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EFFECT OF IRRIGATION WITH RECLAIMED WASTEWATER ON SOIL PROPERTIES AND GROUNDWATER QUALITY IN ZAITON AREA, GAZA, PALESTINE.

MSc. Thesis
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جامعــــــــة الأزهــــــــر – غـــــــزة
عمــادة الدراســات العليــا والبحــث العلمــي
ماجـــستير علـــوم الميـــاه والبيئــــة

نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة عمادة الدراسات العليا بجامعة الأزهر – غزة على تشكيل لجنة المناقشة والحكم على أطروحة الطالب/ **خيري صبري مصطفى عطا الله**، المقدمة لنيل درجة الماجستير في علوم المياه والبيئة وعنوانها:

Effect of irrigation with reclaimed wastewater on soil properties and groundwater quality in Zaiton area, Gaza-Palestine

تأثير الري باستخدام مياه الصرف الصحي المعالجة على خصائص التربة وجودة المياه الجوفية، منطقة الزيتون، غزة ـ فلسطين

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Abstract

Monitoring study was conducted from March to December 2011 to investigate the short-term effect of irrigation with reclaimed wastewater RWW (from Gaza Wastewater Treatment Plant) on physiochemical properties of soil, groundwater and fruits. Two experimental plots planted with olive and citrus trees were used. The experimental sites were located in Zaiton area, south of Gaza city; the first experimental plot (A) was irrigated with fresh water (FW). The second experimental plot (B) was irrigated with RWW. Soil, irrigation water, fruits and olive oil samples were characterized according to standard methods. The electrical conductivity (EC), total dissolve solid (TDS), Nitrite (NO_2), chloride (Cl^-), alkalinity, potassium (K^+), sodium (Na^+), sodium absorption ratio (SAR), chemical oxygen demand (COD), total coliform and fecal coliform were significantly higher in RWW than FW. However, heavy metal in RWW and FW were found to be below standard limits. At the end of the experiment, soil results exhibited no significant variation in infiltration rate, bulk density, and porosity between the two plots (A) and (B). However, significant difference in EC, TDS, NO_3, Cl^-, Mg^{+2}, Ca^{+2}, Na^+ and OM were reported, particular at top soil layer (0-30 cm) more than (30-60 cm) layer. Piper (Trilinear) diagram indicated that there is no significant changes in the hydro chemical facies of groundwater were observed during the study period. Which indicated that short term irrigation by RWW for citrus and olive trees does not affected clearly on the groundwater. Results also showed no microbial contamination in the olive and citrus fruits in both plots. Additionally, the levels of the heavy metals were reported to be low. Olive oil quality parameters indicated no significant variation in refractive index, free acidity, peroxide value and acid value extracted from olive fruits from both plots. The main conclusion of the study is that land application of RWW can be designed and operated in a way such that there are minimum negative effects on the environment. To

further prove this more completely, this research should be collected over a period of 10 years to truly evaluate long-term effects of RWW application.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Description
As^{3+}	Arsenic
B^{-}	Boron
C^{4+}	Carbon
C°	Degrees Celsius
Ca^{2+}	Calcium
Cd^{2+}	Cadmium
Cl^{-}	Chloride
Co^{3+}	Cobalt
Cr^{2+}	Chromium
Cu^{+}	Copper
F^{-}	Fluoride
Fe^{2+}	Iron
Hg^{+}	Mercury
K^{+}	Potassium
Mg^{2+}	Magnesium
Mn^{2+}	Manganese
Na^{+}	Sodium
NH_4^{+}	Ammonia
Ni^{2+}	Nickel
NO_2^{-}	Nitrite
NO_3^{-}	Nitrate
P	Phosphorous
Pb^{2+}	Lead

pH	Hydrogen Ion Activity
SO_4^{2-}	Sulphate
Zn^{2+}	Zinc

ABBREVIATIONS

APHA	American Public Health Agency
BOD_5	Biochemical Oxygen Demand
BIS	Before Irrigation Season
CFU	Colony Forming unit
cm	centimetre
CMWU	Coastal Municipalities Water Utility
COD	Chemical Oxygen Demand
DI	Drip Irrigation
ds/m	deci Siemens per meter
EC	Electrical Conductivity
EIS	End Irrigation Season
EQA	Environment Quality Authority
EPA	Environment Protection Agency
FAO	Food and Agriculture Organization
FC	Fecal Coliforms
FI	Flood Irrigation
FW	Fresh Water
g	gram
GWWTP	Gaza Wastewater Treatment Plant
ha	hectare
HM	Heavy Metal

ICARDA	International Centre for Agriculture Research in Dry Areas
IOC	International Olive Council
IR	Infiltration Rate
IWE	Institute of Water and Environment
Km	Kilo meter
Km^2	Square kilo meter
M	Meter
m^3	Cubic meter
m^3/y	Cubic meter per day
MCL	Maximum Concentration Level
MCM	Million Cubic Meters
MCM/yr	Million Cubic Meters per year
MERAP	Middle East Regional Agriculture Programme
mg/l	Milligram Per Litre
$\mu S\ cm^{-1}$	micro Siemens per cm
MIS	Middle Irrigation Season
ml	millilitre
MOA	Ministry of Agriculture
MOH	Ministry of Health
msl	Mean sea level
NGOs	Non Governmental Organizations.
OM	Organic Matter
PCBS	Palestinian Central Bureau of Statistics
PHG	Palestinian Hydrology Group
PHL	Public Health Laboratory

PS	Palestinian Standard
PWA	Palestinian Water Authority
RWW	Reclaimed Wastewater
SAR	Sodium Absorption ratio
STDEV	Standard Deviation
TC	Total Coliform
TDS	Total Dissolved Solids
TKN	Total Kjeldhal Nitrogen
TSS	Total Suspended Solids
UN	United Nations
UNDP	United Nations Developing Program
UNEP	United Nations Environment Programm
USDA	United States Department of Agriculture
WHO	World Health Organization
WWTPs	Wastewater Treatment Plants

CHAPTER 1

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Background

Gaza Strip is the south-western part of Palestine, located in the south-eastern coast of the Mediterranean Sea, it borders armistice line 1948 to the east and north and Egypt to the south as shown in Figure 1.1. It is approximately 41 kilometers (Km) long, and between 6 and 12 Km wide, with a total area of 378 km^2 (UNEP, 2009). Gaza Strip is considered one of the denser places in the world. The total population of Gaza Strip at mid 2011 was about 1.59 million inhabitants with population density particularly in Gaza Strip is 4353 persons/km^2 (PCBS, 2011).

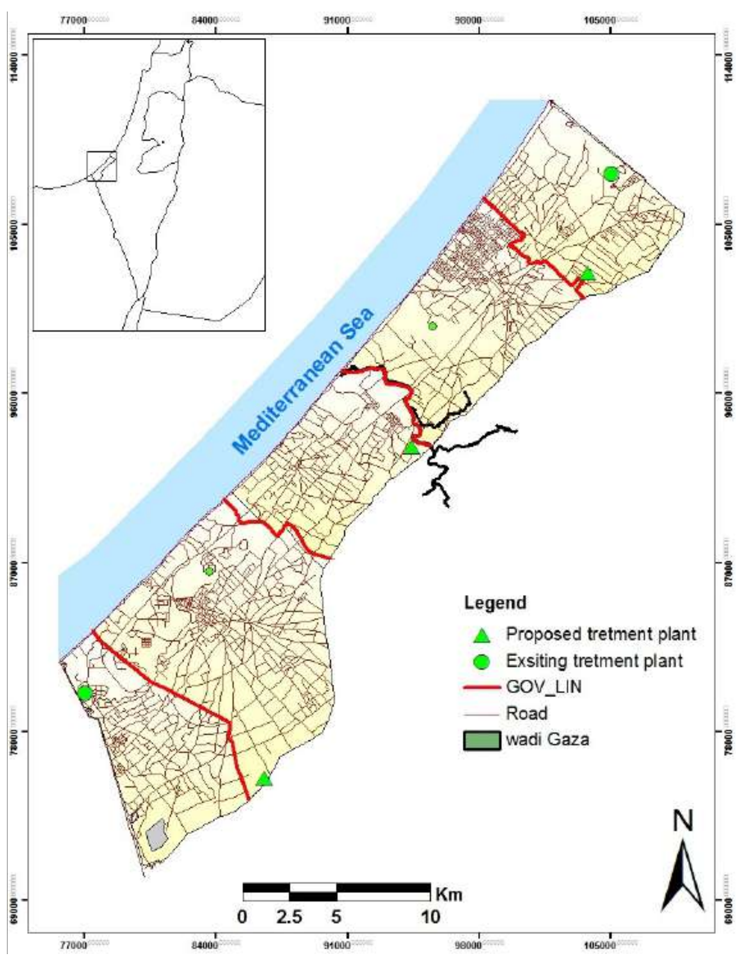

Figure 1.1: Map of Gaza Strip (prepared by Researcher)

Water demand in the Gaza Strip is increasing continuously due to economic development and population increase resulting from natural growth and returnees, while the water resources are constant or even decreasing due to urban development (Hamdan, 2006). The Gaza Strip is classified as a semi-arid region and suffers from water scarcity. The renewable amount of water that replenishes the groundwater system is much less than the demanded amount, and this resulted in deterioration of the groundwater system in both quantitative and qualitative aspects (Nassar *et al*., 2010).

Total abstraction of groundwater in Gaza Governorates exceed 170 Million Cubic Meters per year (MCM /yr), the total water demand for agriculture and domestic use accounts for 81and 91.4 MCM, respectively (PCBS, 2011). 55-60 MCM annual deficit of water balance, due to increasing of the gap between water demand and water supply, as a result of rapid population growth in this small area (Nassar *et al*., 2009).

If the demand for irrigation is calculated on the basis of the food requirements of the growing population, it appears that it will increase from the present usage to 185 MCM /yr by 2020 (PHG, 2006). However, this figure is not a realistic projection for Gaza, because neither the water nor the land to support an increase in agricultural activity exists. Therefore, the estimated future demands for agriculture are based on the actual water amounts of today. Generally, the overall water demand in Gaza Strip is estimated to increase from the present value of to about 260 MCM /yr in 2020 (PHG, 2006).

