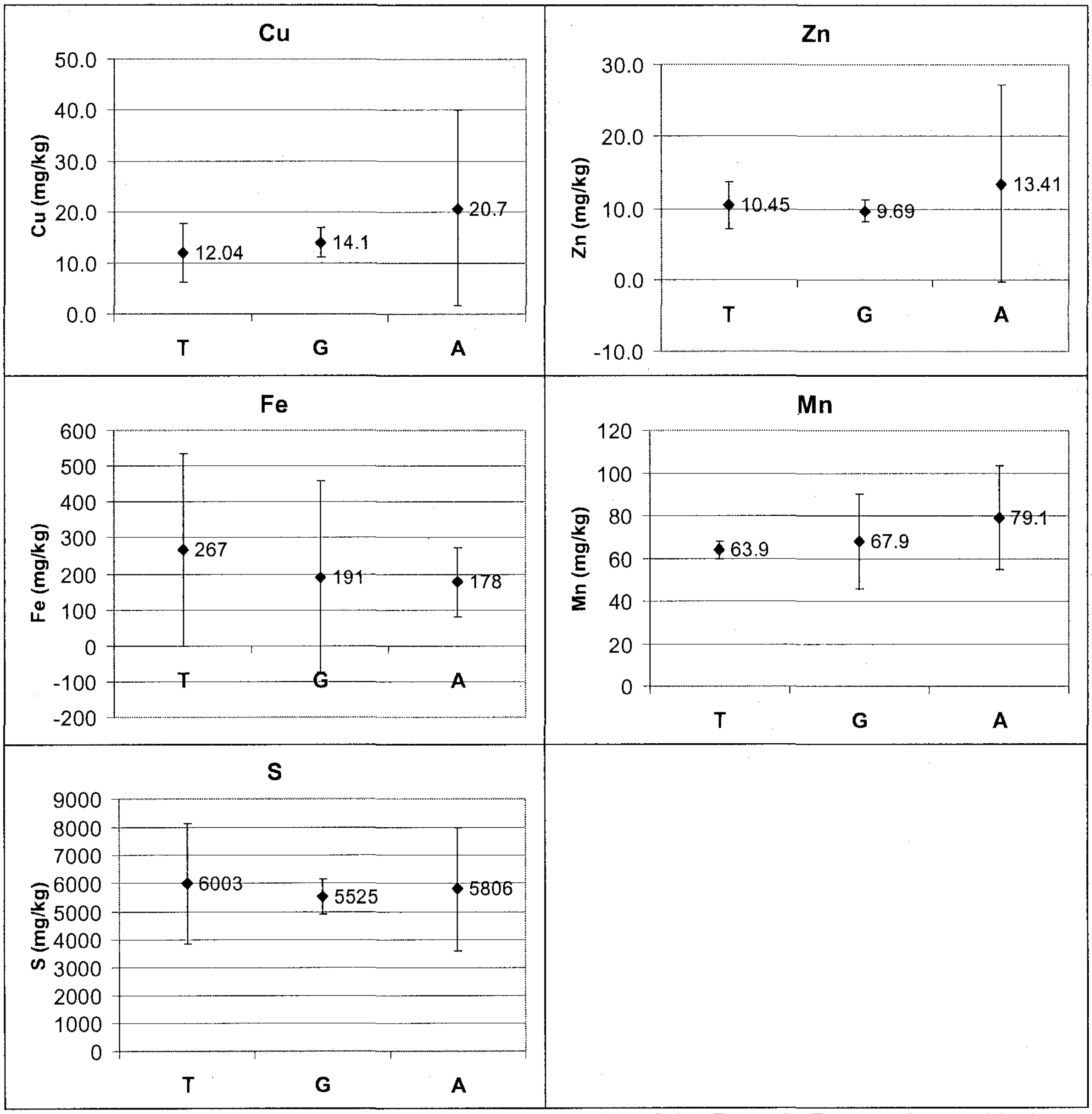


Figure 4.4 Mean Tissue Analysis Results of the Petunia Plants along with the 95% Confidence Intervals
(N = 3 samples), (... continued on next page)



Cont. … Figure 4.4 Mean Tissue Analysis Results of the Petunia Plants along with the 95% Confidence Intervals (N = 3 samples)

The performance of the plants was monitored visually during the growth period. For the geranium plants, no significant differences were noticed among the three groups. For the petunia plants, it was noticed that the group of plants irrigated with alternating irrigation; i.e. irrigated with both tap water and graywater, were not growing as good as the other two groups in terms of size. This observation was also supported by the results of dry weights. The average dry weights at the end of the 7-month irrigation period are shown in Figure 4.5 and 4.6. The reason behind this difference was not clear. Pictures of the plants after 5 months of irrigation are shown in Figures 4.7 to 4.10. Nevertheless, in all groups, petunia plant produced flowers and had good appearance, which is the main concern when dealing with landscape plant.

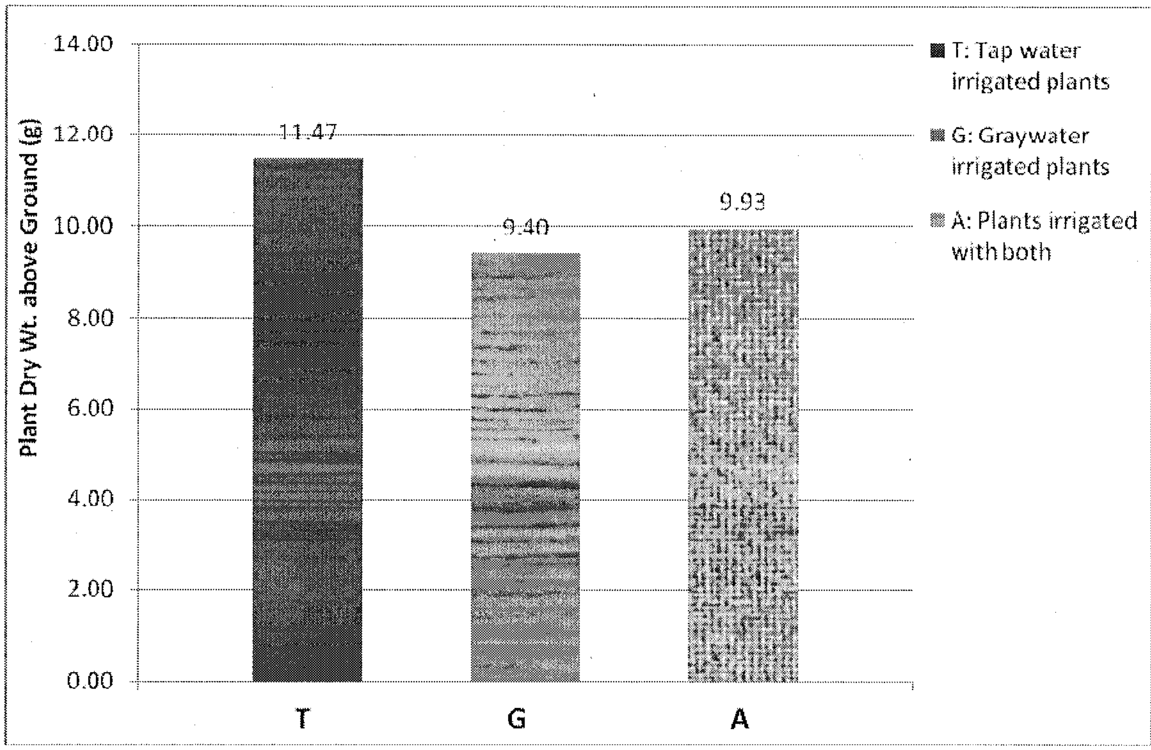


Figure 4.5 Final dry weights of geranium plants

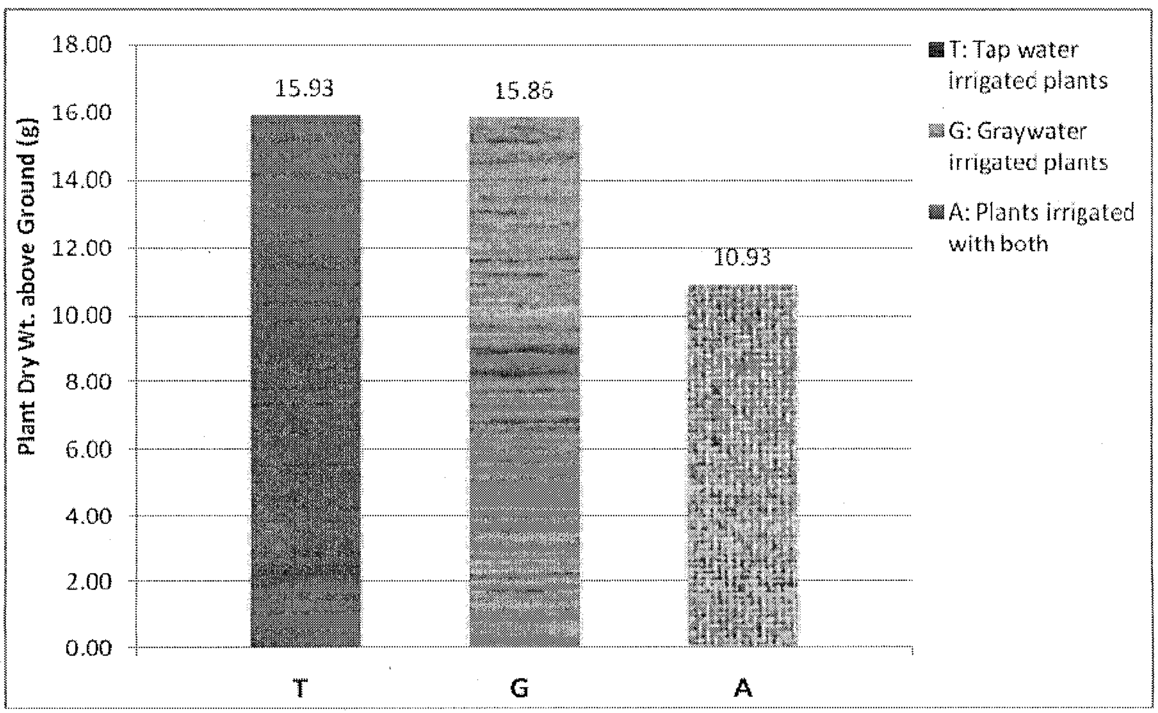


Figure 4.6 Final dry weights of the petunia plants

Figure 4.7 Plants irrigated with tap water inside the greenhouse

Figure 4.8 Plants irrigated with Graywater inside the greenhouse

Figure 4.9 Plants irrigated with both graywater and tap water inside the greenhouse

Figure 4.10 A picture showing all plants

For the grass experiments, at the end of a 7-month irrigation period, the graywater bench was infected by some kind of insects. As a result a significant area of the grass died. However, during the first four months, no difference in color or growth was noticed among all benches. The 3-day growth of the grass was measured and summarized in Figures 4.11 and 4.12. The Figures show that the growth rate was almost the same in all benches. Differences in density were visually noticed in the sense that fresh-water-irrigated grass showed denser appearance than the other grasses in the two benches. Visually, the differences looked significant.

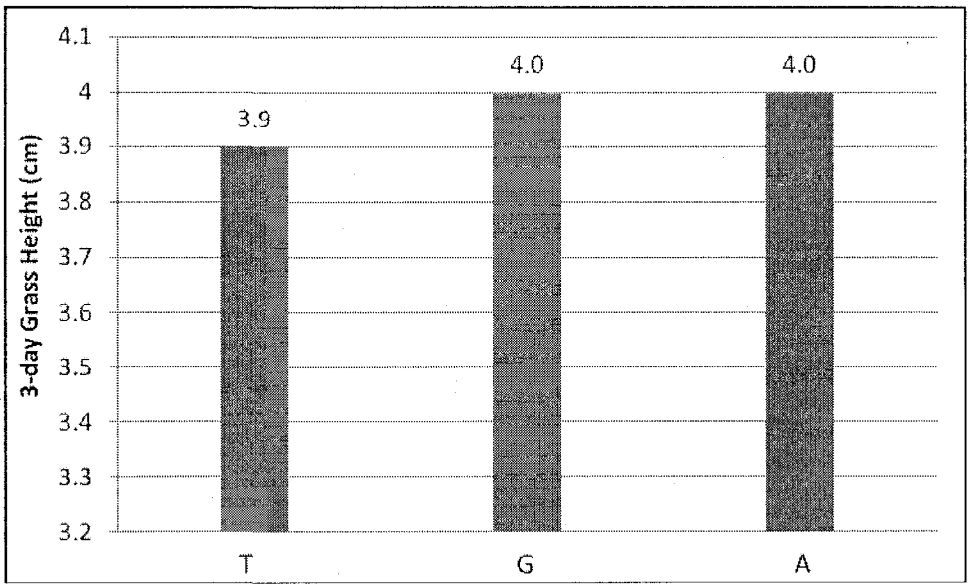


Figure 4.11 Growth rate of Kentucky Blue grass as measure by the 3-day height above a datum

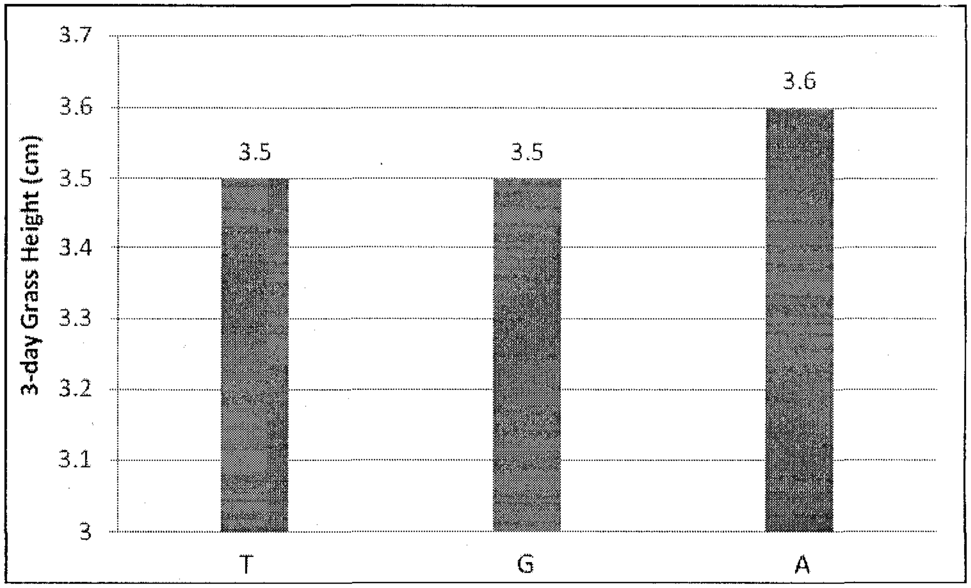


Figure 4.12 Growth rate of Fescue grass as measure by the 3-day height above a datum

B) <u>Results of Soil Experiments</u>

Figurers 4.13 to 4.28 show the concentration of several parameters in the soil. Two soil samples were taken from each bench after a 16-month irrigation period. In Figures 4.13 to 4.28; graywater-irrigated soil is labeled "G", tap-water-irrigated soil is labeled "T", and soil irrigated with both graywater and tap water is labeled "A". Due to that low number of samples it was hard to run the student t-test and the ANOVA to compare among the groups. By looking at these Figures, one can find that the most apparent differences occurred in the following parameters: electrical conductivity (EC), nitrate nitrogen (NO_3-N), sodium (Na), and Sodium Adsorption Ratio (SAR). Of these parameters, Na and SAR seemed to be the most affected by graywater irrigation. Table

4.10 summarizes the increase in the concentration of these parameters as a result of graywater irrigation.

