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Impact of Treated Grey Water on Physical and Chemical Soil Characteristics

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DEDICATION

For my Mother, the soul of my Father, Sisters and Brothers

For My Wife and Kids (Fares & Massa)
For all those, who supported me all the time

Abdalrazzaq Aburahma
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الخلاصة

الغرض من هذا العمل هو توفير المعلومات عن التربة المروية بللمياه الرمادية المعالجة في المنطقة شبه الجافة ذات مناخ البحر الأبيض المتوسط - لفلسطين. تم جمع عينات التربة من ثلاثة حدائق منزلية في قرية بلعين التي يتم ريها بللمياه الرمادية المعالجة على فترات مختلفة بمدى 15 عاما من الري. تم جمع عينات من التربة على عمقين 30سم و 60 سم، وخلال المواسم الرطبة والجافة. تم تحليل عينات التربة التي تم جمعها من النواحي الفيزيائية المختلفة (النفاذية، المسامية والكثافة الظاهرية) والعوامل الكيميائية (مثل الزنك، المنجنيز، النحاس، الحديد، ودرجة الحموضة). بينت النتائج أن اختلاف مواسم الري تؤثر على نوعية التربة المروية بـالمياه الرمادية المعالجة. لم يكن هناك أي أثر سلبي ملحوظ على نوعية التربة بسبب الري بالمياه الرمادية المعالجة بعد فترة طويلة تصل الى 15 عاما. بقيت حموضة التربة ضمن المعدل الطبيعي من 6.5-8 مع الانخفاض الواضح خلال موسم الجفاف مما يشير الى رشح الحوامض خلال موسم الأمطار. وتضاعف تقريبا محتوى التربة من الحديد أثناء موسم الجفاف مقارنة مع موسم الأمطار (من حوالي 15000 ملغ / كلغ إلى 300000 ملغ / كلغ) على عمق 60 سم، ولكن لوحظ انه لا يوجد فرق على عمق 30 سم. هذا يبين غسل عنصر الحديد خلال موسم الأمطار إلى مستوى الحديد تقريبا في التربة المروية بمياه عذبة. لم يتأثر النحاس والزنك في التربة عن طريق الري بللمياه الرمادية المعالجة ؛ مع الاقرار ان نسب تواجد عنصري النحاس والزنك كانت أقل من حد الكشف في المياه الرمادية المعالجة. نفاذية التربة انخفضت خلال موسم الجفاف خاصة في عند عمق 60 سم (7.72E^{-8}m/s) لكنها تعود خلال موسم الأمطار إلى قيمة (4.15E^{-7} m/s) الذي هو أفضل من ذلك للتربة المروية بمياه عذبة (1.10E^{-8} m/s) ومن الجدير ذكره ان بقي معامل النفاذية التي في النطاق المعتدل حسب تعريف منظمة الأغذية والزراعة (10^{-8} - 10^{-6} m/s) في جميع عينات التربة التي تم اختبارها. نسبة امتصاص الصوديوم (SAR) كانت للمياه الرمادية المعالجة في حدود (5.2–7.8) وهو ما يقل عن القيم الموصى بها من قبل المعاير الفلسطيني والمعايير الأردنية. حيث ان التربة تحفاظ على مستوى نفاذيتها الأصلي بعد الري بالمياه الرمادية المعالجة لحوالي 15 عاما، وهذا يعزز الاعتماد على نسب امتصاص الصوديوم الموصى بها من قبل المواصفات الفلسطيني والمعايير الأردنية في منطقة البحر الأبيض المتوسط (في المواسم الرطبة والجافة). يتراكم الكلور خلال موسم الجفاف على عمق 60 سم، ولكن ليس على عمق 30 سم، ثم يتم غسل التربة خلال موسم الأمطار ليصبح تركيز الكلور مماثل للتربة المروية بالمياه العذبة. مع العلم أن تركيز الكلور في المياه الرمادية المعالجة المستخدمة للري كان ضمن الحد المسموح به (350 ملغ / لتر). تركيز المنجنيز في التربة زاد خلال فترة الجفاف عند أعماق 30 سم و 60 سم، وعادت قيمة الى وضع التربة الطبيعي والمروية بمياه عذبة وذلك خلال موسم الأمطار. استنادا إلى نتائج هذا البحث ، يمكن أن ن خلص إلى أن إعادة استخدام المياه الرمادية المعالجة في الري سليما من الناحية البيئية فيما يتعلق بنوعية وخصائص التربة الزراعية في فلسطين.

Abstract

The purpose of this work was to provide information about soil irrigated with treated grey water in the semi arid Mediterranean region of Palestine. Soil samples were collected from three home gardens in Billin Villages irrigated with treated grey water over different periods of as long as 15 years. Soil samples were collected at two depths of 30 and 60 cm, and during wet and dry seasons. The collected soil samples were analysed for various physical parameters (permeability, porosity and bulk density) and chemical parameters (like Zn, Mn, Cu, Fe, pH). The results revealed that seasonal variation influences soil quality when irrigated with treated grey water. There was no noticeable accumulative negative impact on soil quality due to irrigation with treated grey water after a period of as long as 15 years. Soil pH remained within the normal range of 6.5-8 with an apparent decrease during dry season suggesting acid leaching during wet season. Soil Fe content was almost doubled during dry season as compared with wet season (from about 15,000 mg/kg to 30,000 mg/kg) at 60 cm depth, but no difference was noticed at 30 cm depth. This reveals Fe washing during the wet season to almost Fe content in blank soil. Cu and Zn in soil were not influenced by treated grey water irrigation; admitting Cu and Zn were below detection limit in the irrigation treated grey water. Soil permeability decreased during dry season especially at 60 cm depth ($7.72E^{-8}$ m/s) but recovered during wet season to a value of ($4.15E^{-7}$ m/s) that is even better than that of the blank soil ($1.10E^{-8}$ m/s) Worth mentioning that permeability coefficient remained in the moderate range defined by FAO (10^{-6} - 10^{-8} m/s) in the all tested soil samples. The grey water SAR was in the range of (5.2 – 7.8) which is below the recommended values by the Palestinian and the Jordanian standards. Since soil maintained its original permeability after being irrigated with treated grey water for around 15 years, this promotes the adoption of the recommended SAR values by the Palestinian and the Jordanian standards in the Mediterranean region (with wet and dry seasons). Cl^- accumulated during dry season at the depth of 60 cm, but not at 30 cm, and then washed out during the wet season to recover again to similar concentration as of the blank soil. Noting that Cl^- in the irrigation treated grey water was within the standard value (350 mg/l). Mn concentration in soil increased during dry period at 30 and 60 cm depths, and recovered to normal blank value during wet season. Based on the overall results of this research, it can be concluded that reusing treated grey water for irrigation is environmentally sound with respect to soil quality in Palestine.

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LIST OF ABBREVIATIONS

BOD_5	Biochemical Oxidation Demand
Ca	Calcium
Cl^-	Chloride
cm	Centimeter
Cu	Copper
EC	Electrical conductivity
EQA	Environment Quality Authority
gm	Gram
GW	Grey Water
HCO_3	Bicarbonate
K	Potassium
kg	Kilogram
km	Kilometer
Mg	Magnesium
mm	Millimeter
Mn	Manganese
Na	Sodium
NGOs	Nongovernmental organizations
Pb	Lead
ppm	Part per million
PHG	Palestinian Hydrology Group
PWA	Palestinian Water Authority
BDL	Below detection limit
SAR	Sodium Adsorption Ratio
SOM	Soil organic matter
TGW	Treated grey water
TP	Total phosphate
TWW	Treated wastewater
UCL	Upper control limit
WWTP	Wastewater treatment plant
WHO	World Health Organization
Zn	Zinc

Chapter 1

Introduction

1.1 Introduction

The problem of water supply in Palestine is one of the most difficult problems facing Palestinian society. The lack of water resources and the competition between different uses i.e. domestic, agricultural and industrial is increasing with time. Indeed, the limitation of water resources for the Palestinians is mainly due to the Israeli occupation authorities' laws and practices. Israeli settlements control water resources, waste a lot of fresh water quantities, and produce a lot of wastewater which is disposed on Palestinian land contaminating the soil and the limited water resources available for Palestinians.

Cesspits used by Palestinians to dispose their wastewater are a major source of pollution to water resources. These cesspits also form a large burden on the income of the Palestinian families, where some families spend about 20% of their monthly income to manage water and wastewater at house level (PHG, 2007).

Palestine is one of the most water-poor countries of the Middle East due to natural and artificial constraints. It is also one of the most highly populated, a fast developing country in the region and is thought to be under significant environmental stress. Urgent actions are required to mitigate this situation, including environment protection and the utilization of the available non-conventional water resources, precisely, the utilization of the treated wastewater. At present, water needs exceed the available water supply, the gap between water supply and water needs is steadily growing and is calling for the adoption of the integrated water resources management approach and the mobilization of any additional conventional and non-conventional water resources. Treated wastewater is seen as one of the promising solutions that can assist in partially filling the gap of the growing needs for water (Mahmoud and Mimi, 2008). Most of the wastewater is generated from households . The domestic wastewater usually contains disease- causing pathogens and contain heavy metals or toxic components. Controlled treatment of wastewater is essential to reducing potential pollution of surface or groundwater. In addition, treated wastewater can be an excellent source for irrigation purposes.

Food security is at risk because the amount of fresh water that can form sustainable supplies to people is reaching its limits because of Israeli restrictions, which is extended whole of Palestine. The current main source of income is agriculture for the majority of the population. A state of conflict and competition over land and water resources has arisen and continues to prevail. This has had an adverse impact on the living and food security conditions of the household.

Properly treated wastewater can be reused to reduce the demand on high quality freshwater resources. Wastewater recycling increases the availability of water supply, reduces vulnerability to droughts and enables greater human benefit with less use of fresh water. By reducing the need for fresh water and wastewater discharges, water recycling has the potential to make a substantial contribution to meeting human water needs, and reducing mankind's impact on the world's water environment. As in many developing countries, sanitation tends to receive less attention and fewer financial resources than water supply. This leads to a lack of maintenance even for existing wastewater treatment plants (WWTP), as is the case for example in Morocco and Algeria where more than half of the WWTP are not functioning properly (Coppola *et al*., 2004). In many small-to-medium-sized communities, wastewater treatment requirements are met using conventional on-site septic tanks, with effluent being disposed into the groundwater.

In Palestinian rural areas the sewage problem is even more complicated and wastewater management at all stages is inadequate. The existing on-site sewage disposal in rural areas (the majority of the households in the West Bank villages use septic tanks and cesspits) does not accommodate the vast increases in wastewater generated by the population. Thus, untreated sewage contaminates groundwater, wadi beds, and agricultural fields and causes critical community and environmental health risks. Palestinian NGOs with international funds are the only organizations involved in the construction of wastewater treatment plants in the rural areas in the West Bank. For example Palestinian Hydrology Group (PHG), have implemented small scale, low-cost treatment systems of different types and sizes serving between 50 and 1000 inhabitants.

Scarcity of renewable freshwater resources in the Middle East forces all countries to increasingly rely on alternative water sources, such as treated wastewaters (TWW) to sustain irrigated agricultural production. Depending on treatment technology and origin, TWW may contain elevated concentrations of salts, contaminants (heavy metals, xenobiotics) and organic matter which may affect soil structure, soil micro-organisms, plant and groundwater quality if used for agricultural irrigation (Saskatchewan, 2004).

Generally, wastewater treatment and reuse projects in the West Bank are associated with many obstacles, which are mainly political, financial, social, institutional and technical. Political reasons and public acceptance could be considered the main factors affecting the wastewater reuse in agriculture (Mahmoud and Mimi, 2008).

The first house on site grey water treatment plant with effluent reuse has been in operation continuously in Bilin village- Ramallah governorate since 1997 **(**Burnat, 1997 , Burnat *et al*., 2010**).** This site is also an attractive site to investigate the long term effect of treated grey water on soil properties. Bearing in mind that Palestine is characterized with Mediterranean climate with short cold rainy season and long hot and dry period, this climatic variant is expected to influence the soil quality.

Treated grey water characteristic still needs more investigation in order to determine the concentrations of various organic and in organic elements, in order to identify the environmental impacts of treated grey water reuse, including soil physical and chemical properties.

1.2 Research objectives

The main aim of this research study is to asses and evaluate effects of long term reuse of treated grey water on physical and chemical soil characteristics in the West Bank. The specific objectives are:

- To assess soil physical properties (Permeability, Porosity, Soil texture), following long term wastewater application of treated grey water, in different irrigation periods.
- To monitor the impacts of treated grey water on soil chemical properties (pH, Salinity (EC), and heavy metals.
- To assess effect of seasonal variations on soil quality (wet season and dry season).

1.3 Main research question

The aim of this research study is to answer the following question**:**

Do the current practices of long term reuse of treated grey water in irrigation have a noticeable impact on soil characteristics?

Chapter 2

Literature Review

2.1 Introduction

Treated wastewater resource is an environmental, social and economical good that needs to be managed in appropriate way. Palestine, as in most of the neighbouring countries in the Middle East region, acknowledges the importance of this resource in improving the water deficit by reusing the treated wastewater in agricultural production, industrial sector and recharges the aquifer. However, this resource is strictly sensitive and has adverse impacts on the public health. Both negative and positive impacts of the treated wastewater resource should be considered.

The shortage of fresh water resources is an ever-increasing concern worldwide. Particularly in the Middle East and North Africa, the availability of water is reaching critical levels and chronic water stress is expected to continue to dominate the region. As our awareness of the natural limitations of this resource has grown in this region, the reuse of wastewater has taken on greater significance. For many countries, wastewater reuse is now a major part of their overall water management plan. For example, in some Mediterranean countries more than 70% of its treated wastewater is reused for agricultural irrigation. Along with the reuse of wastewater for irrigation comes the need to understand potential environmental impacts of this practice. Large-scale wastewater irrigation programs typically are preceded by conventional treatment measures. Even so, negative impacts, such as the development of soil hydrophobicity, have been documented (Chen *et al*., 2003; Tarchitzky *et al*., 2007).

2.2 Characteristics of household grey water

The characteristics of grey water produced by a household will vary according to the number of occupants, the age distribution, lifestyle, health status and water usage patterns.

There are essentially three different grey water streams, they are:

1. Bathroom grey water (bath, basin, and shower) contributes about 55% of the total grey water volume. Bathroom grey water can be contaminated with hair, soaps, shampoos, hair dyes, toothpaste, lint, body fats, oils and cleaning products. It also has some faecal contamination (and the associated bacteria and viruses) through body washing (Environmental Health Directorate of the Department of Health, 2005).
2. Laundry grey water contributes about 34% of the total grey water volume. Wastewater from the laundry varies in quality from wash water to rinse water to second rinse water. Laundry grey water can have faecal contamination with the associated bacteria and viruses, lint, oils, greases, chemicals, soaps, nutrients and other compounds(Environmental Health Directorate of the Department of Health, 2005).
3. Kitchen grey water contributes about 11% of the total grey water volume. Kitchen grey water is heavily polluted with food particles, cooking oils, grease,

detergents, and other cleaning products such as dishwashing powders. The detergents and cleaning products may be alkaline and contain chemicals that are harmful to soil structure, plants and groundwater. The solid food particles and fats can solidify and are not readily broken down by soil organisms; this can result in blockages in the land application system. It can also cause the soil to become water repellent. It is for these reasons that kitchen wastewater may not be well suited for reuse in all types of grey water systems. (Environmental Health Directorate of the Department of Health, 2005).