The pollution of groundwater is contributing to two main types of water contamination in the Gaza Strip. First, and most importantly, it is causing the nitrate levels in the groundwater to increase. In most parts of the Gaza Strip, especially around areas of intensive sewage infiltration, the nitrate level in groundwater is far above the World Health Organization (WHO) accepted guideline of 50 mg/l. Second, because the water abstracted now is high in salt, the sewage is also very saline and hence infiltrating sewage only adds to the salinity of the aquifer (UNEP, 2009).

The groundwater quality is monitored through all municipal wells and some agricultural wells distributed all over Gaza Strip. The chloride ion concentration varies from less than 250 mg/L in the sand dune areas in the northern and southwestern area of the Gaza Strip to about more than 10,000 mg/L where the seawater intrusion taking place (CMWU, 2010). Due to pumping the wastewater to the open sand dunes, the nitrate ion concentration reaches a very high range in different areas of the Gaza Strip, while the WHO standard recommended nitrate concentration less than 50 mg/L (Abu Nada, 2009).

Most of the wastewater treatment plants (WWTPs) in Gaza Strip are overloaded and are working beyond their designed capacities (Hilles, 2012). The situation with regard to treatment of wastewater or sewage is no less problematic, with huge investment in treatment facilities and associated infrastructure desperately needed to cope with the existing demand, let alone for the future. At present, only 25% of wastewater, or 30,000 m^3 / day, are able to be treated and re-infiltrated for use in green areas and some forms of agriculture. Some 90,000 m^3 of raw or partly treated sewage has to be released daily into the nearby Mediterranean Sea and environs, creating pollution, public health hazards and problems for the fishing industry (UN, 2012). Efficient operation of the existing wastewater systems are hindered due to continued electricity fluctuations.

Reclaimed wastewater is now being considered as a new source of water that can be used for different purposes such as agricultural and aquaculture production, industrial uses, recreational purposes and artificial recharge. Using wastewater for agriculture production will help in alleviating food shortages and reduce the gap between supply and demand (EQA, 2005).

The best way to use treated wastewater is in the irrigation of soils, which can relieve a great deal of pressure on fresh water resources. Replacement of freshwater by treated wastewater is an important conservation strategy contributing to agricultural production, leading to substantial benefits from the use of nutrient-rich wastewater (Bedbabis *et al*., 2010).

Water reuse for irrigation has been largely applied to agriculture due to the advantages related to nutrient recovery possibilities, socio-economic implications, reduction of fertilizer application and effluent disposal, but there are two major drawbacks of the use of untreated domestic wastewater for irrigation: (i) pathogens, organic and inorganic chemical compounds in wastewater, can induce health risks for workers and consumers, exposed via direct or indirect contact with such waters during field work and ingestion of fresh and processed food), and (ii) the long term use of untreated wastewater for irrigation has an impact on the soil composition (Surdyk *et al*., 2010).

1.2 Problem Statement

Due to the increasing demand and fixed supply of the groundwater system in Gaza strip, it became urgent to look for new non conventional water resources to fill the gap in the water budget.

As a result, the groundwater level is falling and the salinity is increasing making the water unsuitable either for human consumption or irrigation purposes. The uncontrolled discharge of untreated sewage and excessive use of fertilizers have led to high nitrate concentrations in certain areas, thus creating an additional pollution of the groundwater resources. Using treated domestic wastewater could be one of the main option to develop the water resources in the Gaza Strip as it represents an additional renewable and reliable water source. Using reclaimed wastewater for agricultural purposes would minimize the deficit of groundwater quantity and would reduce the degradation of the groundwater quality.

In other words Wastewater reuse for agriculture offers the greatest scope for application because it usually has the potential to meet growing water demands, conserve potable supplies, reduce disposal of pollution effluent into surface water bodies, allow lower treatment costs and enhance the economic benefits for growers due to reduced application rates for fertilizer.

1.3 Study Justifications

There is a major potential use of treated wastewater in Gaza strip. However, it is essential that the development of water reuse in agriculture be based on scientific evidences of its effects on environment. Despite meeting the regulation and guidelines, the reuse of wastewater is not entirely a risk-free. Continued research will result in developing new technologies or improving the existent methodologies used for assessment of risk associated with trace contaminants, evaluation of microbial quality, treatment systems, and evaluation of the fate of microbial, chemical and organic contaminants (EQA, 2005).

Moreover, while many wastewater reuse projects have been practiced in Gaza strip, needs to be better assessed with applied research for specific applications a comprehensive short term impact analysis on groundwater, soil and fruits properties. This study will carry out these analysis based on actual field analysis from Zaiton area Pilot Project.

Extensive short term monitoring program were designed for groundwater, soil and fruits along nine months in order to evaluate the adverse effects of irrigation with reclaimed wastewater.

1.4 Scope and Objectives

The overall goal of this study is to identify the most significant impacts resulting from the use of reclaimed wastewater (RWW) as an alternative source of water for irrigation in the agricultural sector. The objectives of this research work are:

- To investigate the short term impacts of RWW irrigation on soil physical and chemical properties.
- To explore the adverse effects on the groundwater quality as a results of short term irrigation by RWW.
- To compare the effects of RWW on the quality of both Citrus and Olives fruits with a control plot.

1.5 Thesis Structure

Chapter one presents the introduction broadly describes water crisis in the Gaza Strip, the wastewater problems and potential to reuse. It presents also the problem statement, study justification, aims and objectives of this study.

Chapter two actually provide a base for this study. Previous studies at different places in the world were described and discussed, Existing guidelines and different standards concerning irrigated water quality were presented and discussed, a brief description on impacts on soil, crops, and ground water was also presented.

a brief description of the Gaza Strip, its location, population, climate and soil is presented in chapter three, a brief description of the groundwater quality and wastewater treatment plants in the Gaza Strip are discussed at the end of the chapter .

Chapter four presents the experimental monitoring program and analyses methods that have been followed in this research. Introduction to the Zaiton Pilot Project with extended site description where the samples have been collected is presented. Physical, chemical and biological parameters for applied wastewater, soil, groundwater and olive fruit and oil were illustrated. Samples collection, preservation and methods of analysis were also described. All media and equipments with analysis methods of physical, chemical, biological parameters and water level measurements were also explained.

Chapter five presented the results and discussion, the data collected from the field and laboratories were presented and discussed.

Conclusions and recommendations of this study are listed in the final chapter six entitled Conclusions.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The interest in reusing wastewater for irrigation is rapidly growing in the world. Moreover, irrigation with municipal wastewater is considered an environmentally sound wastewater disposal practice that helps to minimize the pollution of the ecosystem subjected to contamination by direct disposal of wastewater into surface or groundwater (Kiziloglu *et al*., 2008).

This chapter presents a full picture about the worldwide wastewater reuse and particularly, the history, the current status of wastewater reuse, benefits and disadvantages of wastewater reclamation. and also reviews the results of several field studies concerned with various re-use of reclaimed wastewater to irrigate trees and agricultural crops and their effects on soil physical properties and chemical as well as adverse effects on groundwater and contamination.

2.2 Wastewater Constituents and Compositions

Wastewater is composed of 99% water and 1% suspended, colloidal and dissolved solids. Municipal wastewater contains organic matter and nutrients (N, P, K); inorganic matter or dissolved minerals; toxic chemicals; and pathogens (Hanjara *et al*., 2012).The pollutants belonging to the same category exhibit similar water quality impacts.

The composition of typical raw wastewater (Table 2.1; Pescod, 1992) depends on the socioeconomic characteristics of the residential communities and number and types of industrial and commercial units, such that global demographic and economic change also has implications for environmental health protection and wastewater governance approaches (Hanjara *et al.*, 2012).

Table 2.1: Major constituents of typical raw domestic wastewater (source: Pescod, 1992)

Constituent	Concentration, mg/l		
	Strong	Medium	Weak
Total solid	1200	700	350
Dissolved solids(TDS)	850	500	250
Suspended solids(TSS)	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus(as P)	20	10	6
Chloride(Cl)	100	50	30
Alkalinity(as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

2.3 Wastewater Treatment for Reuse

Water reclamation and nonpotable reuse typically require conventional water and wastewater treatment technologies that are already widely practiced and readily available in many countries throughout the world (EPA, 2004).

Municipal wastewater treatment, typically, consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment (Pettygrove and Asano, 1984). The constituents of concern in wastewater treatment and wastewater irrigation are listed in Table 2.2

Table 2.2: Constituents of concern in wastewater treatment and irrigation with reclaimed wastewater (Source: Partly adapted from Pett ygrove and Asano (1984)).

Constituent	Parameter	Impacts
Plant food nutrients	N, P, K	Excess N: potential to cause nitrogen injury, excessive vegetative growth, delayed growing season and maturity, and potential to cause economic loss to farmer - excessive amounts of N, and P can cause excessive growth of undesirable aquatic species.(Eutrophication) - nitrogen leaching causes groundwater pollution with adverse health and environmental impacts
Solids	Volatile compounds, settleable, suspended and colloidal impurities	-development of sludge deposits causing anaerobic conditions - plugging of irrigation equipment and systems such as sprinklers
Pathogens	Viruses, bacteria, helminthes eggs, fecal coliforms etc.	- can cause communicable diseases
Biodegradable organics	BOD, COD	- depletion of dissolved oxygen in surface water - development of septic conditions - unsuitable habitat and environment - can inhibit pond-breeding amphibians - fish mortality and humus build-up
Dissolved inorganic substances	TDS, EC, Na, Ca, Mg, Cl, and B	- cause salinity and associated adverse impacts - phytotoxicity - affect permeability and soil structure
Stable organics	Phenols, pesticides, chlorinated hydrocarbons	- persist in the environment for long periods - toxic to environment - may make wastewater unsuitable for irrigation
Heavy metals	Cd, Pb, Ni, Zn, As, Hg	- bio accumulate in aquatic organisms (fish and planktons)

		- accumulate in irrigated soils and the environment - toxic to plants and animals - systemic uptake by plants - subsequent ingestion by humans or animals - possible health impacts - may make wastewater unsuitable for irrigation
Hydrogen ion concentrations	pH	- especially of concern in industrial wastewater - possible adverse impact on plant growth due to acidity or alkalinity - impact sometimes beneficial on soil flora and fauna - affect on the availability of N, P, K
Residual chlorine **wastewater**	Both free and combined chlorine	- leaf-tip burn - groundwater, surface water contamination (carcinogenic effects from organochlorides formed when chlorine combines with residual organic compounds) - greenhouse effect

The primary and secondary wastewater treatments improve distinctly the water quality although RWW still retains a substantial amount of organic and metallic compounds. So, the reuse of the RWW can have important supplementary C, N, P and K which had a favorable effect on the growth of certain crops (Klay *et al*., 2010).