Table 4.10 Concentrations of the most Affected Parameters in Soil Samples

Parameter	Concentration in tap-water-irrigated soil	Concentration in graywater-irrigated soil	% Increase
Electrical Conductivity (mmoh/cm)	1.55	2.05	32%
NO_3-N (ppm)	4.50	11.75	161%
Sodium (meq/l)	1.70	5.30	211%
SAR	0.55	1.70	209%

Soil pH and boron concentration in the soil are two parameters that are frequently mentioned as concerns for the health of soil microbes and plants. The 16-month period of irrigation with graywater did not result in any increase in any of these parameters. The reason behind not having an increase in the boron concentration was the low level of boron in the graywater used for irrigation (0.02 mg/L). Therefore, it was not possible to reach a conclusion about the boron effect. The soil pH results are shown in Figure 4.13. For both graywater-irrigated soil and tap-water-irrigated soil, the soil pH was almost neutral at a pH of 7.3. This indicates that the pH is not a concern when irrigating with graywater. The boron concentration in each soil is shown in Figure 4.22.

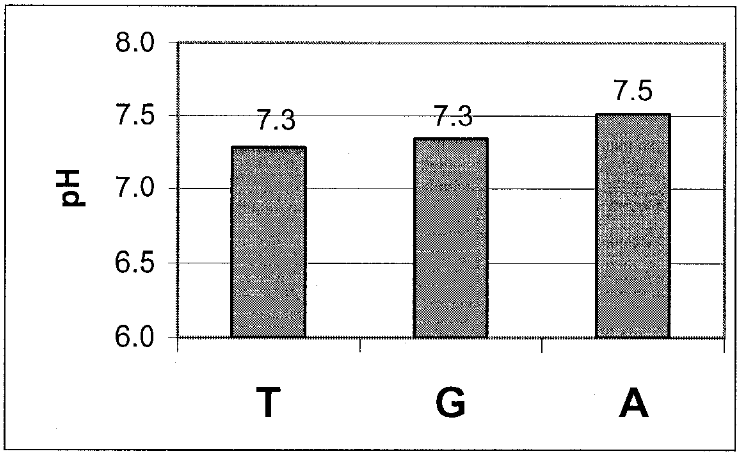


Figure 4.13 Soil pH after 16-month of irrigation
(T=Tap water irrigated soil, G=Graywater-irrigated soil, A= Soil irrigated with Alternating irrigation)