2.3 Composition of household grey water

Table 2.1 presents the microbiological quality (the number of thermotolerant coliforms) of grey water from various sources in a residential dwelling. Thermotolerant coliforms are also known as faecal coliforms (expressed as colony forming units per 100 ml) and are a type of micro-organism which typically grow in the intestine of warm blooded animals (including humans) and are shed in their millions to billions per gram of faeces. A high faecal coliform count is undesirable and indicates a greater chance of human illness and infections developing through contact with the wastewater.

Table 2.1 : Treated grey water biological Characteristics

Characteristic	**Unit**	**limits**
Escherecia coli	cfu/100ml	**
Intestinal Helminthes Eggs	egg/ L	≤1

Source: Water -Reclaimed grey water in rural areas- Jordanian standards (2008)

The chemical and physical quality of treated grey water is shown in Table 2.2. The high variability of the grey water quality is due to factors such as source of water, water use efficiencies of appliances and fixtures, individual habits, products used (soaps, shampoos, detergents) and other site specific characteristics.

Table 2.2 : Treated grey water Physical and Chemical Characteristics

Characteristic	Unit	limits
BOD5	mg/l	300
COD	mg/l	500
DO	mg/l	2
TSS	mg/l	150
pH	Unit	6--9
NO3	mg/l	50
T-N	mg/l	70
Turbidity	NTU	25
Phenol	mg/l	0.05
MBAS	mg/l	25
TDS	mg/l	1500
T-P	mg/l	15
Cl	mg/l	350
SO4	mg/l	500

Source: Water -Reclaimed grey water in rural areas- Jordanian standard (2008)

2.4 Treated wastewater reuse

The interest in reusing wastewater for irrigation is rapidly growing in these Mediterranean countries. Consequently the reuse of wastewater for agriculture is highly encourage. Irrigation with treated municipal wastewater is considered an environmentally sound wastewater disposal practice compared to its direct disposal to the surface or ground water bodies. In addition, wastewater is a valuable source of plant nutrients and organic matter needed for maintaining fertility and productivity levels of the soil. On the other hand, wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts. Consequently, mismanagement of wastewater irrigation would create environmental and health problems to the ecosystem and human beings.

When wastewater will be used continuously as the sole source of irrigation water for field crops in arid regions, excessive amounts of nutrients and toxic chemical substances could simultaneously be applied to the soil-plant system. This would cause unfavourable effects on productivity and quality parameters of the crops and the soil. Therefore, management of wastewater irrigation should consider the wastewater nutrient content, specific crop nutrient requirements, soil nutrient content and other soil fertility parameters.

Wastewater is recognized to have direct effect on soil chemical properties. It affects supply of mineral macro and micro nutrients for plant growth, soil pH, soil buffer capacity, and soil CEC. Mohammad and Mazahreh (2003**)** found at the end of the growing season that soil pH was significantly lower when wastewater application, and they attributed this decrease to the high content of ammonium in wastewater, which its nitrification would serve as a source of hydrogen ions thus causing a decrease in soil pH. It has also been found that wastewater irrigation increased the level of soil salinity due to the wastewater salt content. Other researchers found that wastewater irrigations increased soil nitrogen (N), phosphorus (P) and potassium (K), while heavy metal levels tended to generally increase in soil with increasing number of years of irrigation. In contrary, also they found that soil (Zn) and (Cu) were not significantly affected by wastewater irrigation.

Arid and semiarid regions are characterized by evapo-transpiration that exceeds precipitation during most of the year. Therefore, agriculture in these regions relies on supplementary irrigation to enable productive crop growth. At the same time, one of the main environmental problems in these regions is a shortage of freshwater, which is expected to become more severe in the future because of the growing pressure on water resources, as well as climate change. Therefore, in these regions, one of the challenges facing agriculture, which commonly uses large amounts of water, is to find new sources of water for irrigation. One of the alternatives that have become more common in recent years is the reuse of treated domestic sewage (effluent) for irrigation. Currently, the effluent used for irrigation is mainly obtained after secondary (biological) treatment. However, this effluent differs from freshwater in its salinity, sodicity, pH, and concentrations of microelements, nutrients, dissolved organic matter (DOM), and total suspended solids (TSS), all of which are significantly higher than in freshwater. With regard to soil hydraulic properties, these differences in the quality of the effluent can affect water movement through the soil, either because of differences in the compositions of the percolating solutions, or as a result of changes in the chemical and physicochemical properties of the irrigated soil; changes that could affect soil structure (Lado *et al*., 2009).

Because of the growing interest in the use of effluents for irrigation, and in light of their possible impacts on soils, water resources, and agricultural production, several authors have studied the effects of effluent irrigation on the soil chemical and physical properties. Several mechanisms have been hypothesized to cause changes in soil hydraulic properties when effluent is used for irrigation. The suspended solids in the effluent can block the water-conducting pores in the soil and, in addition, effluent irrigation can change soil chemical and biological properties, as exchangeable sodium percentage (ESP), salinity, organic matter content and quality, and micro-organism activity, all of which can affect the soil-structure stability and soil-pores distribution. Organic constituents applied with the effluent can also increase soil water repellency**.** These effects of effluent irrigation on soil hydraulic properties can be classified into two main types: (i) direct effects—changes in soil hydraulic properties that occur during the movement of the effluent through the soil profile; and (ii) indirect effects changes in soil hydraulic properties that occur after irrigation with effluents, when the soils are leached with rainfall or irrigation water other than effluent. (Lado *et al*., 2009).

In many parts of the world, treated wastewater has been successfully used for irrigation, and many researchers have recognized its benefits. In the Mediterranean countries, treated wastewater is increasingly used in areas with water scarcity and its application in agriculture is becoming an important addition to water supplies. In Greece the possibility of wastewater reuse for irrigation of vegetables has been studied by (Kalavrouziotis *et al*., 2010). They concluded that the future perspectives favour such a reuse, but to accomplish social acceptance, more work is necessary to decrease the health risk factor involved and make the reuse safer.

Several studies have shown the advantages and disadvantages of using wastewater for irrigation of various crops. The reuse of treated wastewater is a good option for increasing water supplies to agriculture. One of its benefits is the plant's use of the water's nutrients and therefore a reduction in the pollution load that wastewater contributes to the surface water supply. However, depending upon its sources and treatments, sewage wastewater may contain high concentrations of salts, heavy metals, viruses and/or bacteria and the reclaimed wastewater application may create undesirable effects in soils and plants with direct effects on soil suitability for cultivation and water resources availability. Current water quality criteria for agricultural reuse have mainly focused on total dissolved solids (TDS), salinity aspects, and the microbiological factors that may cause sanitary problems **(**Ayers *et al*., 1994**).** More specific water quality parameters for the reuse of reclaimed wastewater have been presented in different researches, and there is a considerable interest in the long-term effects of reclaimed wastewater on crops intended for human consumption (Francisco *et al*., 2009).

The use of wastewater for irrigation is well established in arid and semiarid areas around the world. The main advantage of wastewater irrigation, in addition to the

implied nutrient input, is the constant availability of this water resource. Irrigation with untreated wastewater may increase soil organic matter, nitrogen and concentrations of major cations. However, it has been associated with negative impacts on health. Moreover, long-term irrigation with untreated wastewater could lead to a heavy metal accumulation, and a consequent loss of soil quality, depending on the origins of the wastewater. For these reasons, treatment of wastewater is generally recommended before its use in irrigation. The effects on soil properties of irrigation with treated wastewater over different lengths of time have been studied by several authors. Each reported an increase in soil salinity and Na accumulation, with higher values associated with longer periods of treated municipal wastewater irrigation. Such increases in salinity can lead to a decrease in aggregate stability and soil hydraulic conductivity, however, the presence of Ca and Mg in calcareous soils can mitigate this deleterious effects did not observe any changes in soil biological and biochemical parameters after 3 years of irrigation with a tertiary-treated domestic effluent, while found an enhancement of soil enzyme activities following
10 years of treated municipal wastewater irrigation (Adrover *et al*., 2010).

2.5 Trace elements in the environment

Trace elements are released into the environment from the natural weathering of rocks and minerals and from various sources related to human activity. Although the concentration of these elements occurring in nature is generally low, they may directly or indirectly affect the chemical composition of foodstuff and animal feed, potable water supplies and airborne particulates and dust. The practical implication of trace elements in the environment relates to their availability for plant uptake from the soils and their release into water systems. The content of trace elements in soil is an indication of possible excesses or deficiencies for plant nutrition and ultimately animal and human health (Haluschak *et al.*, 1998).

2.6 Factors affecting the concentration and distribution of trace elements in soil

The wide range in concentrations of trace elements observed in the soil and water environment is the result of interaction between various factors affecting geological weathering and soil forming processes (Haluschak *et al.*, 1998):

- mineralogical and chemical characteristics of bedrock,
- soil texture (amounts of sand, silt and clay), Mean concentration of trace elements within the broad textural groups increases with increasing clay content following similar trends noted within individual textural classes
- the effect of glaciation in eroding bedrock material and in the transport and deposition surficial deposits and soil parent materials,
- local soil and hydrological conditions affecting processes of soil formation, soil development and availability of trace elements for plant uptake or concentration in surface or ground water. Weathering during soil formation results in physical disintegration and chemical decomposition of minerals and the release of metals from the parent material to the soil and to solution in soil water and ground water. The practical implication of

trace elements in the environment relates to their availability for plant uptake from the soils and their release into water systems.

2.7 Heavy metal content in soils irrigated by treated wastewater

Soil is an essential natural resource for support of human life; but with time, its degradation has been constantly increasing due to the deposition of pollutants. The background concentration of metals in virgin soil depends primarily on the bedrock type from which the soil parent material was derived. In addition, anthropogenic inputs may increase metal concentrations, especially in highly industrialized parts of the world producing rare and heavy metals. Until recently, most studies concerning soils related to plant nutrition, with most studies published overseas. The study of Maldonado (2008) demonstrated that among the variables, soil type was the only factor showing a statistical difference, which indicates that the resulting concentrations can be largely explained by the type of irrigation the soil had at the time. It was noted that concentrations of nickel, chromium, copper, iron and boron concentrated in deeper soil layers while potassium, sodium, cadmium, and lead showed the opposite effect. In areas where elements were expected to be present in lesser concentrations, the opposite effect was observed with respect to other areas. Instead, sodium, cadmium, chrome, iron and boron, showed higher concentrations, which is contradictory to the established hypothesis for being an area lacking in irrigation. This may be explained by natural concentrations of said elements or, in the case of cadmium, by airborne contamination from the Avalos smelter. It was also noted that organic material is an important variable and that it can influence the mobility of metals in those areas where high concentrations, coincide with constant irrigation. Clearly, the area has been constantly exposed to certain health hazardous metals. More attention is recommended, even though at this time a wastewater treatment plant has been built and partly treated water is used to irrigate the crops (Maldonado *et al.,* 2008). Heavy metals such as lead, chromium, arsenic, zinc, cadmium, copper, mercury and nickel are comcommonly found in contaminated soils (Raymond *et al.*, 2011).

In Saudi Arabia research study was conducted on effect of treated domestic wastewater on physical and chemical characteristics. The research results showed that there was no significant change in the sand, silt, and clay fractions after 458 days of treated domestic wastewater irrigation. The tested parameters included soil pH, which remained within moderately alkaline region after 458 days of treated domestic wastewater irrigation (Al-Othman, 2009).

Soil is a porous media that contains solids, liquids, and gases created at the land surface by weathering processes, derived from biological, geological, and hydrological phenomena (Sposito, 1989). soil define as the medium that supports plant growth, and modulates nutrients and pollutants in the environment (Wang *et al.*, 2003). The soil also works as the main support and fixing agent for the plants body. Table 2.1 shows the typical trace element contents in soil.

Table 2.3: Typical trace element contents in soils in mg/kg. Data are given for the range that can be observed frequently; according to Adriano (2001), Kabata-Penias (2000)

Element	Soil –mg/kg
Antimony	0.1 – 2.0
Arsenic	1.0 - 10
Barium	100 - 1000
Beryllium	0.1 - 10
Boron	2.0 - 100
Cadmium	0.05 – 1.0
Chromium	10-50
Cobalt	1.0 - 10
Copper	10-40
Fluorine	100 - 500
Iron	10000 – 50000
Lead	10 – 30
Manganese	300 - 1000
Mercury	0.05 – 0.5
Molybdenum	0.5 – 2.0
Nickel	10-50
Selenium	0.1 – 2.0
Thallium	0.02 – 0.5
Tin	0.1 - 10
Vanadium	30 - 150
Zinc	20 - 200

2.8 Long term impact of treated wastewater reuse on chemical and physical soil properties

Several authors investigated the impact of long term irrigation with treated wastewater on the

the alteration of soil properties and accumulation of trace metals in soil profiles.(Zhang *et al*., 2007**)** monitored different plots from Palmdale, California that had been irrigated with effluents for various lengths of time (3, 8, and 20 years, respectively). They showed that soil pH values were significantly ($p < 0.05$) lowered in plots with 20-year irrigation to a depth of 140 cm, while EC was elevated for all three plots compared with control. OM, TC and TN contents increased in the top 10-cm soil layers in plots with 8- and 20-year effluent irrigation. Irrigation with effluents also increased both the total and EDTA-extractable metals in the fields. It showed that long-term effluent irrigation could be of agricultural interest due mainly to its organic matter concentrations and nutrients input, however, trace contaminants such as heavy metals in the upper horizons may be accumulated, which may eventually lead to deterioration of soil and groundwater quality and affect the sustainability of land-based disposal of effluent. Similarly, Adrover *et al*. (2010) investigated the chemical properties and biological activity of 21 arable soils, irrigated for more than 20 years with secondary-treated wastewater in the Mediterranean island of Malorca in Spain. Soil quality was evaluated by measuring cation exchange capacity, pH, calcium carbonate equivalent, soil organic matter, total nitrogen, available phosphorus, water-soluble organic carbon, soil microbial biomass, soil basal respiration, and the activities of the enzymes dehydrogenase, β-glucosidase and alkaline phosphatase. No negative effects of the irrigation treatment were observed on the measured soil parameters. Indeed, soil water-soluble organic carbon, soil microbial biomass and β-glucosidase and alkaline phosphatase activities increased under treated wastewater irrigation. Biological activity of soils irrigated with treated wastewater was affected mainly by soil organic matter content. Although the typical crop management of alfalfa, and other forage crops associated with treated wastewater irrigation, may have contributed to the increase of these parameters, the results suggest that irrigation with treated wastewater is a strategy with many benefits to agricultural land management (Adrover *et al*., 2010).