On the other hand, RWW may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts. Consequently, mismanagement of RWW irrigation would create environmental and health problems to the ecosystem and human beings (Rusan *et al*., 2007).

2.3.1 Primary Treatment

Preliminary treatment to screen out, grind up, or separate debris is the first step in wastewater treatment. Primary treatment is the second step in treatment and separates suspended solids and greases from wastewater. Primary treatment is the minimum level of preapplication treatment required for wastewater irrigation. It is considers sufficient treatment if the wastewater is used to irrigate crops that are not consumed by humans and may be sufficient treatment for irrigation of orchards (Pettygrove and Asano, 1984).

2.3.2 Secondary Treatment

Secondary treatment is a biological treatment process to remove dissolved organic matter from wastewater. Wastewater microorganisms are cultivated and added to the wastewater. The microorganisms absorb organic matter from sewage as their food supply. Three approaches are used to accomplish secondary treatment; fixed film, suspended film and lagoon systems. Secondary treatment is the level of preapplication treatment required when the risk of public exposure to wastewater is moderate (Pettygrove and Asano, 1984).

2.3.3 Tertiary Treatment

Final treatment focuses on removal of disease-causing organisms from wastewater and nutrients. Treated wastewater can be disinfected by adding chlorine or by using ultraviolet light or other method.

2.4 The Status of Wastewater Reuse Practice in The Mediterranean Basin

Most Mediterranean countries are arid or semiarid with mostly seasonal and unevenly distributed precipitations. Due to the rapid development of irrigation and domestic water supplies, conventional water resources have been seriously depleted. As a result, wastewater reclamation and reuse is increasingly being integrated in the planning and development of water resources in the Mediterranean region, particularly for irrigation.

2.4.1 Tunisia

RWW irrigation has had Government support since 1975, and since a severe drought in 1989, RWW use in irrigation has been a part of the Government's overall water resources management and environmental pollution control (World Bank, 2010). It is estimated that by 2020 about 20,000-30,000 ha, or about 7-10% of total irrigated area will be using RWW. The current rate of reuse is about 29%, reused for the cultivation of fruit trees, cereals, fodder crops and industrial crops as well as for golf courses and green spaces. Wastewater is also reuse in recharges purposes and conservation of wetlands (Kamoun and Slimi, 2006).

2.4.2 Jordan

Jordan is one of the most water-deprived countries of the Middle East, and has some of the highest groundwater depletion rates. To meet growing water demands, more than 70 MCM of reclaimed wastewater, around 10 percent of the total national water supply, is used either directly or indirectly each year (World Bank, 2010). In 1993 the quantity of reused RWW reached 50 MCM, of which 48MCM for irrigation. In 2008 the amount of RWW reached 80 MCM .the total quantity of reused RWW is expected to grow from 80 MCM in 2008 to about 237 MCM in 2020.the reused RWW in Jordan reach one of the highest levels in the world .the importance of reused wastewater is an essential element of Jordan's water strategy .(MERAP, 2010).

2.4.3 Israel

Israel was a pioneer in the development of wastewater reuse practices (Angelakis *et al*., 1999). It has achieved some impressive accomplishments in reclamation and reuse of wastewater, and at solving issues which arose from using RWW. The total amount of wastewater produced in Israel is approximately 500 MCM/yr including agriculture, industry, and other wastewater consumers. Almost all of the wastewater produced in Israel flows into the main sewage collection systems, while only 2.5% of the wastewater still flows into cesspits. Approximately 450 MCM/yr is being treated at 465 mechanical facilities and stabilization basins, using a variety of technologies. During 2007 total amount of RWW used for agriculture purpose was about 382 MCM. About half of the total amount has been treated to tertiary degree; the rest has been treated to a secondary degree (MERAP, 2010).

In these countries, full fledged regulations set the basic conditions for a safe reuse of wastewater (Angelakis *et al*., 1999). It is therefore necessary to take precautions before reusing RWW. As a result, although the irrigation of crops or landscapes with RWW is in itself an effective wastewater treatment method, a more effective treatment is necessary for some pollutants and adequate water storage and distribution system must be provided before RWW is used for agricultural or landscape irrigation (Angelakis *et al*., 1999).

2.4.5 Palestine

In spite the fact that there are very limited activities in the Palestinian territories for using reclaimed wastewater due to many reasons, there is a great potential for the reuse of this water resource to meet increasing agricultural water demand as a main objective of the Palestinian water sector. The total volume of treated urban wastewater for reuse is projected to be 12.1 MCM/yr for the main Palestinian cities by the year 2010. In comparison, the total water demand is projected to increase by 50 MCM/yr over the years 2005-2010. (MERAP, 2010).

The reuse of treated wastewater could be an important alternative to solve the water deficit crisis in Gaza Strip. According to the Water Sector Strategic Planning Study, about 20,000 dunums are to be irrigated by RWW in the year 2010 and this will increase to about 60,000 dunums in the years 2020. The existing four WWTPs (Beit Lahia, Gaza, KhanYunis and Rafah) are heavily overloaded as a result of the rapid population growth. Currently, most of the effluent discharged from the four existing WWTPs in Gaza Strip is disposed into the Mediterranean Sea. Although the quality of the effluent from Gaza and even Beit Lahia WWTPs would nearly meet class C standards which are progressively match irrigating citrus, fodder crops and olives (EQA, 2005).

2.5 Guidelines for Wastewater Reuse in Agriculture

Wastewater contains microbes and chemicals that pose risk to human and environmental health. Wastewater governance refers to the guidelines, regulations, policies and laws that have been developed to guide wastewater use for agricultural and other uses, and to minimize the risk to public health and the environment. All of it was initiated based on experimental data and results as follows:

-Food and Agriculture Organization (Ayers and Westcot, 1985 and Pescod, 1992), Wastewater treatment and use in agriculture, determine the degree of suitability of a given effluent of irrigation.

-World Health Organization (WHO 1989 and 2006): "Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture", they take into account the treatment process, irrigation system and the crops to be irrigated. This set of guidelines is controversial but has allowed a real development of wastewater reuse.

-American Environmental Protection Agency EPA, 2004 Guidelines for Water Reuse.

2.5.1 Palestinian Standards

Standards for RWW quality for various uses have been established by the Palestinian Ministry of the Environment, but they are often not enforced (McNeill *et al*., 2010). The regulations establish four classes of water from Class A (high quality) to Class D (low quality). The draft Palestinian standard reuse mainly care of; a) Sanitary, b) Environmental and c) Agro technical quality requirements (Abu Nada, 2009).

2.6 Possibilities of Reuse

Two major types of reuse have been developed and practiced throughout the world :

1-Potable uses

- Direct, use of reclaimed water to augment drinking water supply following high levels of treatment
- Indirect after passing through the natural environment

2- Non-potable uses

- Irrigated agriculture
- Use for irrigating parks, public places of forestry (fastest reuse application in Europe :
- Irrigation of golf courses)
- Use for aquaculture
- Aquifer recharge (indirect reuse)
- or uses in industry and urban settlements

The two mostly common types of water irrigation based on RWW quality are:

• Restricted irrigation: use of low quality effluents in limited areas and for specific crops (wooden, fodder and cocked), restrictions are imposed based on the type of soil, the proximity of the irrigated area to a potable aquifer, irrigation method, crop harvesting technique, and fertilizer application rate. It is simple and low cost so farmers must be trained to handle the low-quality effluent.

• Unrestricted irrigation: use of high quality effluents, instead of freshwater, to irrigate any crop (include also vegetables eaten raw) on any type of soil, which means without limitations as contact and even accidental drinking do not pose health risks.

2.7 Quality of RWW

Many schemes of classification for irrigation water have been proposed (Pescod, 1992). Ayers and Westcot, 1985 water quality for irrigation, classified irrigation water into three groups based on salinity , toxicity and miscellaneous hazards, as shown in Table 2.3. These general water quality classification guidelines help to identify potential crop production problems associated with the use of conventional water sources. Irrigation water may be classified into one of three categories namely no restriction, slight to moderate restriction and severe restriction for use.

The quality standard can even vary during irrigation and non irrigation period. The guidelines are equally applicable to evaluate wastewaters for irrigation purposes in terms of their chemical constituents, such as dissolved salts, relative sodium content and toxic ions (Ayers and Westcot, 1985).

Table 2.4 shows recommended guidelines by the Palestinian Standards Institute for RWW reuse characteristics according to different applications such as fodder irrigation, gardens, Playground, industrial crops, landscape and fruit trees.

Table 2.3: Guideline for interpretation of RWW quality for irrigation (modified from Ayers and Westcot, 1985)

Potential irrigation problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity (affects crop water availability)				
EC	ds/m	<0.7	0.7 - 3	>3
TDS	mg/l	<450	450 - 2000	>2000
SAR				
SAR		0-4	4 - 9	>9
Specific Ion Toxicity (affects sensitive crops)				
Sodium (Na)	mg/l	<70	70 - 200	>200
Chloride (Cl)	mg/l	<135	135 - 350	>350
Boron (B)	mg/l	<0.7	0.7 - 3.0	>3.0
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO_3 - N)	mg/l	<5	5 - 30	>30
Bicarbonate (HCO_3)	mg/l	<90	90 - 500	>500

Table 2.4: Recommended Guidelines by the Palestinian Standards institute for RWW reuse characteristics according to different applications (WSI, 2005).