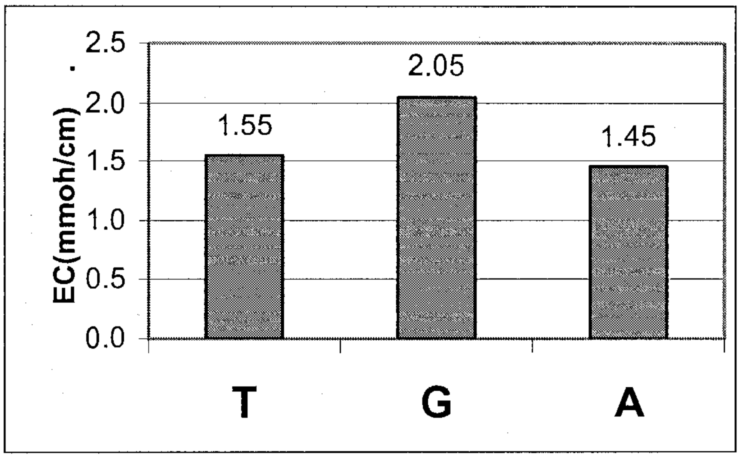


Figure 4.14 Soil Electric Conductivity

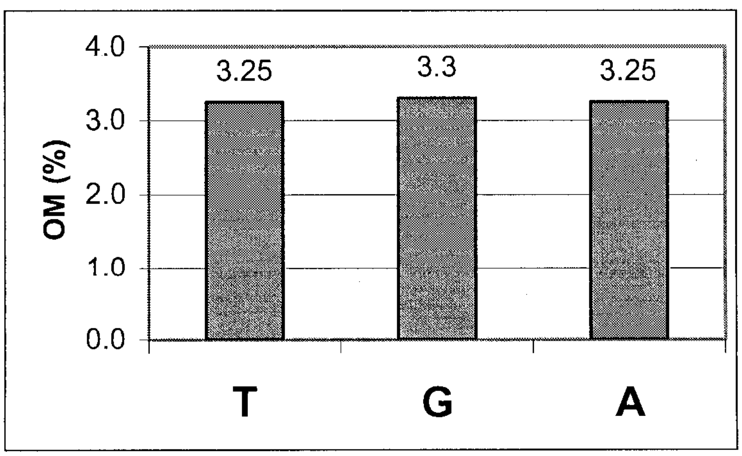


Figure 4.15 Soil Organic Matter

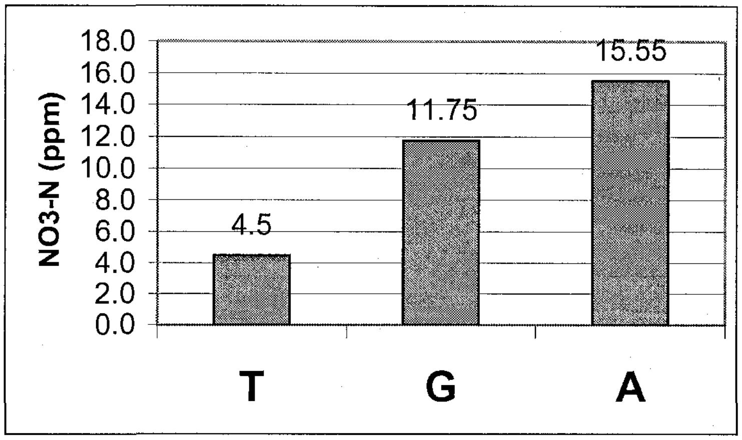


Figure 4.16 Concentration of Nitrate-Nitrogen (NO_3-N) in each soil

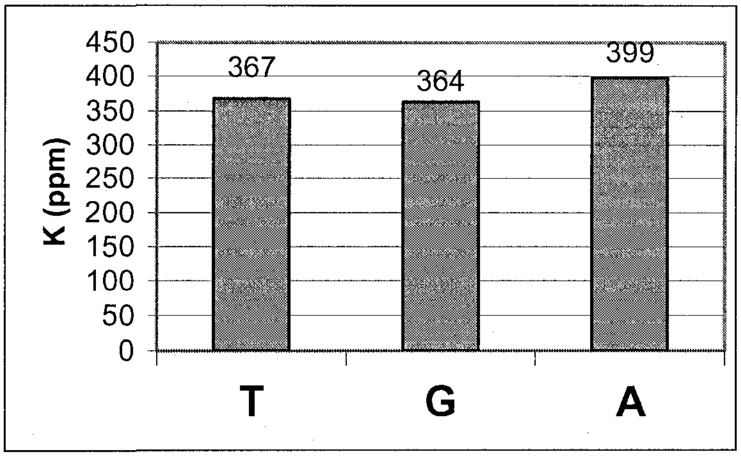


Figure 4.17 Potassium Concentration in Each Soil

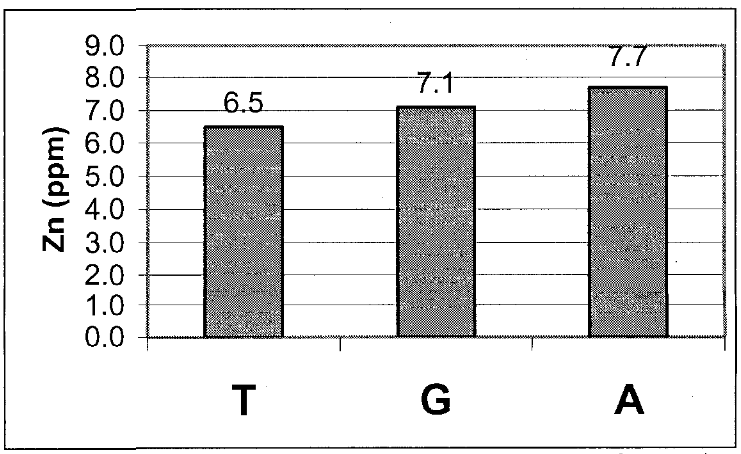


Figure 4.18 Zinc Concentration in Each Soil

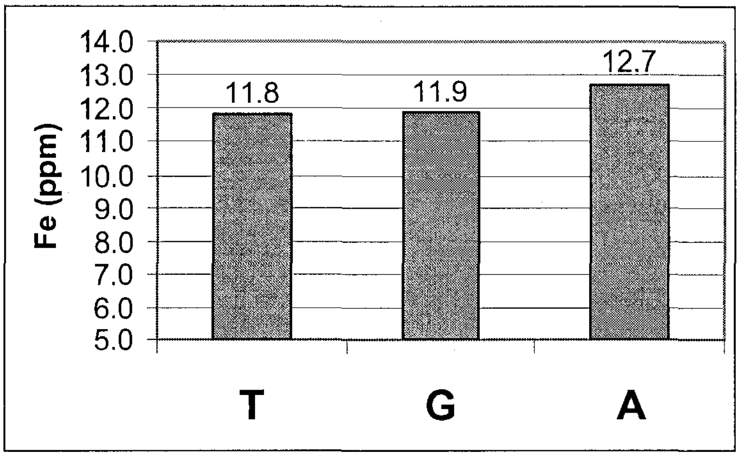


Figure 4.19 Iron Concentration in Each Soil

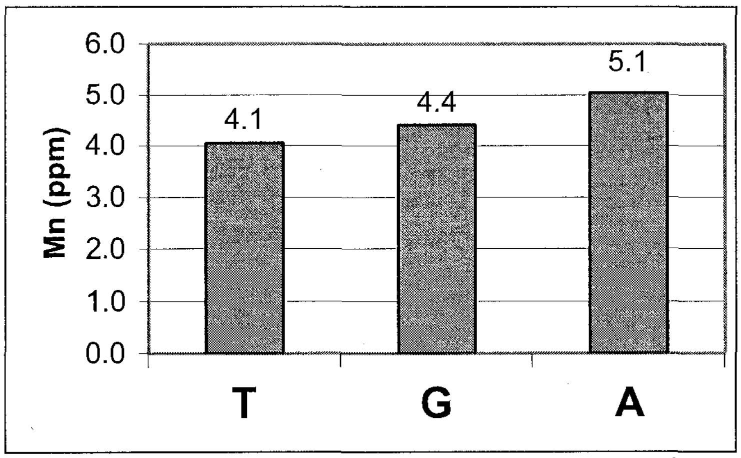


Figure 4.20 Manganese Concentration in Each Soil

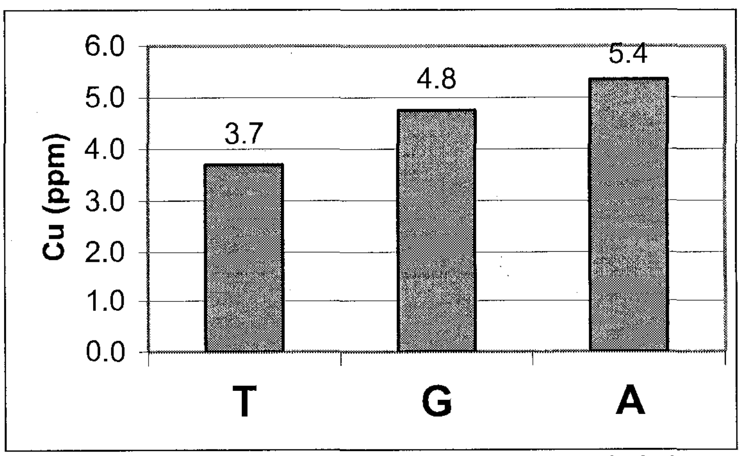


Figure 4.21 Copper Concentration in Each Soil

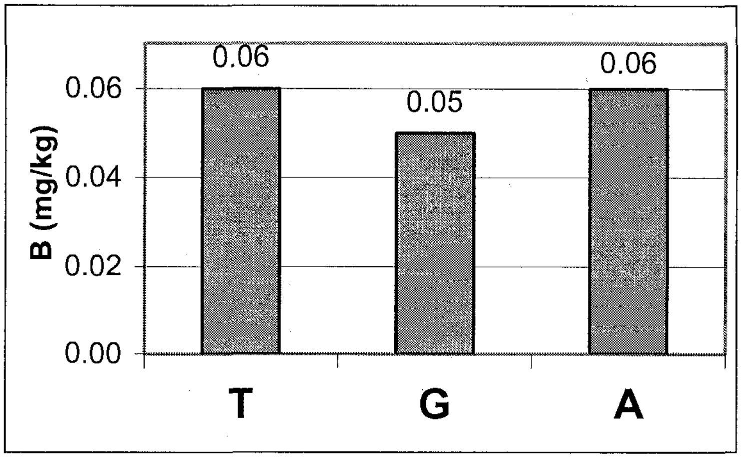


Figure 4.22 Boron Concentration in Each Soil

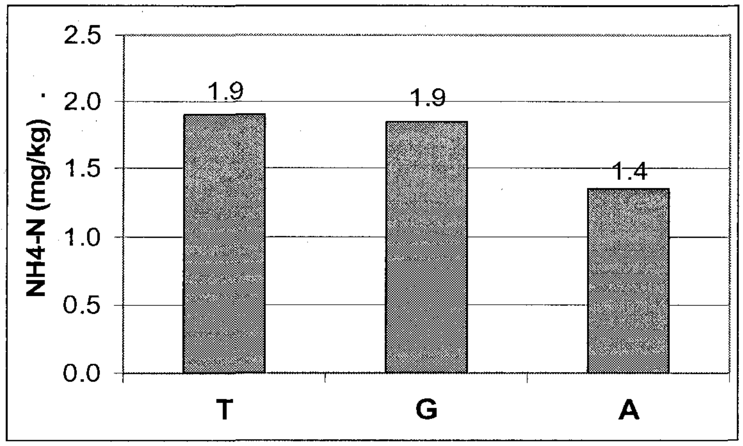


Figure 4.23 NH_4-N in Each Soil

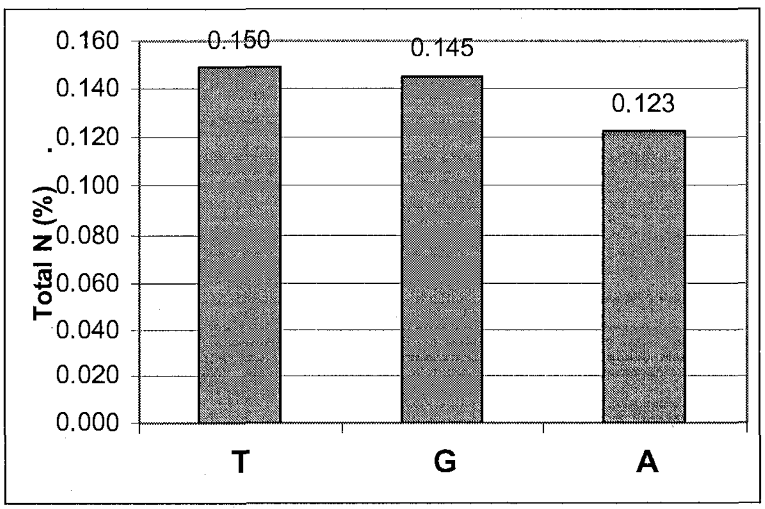


Figure 4.24 Total N Concentration in Each Soil

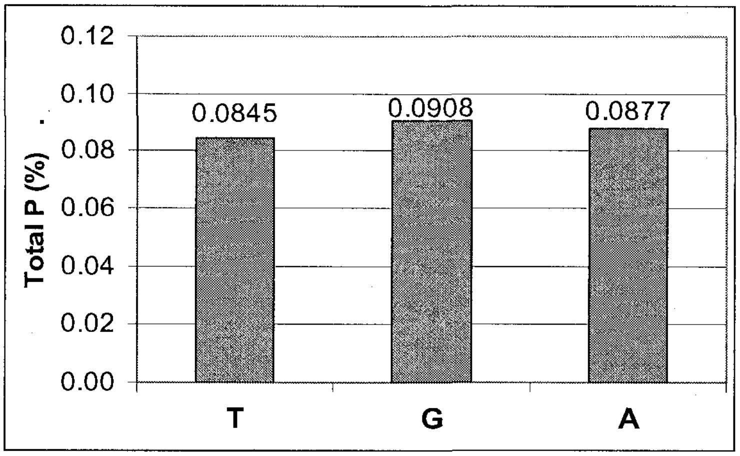


Figure 4.25 Total P Concentration in Each Soil

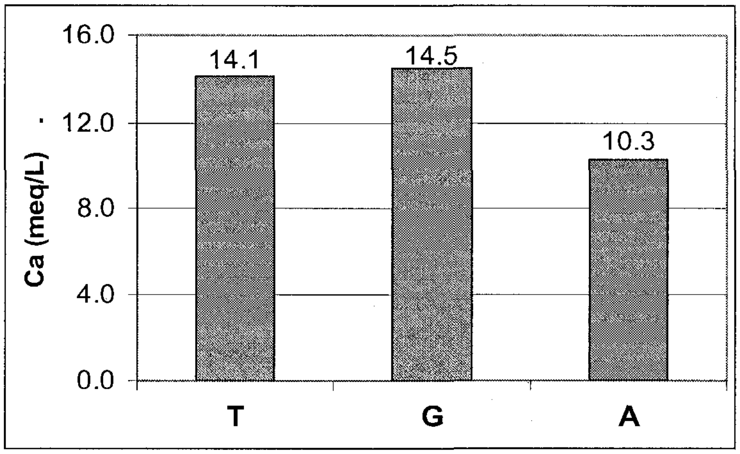


Figure 4.26 Calcium Concentration in Each Soil

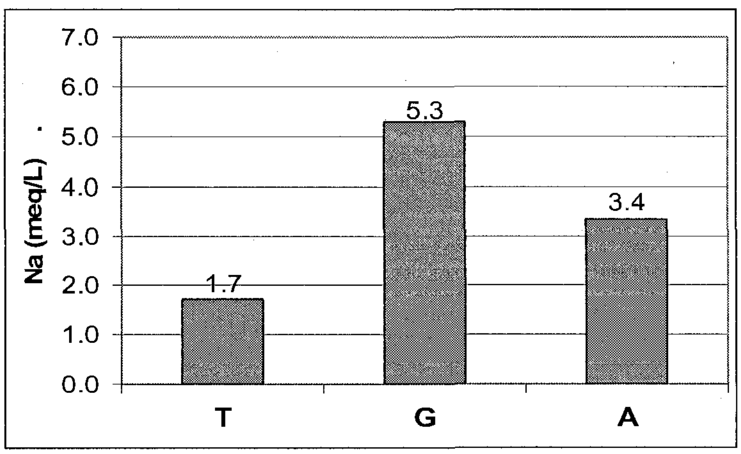


Figure 4.27 Sodium Concentration in Each Soil

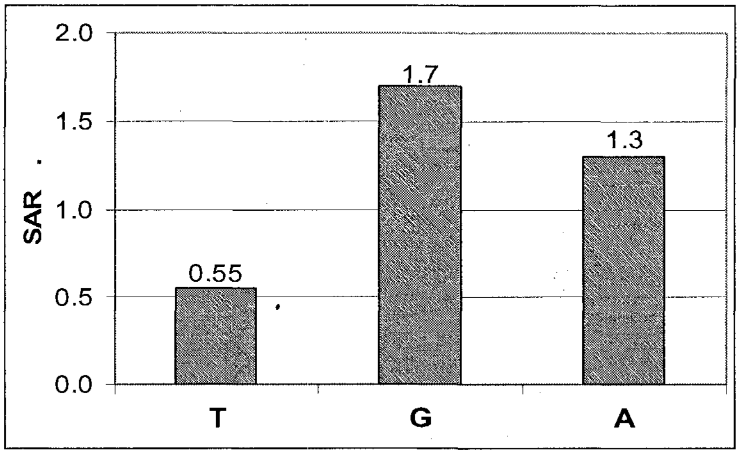


Figure 4.28 Sodium Adsorption Ratio for Each Soil

4.3.4 Summary and Conclusions of Plants and Soil Experiments

Regarding the results of plant experiments, the tissue analysis of the irrigated plants at the end of a 7-months irrigation period revealed that graywater irrigation caused a significant increase in the levels of sodium and total N. Any increase in any of the other parameters was not significant (P, B, Ca, Mg, Fe, Mn, etc). The amount of sodium gained by petunia plants as a result of graywater application was higher than that gained by geranium plants, which is an indication that plants will differ in their uptake. Plants that are less salt tolerant, like petunias, tend to absorb more sodium. While plants that are more salt tolerant, like geraniums, have a better salt exclusion mechanism that allows them to be more salt tolerant. From the plants point of view, this means that if graywater application would be used, salt tolerant plants would be preferred. However, from the soil point of view and considering the long terms, this implies that having plants like petunias would be preferred since they would mine the accumulated salts in soils and then get removed at the end of their season, which is one benefit of planting annuals when considering graywater for irrigation. This conclusion is of special importance in the case of drip irrigation because drip irrigation concentrates the salts in the soil zone around the plant.

Alternating irrigation led to significant lower sodium and total N concentrations.

Regarding the accumulation of boron, the study was not able to reach a conclusion about the effect of boron or boron accumulation in the plant tissues because the concentration of boron was low in the graywater used for this study. This may lead to the conclusion that testing the response of plants under the effect of synthetic graywater is also important and should be done in parallel with the real graywater. An alternative approach would be to apply the same graywater experiments at several locations in order to gain more knowledge about the different effects that graywater quality may have on plants.

The current study also demonstrated that graywater application did not result in an increase in phosphorus concentration in both plants and soils since the use of phosphorus in laundry detergents is banned in the United States. However, if graywater is used in places where the use of phosphorus is permitted, phosphorus concentration in soils and plants is expected to increase. Therefore, reconsidering the amount of fertilizers is recommended in such situations.

Regarding the results of soil experiments, the most apparent differences occurred in the following parameters: electrical conductivity (EC), nitrate nitrogen (NO_3-N), sodium (Na), and Sodium Adsorption Ratio (SAR). Of these parameters, Na and SAR seemed to be the most affected by graywater irrigation.

Chapter 5

POTENTIAL OF GRAYWATER REUSE IN THE GAZA STRIP

5.1 Situation in the Gaza Strip

The Palestinians now are concentrated in the West Bank and the Gaza Strip. According to the World factbook of the CIA, as of July 2007 Gaza Strip is inhabited by about 1,482,400 people living on an area of about 360 km^2, which is slightly more than twice the area of Washington DC. It is indeed considered one of the most densely populated areas in the world (NRC, 1999). The area of the West Bank is about 5,640 km^2 with a population of about 2.4 million people.

Gaza Strip suffers from acute shortage in fresh water. For the Gaza Strip, the only natural fresh water resource is the groundwater. However, this only resource is overused due to the high population and high population growth rate. Seawater intrusion aggravates the situation. The sanitation is not in a better situation. About 20 million m^3/year is being treated in the Gaza Strip, while about none is being treated in the West Bank (NRC, 1999). The water consumption in the Gaza Strip averages at about 80 $L.cap^{-1}.day^{-1}$. Of this amount, only 13 $L.cap^{-1}.day^{-1}$ meets the World Health Organization (WHO) standards for drinking water. Given the current situation, providing sanitation and water supply is nearly impossible (Ghabayen, 2004).

The use of graywater in irrigating the backyard plants is in not a new issue in Palestine. The Agricultural Development Society, which is a local Palestinian NGO, issued several booklets and brochures as guides for the use of graywater. The graywater stream included the kitchen sink wastewater in addition to the other traditional sources defined by this study. The Agricultural Development Society started thinking about the application of graywater in the year 1998 (Yaseen and Burnat, 2002). In the year 2000, the Agricultural Development Society started implementing the idea. About 17 treatment units were constructed in the southern area of Gaza Strip for individual houses (Yaseen and Burnat, 2002). A larger unit serving about 30 families was also constructed in Al-Shouka area in the southern part of Gaza Strip (Yaseen and Burnat, 2002). At the time of writing the booklet by Yaseen and Burnat (2002), 100 individual treatment units were under construction.

The treatment unit used by the Agricultural Development Society is shown in Figure 5.1. As described by two booklets issued by the Agricultural Development Society, the graywater treatment unit consists mainly of two parts: a) An underground part, b) Above-ground part. The details of the treatment unit are described below (as mentioned in the booklets issued by the Agricultural Development Society).

a) Underground part

The underground part starts with a small manhole (40x40x40 cm) to collect the graywater inflow. The manhole also has a screen of 1 cm^2 opening sizes. Four underground chambers made of reinforced concrete follow the manhole. The first chamber is a septic tank. The second and third chambers are anaerobic upflow gravel filters. The only difference between the second and third chambers is the gravel sizes used (2-3 cm in the second chamber and 0.5-1 cm in the third chamber). The graywater coming out of the third chamber is stored in the fourth chamber. When the level of water in the fourth chamber reaches a specific level, a submersible pump works automatically to pump the stored graywater to the other part of the treatment unit (above-ground tank).

b) Above-ground Part

The above-ground part consists of two plastic tanks, each sized from 0.5 to 1.0 m^3. Three filtering layers separated by textile material are placed in the first tank. The layers from top to bottom are sand, coal, and coarse gravel; with a depth of 20cm for each layer. The graywater coming out of this tank drains to the second plastic tank by a perforated pipe placed at the bottom of the coarse gravel layer. The second plastic tank acts as a storage reservoir feeding the irrigation system, which is a drip irrigation system.