Zhang *et al*. (2007) investigated the effects of long term sewage irrigation on agricultural soil microbial structural and functional characterizations in Shandong, China. Soil samples taken from a sewage irrigation area, a partial sewage irrigation area and a ground water irrigation area (control area) were studied. It was found that the microbial utilization of carbon sources in sewage irrigation areas was much higher than that of control area ($P < 0.05$). With the increasing of the amount of sewage irrigation, microbial functional diversity slightly increased by the Biolog analysis; however, the amount of epiphyte decreased by the fatty acid methyl esters (FAME) analysis. The results also showed that the Cr, Zn contents were positively correlated with the values of average well colour development and the microbial diversity, while Hg content showed negative correlation with the microbial parameters. The study suggested that sewage irrigation resulted in an obvious increase of heavy metals content in soil ($P < 0.05$), although the maximum heavy metals concentrations were much lower than the current standard of China. Other soil basic characteristics such as cation exchange capacity (CEC), total nitrogen (N_t) and organic matter in sewage irrigation areas obviously increased ($P < 0.05$). Therefore, it is demonstrated that long-term sewage irrigation had influenced soil microorganisms and soil quality in the studied soils. As a result, it is important to monitor the changes in agricultural soils. Furthermore, the results also confirmed that the methods of Biolog and FAME are effective tools for the assessment of soil microbial structure/function and soil health (Zhang *et al*., 2007).

In India there is a gradual decline in availability of fresh water to be used for irrigation. As a consequence, the use of sewage and other industrial effluents for irrigating agricultural lands is on the rise particularly in peri-urban areas of developing countries. On the other hand, there is increasing concern regarding the exceedance of statutory and advisory food standards for trace metals throughout the world. Hence, a case study was undertaken to assess the long-term effect of sewage irrigation on heavy metal content in soils, plants and groundwater. For this purpose, peri-urban agricultural lands under Keshopur Effluent Irrigation Scheme (KEIS) of Delhi, India were selected where various cereals, millets, vegetable and fodder crops have successfully been grown. Sewage effluents, ground water, soil and plant samples were collected and analyzed mainly for metal contents. Results indicated that sewage effluents contained much higher amount of P, K, S, Zn, Cu, Fe, Mn and Ni compared to groundwater. While, there was no significant variation in Pb and Cd concentrations in these two sources of irrigation water and metal content were within the permissible limits for its use as irrigation water. There was an increase in organic carbon content ranging from 38 to 79% in sewage irrigated soils as compared to tubewell water-irrigated ones. On an average, the soil pH dropped by 0.4 unit as a result of sewage irrigation. Sewage irrigation for 20 years resulted into significant build-up of DTPA extractable Zn (208%), Cu (170%), Fe (170%), Ni (63%) and Pb (29%) in sewage-irrigated soils over adjacent tubewell water irrigated soils, whereas Mn was depleted by 31%. Soils receiving sewage irrigation for 10 years exhibited significant increase in Zn, Fe, Ni and Pb, while only Fe in soils was positively affected by sewage irrigation for 5 years. Among these metals, only Zn in some samples exceeded the phytotoxicity limit. Fractionation study indicated relatively higher build-up of Zn, Cu, Fe and Mn in bioavailable pools of sewage-irrigated soils. By and large, tissue metal concentrations in all the crops were below the generalized critical levels of phytotoxicity. Based on the soil to plant transfer ratio (transfer factor) of metals, relative efficiency of some cereals, millet and vegetable crops to absorb metals from sewage and tube well water-irrigated soils was worked out. Risk assessment in respect of metal contents in some vegetable crops grown on these sewage-irrigated soils indicated that these vegetables can be consumed safely by human (Rattan *et al*., 2005).

2.9 Long term impact of treated grey water reuse on chemical and physical soil characteristics

In Jordan, the use of treated grey water (GW) for irrigation in home gardens is becoming increasingly common. According to a study conducted by Mutah University and The Inter-Islamic Network on Water Resources Development and Management, Amman, Jordan on Effect of treated grey water reuse in irrigation on soil and plants, treated GW produced from 4-barrel and confined trench (CT) treatment units were used for irrigation of olive trees and some vegetable crops.

The quality of treated and untreated GW was studied to evaluate the performance of treatment units and the suitability of treated GW for irrigation according to Jordanian standard. Effect of treated GW reuse on the properties of soil and irrigated plants at Al-Amer villages, Jordan, has been investigated. The results showed that salinity, sodium adsorption ratio (SAR), and organic content of soil increased as a function of time, therefore leaching of soil with fresh water was highly recommended. The chemical properties of the irrigated olive trees and vegetable crops were not affected, while the biological quality of some vegetable crops was adversely affected (Al-Hamaiedeh *et al.*, 2010).

Glasshouse experiments were conducted to examine the effects of grey water irrigation on the growth of silverbeet plants, their water use and changes in soil properties. The experimental treatments included in the study were: irrigating with 100% potable water (control, treatment T0), irrigating with 100% grey water (treatment T1), irrigating with a mixture of grey water and potable water in 1:1 ratio (treatment T2) and irrigating alternate with potable water for one irrigation and grey water for the next (treatment T3). The pH and EC values of the grey water used in the study were 10.5 and 1358_S/cm respectively. Results showed that grey water irrigation had no significant effect on soil total N and total P after plant harvest, but there were significant effects on the values of soil pH and EC. Furthermore, there were no significant effects of grey water irrigation on plant dry biomass, water use and number of leaves. For the treatment that involved irrigating with 100% grey water (treatment T1), there was a significant increase in soil pH and EC when compared with the control and the other two irrigation treatments. The study indicated that irrigating silverbeet plants with potable water and grey water in an alternate pattern (treatment T3) had soil pH and EC levels similar to that of irrigation with 100% potable water. This also meant that irrigating alternate with potable water and grey water could reduce some of the soil health risks associated with the reuse of grey water (Pinto *et al.*, 2010).

A controlled study of the effect of grey water (GW) irrigation on soil properties was conducted, (Micheal *et al*., 2010). Containers of sand, loam and loess soils were planted with lettuce, and irrigated with fresh water, raw artificial GW or treated artificial GW. Grey water was treated using a recirculating vertical-flow constructed wetland. Soil samples were collected every 10 days for the 40-day duration of the study, and plant growth was measured. Soils were analysed for physicochemical and biological parameters to determine changes caused by the different treatments. It was demonstrated that raw artificial GW significantly increased the development of hydrophobicity in the sand and loam soils, as determined by water droplet penetration time. No significant changes were observed for the loess soil under all treatments. Observed hydrophobicity was correlated with increased oil and grease and surfactant concentrations in the soil. Zeta (ζ) potential of the soils was measured to determine changes in the soil particle surface properties as a result of GW irrigation. A significant change in ζ-potential (less negative) was observed in the raw artificial GW-irrigated sand, whereas no difference was observed in the loam or loess Soils irrigated with fresh water or treated GW exhibited no increase in hydrophobicity. Fecal coliform bacteria were absent or <10 CFU g^{-1} in soils irrigated with fresh water or treated GW, but at least 1 order of magnitude higher in raw artificial GW irrigated soils. Only in the last sampling event and only for the loess soil was plant growth significantly higher for fresh water irrigated vs. raw or treated GW irrigated soils. This study demonstrates that treated GW can be effectively used for irrigation without detrimental effects on soil or plant growth; however, raw GW may significantly change soil properties that can impact the movement of water in soil and the transport of contaminants in the vadose zone (Micheal *et al.*, 2010).

The potential public health risk associated with treated GW reuse for irrigation in home gardens has been investigated in the literature reviews. The possible increase in the number and rate of water born diseases due to GW reuse was studied using diarhea as indicator for these diseases. The concentration of some heavy metals in treated GW and the irrigated soil as well as the possible uptake of these metals by the long term irrigated plants have been determined.

Al- Hamaiedeh (2010) showed that there is no increase in the rate of water born diseases after GW reuse for irrigation. The accumulation of heavy metals in the soil was insignificant and the uptake of these metals by the irrigated plants did not occur (Al- Hamaiedeh, 2010).

Grey water contains significant concentrations of materials with potential negative environmental and health impact, such as salts (Friedler, 2004), surfactants (Wiel-Shafran *et al.,* 2006), oils (Travis *et al*., 2008), synthetic chemicals (Eriksson *et al*., 2002) and microbial contaminants (Gross *et al*., 2007). Surfactants and/or food-based oils have been identified as components of GW that can cause water repellency and reduce soil hydraulic conductivity (Lado and Ben-Hur, 2009; Travis *et al*., 2008; Wiel-Shafran *et al*., 2006). Other potential detrimental effects of wastewater reuse include soil aggregate dispersion from sodium accumulation (Misra *et al.,* 2009); microbial risks (Gross *et al.,* 2007); and enhanced contaminant transport (Graber *et al.,* 2001). Various studies show that the long and short terms application of treated and untreated wastewater influencing significantly physical and chemical soil proprieties, while very limited research studies demonstrate the long term application of treated and untreated grey water and its impact on physical and chemical soil properties.

This present research study was undertaken to study and compare the effects of treated grey water irrigation on three commonly used agricultural soils and a grey water treatment plants, with consideration of reused age with treated grey water during wet with absence of treated grey water irrigation, and dry season with irrigation by treated grey water.

2.10 **Soil classification in Palestine**

Palestine is relatively a small geographic area however the soils are remarkably diverse in their properties. This diversity is due to the variation in climatic, origin (parent material) and topographic features. The soils of Palestine have been the subject of many studies since the beginning of this century, when several attempts were made to classify, identify and even map the soils.

In the Jordan Valley, the main soil type according to Reifenberg, is Lisan marls. They are deposits of a former inland lake and consist of loose diluvial marls. The Lisan Marl soils are generally of a rather light nature, their clay content varies from approximately 10 to 20%. High concentration of lime content is present, which varies between 25 and 50%. Where there is no possibility for irrigation, the Lisan marls are covered with a very sparse growth of halophytic plants(Land Research Centre., 1999).

In the Eastern Slopes region, the main soil type are the semi-desert soils, the secondary soil types are the “terra rossa” and the mountain marls. For the semi-desert soils, the formation of sand and gravel is characteristic of desert weathering. As a result of the lack of rain, agriculture is only possible in those quite isolated places where scanty spring showers occur (Land Research Centre., 1999).

In the Central Highlands region, the main soil type is “terra rossa”. This is the most typical soil of the mountains in the West Bank and Gaza Strip and is the product of the Mediterranean climate and soil formation on hard limestone. Its soil reaction is generally neutral to moderately alkaline; and it has a high content of soluble salts. Both the high iron content and the low organic matter are responsible for the red colour. They are mainly of loamy texture. In addition to the “terra rossa” soils, mountain marl soils and alluvial soils are also present in considerable areas. Mountain marl soils are formed from the chalky marls of Senonian and Eocene age. These soils are well distinguished from the “terra rossa” as far as the vegetative cover is concerned. They are not very fertile because of their poor water holding capacity and the high lime content(Land Research Centre., 1999).

In the semi-coastal region, the main soil types are alluvial, “terra rossa” and mountain marls. Alluvial soils are distributed all over the region, but most typically occur in the vicinity of the agroecological sites. These soils are not considered as climatic or zonal soil types. In the West Bank, they are mainly found in the mountainenclosed basins and in the Plain of Jenin. The soils are formed by the deposition of alluviums transported by water. They are generally very deep and of clayey nature. The reddish or brownish alluvial soils brought down from the mountains have at many places been leached out of their lime content (Land Research Centre., 1999).

In the Gaza Strip, the main soil type originates from the dune sands. Dune sands are overlying alluvial soils in a shallow layer creating ideal conditions for fruit plantations. Citrus plantations dominate the area. These dune sands have exceedingly low water holding capacity and very high water permeability. In addition to the sandy soils, loess soils are also occurring in the Gaza Strip. These soils owe their origin mainly to the dust storms of the desert (Land Research Centre., 1999).

Chapter 3

Research Methodology

3.1 Introduction

The research methods involved collection of soil and grey water samples, and analyse them in the labs for selected parameters. Soil samples were collected from the study area, from three different home gardens of which are irrigated with treated grey water. Soil samples were collected in two periods, wet and dry seasons, during one year(June & December, 2010). 15 soil samples were collected during the two periods of sampling, and tested in the labs for two categories, physical tests and chemical tests. Soil samples were collected from the selected home gardens which are planted with Olive trees, Citrus, Almonds and flowers, irrigated separately with treated grey water. Three Soil samples irrigated by fresh water were collected as a control sample from each home garden. usually the families plowing the soil The home gardens seasonally

Physical tests for soil samples were analysed at Geotechnical and Materials Testing Centre (GMT), Ramallah, West Bank. Chemical Tests for soil samples were analysed at Birzeit University laboratories Centre.

Grey water samples were collected from three grey water treatment plants at the study area. The treated effluent samples collected and analysed at Birzeit

University laboratories during period of one and half month. The treated effluent samples were tested for biological and chemical tests.

3.2. Study area

Bilin is a Palestinian village located in Ramallah district, 5 Km eastern the Green Line and 17Km from Ramalah governorate- West Bank. Bilin is situated at an elevation of (300-400) m above sea level. The population of the village is about 1800 persons, living primarily on cultivation and temporary business. The village of Bilin and villages around-Saffa and Kharbatha Bani Hareth, suffer their daily life difficulties and lack of land, particularly after the construction of the Separation Wall aside the village, which penetrates through about 50 % of Bilin village lands, which is about 70% of its agricultural lands.

During summer time the conditions of the water supply become more sophisticated, when the Israeli company provides one-third of the required amount of water, assumed to be 2000 m^3/month, which lead to a manifest degradation in drinking water share per capita that reached 45 litres per capita per day including losses of about 25%. Thus, the village depends on transporting water through Tankers, which costs about 20 NIS/m^3, in addition to purchasing water from nearby village-Kufur Ne’meh-water network which is provided with water by Jerusalem Water Undertaking, however the problem of water scarcity in the village remained.

People in the village dispose wastewater in to cesspits or septic tanks, while some houses builds grey water treatment plants, the treated effluent used to irrigate their home gardens, the treatment technology used is up-flow gravel filter.

3.3 Soil sampling

Soil samples were collected form Bilin Village, three locations were targeted, three home gardens irrigated by treated grey water. In addition to those samples, blank soil samples were collected from the same targeted home gardens. Sampling of soil was conducted two times, one after dry season and other after wet season.

3.3.1 Soil analysis

The soil quality was tested for both physical and chemical parameters:

3.3.1.1 Physical parameters

Soil samples were collected from three home gardens irrigated with treated grey water. The samples were collected over two different periods, dry season and wet season. 15 samples were analysed at GMT labs for the following three parameters: Soil Texture, Permeability, Porosity and Bulk Density. 9 samples were collected and analysed direct after the end of wet season. 6 samples irrigated with treated grey water and 3 samples irrigated by fresh water were collected and analysed direct after the end the wet period. While 6 soil samples irrigated with treated grey water were collected and analysed direct after end of the dry season.