Quality Parameter (mg/l)	Fodder Irrigation		Gardens, Playground, Recreational	Industrial Crops	Landscape	Fruit trees
	Dry	Wet				
BOD_5	20-60	20-40	20	20-60	60	20-60
COD	200	150	150	200	200	150
TDS	1500	1500	1200	1500	1500	1500
TSS	30-90	30-50	30	30-90	30-90	30-90
pH	6-9	6-9	6-9	6-9	6-9	6-9
NO_3-N	50	50	50	50	50	50
PO_4-P	30	30	30	30	30	30

Cl	500	500	350	500	500	400
SO_4	500	500	500	500	500	500
Na	200	200	200	200	200	200
Mg	60	60	60	60	60	60
Ca	400	400	400	400	400	400
SAR	9	9	10	9	9	9
B	0.7	0.7	0.7	0.7	0.7	0.7
FC(CFU/100ml)	≤1000	≤1000	≤200	≤1000	≤1000	≤1000
Pathogens	Free	Free	Free	Free	Free	Free
Nematodes(Eggs/L)	<1	<1	<1	<1	<1	<1
Pb	1	1	0.1	1	1	1
ZN	2.0	2.0	2.0	2.0	2.0	2.0
Fe	5	5	5	5	5	5
Ni	0.2	0.2	0.2	0.2	0.2	0.2

2.8 Microbial Quality

The classification of RWW in microbiological categories, and its use for irrigation, should take into account crops types (edible or not) and their human consumption (without or after processing), health hazards for risk groups (young, old, pregnant or immunocompromised consumers and operators such as farmers), water application technologies and the duration of the irrigation season. All this could allow a wider use of the treated wastewater for irrigation associated with minimal health and environmental risk (Palese *et al*., 2009).

To protect public health, (Table 2.5;WHO, 1989) guidelines recommended no more than one viable human intestinal nematode egg per liter for restricted irrigation; plus no more than one thousand fecal coliform/100ml for unrestricted irrigation (Hanjra *et al*., 2012).

Table 2.5: WHO, 1989 guidelines for using RWW in agriculture

Category	Reuse conditions	Exposed group	Intestinal nematodes (arithmetic mean no. of eggs per liter)	Fecal coliforms (geometric mean no. per 100ml)
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumers, public	≤ 1	≤ 1000
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	≤ 1	No standard recommended
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable

Soil will always take on the characteristics of the water with which it is irrigated. Evaluation should be carried out at regular intervals (minimum six months) to best manage the wastewater reuse projects (Pescod, 1992).

Because of the growing interest in the use of RWW for irrigation, and in light of their possible impacts on soils, water resources, and agricultural production, several authors have studied the effects of RWW irrigation on the soil chemical and physical properties (Abedi-koupi *et al*., 2006; Aiello *et al*., 2007; Rusan *et al*., 2007; Jalali *et al*., 2008; Kiziloglu *et al*., 2008; Lado and Ben-Hur, 2009; Duan *et al*., 2010; Klay *et al*., 2010; Surdyk *et al*., 2010).

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 (Rusan *et al*., 2007).

2.9 Effects of The reuse of RWW for Irrigation

2.9.1 Public Health

RWW can be used for irrigation if public health and environmental protection concerns are fully addressed. Best management practices and supportive policy frameworks are necessary to minimize the risks. The socioeconomic benefits and costs of wastewater irrigation also need assessment to achieve ecologically sustainable development (Hanjra *et al*., 2012).

In countries or regions where poor sanitation and hygiene conditions prevail and untreated wastewater are widely used in agriculture, intestinal worms pose the most frequently encountered health risks as shown in Table2.6. Other excreta-related pathogens may also pose health risks, as indicated by high rates of diarrhea, other infectious diseases, such as typhoid and cholera, and incidence rates of infections with parasitic protozoa and viruses.(WHO, 2006)

Table 2.6: Global mortality due to some diseases of relevance to wastewater use in agriculture (source: Drechsel 2010)

Disease	Mortality (deaths/year)	Comments
Diarrhea	1,682,000	99.7% of deaths occur in developing countries; 90% of deaths occur in children; 94% can be attributed to environmental factors.
Typhoid	600,000	Estimated 16,000,000 cases per year.
Ascariasis	3000	Estimated 1.45 billion infections, of which 350 million suffer adverse health effects.
Hookworm Disease	3000	Estimated 1.3 billion infections, of which 150 million suffer adverse health effects.
Lymphatic Filariasis	0	Mosquito vectors of filariasis (Culex spp.) breed in contaminated water. Does not cause death but leads to severe disability.

Hepatitis A	N/A	Estimated 1.4 million cases per year worldwide. Serological evidence of prior infection ranges from 15% to nearly 100%.

N/A = not available

Three different community groups are at risk from wastewater use activities in agriculture:

Farm or pond workers (and their families, if they all participate in the activities or live at the site where the activities take place); local communities in close proximity to activities, and people who otherwise may have contact with fields, ponds, wastewater or products contaminated by them; product consumers.

2.9.2 Economic Benefits

Water recycling makes economic sense, studies made in several countries have shown that crop yields can increase and the consumption of fertilizers decrease if wastewater irrigation is undertaken under appropriate management, the increase of productivity per unit area is not benefit since effluent irrigation can also provide an increase in agricultural production due to the growth in irrigated area and the possibility of multiple planting seasons. Plant growth, soil fertility and productivity can be enhanced with properly managed wastewater irrigation, through increasing levels of plant nutrients and soil organic matter (Rusan *et al*., 2007).

Abu Nada (2009), study was undertaken to assess the long term impacts of wastewater irrigation on soil and crop parameters. Long term wastewater irrigation increased salt, organic matter and plant nutrients in both soil layers. Alfalfa yield increased as long as the period of wastewater irrigation increases. Alfalfa yield with wastewater irrigation was 240% higher than alfalfa yield by well water in the first year.

The results in Tavassoli *et al*. (2010) and Aghtape *et al*. (2011) experiments showed that irrigation with wastewater significantly increase the fresh and dry forage yield of corn than well water. Also the crudest protein content, ash percentage and macro elements (N, P and K) contents in corn forage were obtained from irrigation with wastewater. This increase could be related to the amount of enough nutritious elements in wastewater (such as N, P and K).

Irrigation of cut flowers (rose) plants by RWW every three days showed higher flower yields per plant and better flower quality parameters. RWW frequencies imposed higher macro and micro nutrients levels in leaves of rose plants (Rusan *et al*., 2008).

2.10 Environmental Implications for Wastewater Reuse

Irrigation with wastewater, in particular, that originating from the domestic one, and some of the potential negative environmental effects that should be considered in the planning and control of reuse systems are outlined in the following:

*Possibility of groundwater contamination. The main problem is associated with nitrates contamination of groundwater which is utilized as a source of water supply. This may occure when a highly porous unsaturated layer above the aquifer allows for deeper percolation of nitrates from the wastewater.

* Buildup of chemical pollutants in the soil, depending on the characteristics of the wastewater, long term irrigation may lead to build up toxic material specially (heavy metals, sodium, chloride, boron) and salinity on the unsaturated layers of the agriculture soil.

2.10.1 Groundwater Resources

Wastewater application has the potential to affect the quality of groundwater resources in the long run through excess nutrients and salts found in wastewater leaching below the plant root zone (Hussain *et al*., 2002).

However, the actual impact depends on a host of factors including depth of water table, quality of groundwater, soil drainage, and scale of wastewater irrigation. For instance the quality of groundwater would determine the magnitude of the impact from leaching of nitrates. If the groundwater is brackish the leaching of nitrates would be of little concern as the water has no valuable use attached to it. The proximity of wastewater irrigation to sources of potable water supplies such as wells or tube wells will influence how to evaluate the severity of groundwater pollution effects (Hussain *et al*., 2002).

Groundwater constitutes a major source of potable water for many developing country communities. Hence the potential of groundwater contamination needs to be evaluated before embarking on a major wastewater irrigation program. In addition to the accretion of salts and nitrates, under certain conditions, wastewater irrigation has the potential to translocation pathogenic bacteria and viruses to groundwater.

The long-term use of wastewater for crop irrigation has interestingly led to an improvement in the salinity of the groundwater. This was offset by evidence of coliform contamination of groundwater which was also observed in Mexico Downs *et al*. (1999), Gallegos *et al*. (1999). A companion study Rashed *et al*. (1995) reveals that in the wastewater irrigated Gabar el Asfar region, concentrations of chloride, sulfate, TDS, and dissolved oxygen in groundwater is much higher than average concentrations in sewage effluents. The leaching and drainage of wastewater, applied for crop irrigation, to groundwater aquifer may serve as a source of groundwater recharge. In some regions, 50-70 percent of irrigation water may percolate to groundwater aquifer (Rashed *et al*., 1995).

The influence of percolated wastewater on groundwater quality and its recharge is thus likely to be substantial. Despite poor quality, groundwater recharge through wastewater application can be a vital environmental and economic service in regions where freshwater supplies are limited and groundwater removal rates exceed replenishment rates. In this context it may be viewed as a benefit under some circumstances. Thus, there is an obvious tradeoff between groundwater recharge benefits and groundwater pollution costs (Hussain *et al*., 2002).

2.10.2 Soil Resources

Impact from wastewater on agricultural soil, is mainly due to the presence of high nutrient contents (Nitrogen and Phosphorus), high total dissolved solids and other constituents such as heavy metals, which are added to the soil over time. Wastewater can also contain salts that may accumulate in the root zone with possible harmful impacts on soil health and crop yields. The leaching of these salts below the root zone may cause soil and groundwater pollution (Hussain *et al*., 2002).

The reuse of the RWW can have important supplementary C, N, P and K which had a favorable effect on the growth of certain crops. It can cause soil quality modification by structure deterioration (salinization splash of clays) and soil pollution (mineral, organic, bacteriological pollution, etc). Therefore, the reuse of this water category will have some serious consequences on natural resources (klay *et al*., 2010).

2.10.3 Soil Salinity

A salinity problem due to RWW quality occurs if salts from the applied irrigation water accumulate in the crop root zone and yields are affected. The potential salinity problem caused by these salts in the irrigation water is evaluated by the guidelines of Table 2.3 (Ayers and westcot, 1985).

Although saline soil can produce acceptable yields, excessively saline irrigation water leads to reduced water available for plant use, which in turn can result in lower stem diameter and subsequently, lower fruit yield. A growing crop has a basic demand for water to produce the maximum yield. Salinity also has an effect on soil water availability, decreasing its availability to the crop in proportion to its salinity. This is called the osmotic effect (Ayers and westcot, 1985). Figure 2.1 shows divisions for relative salt tolerance ratings of agricultural crops and relation with relative crop yield.