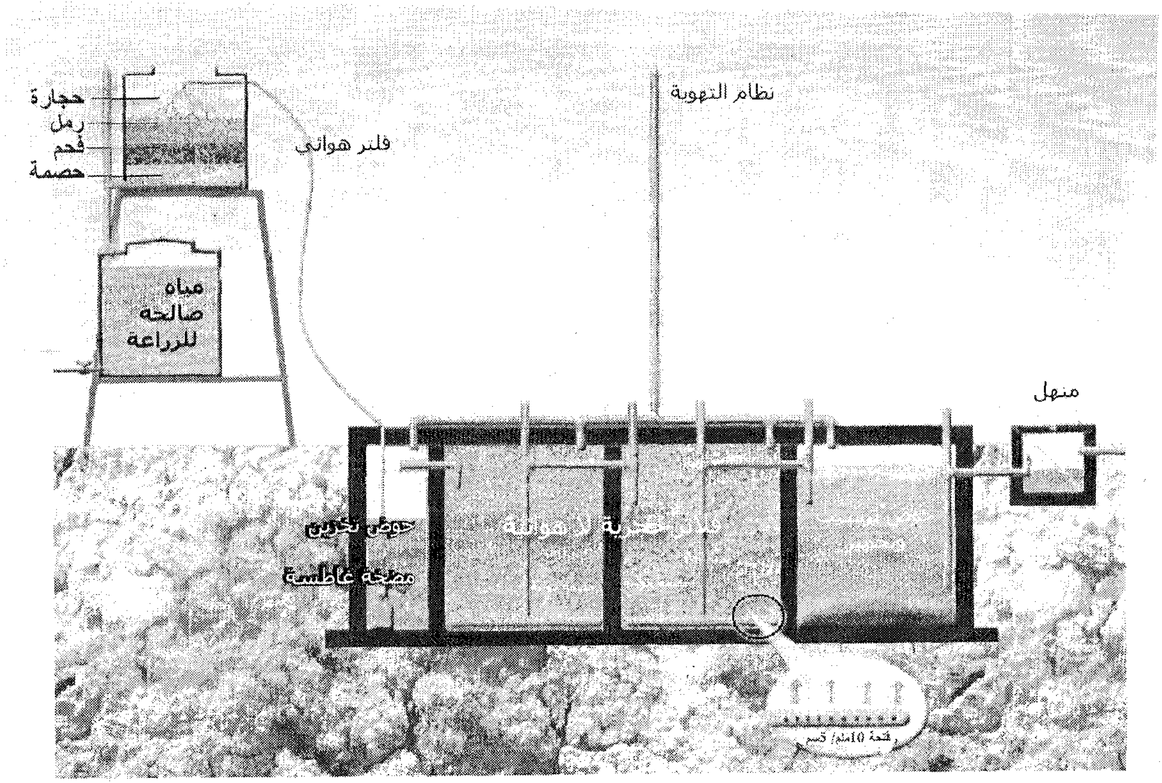


Figure 5.1 Graywater system used by the Agricultural Development Society, Palestine (*Source*: Burnat, unknown year)

A personal interview was conducted with the engineer who supervised the construction of the 100 units, Mr. Mousa Abu Hmaid. He mentioned that farmers were happy about the installed graywater systems. However, several odor complaints have been recorded. As mentioned by Mr. Abu Hmaid, other problems encountered were lack of proper maintenance by the users and malfunctioning of the submersible pump.

Several pictures of the built graywater systems were taken in February 2006. Figures 5.2 and 5.3 show a couple of these pictures.

Figure 5.2 A constructed graywater system used by the Agricultural Development Society in Palestine along with the openings of each treatment chamber

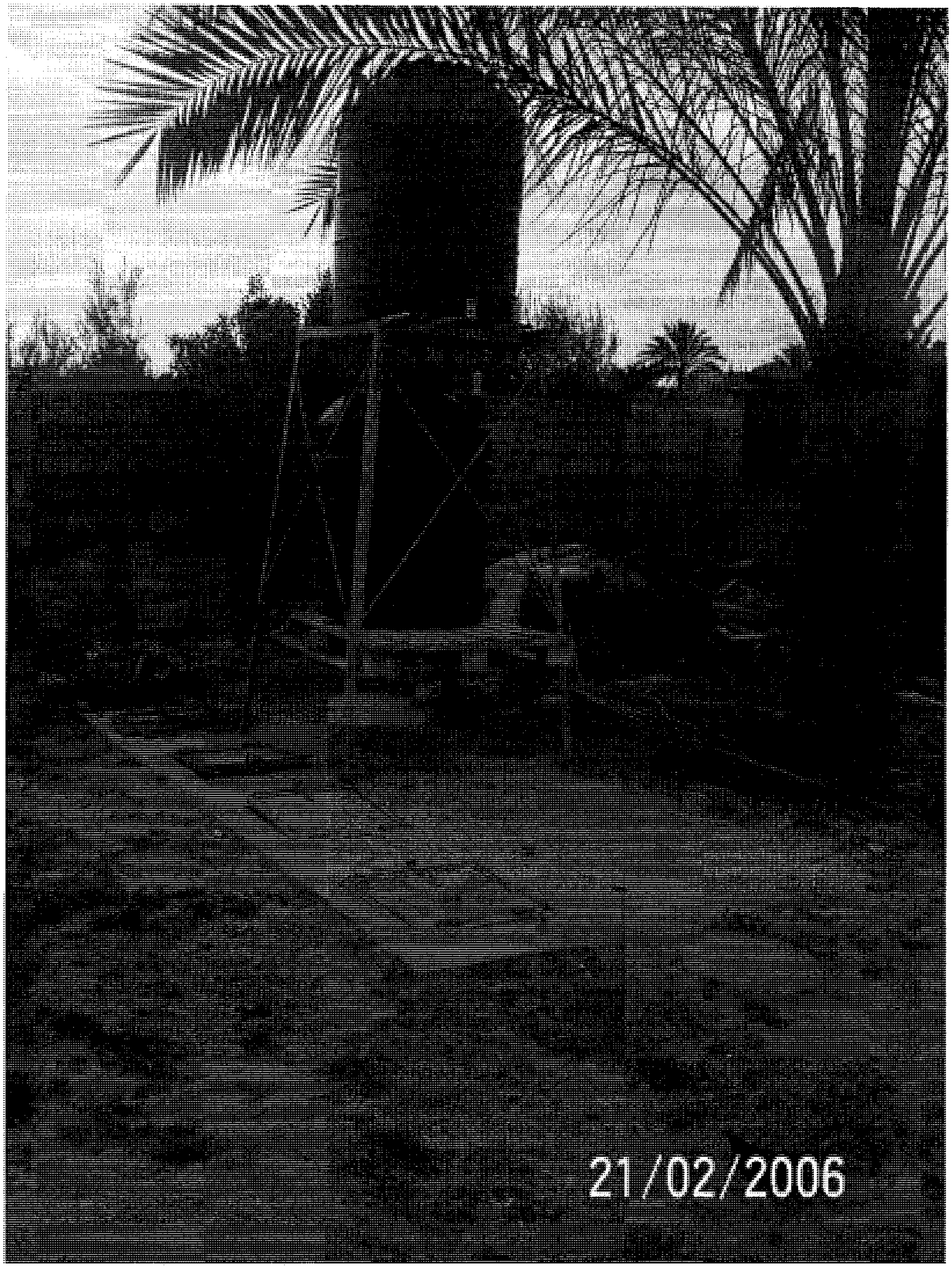


Figure 5.3 A constructed graywater system used by the Agricultural Development Society in Palestine

5.2 Evaluation of Potential for Residential Graywater Reuse in Gaza Strip

The research question associated with this part can be phrased as: Would graywater use for landscape irrigation be acceptable to the people of Gaza Strip, Palestine?

5.2.1 General

The goal of this section is to investigate the general acceptance of the Gaza Strip residents to the use of graywater in landscape irrigation. According to Rea and Parker (2005), there are three main methods for data collection: 1) Survey research, 2) direct measurement, 3) observation. Among the three main methods, surveys are particularly well suited to the study of public opinion (Babbie, 2001). Certainly, the use of surveys as a research tool has become a widely accepted idea. Politicians, commercial enterprises, television and radio programs, government agencies, financial institutions, restaurants, etc use surveys for different purposes. For example, commercial enterprises may use survey findings to review their market strategies and establish newer market strategies. Also, politicians rely heavily on surveys for guidance in their campaign strategies (Rea and Parker, 2005). The application of surveys is not only limited to the design of new programs or projects, it is also used in assessing the effectiveness of programs (whether social, educational, recreational, etc) and checking if facilities are meeting the needs of the community.

5.2.2 Materials and Methods

To investigate the acceptance of using graywater in landscape irrigation to the people of Gaza Strip, a survey has been designed in a way to collect data that can inform the researcher about research questions. Most likely, surveys cover only a sample of the whole population; i.e. sample surveys are carried out. The idea of a sample survey is to make a generalization about a large population by studying only a small portion of that population (Rea and Parker, 2005). Information derived from a relatively small number of people is considered an accurate representation of significantly larger number of people because of the systematic application of the technique of scientific sample survey research (Rea and Parker, 2005).

The acceptance of graywater usage has been investigated through distributing a number of questionnaires to the people of Gaza Strip. The questionnaires were administered in the form of personal interviews in which the interviewer selected houses randomly and ran the interview with the respondent. The interviewer starts with explaining the problem to the respondent followed by asking the questionnaire questions. The background information of the respondent was taken at the end of the interview. The questionnaire results have been analyzed using the SPSS statistics software. Box 5-1 shows the Arabic version of the questionnaire, which is the version that has been used in the study. The English translation of the questionnaire is shown in Box 5-2.

Box 5-1
Questionnaire Distributed to the People of Gaza Strip (Arabic)

استبيان
حول مدى تقبل المواطنين في قطاع غزة لاستخدام المياه العادمة الرمادية في ري بعض مزروعات الزينة والأشجار

يعتبر الانقطاع المتكرر للمياه من المشاكل الرئيسة التي يعاني منها مجتمعنا الفلسطيني سواء في المجتمعات المدنية أو الريفية.
ويزداد الوضع تفاقماً عندما يتعلق الأمر بالمناطق الغير موصولة بشبكة الصرف الصحي, حيث يتم التخلص من مياه الصرف بطرق بدائية غير صحية وضارة بالبيئة المحيطة.
وقد تم طرح العديد من البدائل لحل هذه المشكلة عن طريق توفير بدائل يستطيع المواطن من خلالها تقليل استهلاك المياه البلدية وتقليل كمية مياه الصرف الصحي أيضاً. ومن هذه البدائل استخدام **المياه العادمة الرمادية – وهي مياه الصرف الناتجة عن <u>مغاسل الحمامات والدش والبانيو والغسالة</u>** – حيث يتم استخدام هذه المياه في ري مزروعات الحديقة مثل مزروعات الزينة والأشجار والأشجار المثمرة. وبالإضافة إلى تقليل كميات المياه البلدية المستهلكة فإن استخدام هذا النوع من المياه سيخفف من مشاكل الحفر الامتصاصية مثل النضح المتكرر.
ان هذا الاستبيان يهدف الى قياس مدى تقبل المواطنين في قطاع غزة لاستخدام المياه العادمة الرمادية في ري بعض مزروعات الزينة والأشجار.، وهو يعتبر جزء من أطروحة دكتوراة، ولذلك نأمل منك اخي المواطن التكرم بتعبئة الاستبيان بدقة حتى يعكس الاراء الحقيقية للمواطنين بالنسبة لاستخدام المياه العادمة .، وان هذا الاستبيان هو فقط لأغراض البحث العلمي ولن يستخدم لاية اغراض اخرى.

نقدر لكم مساعدتكم وتكرمكم بتعبئة الاستبيان
وتفضلوا بقبول فائق الاحترام

الباحث
رمضان يحيى الخطيب

<u>أولاً:</u> أسئلة الاستبيان

1. ما هي نوعية المزروعات التي تزرعها في الحديقة المحيطة بمنزلك؟ (أشجار مثمرة، زينة، إلخ)

2. بالنسبة لك هل تمثل مشكلة المياه في قطاع غزة عائقاً في ري مزروعات الحديقة المحيطة بمنزلك؟
☐ نعم ☐ لا

3. إذا كانت الإجابة على السؤال السابق (نعم) فهل المشكلة تكمن في:
☐ عدم توفر المياه بشكل دائم ☐ ارتفاع سعر المياه ☐ كليهما ☐ أسباب أخرى (الرجاء التوضيح) ________________

4. إذا كانت الإجابة نعم للسؤال رقم (2) ، فهل تعاني من مشاكل سقاية المزروعات في
☐ شهور الصيف فقط
☐ المعاناة في كل من الصيف والشتاء، ولكنها ملموسة أكثر خلال شهور الصيف
☐ لا فرق بين الفصلين ، أي أن المشكلة قائمة في كليهما بدرجة واحدة

5. **هل منزلك موصول بشبكة الصرف الصحي؟** ☐ نعم ☐ لا
6. **هل تتقبل فكرة استخدام المياه الرمادية المعالجة في ري مزروعات الحديقة الملحقة ببيتك؟**
☐ نعم ☐ لا

7. **إذا كانت الإجابة على السؤال السابق هي "لا "، فالسبب هو (يمكن اختيار اكثر من سبب):**
☐ تكلفة الري قليلة نسبيا ☐ تكاليف بناء وحدة المعالجة ☐ تكاليف الصيانة
☐ صغر مساحة أرضي ☐ أسباب أخرى. (الرجاء التوضيح ____________________)

8. **إذا علمت أن نظام المعالجة المقترح سيكلفك حوالي خمسمائة دولار (2500 شيكل) هل تتقبل فكرة استخدام المياه الرمادية المعالجة في ري مزروعات الحديقة الملحقة ببيتك؟**
☐ نعم ☐ لا

9. **إذا علمت أن نظام المعالجة المقترح سيكلفك فقط خمسين دولار (250 شيكل) , أما بقية التكلفة فستتكفل بها مؤسسة أهلية، فهل تتقبل فكرة استخدام المياه الرمادية المعالجة في ري مزروعات الحديقة الملحقة ببيتك ، علماً بأنه مطلوب منك القيام بأعمال بسيطة بغرض الصيانة الدورية لنظام المعالجة المصمم في بيتك؟**
☐ نعم ☐ لا

10. **إذا كانت إجابتك "لا" على سؤال رقم "9" ، فما هو السبب الرئيسي (أو الأسباب) الذي يدعوك إلى اتخاذ مثل هذا القرار؟**

11. **إذا قررت الموافقة على تركيب نظاماً لتجميع ومعالجة المياه الرمادية ، فهل ستستخدمه:**
☐ طوال العام ☐ في الصيف فقط ☐ صيفاً وشتاءً ولكن بدرجة أقل في الشتاء

<u>ثانياً</u>: معلومات شخصية

1- الوظيفة:
☐ مزارع ☐ تاجر ☐ موظف حكومي ☐ موظف قطاع خاص
☐ عامل ☐ صاحب مهنة (صانع) ☐ اخرى (حدد)__________

2- الجنس:
☐ ذكر ☐ أنثى

3- العمر: ____________ سنة

4- مستوى التعليم:
☐ غير متعلم ☐ أقل من الثالث الإعدادي ☐ ثانوية
☐ دبلوم ☐ بكالوريوس ☐ دراسات عليا

5- اجمالي الدخل الشهري لجميع أفراد المنزل:
☐ أقل من 1500 شيكل ☐ من 1500 إلى 2000 شيكل ☐ من 2000 إلى 3000 شيكل
☐ من 3000 إلى 4500 شيكل ☐ أكثر من 4500 شيكل

6- عدد العائلات التي تعيش في المنزل: __________
7- عدد الأفراد الذين يعيشون في المنزل: __________

8- مساحة الحديقة أو الأرض المزروعة المحيطة بالمنزل (بالأمتار المربعة)

9- قيمة فاتورة المياه الشهرية الخاصة بمنزلك في فصل الصيف تقريبا (بالشيكل) _______ (أو بـالمتر المكعب) _______
10- قيمة فاتورة المياه الشهرية الخاصة بمنزلك في فصل الشتاء تقريبا (بالشيكل) _______ (أو بـالمتر المكعب) _______
11- منطقة السكن: ☐ شمال غزة ☐ مدينة غزة وضواحيها ☐ المعسكرات الوسطى ☐ جنوب غزة (خانيونس ورفح)

Box 5-2
Questionnaire Distributed to the People of Gaza Strip (English)

Questionnaire

The Acceptability of Gaza Strip Residents for Using Graywater in Landscape Irrigation

The frequent water outage is one of the main problems the Palestinian community suffers from. The situation is more exacerbated when knowing the other end of the problem, which is not having a sewer network. That means that wastewater is discharged in unsanitary ways, which will finally lead to environmental disasters.