3.3.1.2 Chemical parameters

Soil samples were collected from three home gardens, irrigated by treated grey water, the samples were collected in two different periods, dry season and wet season, total of 15 samples were analysed at Birzeit university Laboratories for the following parameters: pH, EC, Cl, Mg, Ca, P, B, Na, TOC, Ash, TKN, Zn, Cu, Fe and Fecal Coliforms. 9 sample collected and analysed direct after end of the wet season and 6 samples collected and analysed direct after end of the dry period, while 3 samples irrigated by fresh water. All samples were collected from each home garden from two levels of depths from the surface of soil, 30cm and 60cm respectively.

3.4 Sampling of treated grey water

15 samples of treated grey water were collected and analyzed, time interval composite samples each consisted of three sub-samples of treated grey water were collected during day time (09:00 – 18:00) once weekly over five weeks (2 L for each). Samples were stored at 4 ºC until they were transferred to the lab and analyzed.

Samples were analyzed for COD, BOD_5, TOC, TSS, TDS, Cl^-, $NH4^+$, TKN, total phosphate, ortho $PO4^{-3}$, $SO4^{-2}$, FC, pH, alkalinity, turbidity, DO, EC, Na, K, Ca, Mg, Mn, Cu, Fe, Zn, surfactants, all according to standard methods (APHA, 1995).

3.5 Analytical Methods of treated grey water

Several analytical methods for treated grey water parameters, namely chemical, physical and microbiological were analyzed.

3.5.1 Chemical parameters

3.5.1.1. Chemical Oxygen Demand (COD)

COD was measured using closed reflux method (acid destruction at 150 °C for 120 minutes) where the absorbance was then measured by spectrophotometer at 600 nm wavelength.

3.5.1.2. Biological Oxygen Demand (BOD)

Treated grey water samples were analyzed for BOD_5 at $20^{\circ}C$.

3.5.1.4. Kjeldhal Nitrogen (TKN)

The Kjeldhal method (digestion, distillation and titration) was used to determine the amount of organic and ammonium nitrogen.

3.5.1.5. Ammonia ($NH4^+$)

Nesslerization method using spectrophotometer at absorbance of 425 nm wavelength was used to determine the amount of Ammonia (NH_4^+-N) from paper-filtered samples.

3.5.1.6. Sulfate (SO_4^{-2})

Spectrophotometer at absorbance of 420 nm wavelengths was used to measure the amount of sulfate from paper-filtered sample.

3.5.1.7. Total Phosphorous (Total P) and Ortho-Phosphate (PO_4^{-3})

Spectrophotometer at absorbance of 880 nm wavelengths was used to determine the amount of total phosphorous, from digested treated grey water sample and *ortho*-phosphate from membrane-filtered sample.

3.5.1.8. Dissolved oxygen (DO)

DO was measured in situ by a DO meter.

3.5.2 Physical parameters

The treated grey water samples were analysed for the following physical parameters: Total suspended Solids (TSS), Total dissolved solids (TDS), turbidity, pH, electrical conductivity (EC) and Temperature.

3.5.2.1. Total suspended Solids (TSS)

Total suspended solids were measured according to Standard Methods (APHA, 1995) by oven drying at 105 ºC of filtered samples using paper of glass microfiber filters (GF/C 125 mm f, CATNO 1822 122 Whatman)

3.5.2.2. Total Dissolved Solids (TDS), Electrical conductivity and pH

TDS, EC and pH were measured in situ by a multipurpose EC pH meter (HACH).

3.5.2.5. Temperature

Treated grey water temperature was measured in situ by alcohol thermometer.

3.6. Description of household grey water treatment plant used at the research area

The house plumbing fixtures installations were changed so as to separate the grey and black wastewater streams. The black wastewater (from toilet) is discharged into the existing conventional cesspit. While grey water is directed to the treatment plant. The main treatment part is anaerobic process followed by aerobic controlled multi-layer filter (coal, gravel). The upflow gravel filter is designed as gravity loaded system, works at maximum flow at day hours and zero flow at night hours.

The gravel filter media are mainly hard crushed gravel of hard limestone of 0.7 to 3 cm in size. The pilot plants have been constructed with concrete basement and bricks for side and internal compartments. The septic tank –upflow gravel filter is divided into four compartments, where the first compartment is used as septic tank and grease trap, the second and the third are used as upflow graduated gravel filters, and the fourth compartment is used as a balancing tank for treated wastewater where a submersible pump is installed. The pump lifts the water to a multi-layer aerobic filter, the water pass through the layers (coal, gravel) to a storage tank from where it goes to the home garden irrigation network.

The septic tank receives the grey water (shower, kitchen, sinks and washing machine) from the house through a 2-inch or 4-inches diameter PVC pipe. The wastewater flows into the septic tank by means of a T shaped inlet pipe, with one end directed upward, and subjected to atmospheric pressure and the other at a level of about 30 cm from the bottom of the septic tank. The retention time of the wastewater in the septic tank is 1.5 to 2 days. Accumulation of grease occurred by installing a T-shape pipe at the outlet of the septic tank at same level of the inlet T shape pipe. The layout of the pilot plant is shown Figure 1.

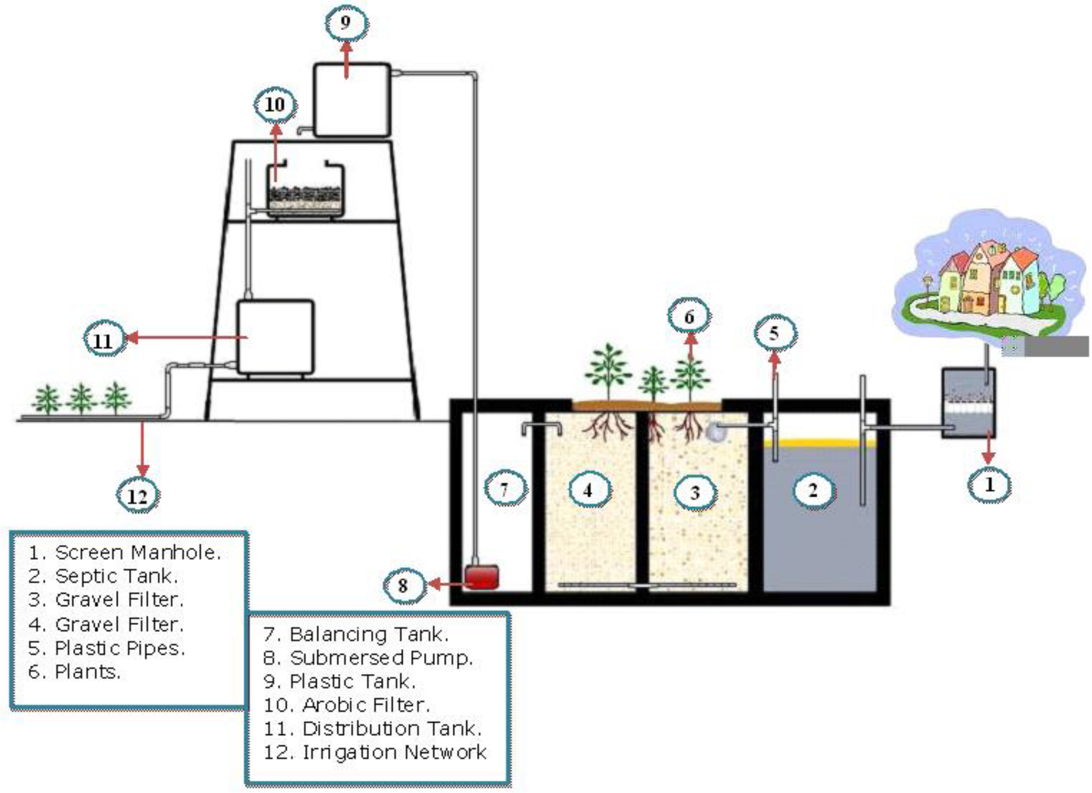

Figure 1: Layout of the grey water treatment in Bilin Village plant (PHG, 2007)

3.7 Grey water Sampling

Field visits were carried out to determine grey water sampling, and grey water treatment units locations in Bilin village, three unites were chosen. These locations were chosen according to the following criteria:

1. Grey water treatment unit age.
2. Long term reuse period.
3. Planted home garden.
4. Family size which used the grey treatment unit.

Table 3.3 summarizes the grey water sampling locations in Bilin village, which chosen according to the mentioned criteria.

Table 3.1 : Treated Grey water sampling locations in Bilin village

ID	Family name	Family size/members	Reuse age/year
A	Mostafa Omare mostafa	11	10
B	Mohamad Yassen Burnat	14	15
C	Adeb Aburahma	8	8

Treated effluent reuse to irrigate the home gardens. During period of five weeks in the summer of 2010, 15 composite samples of treated effluent, 5 sampled each treatment plant, were collected from three grey water treatment plants, which used to irrigate the home gardens were the soil samples had been collected.

Chapter 4

Results and Discussion

4. 1 Treated grey water analysis

The results of treated grey water characteristics, in terms of physical, chemical and heavy metals were determined for grey water samples analysis. Table 4.1 shows recommended values for using wastewater in irrigation. While Table 4.2 illustrating Statistical Analysis of the measured grey water parameters. The analyzed parameters are discussed in the following section.

Table 4.1: Standard parameters values for using wastewater in irrigation (FAO,1992)

Parameter	Unit	Degree of restriction in use		
		None	Slight to moderate	Sever
Salinity(EC)	µSemins	< 700	700 – 3000	> 3000
SAR	Indicator	< 3	3 – 9	> 9
Chloride (Cl-)	mg/l	< 142	142 – 355	> 355
Nitrogen (NO3-N)	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO3-)	mg/l	< 92	92 - 519	> 519
Iron	mg/l	Max recommended concentration 5		
Zinc	mg/l	Max recommended concentration 2		
Copper	mg/l	Max recommended concentration 0.2		
pH	Normal range (6.5 - 8)			

Table 4.2 Characteristics of treated grey water

Parameter	Unit	Min			Max			Mean			Standard Dev			overall General Min	overall General Max	overall General Mean	overall General SD	Palestinian-limits-TWW
		TP "A"	*TP "B"*	*TP "C"*	*TP "A"*	*TP "B"*	*TP "C"*	*TP "A"*	*TP "B"*	*TP "C"*	*TP "A"*	*TP "B"*	*TP "C"*					
T	^{0}C	20	18	18	22	22	22	22	20	20	0.97	1.42	1.41	18	22.2	20.6	1.4	
BOD$_5$	mg/l	34	35	32	64	58	52	48	45	42	13.83	10.37	9.39	32	64	45.1	10.9	40
COD	mg/l	85	64	72	137	147	144	108	113	95	21.23	35.23	28.78	63.5	147	104.7	27.2	150
TSS	mg/l	36	152	16	244	328	188	131	234	104	86.09	86.83	61.45	16	328	152.0	91.2	30
TDS	mg/l	268	212	245	286	221	267	276	218	251	8.66	4.27	10.71	212	286	248.3	26.1	1200
Chloride Cl	mg/l	278	272	287	301	291	323	291	279	304	9.93	8.95	14.64	272	322.6	291.2	14.8	350
NH4-N	mg/l	17	9	9	49	33	16	35	19	12	13.80	11.92	2.46	8.6	48.8	21.9	13.8	50
TKN	mg/l	28	33	18	63	51	46	47	41	31	15.43	6.76	11.63	17.6	62.7	39.5	12.9	NA
SO$_4$	mg/l	3	15	9	25	55	21	20	26	15	9.47	16.52	4.73	2.8	54.7	20.4	11.5	500
PO$_4$	mg/l	4.3	0.1	2.2	11.6	7.4	8.8	9.2	5.2	5.3	2.84	2.95	2.74	0.1	11.6	6.6	3.3	30
FC		8	16	2	280	340	210	115	134	64	133.52	148.07	84.54	2	340	104.3	119.8	200
pH		7.2	7.0	7.3	7.4	7.4	7.6	7.3	7.2	7.4	0.10	0.21	0.09	6.95	7.55	7.3	0.2	6 - 9
Alkalinity	mg/l	265	147	171	783	449	592	483	275	344	271.58	151.88	216.76	146.9	783.4	367.5	221.6	NA
Turbidity	NTU	123	111	23	275	423	93	195	218	49	81.01	132.11	29.73	23	423	151.2	116.1	NA
DO	mg/l	0.2	0.4	0.2	2.4	1.9	2.5	1.1	0.9	0.8	1.02	0.65	0.95	0.23	2.48	0.9	0.8	>0.5
EC	ms	550	447	507	601	465	558	577	454	522	20.95	7.63	23.96	447	601	517.7	55.0	NA
Na	mg/l	250	209	195	270	245	247	260	221	219	7.27	14.10	20.83	195	270	233.3	24.3	200
K	mg/l	36	20	22	38	24	27	37	22	24	0.73	1.79	2.35	19.9	37.8	27.6	7.1	NA

Ca	mg/l	91	86	145	105	97	167	98	91	153	5.63	4.04	8.44	85.7	167	113.9	29.1	400
Mg	mg/l	33	31	33	39	37	37	35	33	35	2.12	2.65	1.81	30.5	38.5	34.3	2.3	60
Total P	mg/l	5	2	2	6	3	2	6	2	2	0.16	0.43	0.26	1.5	5.8	3.4	1.8	NA
Mn	ppb	7	4	4	62	38	142	45	18	83	22.12	16.04	51.82	4	142	48.9	41.7	0.2 mg/l
Cu	ppb	0	0	0	0	0	0	BDL	BDL	BDL	BDL	BDL	BDL	0	0	BDL	BDL	0.2 mg/l
Fe	ppb	11	11	15	127	22	84	42	16	44	48.07	4.72	26.94	11	127	34.1	32.3	5 mg/l
Zn	ppb	0	0	0	0	0	0	BDL	BDL	BDL	BDL	BDL	BDL	0	0	BDL	BDL	0.01 mg/l
SAR		7.8	6.7	5.2	7.8	6.7	5.2	7.8	6.7	5.2	7.8	6.7	5.2	7.8	6.7	5.2	7.8	10

Note: Overall mean: all the samples were analyzed

4.1.1 BOD_5

Figure 2 illustrates the mean values of effluent BOD_5 from the three targeted grey water treatment plants. While Table 4.2 illustrates the overall values of the analysed samples of treated grey water, which showed that the minimum BOD_5 value was 32 mg/l while the maximum was 64 mg/l. The overall BOD_5 average was 45.1 mg/l with a standard deviation of 10.9. The BOD_5 values did not vary with the lifetime of the treatment plants, since the values are very close and meet the standard limit values recommended irrigation purposes (Table 4.2). All of the BOD_5 values indicate that treated grey water can be used for unrestricted irrigation purposes.