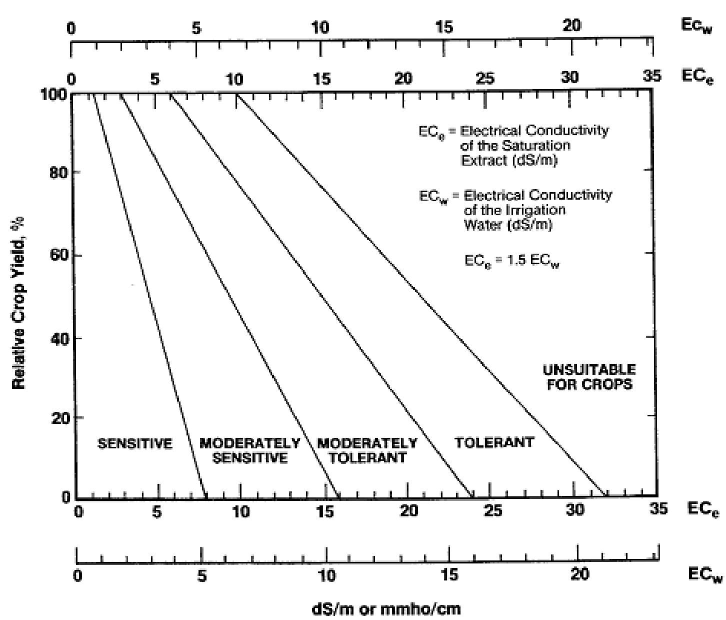

Figure: 2.1 Divisions for relative salt tolerance ratings of agricultural crops (Source Ayers and Wescots, 1985)

In order to compensate for the salt accumulation, irrigation with highly saline water requires larger and more frequent applications than irrigation with good quality water (Burt and Isbell 2005). If the water management, as locally applied, accomplishes more leaching than the guidelines have assumed, salts will not accumulate to as great an extent, and slightly higher salinity in the irrigation water could be tolerated. If leaching is less, salts will accumulate to a greater extent and salinity problems and yield reductions may be experienced at lower water salinity than the guidelines (Ayers and westcot, 1985).

No salinity problem is expected for waters having an EC <0.7 dS/m. But waters in the 0.7 – 3 dS/m range (slight to moderate salinity) may require practices if full production is to be achieved. Waters with EC >3 dS/m requires very intensive and careful management to control salinity including such drastic steps as changing to a more salt to tolerant crop or greatly increasing leaching fraction (Pettygrove and Asano, 1984).

Several authors have studied the effects of RWW irrigation on the soil chemical and physical properties; including soil salinity problems (Abedi-koupi *et al*., 2006; Aiello *et al*., 2007; Rusan *et al*., 2007; Jalali *et al*., 2008; Kiziloglu *et al*., 2008; Abu Nada, 2009; Al-Shdiefat *et al*., 2009; Lado and Ben-Hur, 2009; Duan *et al*., 2010; Galavi *et al*., 2010; Klay *et al*., 2010; Pedrero *et al*., 2010; Surdyk *et al*., 2010; Coronado *et al*., 2011; Mojiri, 2011). Although the difference conditions of the previous studies such as period of RWW application, RWW quality and crops types, but the results in these field studies indicate increasing of soil salinity which irrigated with RWW as a function with time than control unit (soil irrigated with water well).

2.10.4 Soil Sodicity

In addition to their effects on the plant, sodium salts in irrigation water may affect soil structure and reduce the rate at which water moves into the soil as well as reduce soil aeration. If the infiltration rate is greatly reduced, it may be impossible to supply the crop or landscape plant with enough water for good growth (Pett ygrove and Asano, 1984).

High sodium in the irrigation water can cause a severe soil permeability problem. Meeting the crop water demand under these conditions may become extremely difficult. In addition, other problems such as crop germination, soil aeration, disease and weed control due to surface water ponding and stagnation may need special consideration (Ayers and Wescots, 1985). The most reliable index of the sodium hazard of irrigation water is the sodium adsorption ratio (SAR) according to the equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

RWW are normally high enough in both salt and calcium, and there is little concern for water dissolving and leaching too much calcium from the surface soil. However, RWW are relatively high in sodium; the resulting high SAR is a major concern in planning RWW reuse projects (Pettygrove and Asano, 1984).

Lado and BenHur, (2009) finding, an increase of soil sodicity, caused by RWW irrigation. In a non-calcareous, sandy soil, the higher sodicity in the RWW-irrigated soil led, under rainfall conditions, to enhanced seal formation, reduced infiltration, and increased runoff, as a result of enhanced clay dispersion. In contrast, for calcareous soil under similar conditions, no effect of RWW irrigation on runoff and soil loss was observed. This was, probably, because of the release of Ca during the dissolution of CaCO3; this Ca replaced exchangeable Na, thereby reducing the soil sodicity to its natural levels (Lado and BenHur, 2009).

Abedi-Koupai *et al*. (2006) investigated the effect of RWW on soil chemical and physical properties in an arid region. Irrigation system had a significant effect on infiltration rate, bulk density and total porosity during growing season. The RWW trial therefore resulted in an increase in infiltration rate compared to the groundwater trial.

Travis *et al*. (2010) demonstrated that treated greywater can be effectively irrigated without detrimental effects on soil or plant growth; however, raw greywater may significantly change soil properties that can impact the movement of water in soil and the transport of contaminants in the vadose zone (Travis *et al*., 2010).

Because of the interaction between RWW irrigation and soil properties, it is necessary to identify sensitive regions and soils prior to irrigation with RWW, to prevent possible deleterious effects on soil structure and hydraulic properties (Lado and Ben-Hur, 2009).

2.10.5 Specific Ion Plant Toxicity

Toxicity problem is different from the salinity and the permeability problems, in that toxicity occurs within the crop itself as a result of the uptake and accumulation of certain constituents from the irrigation water and may occur even though salinity is low. The toxic constituents of concern are sodium, chloride or boron. They can reduce yields and cause crop failure. Not all crops are equally sensitive but most tree crops and other woody perennial-type plants are (Ayers and Wescots, 1985).

The most prevalent toxicity from the use of RWW is from boron. The source of boron is usually household detergents or industrial plant. Chloride and sodium also increase during domestic usage, especially where water softeners are used (Pett ygrove and Asano, 1984).

2.10.5.1Sodium

Use of irrigation water high in sodium will usually result in a soil high in sodium but it may take several irrigations to cause the change. The crop takes up sodium with the water and it is concentrated in the leaves as water is lost by transpiration. Damage (toxicity) can result if sodium accumulates to concentrations that exceed the tolerance of the crop. Leaf burn, scorch and dead tissue along the outside edges of leaves are typical symptoms.

2.10.5.2 Chloride

Chloride is not adsorbed by soils but moves readily with the soil water. It is taken up by the roots and moved upward to accumulate in leaves similar to sodium. The toxicity symptom for chloride, however, is different: the leaf burn or drying of leaf tissues typically occurs first at the extreme leaf tip of older leaves rather than at the edges and progresses from the tip back along the edges as severity increases.

2.10.5.3 Boron

Boron is one of the essential elements for plant growth but is needed in relatively small amounts. If excessive, boron then becomes toxic. A boron toxicity problem is usually associated with boron in the irrigation water, but may be caused by boron occurring naturally in the soil. The sensitivity to boron appears to affect a wide variety of crops while sodium and chloride toxicities were mostly centred on the tree crops and woody perennials.

2.10.6 Trace Element Toxicities

Beside pathogens, wastewater can also be a source of high levels of heavy metals and organic toxic compounds. Contamination can occur, in the case of metals and some organic chemicals, through absorption from the soil, which strongly depends on the location (possible contamination sources), the environmental conditions (particularly the soil), bio-availability (in the case of some contaminants), type of plant and agricultural practices (quantity of water applied and irrigation method) (Drechsel, 2010).

The long term use of untreated wastewater for irrigation has an impact on the soil composition especially through heavy metal (HM) accumulation. This has been demonstrated by several previous studies investigated the cumulative effects on heavy metal levels in soils irrigated over two years.

Abedi-Koupai *et al*. (2006) investigated the Effect of treated wastewater on soil chemical and physical properties in an arid region, the results show accumulation of Pb, Mn, Ni and Co in the soil increased significantly in the soil irrigated with wastewater as compared to the soil irrigated with groundwater. The accumulation of Pb, Mn, Ni, Co, Cu and Zn decreases with the soil depth.

Kaly *et al*. (2010) and Mojiri (2011) studies have the same, accumulation of heavy metals in the soil as a results of the long term use of untreated wastewater for irrigation. Increasing the heavy metal content in soil also increases the uptake of heavy metals by plants depending upon the soil type, plant growth stages and plant species (Khan *et al*., 2011).

The evidences of Mojiri (2011) research "Effects of municipal wastewater on accumulation of heavy metals in soil and wheat with two irrigation methods" indicated that urban wastewater caused increase of heavy metals in wheat with both irrigation methods (Flood irrigation FI and Drip irrigation DI). Accumulation of heavy metals in roots was more than in leaves in FI and DI system.

However Surdyk *et al*. (2010) study illustrated the impact of irrigation with treated low quality water on the heavy metal contents of a soil-crop system; the results indicate that the soil contents in inorganic elements at the end of the three irrigation years are similar to the initial state. After the third harvest, no impact of the irrigation water on potato quality could be detected except for total sugar and sugar in total solids. The principal conclusion of this investigation is that, when appropriately treated, low quality feed waters with high heavy metal contents can be used for irrigation over several years without significant degradation of soil and produces.

The results of the Farjood and Amins (2011) study in water wells of south and southeast Shiraz (surface and groundwater polluted with wastewater), indicated that the concentrations of Cd, Cr, Fe, Mn, and Pb exceed permissible values for crop production.

CHAPTER 3

DESCRIPTION OF

THE STUDY AREA

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3.1 Geography and Location

Gaza Strip is the south-western part of Palestine that is located on the south-eastern coast of the Mediterranean Sea. between longitudes 34° 2” and 34° 25” east, and latitudes 31° 16” and 31° 45” north Its area is about 378 km^2 with a length of 45 km and a width between 6 and 12 km. It is confined between the Mediterranean Sea in the west, Egypt in the south and the occupied Palestine in 1948 in the east and the north. The location of the Gaza Strip is shown in Figure 3.1.