Several solutions have been suggested to ease such problems in order to minimize the amount of fresh water used and the amount of wastewater discharged. One of these solutions is to use graywater, which is the wastewater coming out of bathroom basins, shower, bathtub, and laundry. Such water can be used to irrigate the backyard plants. Besides minimizing the fresh water consumption, the use of graywater will reduce the emptying frequency of the septic tanks and the cesspits.

The goal of this questionnaire is to test for the acceptance of the Gaza Strip residents for the use of graywater in irrigating the backyard plants. It is merely a part of a PhD dissertation and will only be used for scientific purposes. Please answer the questionnaire questions to the best of your knowledge so that true results might be obtained at the end.

I. Questionnaire Questions

1. **What types of plants are you cultivating?**

2. **Does the ongoing water crisis affect your ability to irrigate your backyard?**
   ☐ Yes ☐ No

3. **If the answer for the previous question is "yes", your problem is really:**
   ☐ Water outage ☐ High water prices ☐ Both ☐ Other reasons

4. **If the answer for question 2 is "yes", the season in which you really suffer is:**
   ☐ Summer only
   ☐ I suffer in both summer and winter, but I feel it more during the summer
   ☐ There is no difference; i.e. I have the same level of sufferring in both

5. **Is your house connected to the sewer network?**
   ☐ Yes ☐ No

6. **Would you accept using the partially treated graywater in irrigating your backyard plants?**
   ☐ Yes ☐ No

7. **If your answer for the previous question is "No", what is/are the reasons behind this decision? (you can choose more than one reason)**
   ☐ Water is relatively cheap for me
   ☐ The cost of building the treatment unit
   ☐ The cost and burden of maintaining the treatment unit
   ☐ I have a very small backyard
   ☐ Other reasons (Please elaborate more if possible ______________________)

8. **If the suggested treatment system will cost you $500 (2500 NIS), would you still accept the idea of using graywater in irrigating your backyard plants**
   ☐ Yes ☐ No

9. **If the suggested treatment system were to cost you only $50 (250 NIS), with the rest to be contributed by an NGO, would you accept the idea of using graywater in irrigating your backyard plants**
   ☐ Yes ☐ No

10. **If your answer to question 9 was no, what is the main reason why you would still not utilize a graywater system?**

11. If you decided that you are going to install a graywater system, when would you use the system?

☐ Year around ☐ In summer only ☐ In both summer and winter, but more extensively in the summer

II. Background information

Occupation

☐ Farmer ☐ Merchant ☐ governmental employee
☐ Private sector employee ☐ Laborer ☐
☐ Other

Age: ___________ **Gender:** ☐ M ☐ F

Education

☐ Illitrate ☐ Less than 9th grade ☐ High school
☐ Two-yr degree ☐ Bachelor ☐ Masters or higher

Total household monthly income

☐ Less than 1500 NIS ☐ From 1500 to 2000 NIS ☐ From 2000 to 3000 NIS
☐ From 3000 to 4500 NIS ☐ More than 4500 NIS

Number of families living in the house: _________.
Number of individuals living in the house: _________.

Average monthly water bill value in summer months: __________ (NIS)
Average monthly water bill value in winter months: __________ (NIS)

Area where you reside: ________________________________

Sample size determination: Enough sample size should be chosen in order to make a valid generalization about the entire population. In order to determine the proper sample size, one needs to define three factors; a) the population, b) level of confidence, and c) Confidence interval.

a) Population: Regarding the population, the target population in this research is not all the people living in the Gaza Strip. Rather, it is any person living in the Gaza

Strip and having a backyard for his/her house. The population of the Gaza Strip is about 1.4 million people. According to the Palestinian Central Bureau of Statistics (PCBS, 1997), the total number of houses and villas in the Gaza Strip is 83,677, which constitutes about 72% of the buildings in the Gaza Strip. Table 5.1 shows the types of buildings in the Gaza Strip. This number, 83,677 houses, will be considered as the population size.

Table 5.1 Buildings in Gaza Strip by Type of Building

Type of Building	Number	Percentage
Villa	**645**	0.6
House	**83,032**	71.3
Multi-storey apartment building	16,161	13.9
Tent	232	0.2
Marginal	1,487	1.3
Establishment	10,117	8.7
Under Construction	4,338	3.7
Other	433	0.4
Not Stated	-	-
Total	**116,445**	**100.0**

Source: Palestinian Central Bureau of Statistics (PCBS, 1997)

b) Level of Confidence: According to Rea and Parker (2005), sample size is a primary contributor to the success in achieving a certain degree of sampling accuracy. Therefore, the sample size is also a function of the level of confidence that a researcher desires. A 99% confidence level requires larger sample size than the 95% confidence level in order to fulfill the higher confidence level. The level of confidence is the risk of error the researcher is willing to accept for the study in hands (Rea and Parker, 2005). However, the use of 99% confidence level might lead to wrong decisions associated with type II error, which is the error that derives from being conservative and not acting on the results, while acting would be the correct action. The 95% confidence level is now widely used and accepted in the research community since it represents a reasonable balance between the type I and type II errors (Rea and Parker, 2005). For the current research about the use of graywater for landscape irrigation in the Gaza Strip, the 95% confidence level will be used.

c) ***Confidence Interval***: Besides the population size and the confidence level, confidence interval is the third factor considered in the sample size determination. The confidence level and the confidence interval are interrelated factors. The confidence interval around the mean is equal to:

$x \pm Z \,.\, s/n^{1/2}$, where s = sample standard deviation,
n = sample size
Z = Z score for various levels of confidence

$Z.s/n^{1/2}$ is the margin of error.

A procedure found in Rea and Parker (2005) was used in the determination of the sample size (Box 5-3).

Box 5.3 Sample Size Calculations*

A) For Large Populations:

Margin of error in terms of proportions, $ME_p = \pm Z_a(\sigma_p)$

Where

ME_p = margin of error in terms of proportions

Za = Z score for various levels of confidence

σ_p = standard error for a distribution of sample proportions

...Continue Box 5.3

The standard error of the true population proportion is $= [p(1-p)/n]^{1/2}$

Therefore, $ME_p = \pm Z_a \,.\, [p(1-p)/n]^{1/2}$ ..

Solving for n, $n = \left((Z_a / ME_p).\sqrt{p(1-p)}\,\right)^2$

Therefore, in order to calculate the appropriate sample size, the values of Z_a , ME_p , and p must be known. Z_a depends on the level of confidence. For 95% confidence level, Z_a is set at 1.96. The margin of error (ME_p) is commonly set not to exceed 10 percent. A more typical range commonly used is from 3 to 5 percent. Prior to conducting the survey, the true proportion (p) is unknown. Conservatively, the true proportion can be set to $p = 0.5$ which would result in the highest sample size.

Therefore: $n = \left((Z_a\,(0.5) / ME_p)\right)^2$. .... (1)

B) **<u>For Small Populations</u>**:

Rea and Parker (2005) considered the population size of 100,000 as the distinction between the large and small populations. For small populations; i.e. less than 100,000, the sample size will be calculated using the following formula

$n = Z_a^2 (0.25).(N) \,/\, \left(Z_a^2 .(0.25) + (N\text{-}1).(ME_p)\right)$... .... (2)

Adapted from: Rea and Parker (2005)

By looking at formula (1) in Box 5.3, it is noticed that in order to determine the sample size, the researcher needs to define the confidence level and the margin of error that are acceptable for the study in hands. For the confidence level, a 95% confidence level is widely used and accepted in the research community (Rea and Parker, 2005). For the margin of error, a range of 3% to 5% is typically used. A 5% margin of error was used in this study. The minimum sample size in order to achieve a 95% confidence level and a 5% margin of error can be calculated by using formula (1) in Box 5.3 :

$$n = \left(\left(1.96\,(0.5) / ME_p \right) \right)^2 = \mathbf{385} \quad ,$$

which is the required sample size for a large population.

For the case of this study, the population size is 83,677, which is considered in the side of the small population as defined by Rea and Parker (2005). Rea and Parker (2005) considered the population size of 100,000 as the threshold separating the large population from the small population. Therefore, formula (2) in Box 5-3 should be used. The use of formula (2) resulted in almost the same sample size calculated by formula (1); i.e. a sample size of 385. A sample size of 511 questionnaires was used in this study.

5.2.3 Results of Completed Surveys

5.2.3.1 Completed Surveys and General Characteristics

The number of questionnaires completed in this study was 511. As mentioned in the Methodology section, in order to achieve a 5% margin of error and a 95% confidence level, the sample size should be at least 385; i.e. at least 385 questionnaires should be distributed. The whole Gaza Strip was divided into four areas: 1) Northern area of Gaza Strip, 2) Gaza City and suburbs, 3) Middle refugee camps, 4) Southern area of Gaza Strip. About 470 of the respondents were male while 41 were female. The ages of the interviewed people ranged from 22 to 71, with a mean and median of 40.7 and 40.0 respectively.

5.2.3.2 Results of the Main Questions

The most important questions in the survey were questions 6, 7, 8, and 9. Question 6 asked about whether the respondent would accept the idea of using graywater for irrigation or not. Question 7 is directed to those who did not accept the idea of using graywater in question 6 by inquiring about the reasons behind not accepting the use of graywater. Questions 8 and 9 bring the cost of the graywater system into the picture, asking the respondents again about whether or not graywater use would be acceptable knowing that the cost for installing a graywater system are $500 for question 8 and $50 for question 9. Of course, the respondents did not know about question 9 till they answered question 8.

Results of Question 6:

Would you accept using the partially treated graywater in irrigating your backyard plants?

The main question in the questionnaire was question number 6, in which the interviewee is asked whether he/she accepts the idea of using graywater in irrigating the backyard plants. The results of this question are shown in Figure 5.4. The Figure shows that 83.6% of the interviewed people accept the idea of using graywater in irrigating the backyard plants, and 16.4% reject the idea. This initial high acceptance rate is encouraging since at least it shows that the people in the Gaza Strip did not reject the idea from the beginning. At this stage of the questionnaire, nothing was mentioned about the cost of the graywater system. It is expected that the cost of installing a graywater system will have an effect on the people's decision.

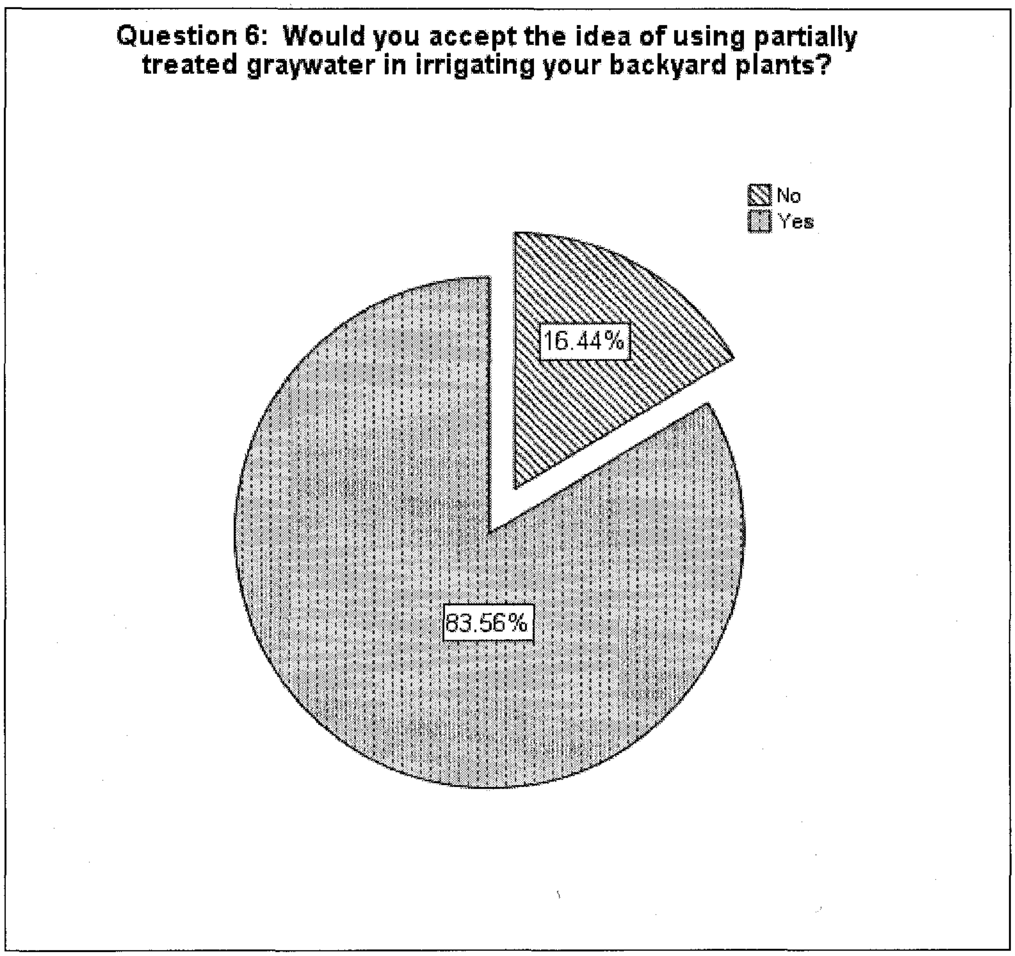


Figure 5.4 Response to question 6

Results of Question 7:

If your answer for the previous question is "No", what is/are the reasons behind this decision? (You can choose more than one reason)

- ☐ Water is relatively cheap for me
- ☐ The cost of building the treatment unit
- ☐ The cost and burden of maintaining the treatment unit
- ☐ I have a very small backyard
- ☐ Other reasons (Please elaborate more if possible ______________________)

Question 6 was followed by another question (question 7) to identify the reasons behind not accepting the idea of using graywater. Figure 5.5 summarizes the responses to question number 7. Although the rejection rate was only 16.4%, it is necessary to know the reasons behind this rejection. Knowing the reasons behind not accepting the use of graywater may help researchers understand the obstacles that may stand on the way.