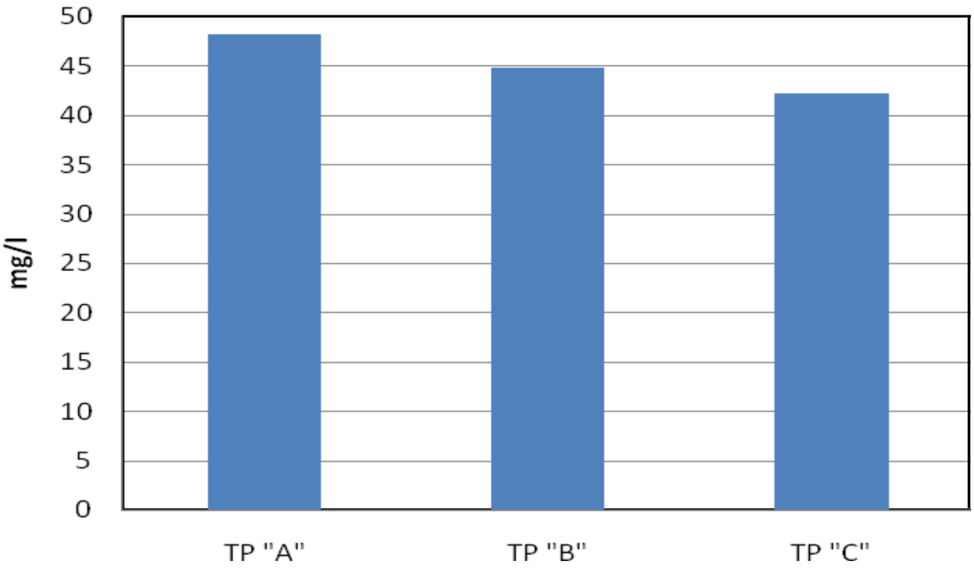

Figure 2: Average effluent BOD_5 values in treated grey water from the three targeted treatment plants in Bilin village

4.1.2 COD

Figure 3 illustrates the mean values of effluent COD from the three targeted grey water treatment plants. While Table 4.2 illustrates the overall COD values of the analysed samples results of treated grey water, which shown the average minimum COD value was 63.50 mg/l while the maximum was 147.7 mg/l. The overall COD average was 104.7 mg/l with a standard deviation of 27.2. The COD values did not vary within the lifetime of the treatment plants, since the values are very close and match the standard limits values recommended for irrigation purposes. All of the measured COD values indicate that treated grey water can be used for irrigation purposes.

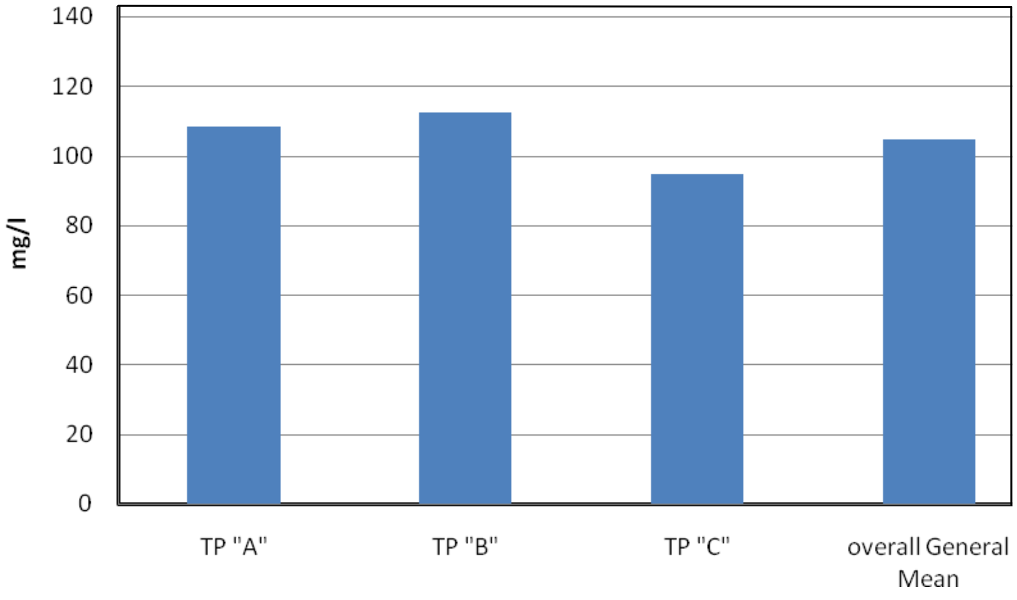

Figure 3: Average effluent COD values in treated grey water from the three targeted treatment plants in Bilin village

4.1.3 TSS, TDS, EC, pH & Turbidity

Going through the three grey water treatment plants in the research area, a general trend was observed for all parameters measured through the GWTPs, where the overall average values were recorded for TSS, TDS, EC, pH & Turbidity parameters in the following table:

Table 4.3: Overall average values of TSS, TDS, EC, pH & Turbidity parameters

Parameter	Unit	Overall General Min	Overall General Max	Overall General Mean	Overall General SD
TSS	mg/l	16	328	152.0	91.2
TDS	mg/l	212	286	248.3	26.1
EC	ms	447	601	517.7	55.0
pH		6.95	7.55	7.3	0.2
Turbidity	NTU	23	423	151.2	116.1

Note: Overall mean: All the samples were analyzed

Based on the inorganic constituents, treated grey water treatment plants is considered acceptable for unrestricted irrigation purposes according to the FAO limits and Palestinian standards, due to the values of dissolved cations and anions which results in low values of EC (reaches a maximum of 601 µS/cm) and TDS (reaches maximum of 286 mg/l).

Figures 4&5 show the average values of TSS, TDS and EC for the three targeted grey water treatment plants effluent in the research area.

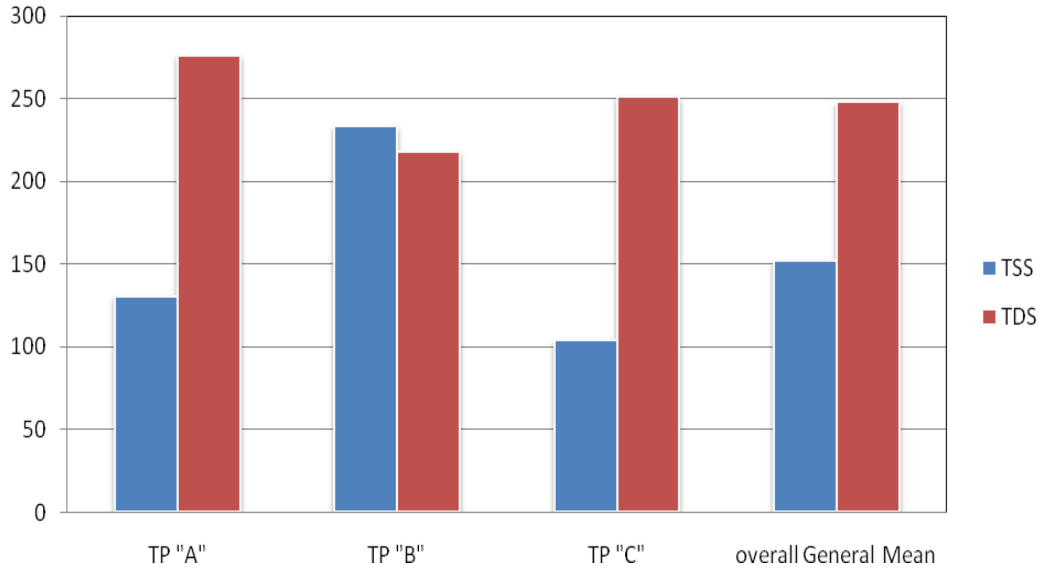

Figure 4: Average values of TSS and TDS measured for treated grey water

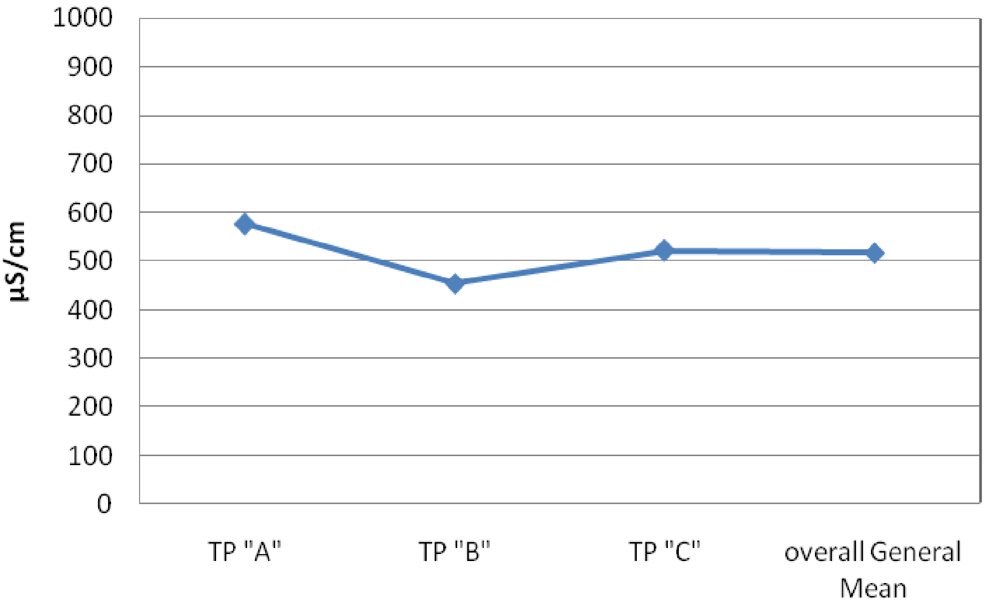

Figure 5: Average values of EC measured for treated grey water

Conductivity gives information about the concentration of dissolved salts. An EC value doesn’t exceed the local and an international standard limits which reaches a maximum value of 601 µS/cm (Figure 5). The similar trend was found for turbidity, while vary in results values from treatment plant to the others, (Figure 6). The reason of increasing in turbidity values referred to lack of regular maintenance for treatment plants as well as the possibility of leakage of soil and dirt from outside of the treatment plants.

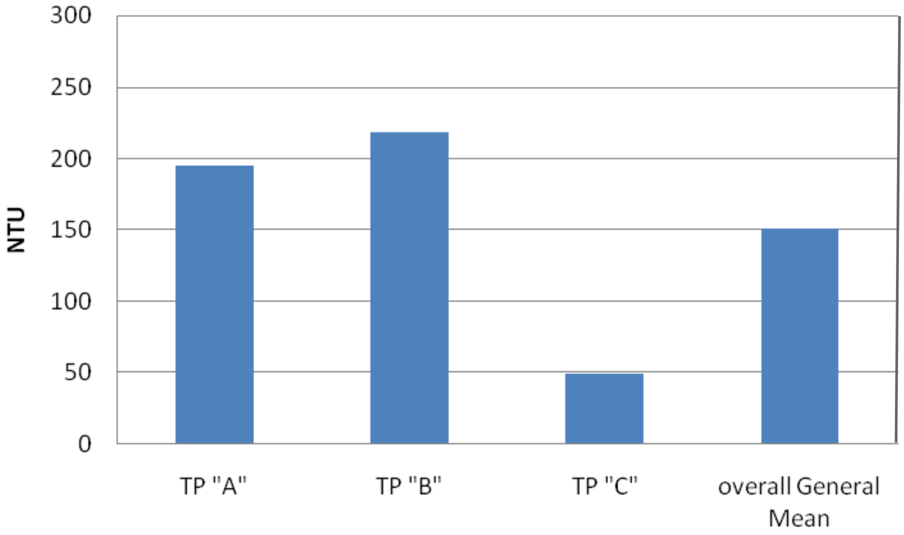

Figure 6: Average values of turbidity measured for treated grey water

The pH measured for 15 samples as shown in figure 7. The Maximum value reached 7.55 while the minimum value was 6.95. All results fall within the pH standard range for unrestricted irrigation purposes. However, the overall average was 7.3 and falls within the standard limits. The variability of pH values indicates that the constituents of grey water are not steady and changes from acid to base depend on the discharged grey water from domestic sources.

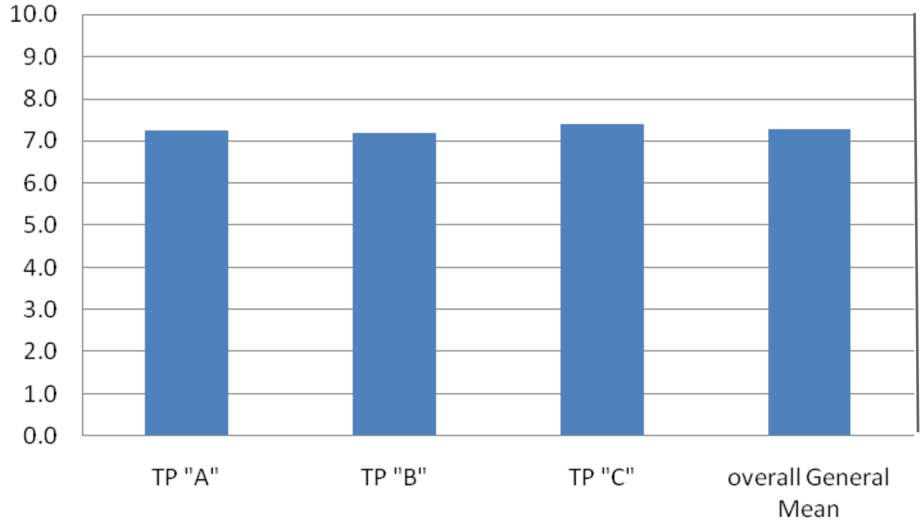

Figure 7: Average values of pH measured for treated grey water

4.1.4 Chloride

From the results that are shown in Figure 8 and Table 4.2, it was found that minimum chloride overall average value was 272 mg/l while the maximum overall average was 322.6 mg/l and overall results average is 291.2 mg/l. All samples have slight to moderate restrictions to be used in irrigation, and does not exceed the recommended limits.

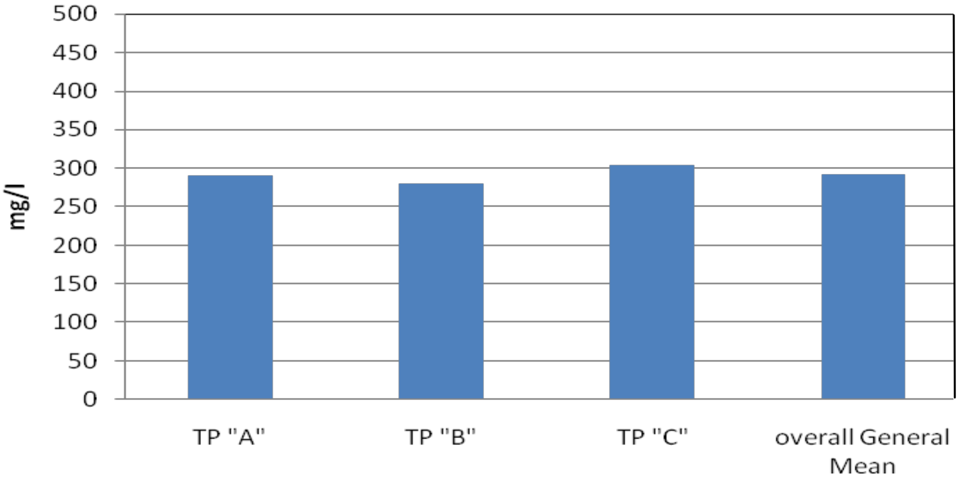

Figure 8: Average values of Cl^- measured for treated grey water

4.1.5 Mg, Ca, Na and K

The four major cations were analyzed during the research study are presented in Figure 9. The presented data are within the allowable concentration for unrestricted irrigation.