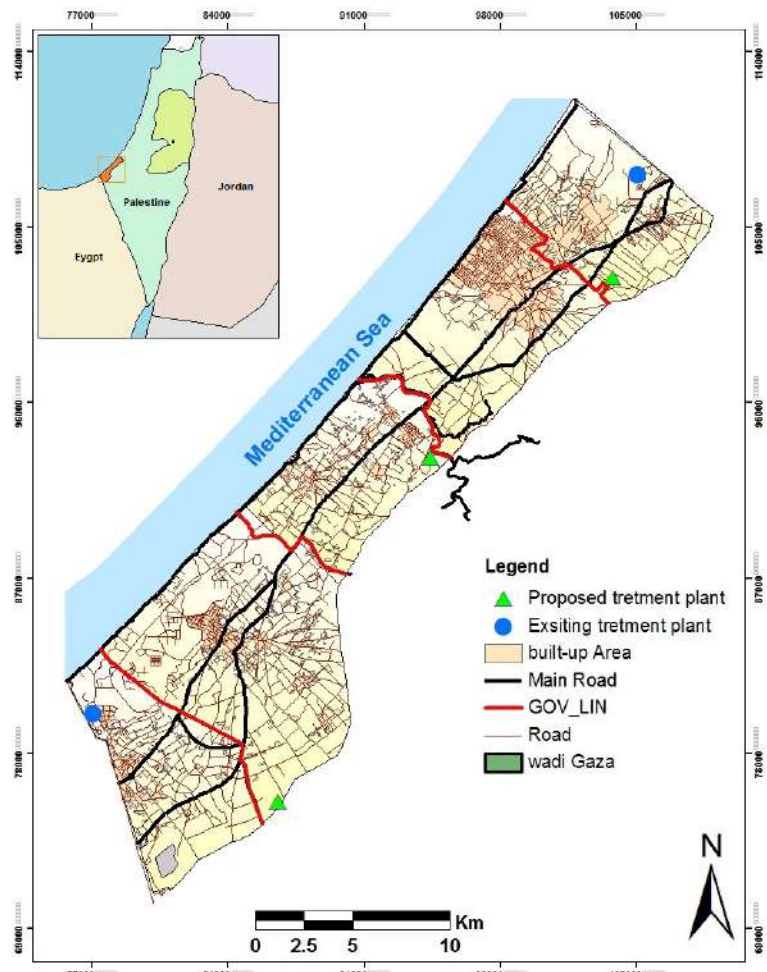

Figure 3.1 Location map of the Gaza Strip (prepared by Researcher)

3.2 Demographic Status

Gaza Strip is considered one of the denser places in the world. The total Population of the Palestinian territory at mid 2011 was about 4.17 million, 2.58 million in West Bank and 1.59 million in Gaza Strip. Population density particularly in Gaza Strip is 4353 persons/km^2 (PCBS, 2011).

3.3 Metro-Climatologically Conditions

3.3.1 Climate

The whole Gaza Strip is located in a transitional zone between the temperate Mediterranean climate to the west and north and the arid desert climate of the Negev and Sinai deserts to the east and south, and pressure line has a typical Semi-Arid Mediterranean climate, with long hot dry summer caused by eastward extension of the Azores high pressure and a mild wet winter resulted from a penetration of mid-latitude depressions accompanied by westerly wind moving eastward over the Mediterranean basin. The proximity of the Mediterranean Sea has a moderating effect on temperatures and promotes high humidity throughout the year. There are two well defined seasons: the wet season starting in October and extending into April, and the dry season from May to September (UNDP, 2010).

3.3.2 Temperature

Temperature gradually changes throughout the year, reaches it's maximum in August (summer) and its minimum in January (winter), average of the monthly maximum temperature range from about 17.6 C° for January to 29.4 C° for August. The average of the monthly minimum temperature for January is about 9.6 C° and 22.7 for August. (Aish, 2004).

3.3.3 Precipitation

The rainfall in the Gaza Strip gradually decreases from the north to the south, as shown in Figure 3.2. Average historical rainfall (25 years) is 358.5 mm/year. The values range from 418 mm/year in the north to 236 mm/year in the south. Peak months for rainfall are December and January (MOA, 2010 Unpublished Data).

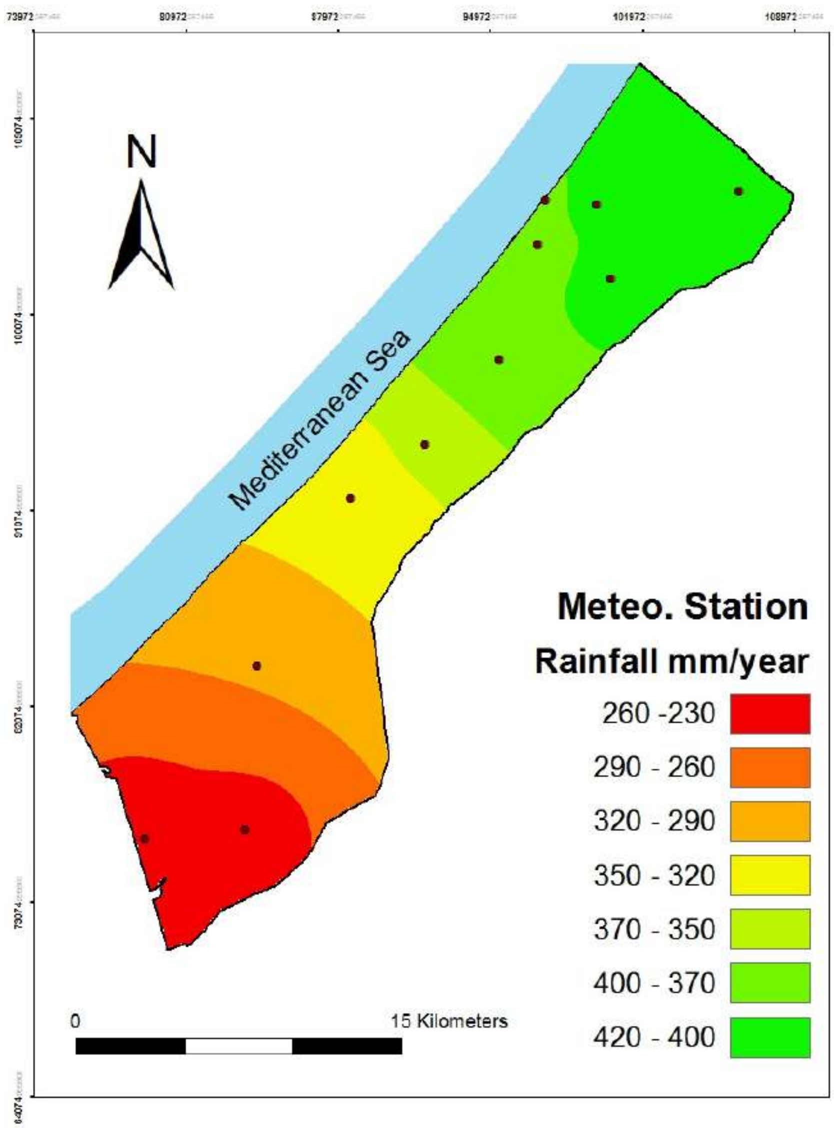

Figure 3.2 Spatial distribution of average annual rainfall in the Gaza Strip (prepared by Researcher)

3.4 Topography

The topography of Gaza Strip is characterized by elongated ridges and depressions, dry streambeds and shifting sand dunes. Land surface elevations range from mean sea level (msl) to about 110 msl, as shown in Figure 3.3 .There are three surface water features in Gaza Strip: Wadi Gaza, Wadi Silka, and Wadi Halib (Selah, 2007).

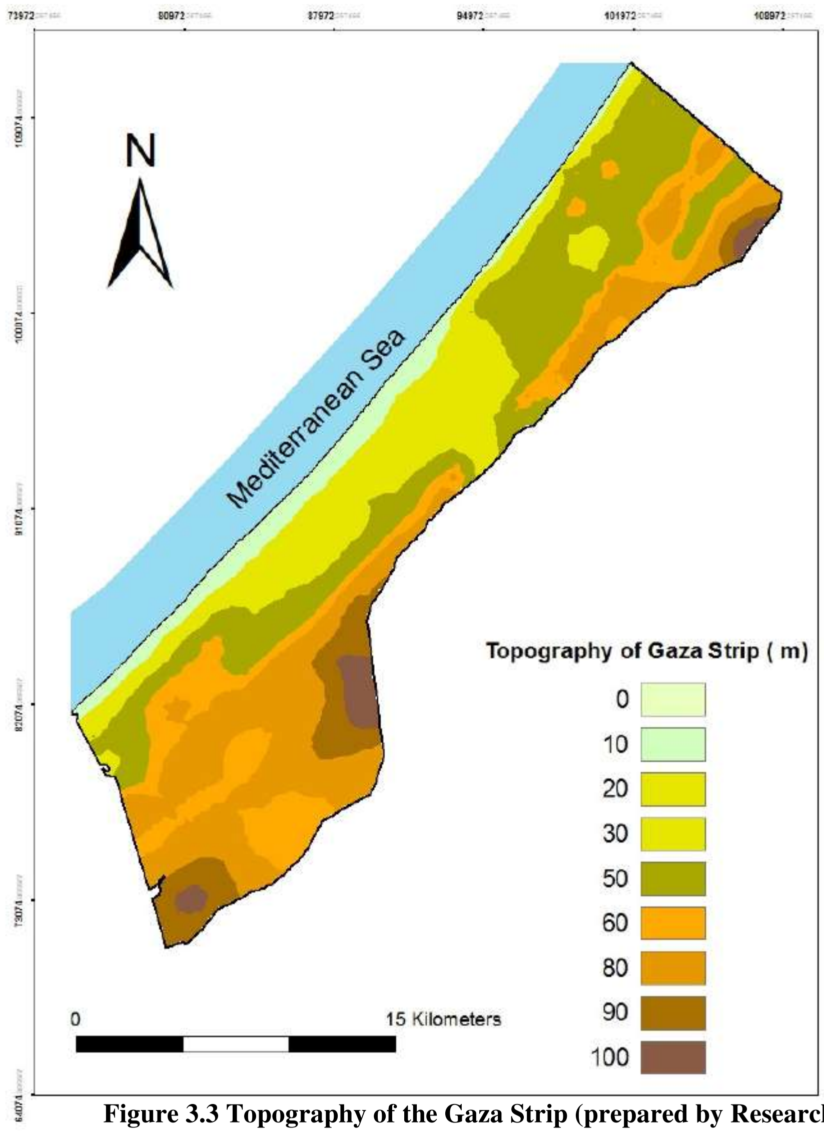

Figure 3.3 Topography of the Gaza Strip (prepared by Researcher)

3.5 Soil

The soil in the Gaza Strip is composed mainly of three types, sands, clay and loess. The sandy soil is found along the coastline extending from south to outside the northern border of the Strip, at the form of sand dunes. The thickness of sand fluctuates from two meters to about 50 meters due to the hilly shape of the dunes. Clay soil is found in the north eastern part of the Gaza Strip. Loess soil is found around Wadies, where the approximate thickness reaches about 25 to 30 m. (Aish *et al*., 2010).