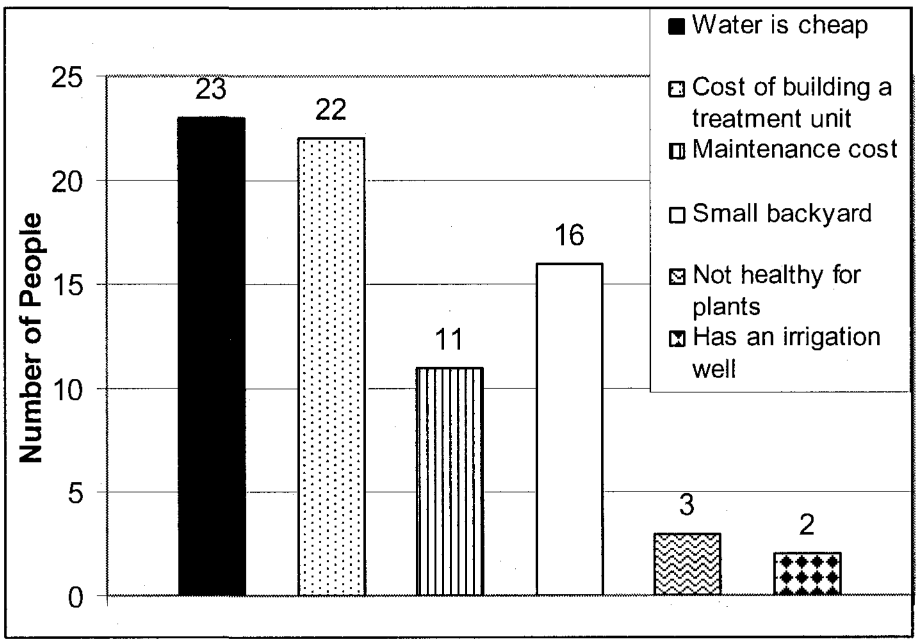


Figure 5.5 Response to question 7 (Reasons behind not accepting graywater)

Results of Question 8:

If the suggested treatment system will cost you $500 (2500 NIS), would you accept the idea of using graywater in irrigating your backyard plants?

Accepting the concept of using graywater does not necessarily mean the acceptance of installing a graywater system. Question 6 was merely a question that did not go into the cost of the system. Due to the hard financial situation in the Gaza Strip, it is expected that the cost of installing a graywater system will have a large effect on the people's decision. Therefore, question number 8 was formulated in a way to mention the cost of a graywater system and check if the interviewee is willing to pay the cost. Figure 5.6 shows that the huge acceptance rate (83.6%) obtained for question 6 reversed when the interviewed people knew that the system would cost $500, with the whole cost to be paid by them. About 90% of the interviewed people rejected using graywater when they knew about the $500 cost to build such system. This attitude may reveal that people do not feel that a graywater system will be a financially feasible option. It also may reveal that the people's financial situation does not allow them to think about paying $500 for a graywater system.

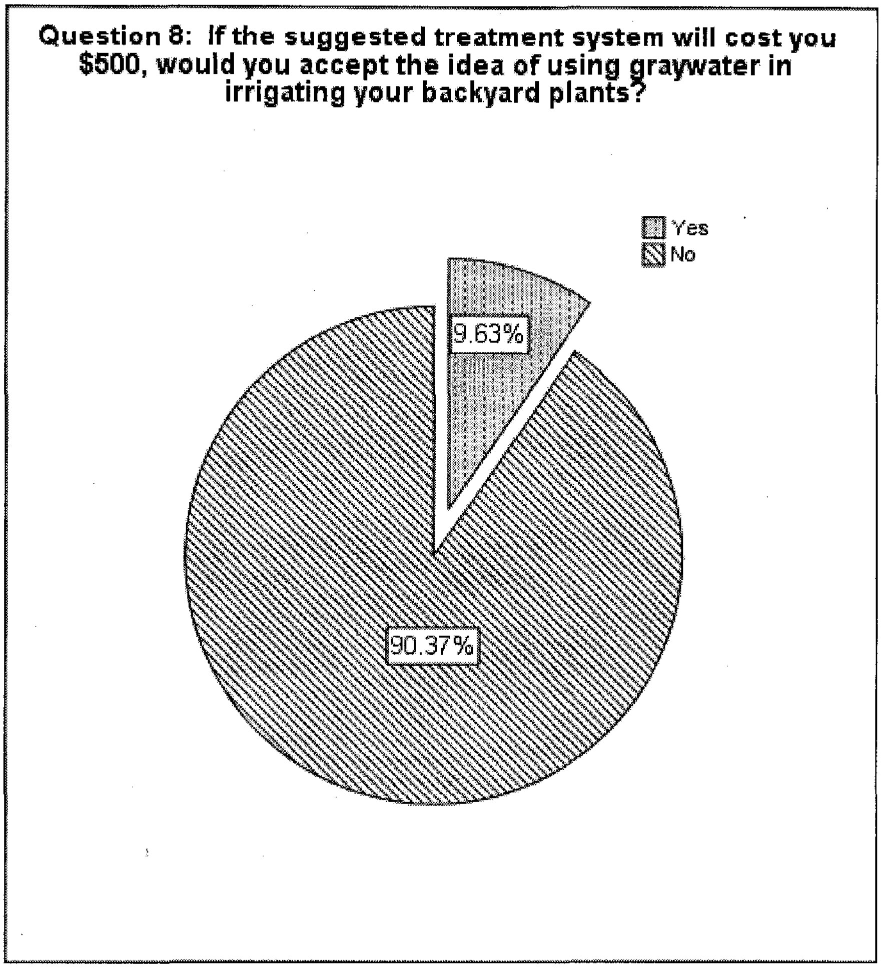


Figure 5.6 Response to question 8

Results of Question 9:

If the suggested treatment system were to cost you only $50 (250 NIS), with the rest to be contributed by an NGO, would you accept the idea of using graywater in irrigating your backyard plants

The results of question 8 showed that the cost of installing a graywater system plays a major role in the decision of whether a graywater use is accepted or not. The results of question 8 also revealed that a $500 is a high cost for the residents of the Gaza Strip. In an attempt to check the seriousness of the people who initially accepted the concept of using graywater in question 6 and the sensitivity of the cost of installing a graywater system, question 9 was formulated. The interviewee was asked if he/she would accept the use of graywater for the cost of $50, with the rest to be contributed by an NGO. The drop of the cost from $500 to $50 reversed the situation from a high rejection rate (as in question 8) to a high approval rate (Figure 5.7). About 84% of the interviewed people accepted the use of graywater if the cost was only $50, with the rest to be contributed by an NGO. Again, the results of this question show how the financial side is such an important player in the decision.

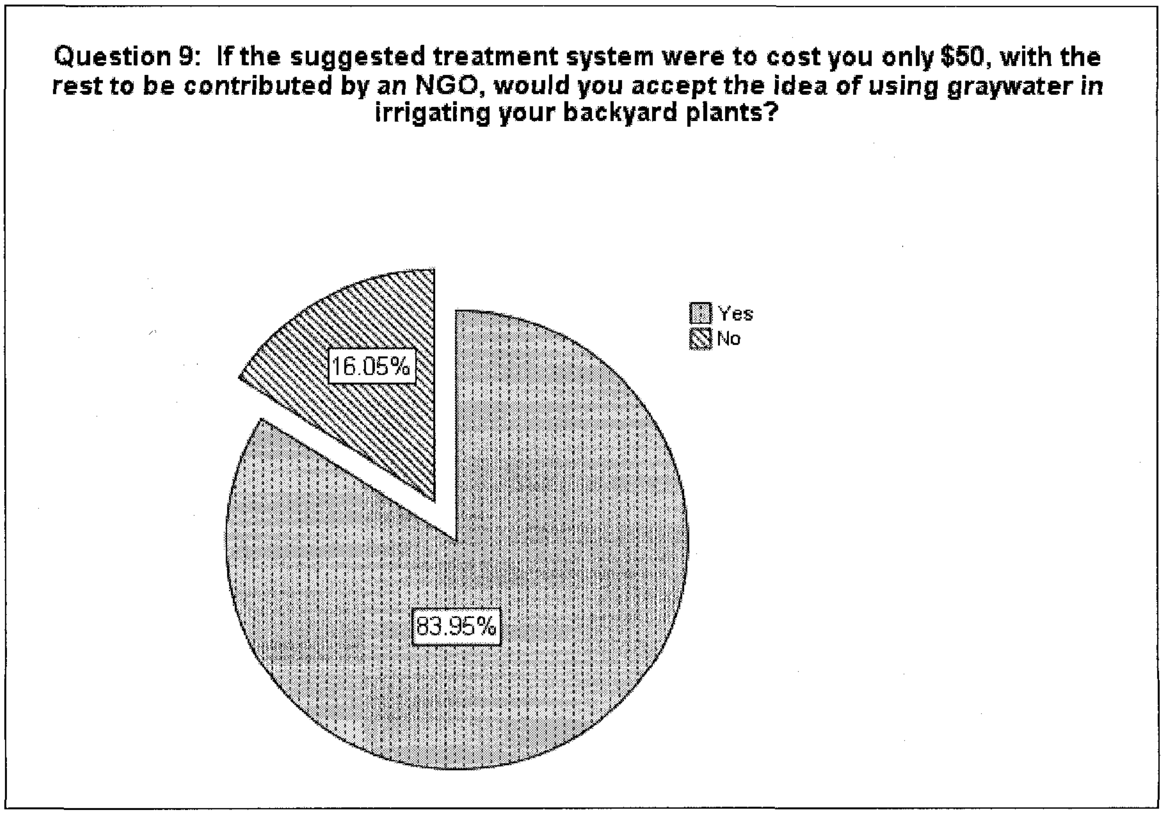


Figure 5.7 Response to question 9

5.2.3.3 Other Important Questions and Relationships

In order to better understand the behavior of people and connect their answers to their situation, other questions were asked. In question #2, the interviewee was asked whether the ongoing water crisis affect the ability to irrigate the backyard. About 45% confirmed that the ongoing water crisis affects their ability to irrigate their backyards, while the rest said that the water crisis does not affect their ability to irrigate their backyards (Figure 5.8).

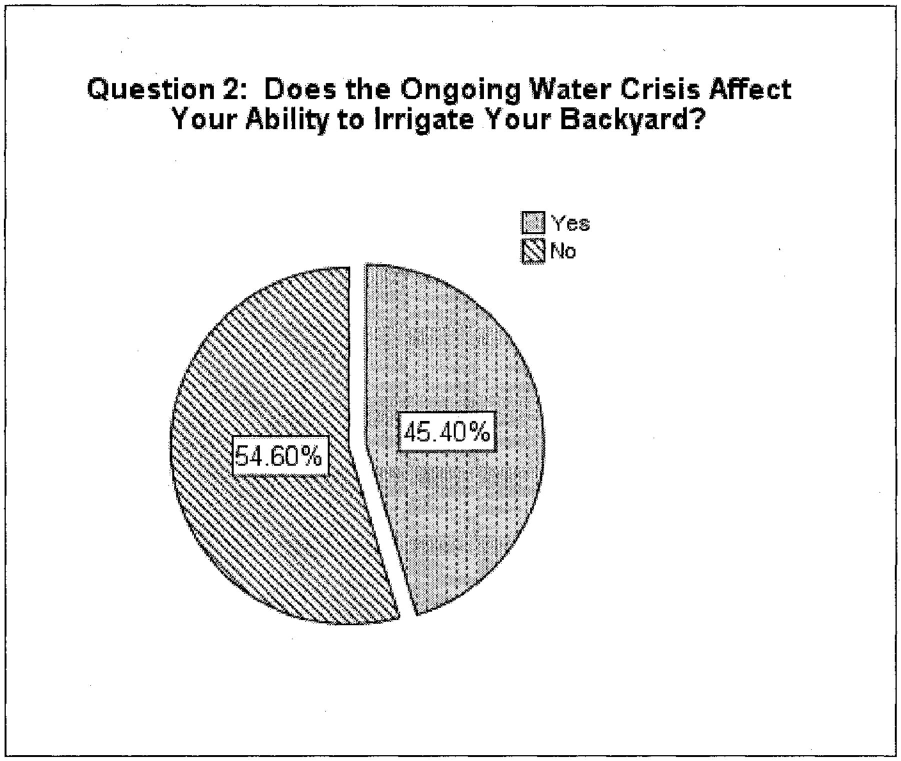


Figure 5.8 Response to question 2

Respondents who confirmed having a water problem were asked about the reasons behind their feeling. Their response is shown in Figure 5.9. About 75% of them mentioned that the water outage is the main reason, while about 18.2% mentioned that it is due to both water outage and water prices. That means that about 88% of the sample confirm that water outage is a main problem. This is encouraging for the use of graywater because the use of graywater is considered to be a drought-proof tool. During times of water outage, graywater can serve as an alternative.