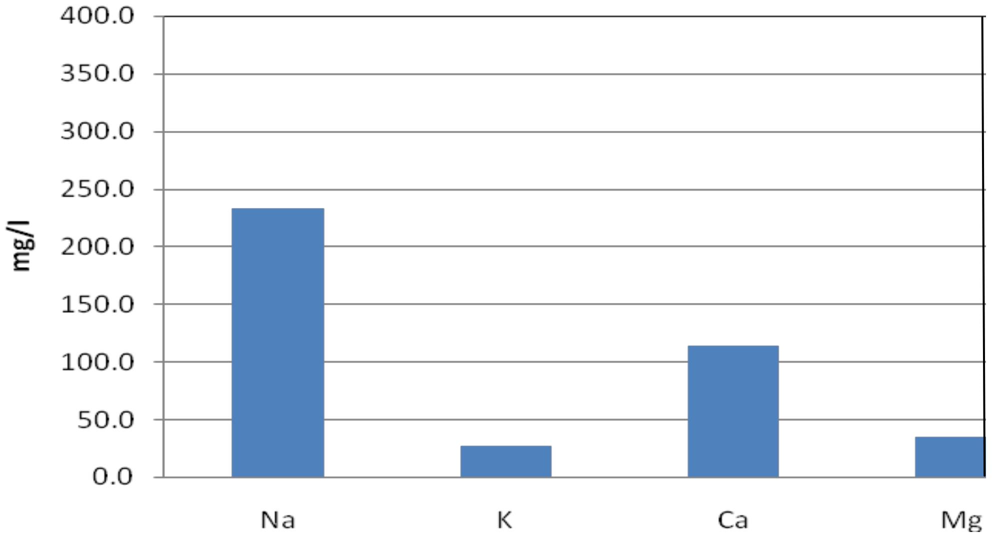

Figure 9: Overall average values of Mg, Ca, K and Na measured for treated grey water

4.1.6 NH_4

The NH_4 – N values presented in Figure 10 and falls within the allowable concentration for unrestricted irrigation according to the Palestinian standard limits.

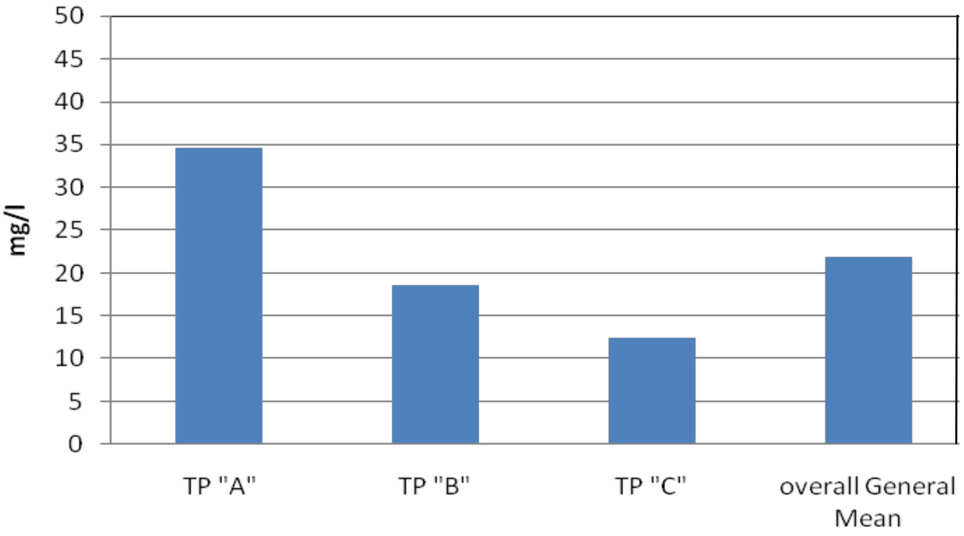

Figure 10: Average and Overall average values of NH_4-N measured for treated grey water

4.1.7 DO

Figure 11 show significant variation in DO according to the Palestinian standard limits, the main reason for this variation is that some families don’t use the aerobic filter before irrigation process.

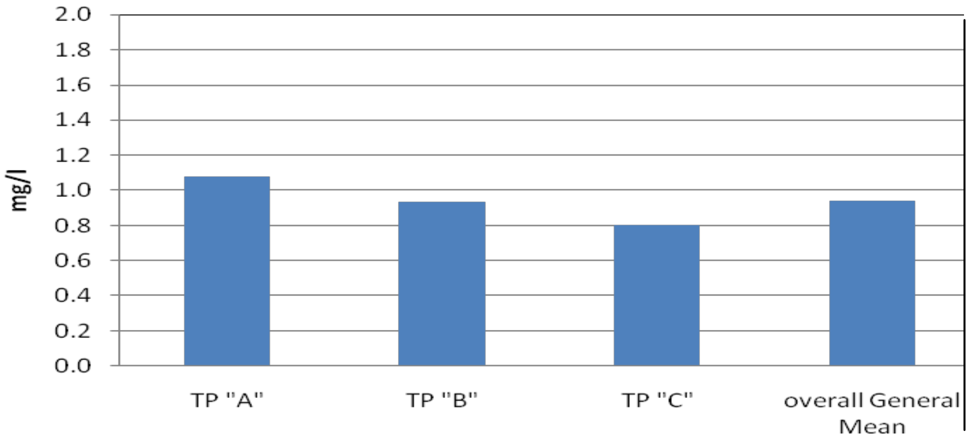

Figure 11: Average and Overall average values of DO measured for treated grey water

4.1.8 Fecal coliform (FC)

Fecal Coliform is used as indicator for pollution in water analysis, their numbers depend on conditions of domestic use in the drainage from the household. Figure 12 shows the average results of certain set of samples with variation in number of fecal coliforms colonies in the treated effluent grey water. The maximum numbers of FC colonies was 340 CFU at grey water treatment plant B, the main reason of this highest number, is that this family have small kids. While the other analyses results almost fall within the Palestinian standards limits.

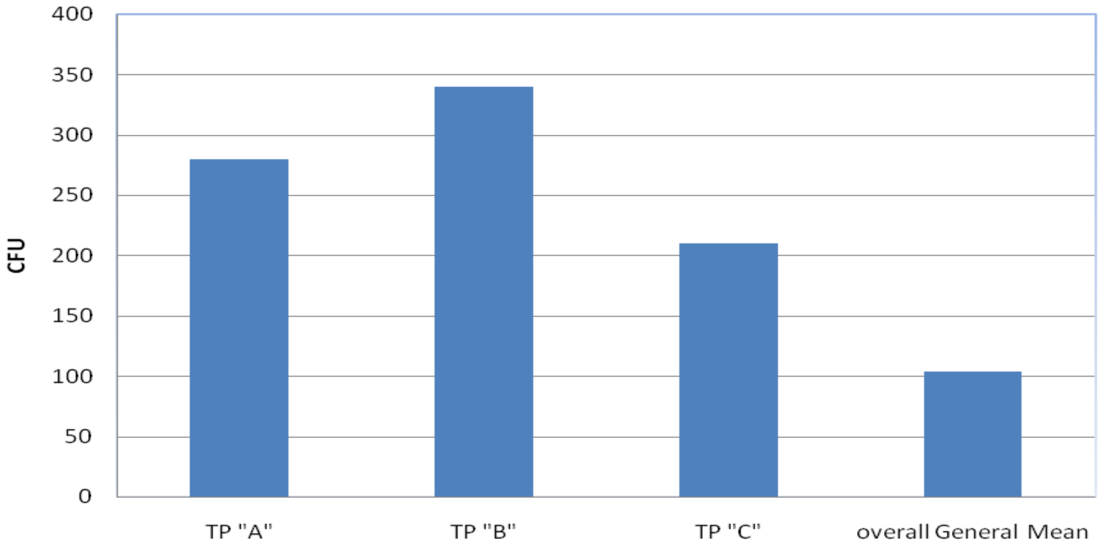

Figure 12: Maximum numbers and overall average values of FC colonies measured for treated grey water

4.1.9 Total Phosphate (TP)

TP values are presented in Figure 13. It was found that the minimum TP value was 2 mg/l and the maximum was 6 mg/l with an overall average value of 3.4 mg/l. This implies that this amounts of phosphates in treated grey water can be used as a fertilizers for plants.

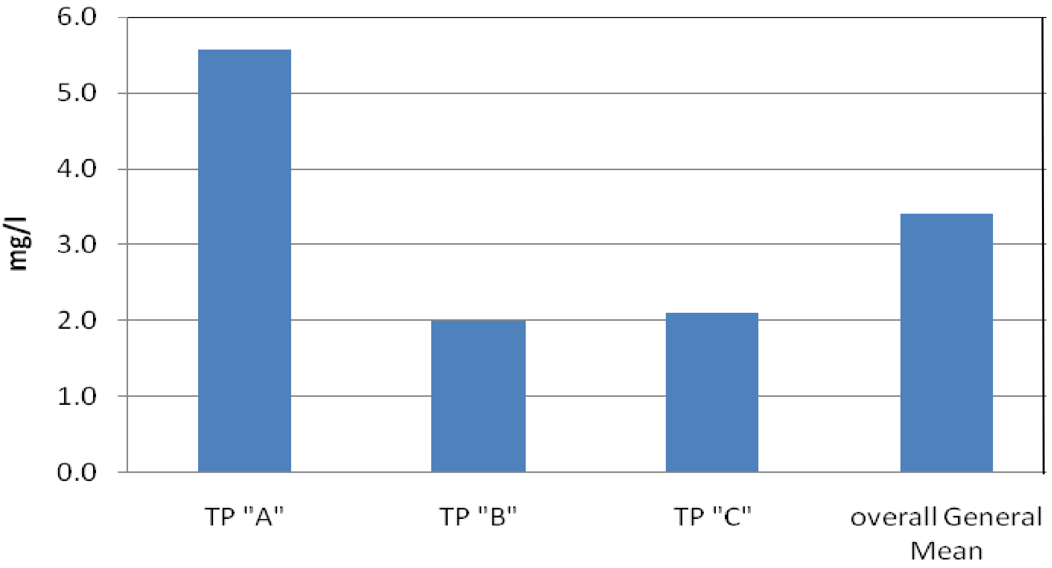

Figure 13: The average and overall average values of TP measured for treated grey water

4.1.10 Sodium Adsorption Ratio (SAR)

Depending on the measured values of sodium, calcium and magnesium, SAR was calculated for 15 samples as depicted in Figure 14 by using the following formula:

$$\text{SAR} = \frac{Na}{\sqrt{\left(\frac{Mg+Ca}{2}\right)}}$$

The minimum overall average SAR value was 5.25, while the maximum average value was 8.3 with an overall average of 7.1 and overall standard deviation of 1.05. It was found that all results values fall within the Palestinian standards and Jordanian limits that can be used for restricted irrigation.

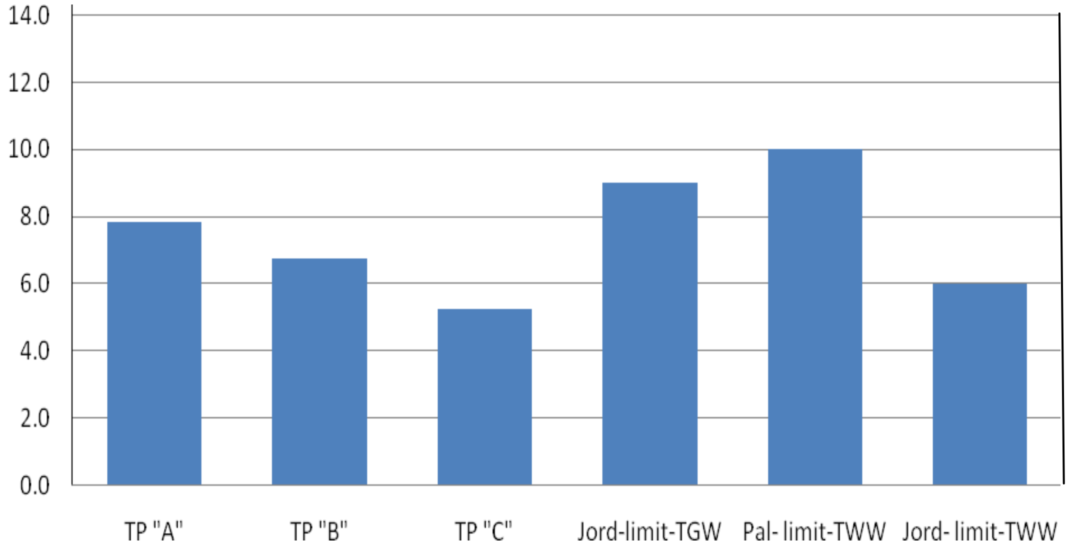

Figure 14: The average and overall average values of SAR measured for treated grey water

4.1.11 Heavy metals (Mn, Cu, Zn and Fe)

As shown in Table 4.2 Mn, Cu, Zn and Fe analysis results values fall within the Palestinian and international standards limits that can be used for irrigation with no restrictions.

4.2 Soil results

The soil quality tests were analysed for two types of quality characterisations, chemical and physical analysis.

4.2.1 Sampling and analytical methods

Soil samples were collected form Bilin Village, three locations were targeted, the three home gardens irrigated by treated grey water. In addition blank soil samples were collected from the same targeted home gardens. Sampling methodology is to collect the soil samples at two different periods, dry and wet seasons. Soil chemical properties, include heavy metals content, pH and EC, while soil physical properties, include soil texture, permeability and porosity.

The representative soil samples were dried in an oven at 70 °C for 24 hours and sieved down to 0.2 mm in diameter. Soil were analyzed with inductive coupled plasma (ICP) against multi- element standard. After that the soil were ignited at 550-600 °C for 4.5 – 5 hours, then cooled in desiccators at room temperature. The digested Ash content was mixed directly with concentrated nitric acid and hydrochloric acid for a minimum of 3- 4 hours until solution is clear. Finally, the clear solution were filtered through (Wattman #1) and diluted with distilled water to the required volume and analyzed by ICP.

4.2.2 Chemical analysis and results

Table 4.3 shows the overall results and variations during the two dry and wet seasons irrigated by treated grey water.