3.6 Hydrogeology

Rainfall is the main source of groundwater recharge area in the Gaza strip, aquifer is naturally recharged by precipitation and additional recharge occurs by irrigation return flow. The consumption has increased substantially over the past years; the total groundwater use in year 2010 is about 172.4 MCM/yr, the agricultural use about 81 MCM/yr, domestic and industrial consumption about 91.4 MCM/yr (PCBS, 2011). The groundwater level ranges between 9 m below mean sea level (msl) to about 11 m above mean sea level. As shown in Figure 3.4.

3.7 Water Quality

Groundwater is increasingly being subjected to over-exploitation for agricultural, municipal and industrial uses increases the possibility of quality deterioration. As shown in Figure 3.5, landfill leachate, agricultural activities, discharge treated wastewater, septic tank, sewage leakage and sea water intrusion are issues causes a serious deterioration in the quality of groundwater.

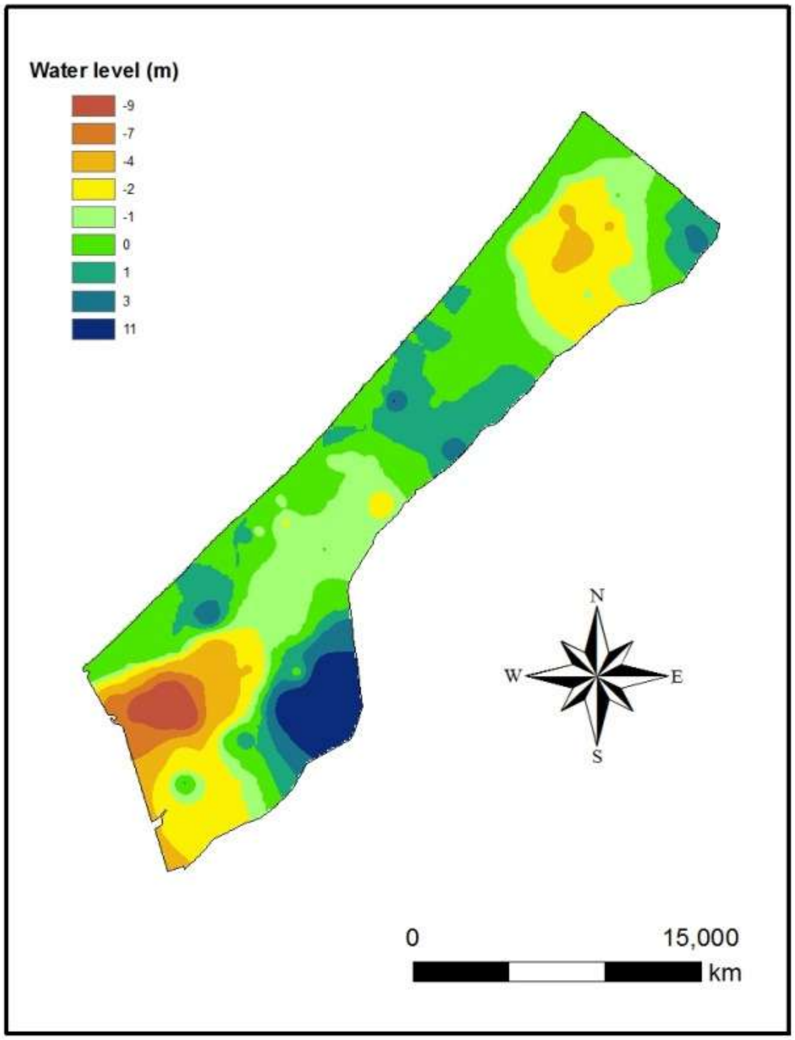

Figure 3.4: Contour map of groundwater level for year 2008 (prepared by Researcher).

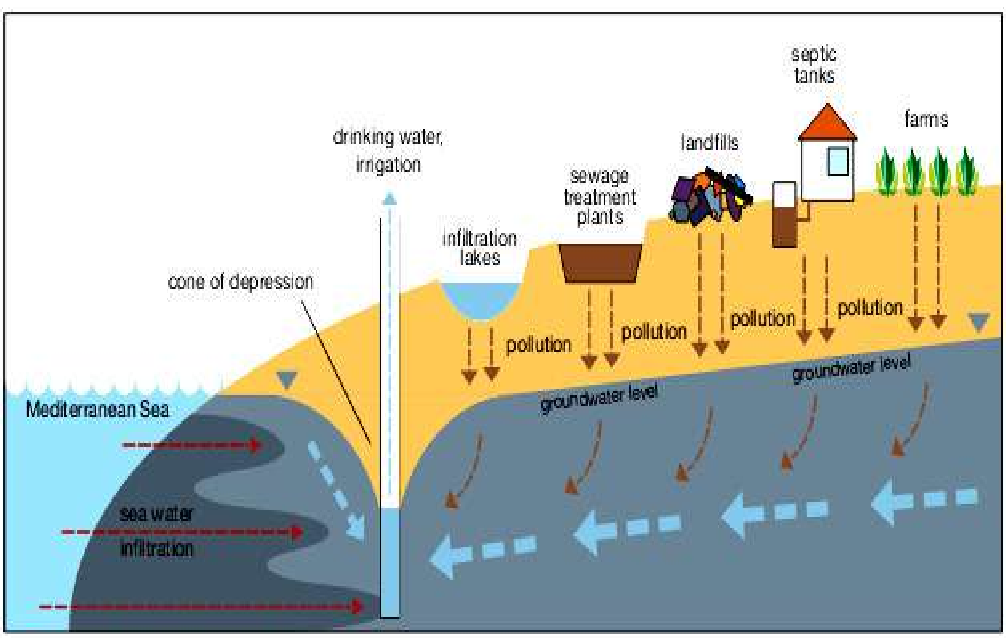

Figure 3.5: Groundwater pollution in the Gaza Strip (schematic) (source: UNEP, 2009).

3.7.1 Chloride

The deterioration of groundwater quality in the Gaza Strip coastal aquifer mainly the result of the seawater intrusion in to the aquifer and the local up coning. This is due to the lowering of fresh water level in the relation to excessive groundwater abstraction (Qahman, 2001). The major documented water quality problem is elevated chloride (salinity) concentration in the aquifer, the relationship between sodium and chloride in the coastal area indicates that the aquifer experienced seawater intrusion (Al-Khatib and Al-Najar, 2011). Figure 3.6 shows update chloride concentration in Gaza strip. It is clear from this figure that most chloride concentration above the maximum contaminant levels (MCL) which are 250 mg/l. Water meeting the WHO Cl - standard was found primarily in the northern parts and scattered in more isolated areas in the rest of Gaza.

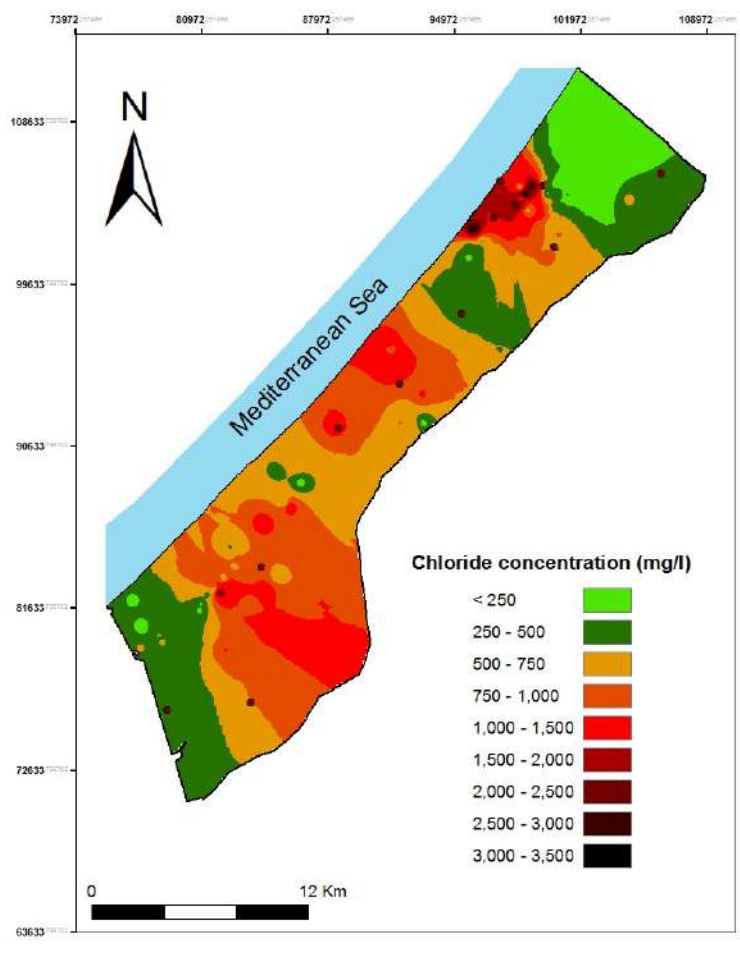

Figure3.6: Chloride concentrations map of the Gaza Strip for year 2011(prepared by Researcher).

3.7.2 Nitrate

Nitrate in groundwater in the Gaza Strip, has become a serious problem in the last decade. Figure 3.7 shows Nitrate concentration of the Gaza Strip for year 2011. As a result of extensive use of fertilizers, discharging of wastewater from treatment plants, and leakage of wastewater form cesspools, increased levels of nitrate up to 400 mg/l have been detected in groundwater. Nitrate concentrations more than 50 mg/l are very harmful to infant, fetuses, and people with health problems. (Baalousha, 2008). The nitrate level in groundwater is far above the WHO accepted guideline of 50 mg/l as nitrates. Areas of high nitrate concentrations are found in the vicinity of wastewater discharging areas, solid waste dumping sites and Wadi Gaza (Shomar *et al*., 2010).