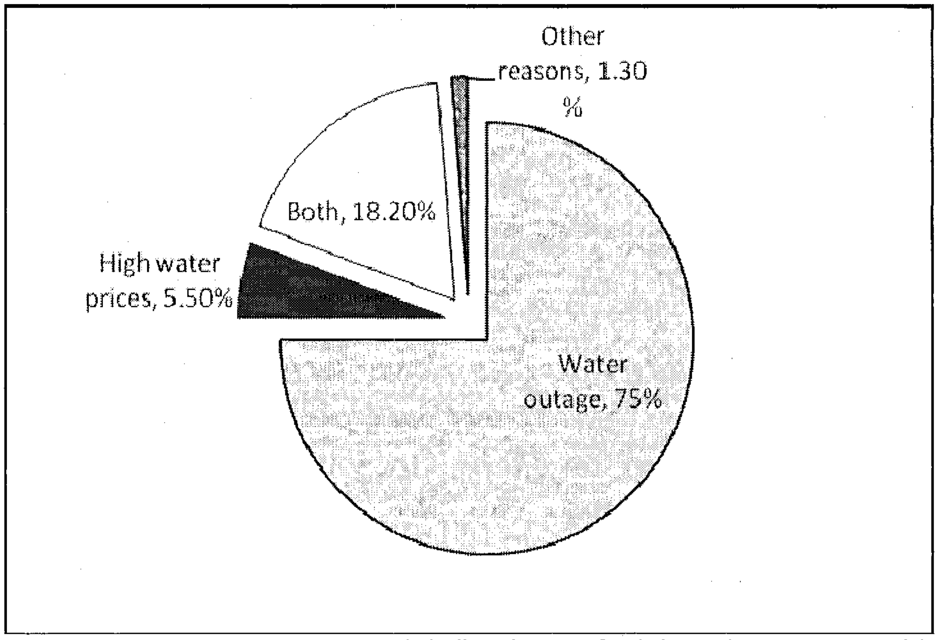


Figure 5.9 Response to question 3 (Why do you feel there is a water problem?)

Other useful relationships can be drawn from the survey. For example the response regarding the acceptability of using graywater (question #6) can be related to other variables; e.g. being connected to the sewer network or not, level of income, area of residence, etc. To infer such relationships, cross tabulations and Chi-square test have been used using the SPSS software. Several hypotheses were formulated and tested:

1) Being connected to the sewer network has no effect on the decision of whether or not to accept the use of graywater
2) The people's response regarding the acceptability of using graywater does not vary with the occupation of the interviewee

3) Area of residence does not affect the people's response regarding the acceptability of using graywater
4) The level of education does not affect the people's opinion regarding the use of graywater for backyard irrigation
5) The level of income does not affect the people's opinion regarding the use of graywater for backyard irrigation

Null Hypothesis 1:

Being connected to the sewer network has no effect on the decision of whether or not to accept the use of graywater.

The purpose of this hypothesis is to determine whether or not a relationship exists between the acceptability of using graywater and being connected to the sewer network. Table 5.2 shows a cross tabulation illustrating the difference in response between each group (the group connected to the sewer network and the group not connected to the sewer network) along with the expected responses.

The actual responses were compared with the expected responses using the Chi square test at the 0.05 significance level. Surprisingly, the calculated Chi-square value was 0.608, which is much smaller than the critical Chi-square value 3.841. This indicates that the null hypothesis cannot be rejected. Therefore, there is no relationship between accepting the use of graywater and being connected to the sewer network.

Table 5.2 Acceptability of Using Graywater vs. Being Connected to Wastewater Network (Cross tabulation)

			Accept the idea of using graywater?		**Total**
			No	Yes	No
Connected to the wastewater network?	**Yes**	Count	68	321	389
		Expected Count	64.3	324.7	389.0
		% within Connected to the wastewater network?	**17.5%**	**82.5%**	100.0%
		% within Accept the idea of using graywater?	81.0%	75.7%	76.6%
		% of Total	13.4%	63.2%	76.6%
	No	Count	16	103	119
		Expected Count	19.7	99.3	119.0
		% within Connected to the wastewater network?	**13.4%**	**86.6%**	100.0%
		% within Accept the idea of using graywater?	19.0%	24.3%	23.4%
		% of Total	3.1%	20.3%	23.4%
Total		Count	84	424	508
		Expected Count	84.0	424.0	508.0
		% within Connected to the wastewater network?	**16.5%**	**83.5%**	100.0%
		% within Accept the idea of using graywater?	100.0%	100.0%	100.0%
		% of Total	16.5%	83.5%	100.0%

Null Hypothesis 2:

The people's response regarding the acceptability of using graywater does not vary with the occupation of the interviewee.

Table 5.3 shows a cross tabulation illustrating the actual and expected response of each working category (farmer, merchant, etc). The Chi-square test was run at the 0.05 significance level. The calculated Chi-square value was 9.294, which is less than the critical Chi-square value (12.592). This indicates that the null hypothesis should be accepted. Therefore, there is no relationship between accepting the use of graywater and the occupation of the respondent. By taking a closer look at Table 5.3, and unlike what was expected, one may notice that the acceptance rate of the farmers was similar to those of other occupations like merchants, governmental employees, private sector employees, and skilled worker. The only exception was with the laborer's category which showed the highest rejection rate among all categories (28.8%).

Table 5.3 Acceptability of Using Graywater vs. Occupation (Cross tabulation)

			Accept the idea of using graywater?		**Total**
			No	Yes	No
Occupation	**Farmer**	Count	24	130	154
		Expected Count	25.3	128.7	154.0
		% within Occupation	**15.6%**	**84.4%**	100.0%
		% within Accept the idea of using graywater?	28.6%	30.4%	30.1%
		% of Total	4.7%	25.4%	30.1%
	Merchant	Count	13	56	69
		Expected Count	11.3	57.7	69.0
		% within Occupation	**18.8%**	**81.2%**	100.0%
		% within Accept the idea of using graywater?	15.5%	13.1%	13.5%
		% of Total	2.5%	11.0%	13.5%
	Governmental employee	Count	19	117	136
		Expected Count	22.4	113.6	136.0
		% within Occupation	**14.0%**	**86.0%**	100.0%
		% within Accept the idea of using graywater?	22.6%	27.4%	26.6%
		% of Total	3.7%	22.9%	26.6%
	Private sector employee	Count	6	32	38
		Expected Count	6.2	31.8	38.0
		% within Occupation	**15.8%**	**84.2%**	100.0%
		% within Accept the idea of using graywater?	7.1%	7.5%	7.4%
		% of Total	1.2%	6.3%	7.4%

...Continue Table 5.3

	Laborer	Count	15	37	52
		Expected Count	8.5	43.5	52.0
		% within Occupation	**28.8%**	**71.2%**	100.0%
		% within Accept the idea of using graywater?	17.9%	8.7%	10.2%
		% of Total	2.9%	7.2%	10.2%
	Skilled worker	Count	6	33	39
		Expected Count	6.4	32.6	39.0
		% within Occupation	**15.4%**	**84.6%**	100.0%
		% within Accept the idea of using graywater?	7.1%	7.7%	7.6%
		% of Total	1.2%	6.5%	7.6%
	Other	Count	1	22	23
		Expected Count	3.8	19.2	23.0
		% within Occupation	**4.3%**	**95.7%**	100.0%
		% within Accept the idea of using graywater?	1.2%	5.2%	4.5%
		% of Total	.2%	4.3%	4.5%
Total		Count	84	427	511
		Expected Count	84.0	427.0	511.0
		% within Occupation	**16.4%**	**83.6%**	100.0%
		% within Accept the idea of using graywater?	100.0%	100.0%	100.0%
		% of Total	16.4%	83.6%	100.0%

Null hypothesis 3:

Area of residence does not affect the people's response regarding the acceptability of using graywater.

A cross tabulation illustrating the variables and the responses in this case is shown in Table 5.4. The results of Chi-square test revealed that the null hypothesis should be rejected since the calculated Pearson Chi-square value was 16.259, which is larger than the critical Chi-square value (7.815). This is an indication of a genuine difference among the categories, which are the areas of residence in this case. Therefore, there is a relationship between accepting or rejecting the idea of using graywater and the area of residence. The Chi-square value does not give information about the strength of this relationship. It only indicates whether the relationship is statistically significant or not. To measure the strength of this relationship, Cramer's *V* measure was used. Cramer's *V* was calculated for this case to be 0.178, which only indicates a weak association.

By taking a closer look at the rejection and acceptance rates for each category (categories being the areas of residence), one can find that the highest rejection rates (about 29%) were encountered in the middle refugee camp area, which is an area of houses very close to each other, with very small backyards. The highest acceptance rates (about 91%) were encountered in the northern area of the Gaza Strip, which is well known to be an agricultural area, with large backyards.

Table 5.4 Acceptability of Using Graywater vs. Area of Residence (Cross tabulation)

			Accept the idea of using graywater?		**Total**
			No	Yes	No
Area of residence	**North area of Gaza Strip**	Count	7	74	81
		Expected Count	13.3	67.7	81.0
		% within Area of residence	**8.6%**	**91.4%**	100.0%
		% within Accept the idea of using graywater?	8.3%	17.3%	15.9%
		% of Total	1.4%	14.5%	15.9%
	Gaza and Metro Gaza	Count	12	89	101
		Expected Count	16.6	84.4	101.0
		% within Area of residence	**11.9%**	**88.1%**	100.0%
		% within Accept the idea of using graywater?	14.3%	20.8%	19.8%
		% of Total	2.3%	17.4%	19.8%
	Middle refugee camps	Count	29	72	101
		Expected Count	16.6	84.4	101.0
		% within Area of residence	**28.7%**	**71.3%**	100.0%
		% within Accept the idea of using graywater?	34.5%	16.9%	19.8%
		% of Total	5.7%	14.1%	19.8%
	South area of Gaza Strip	Count	36	192	228
		Expected Count	37.5	190.5	228.0
		% within Area of residence	**15.8%**	**84.2%**	100.0%
		% within Accept the idea of using graywater?	42.9%	45.0%	44.6%
		% of Total	7.0%	37.6%	44.6%
Total		Count	84	427	511
		Expected Count	84.0	427.0	511.0
		% within Area of residence	**16.4%**	**83.6%**	100.0%
		% within Accept the idea of using graywater?	100.0%	100.0%	100.0%
		% of Total	16.4%	83.6%	100.0%

Null Hypothesis 4:

The level of education does not affect the people's opinion regarding the use of graywater for backyard irrigation.

Table 5.5 is a cross tabulation showing the actual and expected responses of each group of people. Groups were divided according to their education level as shown in

Table 5.5. The calculated Chi-square value was 20.89, which is larger than the critical Chi-square value (11.07). Therefore, the null hypothesis should be rejected with the conclusion that the level of education affects the people's opinion regarding the use of graywater for backyard irrigation. Cramer's *V* measure of association was calculated to be 0.203, which indicates a moderate association.

Table 5.5 Acceptability of Using Graywater vs. Level of Education (Cross tabulation)

			Accept the idea of using graywater?		**Total**
			No	Yes	No
Education	**Illiterate**	Count	20	36	56
		Expected Count	9.2	46.8	56.0
		% within Education	**35.7%**	**64.3%**	100.0%
		% within Accept the idea of using graywater?	23.8%	8.5%	11.0%
		% of Total	3.9%	7.1%	11.0%
	Less than 9th grade	Count	8	66	74
		Expected Count	12.2	61.8	74.0
		% within Education	**10.8%**	**89.2%**	100.0%
		% within Accept the idea of using graywater?	9.5%	15.5%	14.5%
		% of Total	1.6%	13.0%	14.5%
	High school	Count	10	86	96
		Expected Count	15.8	80.2	96.0
		% within Education	**10.4%**	**89.6%**	100.0%
		% within Accept the idea of using graywater?	11.9%	20.2%	18.9%
		% of Total	2.0%	16.9%	18.9%
	2-yr degree	Count	15	61	76
		Expected Count	12.5	63.5	76.0
		% within Education	**19.7%**	**80.3%**	100.0%
		% within Accept the idea of using graywater?	17.9%	14.4%	14.9%
		% of Total	2.9%	12.0%	14.9%
	Bachelor	Count	25	152	177
		Expected Count	29.2	147.8	177.0
		% within Education	**14.1%**	**85.9%**	100.0%
		% within Accept the idea of using graywater?	29.8%	35.8%	34.8%
		% of Total	4.9%	29.9%	34.8%

...Continue Table 5.5					
	Masters or higher	Count	6	24	30
		Expected Count	5.0	25.0	30.0
		% within Education	**20.0%**	**80.0%**	100.0%
		% within Accept the idea of using graywater?	7.1%	5.6%	5.9%
		% of Total	1.2%	4.7%	5.9%
Total		Count	84	425	509
		Expected Count	84.0	425.0	509.0
		% within Education	**16.5%**	**83.5%**	100.0%
		% within Accept the idea of using graywater?	100.0%	100.0%	100.0%
		% of Total	16.5%	83.5%	100.0%

Null Hypothesis 5:

The level of income does not affect the people's opinion regarding the use of graywater for backyard irrigation.

Table 5.6 is a cross tabulation showing the actual and expected responses of each group of people. Groups were divided according to their level of income as shown in Table 5.6. The calculated Chi-square value was 16.235, which is larger than the critical Chi-square value (9.488). Therefore, the null hypothesis should be rejected with the conclusion that the level of income affects the people's opinion regarding the use of graywater for backyard irrigation. Cramer's *V* measure of association was calculated to be 0.180, which indicates a weak association.

Table 5.6 Acceptability of Using Graywater vs. Level of Income (Cross tabulation)

			Accept the idea of using graywater?		Total
			No	Yes	No
Total household monthly income	**Less than 1500 NIS**	Count	15	43	58
		Expected Count	9.7	48.3	58.0
		% within Total household monthly income	**25.9%**	**74.1%**	100.0%
		% within Accept the idea of using graywater?	17.9%	10.3%	11.6%
		% of Total	3.0%	8.6%	11.6%
	From 1500 to 2000 NIS	Count	19	66	85
		Expected Count	14.2	70.8	85.0
		% within Total household monthly income	**22.4%**	**77.6%**	100.0%
		% within Accept the idea of using graywater?	22.6%	15.8%	16.9%
		% of Total	3.8%	13.1%	16.9%
	From 2000 to 3000 NIS	Count	20	160	180
		Expected Count	30.1	149.9	180.0
		% within Total household monthly income	**11.1%**	**88.9%**	100.0%
		% within Accept the idea of using graywater?	23.8%	38.3%	35.9%
		% of Total	4.0%	31.9%	35.9%
	From 3000 to 4500 NIS	Count	16	114	130
		Expected Count	21.8	108.2	130.0
		% within Total household monthly income	**12.3%**	**87.7%**	100.0%
		% within Accept the idea of using graywater?	19.0%	27.3%	25.9%
		% of Total	3.2%	22.7%	25.9%
	More than 4500 NIS	Count	14	35	49
		Expected Count	8.2	40.8	49.0
		% within Total household monthly income	**28.6%**	**71.4%**	100.0%
		% within Accept the idea of using graywater?	16.7%	8.4%	9.8%
		% of Total	2.8%	7.0%	9.8%
Total		Count	84	418	502
		Expected Count	84.0	418.0	502.0
		% within Total household monthly income	**16.7%**	**83.3%**	100.0%
		% within Accept the idea of using graywater?	100.0%	100.0%	100.0%
		% of Total	16.7%	83.3%	100.0%

A closer look at Table 5.6 shows that the average income categories (2000 to 3000 NIS and 3000 to 4500 NIS) were the categories of the lowest rejection rates (11% and 12% respectively). Fortunately, those categories constituted about 60% of the interviewed people, which means that they are the majority of the people. The highest income category (4500 NIS and above) proved to be the least accepting, with a rejection rate of about 29%.