Table 4.4: Overall average results for the tested soil parameters during wet and dry seasons, irrigation by treated grey water

Parameter	Test Unit	Overall Average Blank	Overall Max		Overall Min		Overall Average	
			Wet	Dry	Wet	Dry	Wet	Dry
pH		7.9	8.414	6.682	8.056	6.328	8.15	6.48
Conductivity	µs/ cm	0.8	0.73	1.91	0.3	0.53	0.46	1.07
Chloride	mg/Kg	75.7	88.25	5997	29.87	247	48.87	1900.80
Magnesium	mg/Kg	7824.0	12018	7738	3624	4560	5771.67	6224.20
Calcium	mg/Kg	86508.0	145261	114730	40508	48254	81619.33	89668.60
Potassium	mg/Kg	2269.7	2054	10701	1204	3526	1711.67	5805.80
Boron	mg/Kg	66.5	72	98	27.4	43	47.08	71.80
Phosphate	mg/Kg	9323.3	8668	5578	1672	2461	5394.33	3952.00
Sulfates	mg/Kg	36.8	32.66	83.6	29.27	35.77	30.94	50.39
Sodium	mg/Kg	1075.3	1165	1807	843	900	1041.33	1304.00
TOC	%	6.0	5.48	4.55	3.94	3.05	4.94	3.97
Ash	%	88.9	92.56	94.16	89.78	91.47	90.76	92.51
Kjeldahl N	%	0.1	0.171	0.69	0.099	0.52	0.13	0.62
Manganese	ppb	454.3	478	910	390	623	441.00	763.40
Zn	ppb	128.0	117	168	81	123	95.85	151.00
Cu	ppb	31.2	30	18	19	2	23.43	12.00
Fe	ppb	20032.3	23338	30717	13720	29	18191.50	21845.60
Fecal Coliforms	cfu/g	520.0	6500	20	2164	10	4332.00	15.00

Note: Overall mean: All the samples were analyzed

Table 4.5: overall average results for the tested soil parameters during wet and dry seasons and two different depths, irrigation by treated grey water

Parameter			**pH**	**EC**	**Ci-**	**Mg**	**Ca**	**K**	**B**	**Mn**	**P**	**SO4**	**Na**	**TOC**	**Ash**	**K N**	**Zn**	**Cu**	**Fe**
Limit	**Season**	**Unit** **cm**		**µs/cm**	**mg/Kg**	**mg/Kg**	**mg/Kg**	**mg/Kg**	**Mg/Kg**	**ppb**	**mg/Kg**	**mg/Kg**	**mg/Kg**	**%**	**%**	**%**	**ppb**	**ppb**	**ppb**
Max	**Wet**	30	8.15	0.55	59.54	5178	109131	2000	72	478	8668	32.2	1165	5.44	92.56	0.17	114	26.3	20436
		60	8.41	0.73	88.25	12018	145261	2054	58	478	7145	32.66	1116	5.48	92.56	0.14	117	30	23338
Min	**Wet**	30	8.06	0.3	29.91	3922	40508	1307	33.1	424	1672	29.27	843	3.94	89.78	0.01	81.4	20.9	15020
		60	8.11	0.37	33.78	3624	52419	1204	27.4	390	2930	29.87	972	3.92	89.78	0.13	81	19	13720
Max	**Dry**	30	6.68	1.12	1098	7738	114730	5765	81	753	5578	39.98	1289	4.55	94.16	0.69	162	16	24144
		60	6.51	1.91	5997	7489	105000	10701	98	910	4697	83.6	1807	4.1	92.59	0.62	168	18	30717
Min	**Dry**	30	6.33	0.53	247	4933	48254	3526	43	623	2529	35.77	900	3.05	91.47	0.59	123	2	29
		60	6.45	1.02	1672	4560	72361	4860	78	823	2461	56.6	1319	3.92	92.29	0.52	151	10	30400
Average	**Wet**	30	8.10	0.40	41.08	4703	76502	1726	49.7	452.3	5628	30.53	1017	4.94	90.76	0.13	96.5	23.7	17535
		60	8.21	0.51	56.65	6841	86737	1697	44.47	429.7	5161	31.34	1066	4.93	90.77	0.13	95.2	23.17	18848
Average	**Dry**	**30**	6.48	0.81	611.7	6357	90327	4489	61	694.7	4201	37.25	1131	3.937	92.56	0.64	145	16.33	16037
		60	6.48	1.46	3835	6025	88681	7781	88	866.5	3579	70.1	1563	4.01	92.44	0.57	160	14	30558.
Average Blank	**Wet**	30 - 60	7.93	0.80	75.72	7824	86508	2270	66.47	454.3	9323	36.76	1075	5.997	88.86	0.11	128	31.2	20032

Note: Overall mean: All the samples were analyzed

4.2.2.1 pH and EC

Figure 15 shows the mean pH for each level and each season.

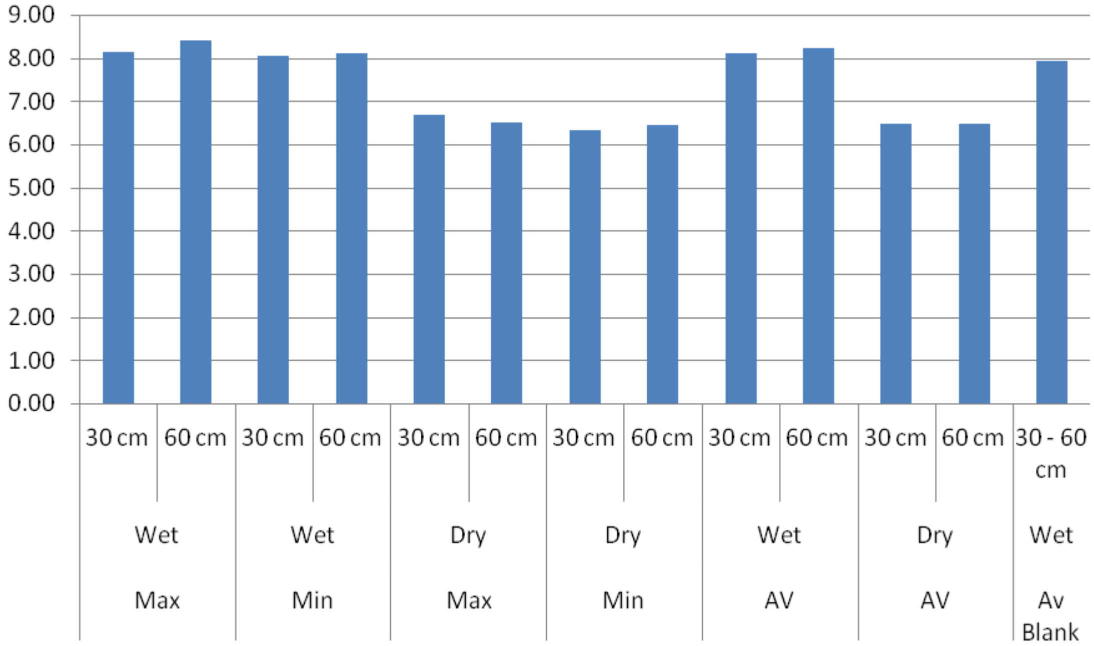

Figure 15: Influence on the pH level under different variations of depth and seasons

The variation of pH values, seems to be constant between the two different depths, while the pH significant show the value decreased in the dry season with irrigation by treated grey water. This indicates the further biochemical conversion of remaining pollutants in the treated grey water.

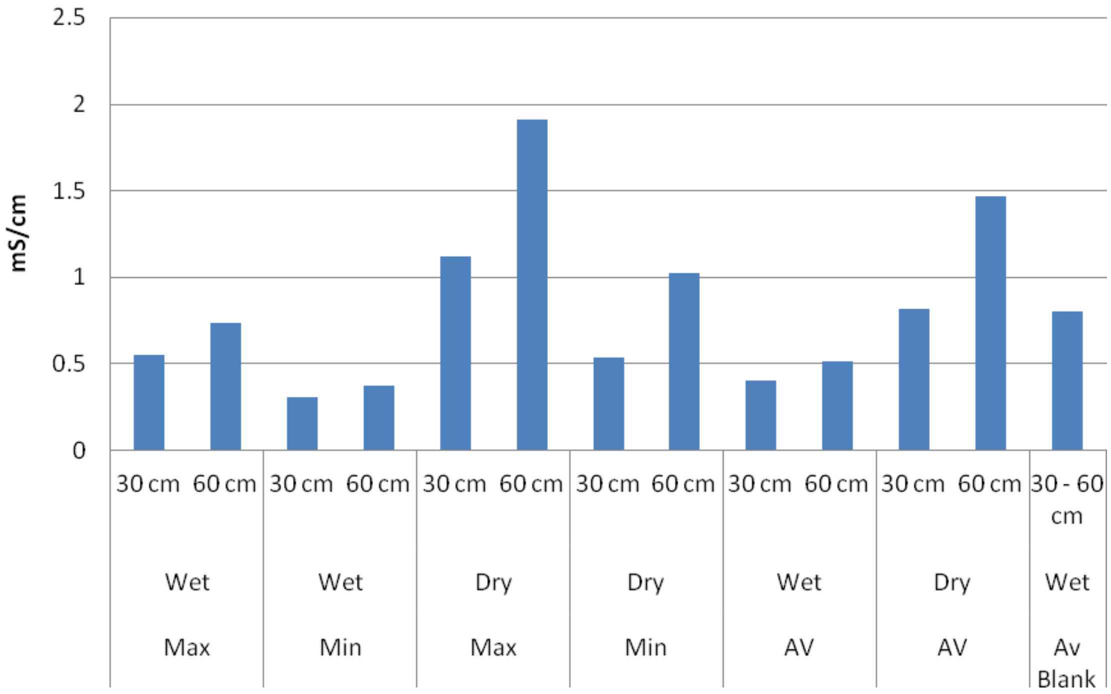

Figure 16: Influence the EC level under different variations of depth and seasons

Soil electrical conductivity (EC) is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics. Figure 16 shows that in the wet season washing the accumulated minerals in soil during the dry season under irrigation with treated grey water. Similarly, Mohammad and Mazahreh (2003) fund that wastewater irrigation increased the level of total salinity due to the wastewater salt content. According to Lado *et al*. (2009) arid and semi arid regions are characterised by evapo-transpiration that exceeds precipitation during most of the year, therefore agriculture in these regions relies on supplementary irrigation to enable productive crop growth. Interesting that the results of this research reveal that salinity goes back to normal values due to wash with rain water under the investigated climatic conditions in Palestine. Therefore, supplementary irrigation with the scarce water is not deemed necessary for salt removal from soil.

4.2.2.2 Heavy metals (Zn, Cu & Fe)

The concentrations of Zn, Cu and Fe in soils receiving treated grey water were not significantly higher than values in blank control. The results also do not show any relationship between periodic time of grey water applications and heavy metals accumulations in the different depths and different seasons, while the results of blank samples show highest values, as shown in Figures (17, 18 & 19). Similar observations were reported by Mohammad and Mazahreh (2003) who also found that soil Zn and Cu were not significantly affected by wastewater irrigation. Also in China, Zhang *et al.* (2007) reported soil salinity increase due to irrigation with treated wastewater, but remained within the acceptable standards of China.

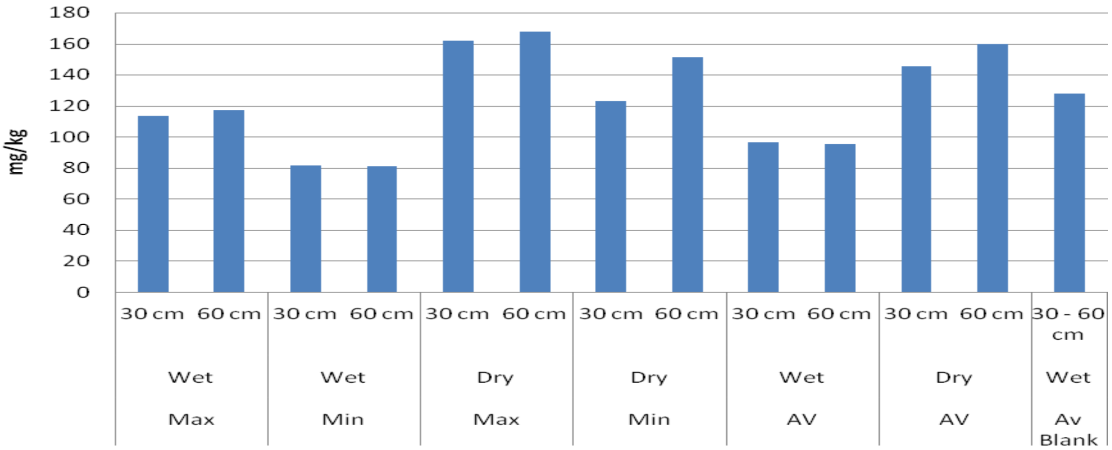

Figure 17: Zn concentration in soil under different variations of depth and seasons

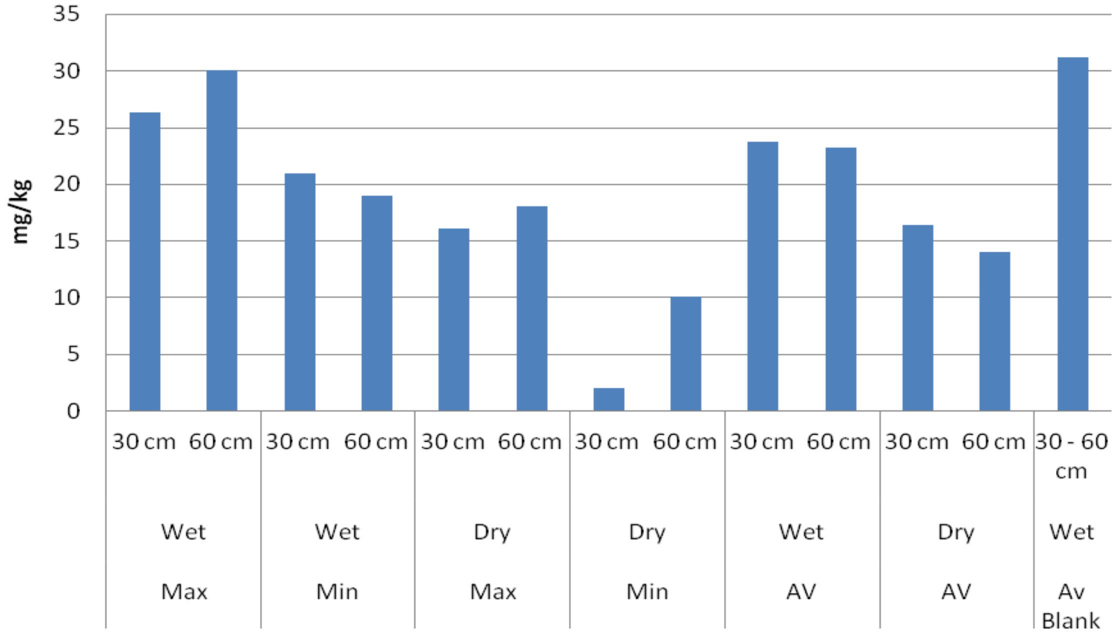

Figure 18: Cu concentration in soil under different variations of depth and seasons

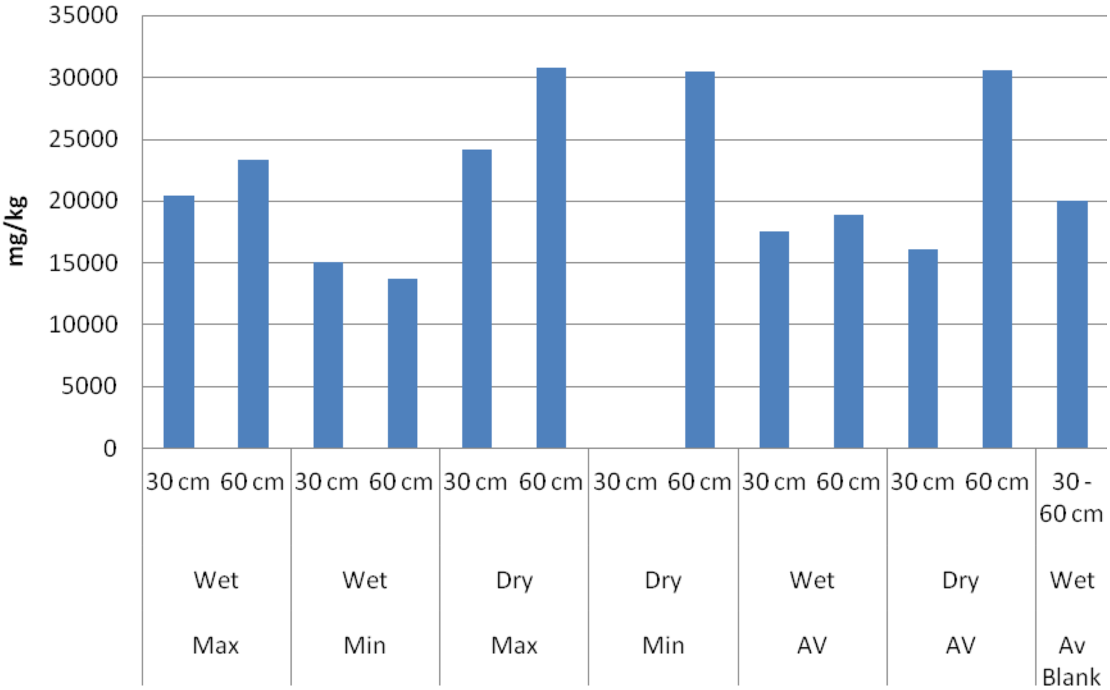

Figure 19: Fe concentration in soil under different variations of depth and seasons

4.2.3 Effect of treated grey water on soil physical properties

4.2.3.1 Analysis Methodology

Physical analysis were done for the following four parameters:

1-The constant head permeability test method involves flow of water through a column of cylindrical soil sample under the constant pressure difference. The test is carried out in the permeability cell, or permeameter, which can vary in size depending on the grain size of the tested material.

2-Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm3.

3-Porosity of surface soil typically decreases as particle size increases. This is due to soil aggregate formation in finer textured surface soils when subject to soil biological processes. Aggregation involves particulate adhesion and higher resistance to compaction. Typical bulk density of sandy soil is between 1.5 and 1.7 g/cm^3. This calculates to a porosity between 0.43% and 0.36 %. Typical bulk density of clay soil is between 1.1 and 1.3 g/cm^3. This calculates to a porosity between 0.58 % and 0.51% (Wikipedia, 2012).

4.2.3.2 Results and Analysis

4.2.3.2.1 Coefficient of permeability and soil texture

The average Coefficient of permeability at the Dry and Wet seasons at 30 cm depths were 8.7E-07 and 4.15E-07 m/s, respectively and blank soil was 5.21E-06 m/s, while the average Coefficient of permeability at the Wet and dry seasons at 60 cm depth were 5.21E-06 and 1.77E-06. Therefore, the application of treated grey water show no significant difference. Figure 20 shows the range of the Coefficient of permeability (FAO, 2012) and (Tables 4.6 & 4.7) show the analyses results for permeability and soil texture

Table 4.6 : Average coefficient of permeability for soil irrigated by treated grey water

Parameter	Depth	**30 cm depth**		**60 cm depth**		**Blank**
	Season	**wet season**	**dry season**	**wet season**	**dry season**	**wet season**
Coff. of Permeability	(m/s)	8.7E-07	4.15E-07	5.21E-06	1.77E-06	1.10E-08

Soil texture refers to the percentage by weight of sand (particles between 0.05 to 2.0 mm), silt (0.002 to 0.05 mm), and clay (<0.002 mm) in a soil sample. It is based on that part of a field dried soil sample that passes through a 2-mm sieve (if coarse material greater than 2 mm in diameter makes up more than 15% of a field sample, then the soil can be classified as gravelly or stony). The type of soil particle (sand, silt or clay) that makes up the highest percentage of the sample is used to describe the soil texture class. When no one of the three fractions is dominant, the textural class is loam (refer to Gliessman, 1998). The method used to determining soil texture, is a quantitative method using special soil sieves with meshes of different grades; a pre-weighed sample of dried soil is put on top of a column of these sieves and shaken for 30 minutes. The soil collected in each progressively smaller mesh sieve is carefully collected and weighed, and distributions of the various size soil particles can calculated as a percent of the total weight of the sample.

Table 4.7: Soil texture for samples in the targeted locations

Treated Grey water		
location	Soil Texture	Blank
A	clay with sand	clay with sand
B	clay with sand	clay with sand
C	clay with sand	clay with sand

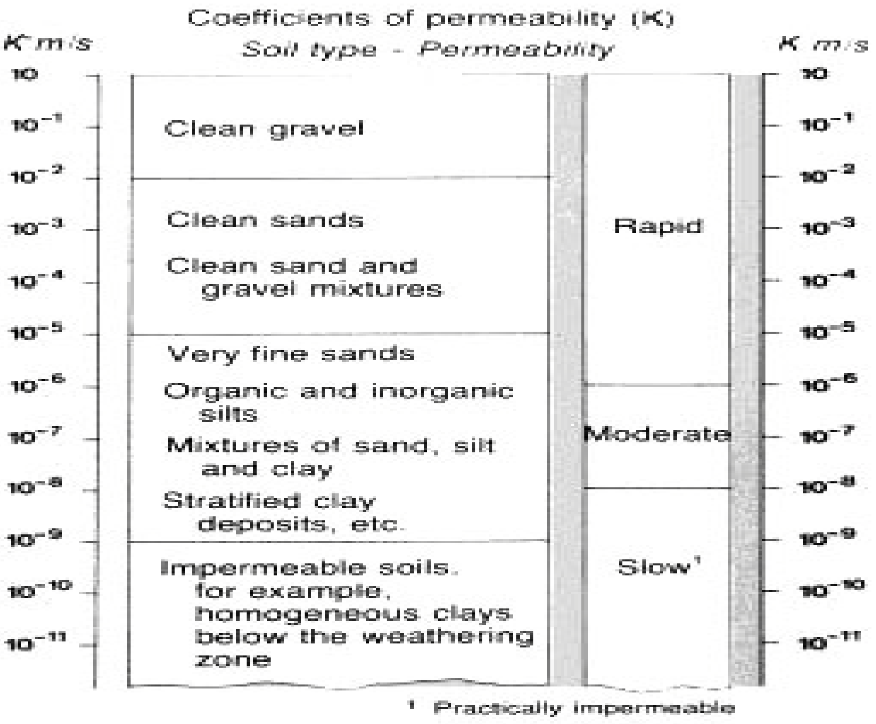

Figure 20: Classification of the soil coefficient of permeability (FAO, 2012)

4.2.3.2.2 Soil bulk density

Figure 21 shows soil bulk density which irrigated by treated grey water increased significantly in wet season, and very low decreasing in dry season. This was due to the particles dispersion and sedimentation of clay particles. Although the grey water contains considerable organic matters but there was no effect on the soil bulk density.

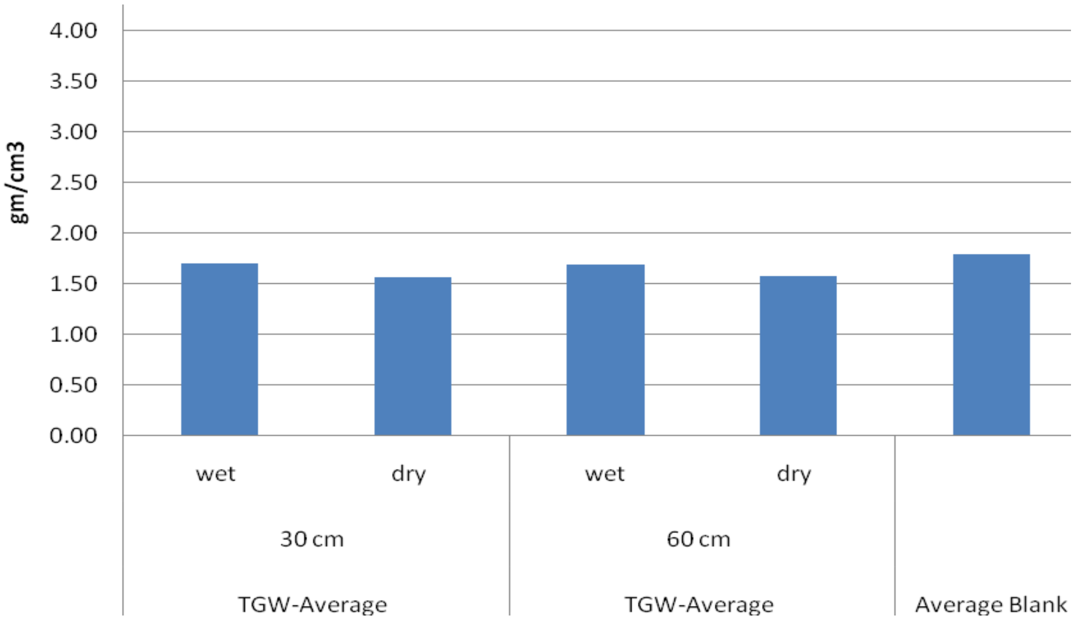

Figure 21: Soil bulk density during wet and dry seasons at two depths

4.2.3.2.3 Soil Porosity

The grey water irrigation caused a reduction in the soil porosity; however there was not statistically significant difference between the blank and grey water irrigation treatments Figure 22 . The average soil porosity irrigated by treated grey water, at 30 & 60 cm depth at dry season, is 54.25 and 50.33 %, respectively. While in blank at depth 30 cm, the porosity was 44.33 %.

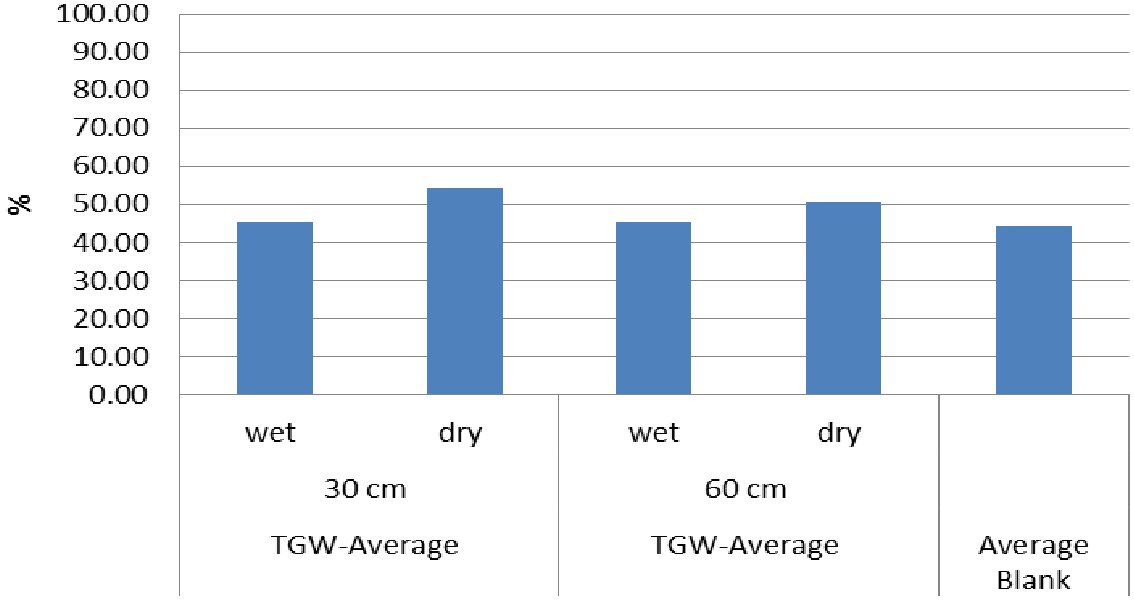

Figure 22: Soil porosity during wet and dry seasons at two depths

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The main finding of this research is that reusing treated grey water for irrigation is environmentally sound with respect to soil quality in the study area. The specific conclusions are:

- Seasonal variation influences soil quality when irrigated with treated grey water, with no influence of irrigation period (up to 15 years)
- Soil quality remained non affected due to irrigation after a period of as long as 15 years
- Soil pH remained within the normal range of 6.5-8 with an apparent decrease during dry season suggesting acid leaching
- Fe concentration was almost doubled during dry season as compared with wet season (from about 15,000 mg/kg to 30,000 mg/kg) at 60 cm depth with no difference from 30 cm depth. This reveals Fe washing during the wet season to almost Fe concentration in blank soil sample.
- Cu and Zn in soil were not influenced by treated grey water irrigation, since Cu and Zn were below detection limit in grey water.
- Soil permeability was decreased during dry season especially at 60 cm depth ($7.72E^{-8}$) but recovered during wet season ($4.15E^{-7}$) which is almost better than the blank values ($1.10E^{-8}$). Worth mentioning that permeability

coefficient remained in the moderate range defined by FAO (10^{-6} - 10^{-8} m/sec)

- The grey water SAR was in the range of (5.2 – 7.8) which is below the recommended values by the Palestinian and the Jordanian standards. Since soil maintained its original permeability after being irrigated with treated grey water after around 15 years. This result confirms that the recommended SAR values by the Palestinian and the Jordanian standards are rational for the Mediterranean area (with wet and dry seasons).
- Cl^- accumulates during dry season at the depth of 60 cm, but not at 30 cm, and then washed out during the wet season to recover again to similar concentration as of the blank soil. Noting that Cl^- in the irrigation treated grey water was within the standard value (350 mg/l)
- Mn concentration in soil increased during dry period at 30 and 60 cm depth, and recovered to normal blank value during wet season.

5.2 Recommendations

The findings allow recommending framers and families in rural areas, to continue reusing the treated grey water for restricted irrigation, without apprehensive for long term reuse. Also, it’s recommended to legalize the reuse of treated grey water in agricultural irrigation.

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