5.2.4 Summary of Completed Surveys Results

The vast majority of Gaza Strip residents accepted the use of graywater for the backyard irrigation. The initial acceptance rate was about 84%. As expected, the cost of installing a graywater system played a major role in the final decision of respondents. When the respondents knew about the $500 cost of installing the graywater system, the high acceptance rate of 84% turned into a high rejection rate of 90%. The situation returned back to high acceptance rate (about 84%) as soon as the respondents knew that they would only pay $50, while the rest will be contributed by an NGO. This last change indicates that respondents were serious in accepting the idea of using graywater, knowing that they will pay in case they decide to install a system. Therefore, the introduction of other incentives may result in better encouragement.

The study also revealed that water outage seemed to be the strongest reason behind the feeling of having a water problem. This is encouraging for the future of graywater use because graywater can be the alternative during times of water outage.

The study also demonstrated that being connected to the sewer network or not did not affect the decision of accepting the graywater use. Also, there was no relationship between accepting the use of graywater and the occupation of the respondent. A relationship, however weak, was found between accepting the use of graywater and the area of residence. The middle refugee camps area showed the lowest acceptance rates. A moderate association was found between the level of education and accepting the use of graywater. Illiterate respondents showed the highest rejection rates among all education categories. A weak relationship was found between the level of income and the acceptability of using graywater, with the highest-income category being the highest in rejection. The middle-income categories (2000 to 3000 NIS and 3000 to 4500 NIS) had the highest acceptance rates.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 Graywater Characteristics

The experimental program examining graywater treatment schemes revealed that stored graywater had a quality resembling a low-strength untreated domestic wastewater, indicating that treatment is essential. Indicator organisms, including total coliforms, fecal coliforms, and *E. coli*, were consistently detected in stored graywater at high levels that are comparable to those found in medium-strength untreated domestic wastewater, indicating the potential existence of pathogens and the necessity to apply proper treatment techniques - including disinfection. Another difference between wastewater and graywater was the higher amount of slowly biodegradable organic matter in graywater as compared to that in raw wastewater as indicated by the COD/BOD ratio. However, the ratio obtained still ranks in the relatively readily degradable category, indicating that biological treatment has a good success potential and should be investigated.

6.1.2 Graywater Treatment

Biological treatment is necessary to achieve acceptable graywater quality. Not adopting a biological treatment technique would result in significantly high values of BOD, COD, and turbidity. This was demonstrated in schemes VI and VII of the graywater treatment, in which the combination of coarse filter and the UV disinfection unit was not sufficient in achieving significant and acceptable treatment accomplishments.

It is necessary to use a coarse filter ahead of the treatment train. The observations from this study showed that the coarse filter was successful in removing hair and similar objects.

The users of a graywater system need to be careful about what they dump in the graywater system. This study showed that dumping strange material in the graywater system could have detrimental effects on the system. For example, observations from the current study showed that cleaning paintbrushes led to quick clogging of the coarse filter and high turbidity values.

The pleated 5-micron filter does not significantly reduce the levels of turbidity and suspended solids in graywater. This shows that the particles causing turbidity in graywater have sizes smaller than 5 microns. The only positive effect that the 5-micron filter had was flow reduction and therefore an increased contact time within the UV disinfection unit, which consequently resulted in significantly better disinfection results. This leads to the conclusion that increasing the contact time within the UV disinfection unit is an effective way of having a better disinfection of graywater. This is an encouraging point for the use of UV disinfection ahead of a drip irrigation system since the flow rate in the drip system is known to be lower than some other irrigation systems.

In the light of the operation of the graywater treatment system used in this study, it seems that the following combination/arrangement of treatment units can be effective in reducing the common water quality contaminants:

- Graywater tank receives the graywater inflow. This tank should be aerated for the biological treatment to take place.
- Aeration should be followed by an appropriate settling period to effect the settling of the flocs that have been formed during the aeration process.
- The settled graywater should be drained by gravity to a second tank underneath the first tank. A coarse filter should be used between the two tanks.
- The second graywater tank should be connected to a recycle line that comprises a UV disinfection unit. The existence of this recycle line will give the user a chance to add more treatment units (e.g. disinfection using chemicals for the use in toilet flushing).

6.1.3 Plant and Soil Experiments

After seven months of irrigation and considering the three groups: the plants irrigated with graywater, the plants irrigated with tap water, and the plants irrigated in an alternating way with both graywater and tap water; several conclusion were reached regarding the effects of graywater irrigation on soils and plants.

The accumulation of sodium in plant tissues is one of the highest concerns when using graywater for irrigation. Therefore, the graywater user may consider options like irrigation in an alternating way using both graywater and tap water. The user may also consider diluting graywater with tap water since this is the only feasible way of reducing the sodium concentration in the graywater stream. The benefit of alternating irrigation was demonstrated by the plant tissue analysis results, which showed that irrigating with both tap water and graywater significantly reduced the sodium and total-N concentrations at the 95% confidence level. Despite this reduction in the concentration of several elements and compounds, it was found in this study that petunia plants irrigated with both graywater and tap water did not grow as well as the other groups (as demonstrated by the dry plant mass above ground). Since geranium plants did not show differences in growth or quality in all irrigation types, it seems that some plants are not affected by alternating between graywater and tap water, while others (like petunias) are affected by the process of alternating between graywater and tap water. In light of this, diluting graywater with tap water should be investigated and given more attention since it would provide the plants with a more consistent water quality and less concentration of sodium, chloride, and other dissolved matter.

Despite the accumulation of several elements and compounds (e.g. sodium, total nitrogen, and nitrate nitrogen) in the graywater irrigated plants, the plants (annual plants) performed well and seemed not significantly affected by such accumulation. Given that one of the plants was petunia, which is a salt sensitive annual plant, one can come to the conclusion that annuals should be considered for graywater irrigation.

The study was not able to reach any conclusion about the boron effects since the graywater had a low boron concentration.

The study also demonstrated that the salt exclusion mechanism in geranium plants resulted in lower sodium concentration compared to that found in the petunia plants. This indicates that if graywater will be used for irrigation, the user should choose the more salt tolerant plants. This conclusion is true from the plant point of view. However, from the soil point of view and considering the long term effects, the same result implies that having plants like petunias would be preferred since they would mine the accumulated salts in soils and then get removed at the end of their season, which is one benefit of planting annuals when considering graywater for irrigation. This conclusion is of special importance in the case of drip irrigation because drip irrigation concentrates the salts in the soil zone around the plant.

6.1.4 Potential of Graywater Reuse in the Gaza Strip

The overall conclusion is that the vast majority of Gaza Strip residents would accept the use of graywater for irrigating their backyards. However, the cost of constructing the graywater system plays a major role in the people's decision. A $500.00 cost for a graywater system is unacceptable cost for the people of the Gaza Strip. The Gaza Strip people seemed to be serious in their decision of accepting the use of graywater since they accepted the idea of using graywater in spite of knowing that they should take care of the maintenance and pay $50.00 towards the construction costs, with the rest to be contributed by an NGO. This leads to the conclusion that promoting graywater reuse in Gaza Strip would require the introduction of certain incentives. Without such incentives, the idea will not be attractive to the people of the Gaza Strip.

The study also showed that graywater would be less popular in the refugee camps, among illiterate people, and among people of very high income and very low income.

6.2 RECOMMENDATIONS

1. A key factor in the success of convincing people to use graywater is the existence of dual plumbing system in the house since such system is a significant factor in the cost of installation as revealed by many studies. Therefore, if graywater reuse is to be encouraged by a city, the city should encourage – or even mandate – the existence of a dual plumbing system during the construction of the house. A color coding system for the plumbing system should be adopted and well introduced to the engineers and construction people.
2. Since the cost of constructing and maintaining a graywater system plays an important role in the people's decision to use graywater, further research (including scale economic studies) should be carried out to investigate the use of graywater at the community level to reduce the costs.
3. Clear and applicable graywater rules should be developed in order to achieve two main goals, which are: to encourage the use of graywater and to use it safely. The rules should take into account the cost of graywater systems, which plays a significant role in people's decision. Developed rules should also consider easier

permitting procedures to encourage the use of graywater. The rules should also include clarifications about the best soaps, detergents, and shampoos to use in order to minimize the effects on plants and soils.

4. Appropriate risk analysis should be performed to clarify the risks associated with the reuse of graywater for the regulating agencies. Based on the results of the risk analysis, new standards for graywater treatment (specific to graywater) should be developed.
5. The use of the traditional indicator organisms (e.g. Fecal coliforms, *E. coli*) should be reviewed since they do not truly represent the existence of pathogens in graywater (both in number and in persistence to disinfection). Proper indicator organisms should be used for graywater.
6. Before adopting a graywater treatment system in a country, the general graywater characteristics should be well known since such characteristics will vary by factors like the amount of water consumption and the water use in the house.
7. Disinfection is a treatment process that should always be included. UV disinfection seems to be the most reliable and the easiest to use by a homeowner. However, guidance should exist on the proper disinfection dose that should be used to ensure sufficient disinfection of pathogens. Specifying the dose would require

combining both the flow rate and the UV intensity along with a target pathogen.

8. The potential clogging of drip irrigation system as a result of graywater application should be investigated.

9. The mechanism of alternating the application of both graywater and tap water should be further investigated to finally reach the optimum and safest graywater application for the plants and soils. Diluting graywater with tap water seems to be a better approach for the health of soil, but this needs to be confirmed by studies comparing the two approaches (dilution with tap water vs. alternating between graywater and tap water).

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Appendix

Results of Graywater Treatment Experiments

	Date	TSS	TDS	Turb.	COD	BOD	TC (#/100 ml)	FC (#/100 ml)	*E. coli* (#/100 ml)	HPC (#/ml)
Scheme I	09.27.2006	31.5	--	123	352	94	--	--	--	--
	09.27.2006	20.0	--	124	354	140	--	--	--	--
	11.15.2006	5.5	121.5	90	254	102	2.80×10^{7}	1.70×10^{5}	1.00×10^{4}	2.60×10^{6}
	11.15.2006	20.0	115.7	90	262	93				
	02.07.2007	8.5	93.5	79	292	101	2.64×10^{7}	8.90×10^{5}	1.00×10^{4}	1.47×10^{8}
	02.07.2007	14.0	93.0	77	286	86				
	05.02.2007	23.3	138.3	62	267	76	6.40×10^{6}	5.30×10^{5}		
	05.02.2007	25.7	146.7	66	259	103				
Scheme II	10.06.2006	--	--	--	--	--	3.40×10^{5}	1.00×10^{5}	1.00×10^{4}	5.90×10^{6}
	11.01.2006	92.0	--	--	256	54	3.00×10^{6}	4.20×10^{5}	1.00×10^{4}	2.06×10^{8}
	11.01.2006	--	--	--	253	75	--	--	--	--
	11.09.2006	--	--	--	--	--	8.00×10^{7}	1.60×10^{6}	1.00×10^{4}	1.98×10^{8}
	12.05.2006	91.0	123.0	181	328	41	2.60×10^{8}	1.26×10^{4}	9900	3.20×10^{8}
	12.05.2006	93.5	139.7	156	307	43	--	--	--	--
	12.12.2006	--	--	101	232	--	2.00×10^{7}	3200	300	1.00×10^{5}
	12.12.2006	--	--	117	227	--				
Scheme III	10.06.2006	12.0	142.0	34.2	111	24	1.00×10^{6}	340	10	6.00×10^{5}
	12.13.2006	11.6	150.7	34.7	105	20				
	01.09.2007	8.6		40.5	126	20	9.00×10^{4}	80	10	2.73×10^{6}
	01.09.2007	7.2		40.8	126	20				
	02.14.2007			26	119		5.50×10^{5}	210		
	02.14.2007			26	119					
	02.27.2007			15.2	80					
	02.27.2007			15.2	80					
	03.08.2007			29.0	105					
	03.08.2007			29.0	105					
	04.04.2007			14.4						
	04.04.2007			15.1						
	04.11.2007			14.1	52					
	04.11.2007			14.3	52					
	04.25.2007	16.67	155.3	17.1	102	10				
	04.25.2007	14.67	154.3	16.1	102	9				
	09.10.2007			7.7	64					
Scheme IV	10.06.2006		150.0	32.9	106			10	0	3.30E+04
	12.14.2006		176.6	32.2	100					
	01.09.2007	1.67		37.2	117	18	400	10	0	2.10E+04
	01.09.2007	0.28		37.5	117					
	02.14.2007	12.50		25.6	115		470	70	0	
	02.14.2007	10.75		25.3	111					
	02.21.2007	13.67	136.3	17.5	85		600	50	0	
	02.21.2007	15.28	126.9	17.7	82	7				
	02.27.2007	17.50	120.6	12.7	67	8	280	38	0	500
	02.27.2007	15.28	113.3	13.1	66	10				
	03.08.2007	11.67	90.7	27.5	94	16	172	2	0	

	03.08.2007	9.00	93.0	27.5	95	14				
	04.25.2007	12.67	134.7	14.4	84		870	156	0	1110
	04.25.2007	13.33	132.3	14.5	83					
	05.16.2007			9.4	67	8				
	05.16.2007			9.4	68	8				
Scheme V	10.06.2006	20.25	110.3	5.0	55	6.7	64	13	0	
	03.21.2007	20.25	101.8	5.1	51	5.8				
	04.04.2007	35.50	109.0	12.1			113	19	0	4510
	04.04.2007	50.00	101.0	12.0						
	04.11.2007	27.67	93.7	13.6	46		91	16	0	
	04.11.2007	14.00	102.3	13.6	44					
	09.10.2007	20.00		6.6	60	18				
	09.10.2007			6.7	56	18				
Scheme VI		24.33		61.9	254		19100	390	10	
		25.00		59.7	255		31000	5100	3	
Scheme VII		22.33		63.7	241		490	30	10	
		23.75		64.6	247		4600	131	4	