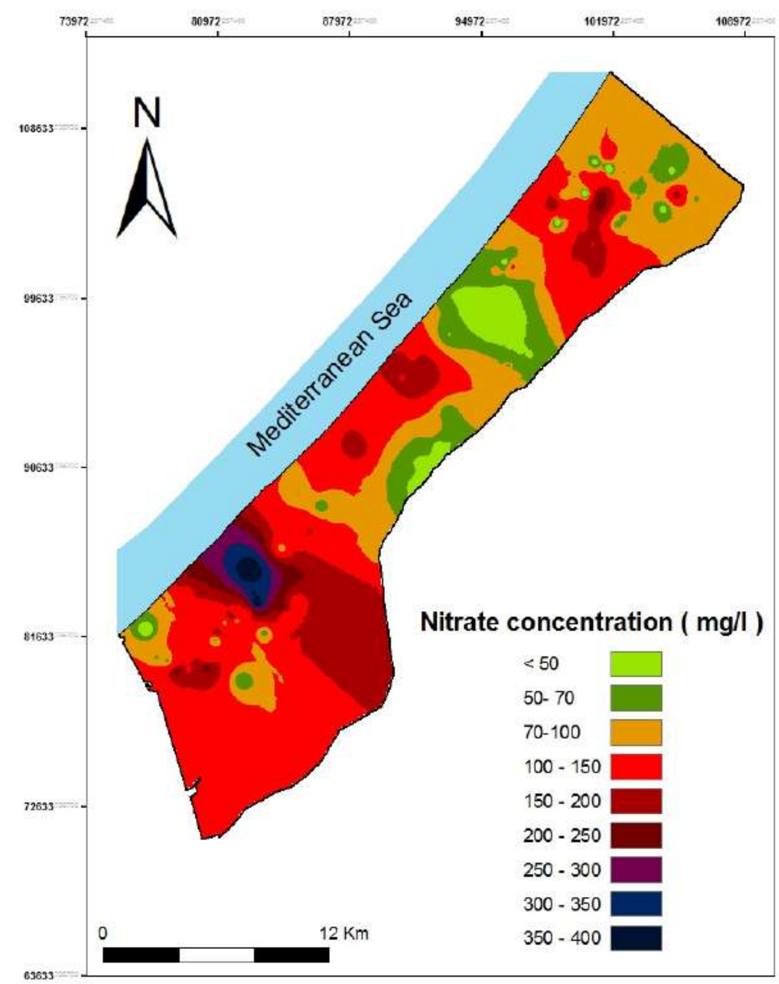

Figure 3.7: Nitrate concentration map of the Gaza Strip for year 2011 (prepared by Researcher).

Based on the relation between land use and nitrate concentration in groundwater, sources of nitrate were identified. These sources are: (1) leakage from wastewater treatment plants, (2) leakage from cesspits, and (3) intensive agricultural activities. It was found that the leakage of wastewater from cesspits and over-loaded treatment plants has greater influence on groundwater nitrate contamination more than agricultural activities. (Baalousha, 2008).

3.8 Wastewater Treatment in Gaza Strip

Wastewater management, including the collection, treatment and disposal of wastewater has been a major environmental challenge in the Gaza Strip for several decades. Recent reports indicate that 81.9 percent of the population now lives in areas with sewage networks, while the remainder uses porous cesspit or tight cesspit (PCBS, 2011).

There are four WWTPs operating in the Gaza Strip: Beit-Lahia WWTP in the north, Gaza WWTP in the Gaza City, Khan Yunis WWTP and Rafah WWTP in the south. The type of treatment, quantity and final disposal of each plant is summarized in Table 3.1.

Table 3.1: Existing WWTPs in Gaza strip (UNEP, 2009)

Parameter	**WWTP**			
	Beit-Lahia	**Gaza**	**Khan Yunis**	**Rafah**
Quantity $m^{3/}$day	20000	60000	9000	16000
Treatment method	Aerobic, anaerobic Lagoons and polishing ponds	Aerobic and ,anaerobic Lagoons and bio-tower	Aerobic and anaerobic Lagoons	Treatment lagoons
Type of disposal and ruse	Surrounding sand dunes	75% to the sea and 25 % infiltrated to the ground aquifer	Infiltration to Ground	Pipeline to sea

3.9 Experimental Site Location and Description

This research was conducted in Zaiton area (Longitude 34°25'33.67"E and Latitude 31°29'12.42"N) region located in south Gaza governorate, 800 meter far away from GWWTP, as shown in Figure 3.8.

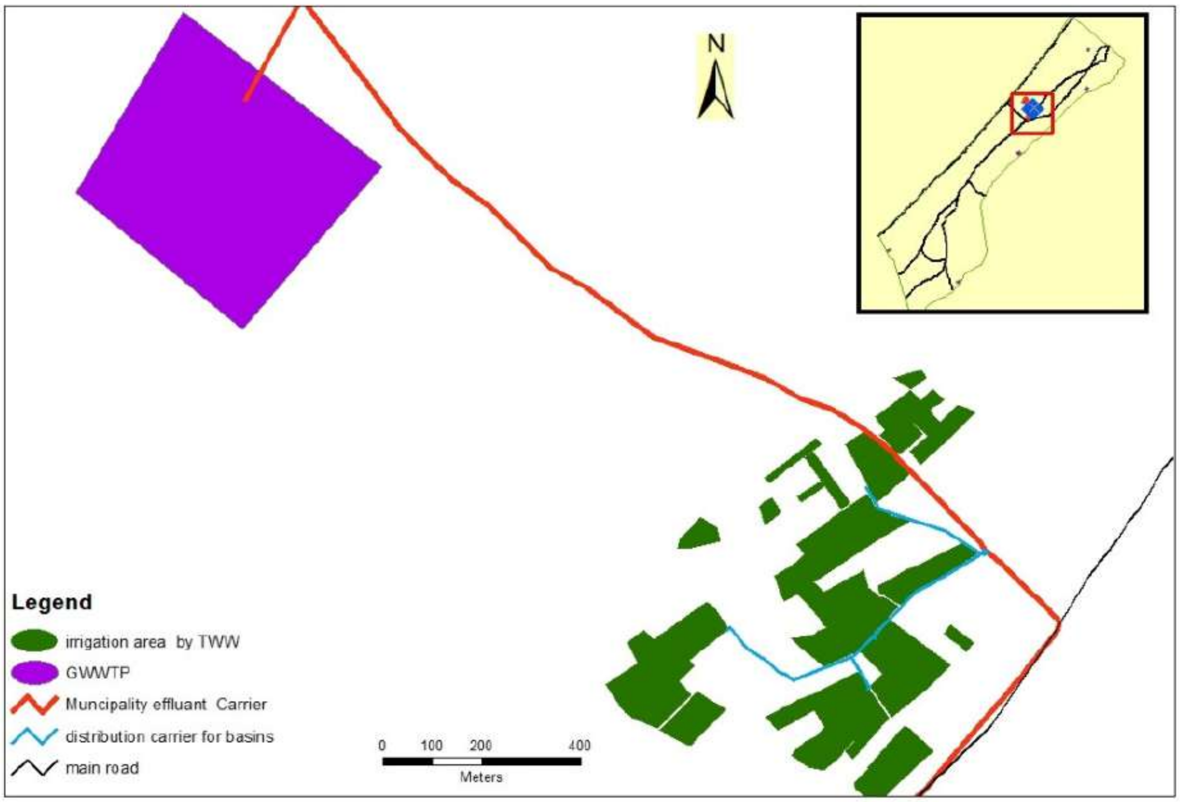

Figure 3.8: Research Site Location

3.9.1 Experimental Site History

Before the end 2009 this area are categorized as an agricultural area in Gaza city, and cultivated with citrus fruits and olive trees as well as various field crops of vegetables, good system and network of irrigation supplies from numbers of agriculture wells existed.

This area exposed in the last Israeli war (Operation cast Lead) on the Gaza Strip at the end of 2008 to aerial bombardments and bulldozing wide farmland led to the destruction of fruit trees , perennial trees such as citrus and olives, irrigation network and most of agriculture wells existing in the area.

3.9.2 The Current Situation at the Site

Rehabilitation of the area and planted trees made after Israeli war on the Gaza Strip through the municipalities, the Ministry of Agriculture (MOA), Palestinian Nongovernmental Organizations (NGOS), local and international relief Organizations. Also rehabilitation of agricultural wells and extend the irrigation network and providing farmers with agricultural tools, fertilizers, compost and pesticides was carried out at different times throughout the past two years.

3.9.3 Short Description of The Existing (RWW) Reuse Project

Implementation of the project from the Palestinian Hydrology Group(PHG) and funded by the Spanish cooperation, the project aims at improving the water infrastructure for agricultural use and the organization and institutional capacities for its management in the areas of Al Zaiton, which were dramatically affected by the Israeli military Operation cast Lead.

In order to do so, a treated wastewater reuse system was rehabilitated and extended in an area of 176 dunums belonging to 25 families, where the infrastructure created by two pilot project has been completely destroyed. The rehabilitation and extension of the system to reuse treated wastewater include the reclamation of 116 dunums of land that have been devastated by the Israeli attacks (leveling, plowing and planting of 1.000 olive and citrus trees), the installation of the main pipe going to the lands to be irrigated, the digging of 6 accumulation basins, each one with its own pump and filtering station (which includes sand, disc and screen filters) and the installation of pipes for drip irrigation.

The area includes 6 groups, at each group of farms, a pond (100 m^3 capacity) to store the wastewater and needed for the irrigation season At the same time, a monitoring program implemented in order to supervise the impact of the reuse of treated wastewater both on the land and on the product, while controlling the possible health and environmental risks.

CHAPTER 4

RESEARCH

METHODOLOGY

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Research Duration

This short term study was carried out from (March to December 2011), in Olive and Citrus orchards located in the coastal plain of southern Gaza governorate, Zaiton area, (34.4364 longitude, 31.4782 latitude), where the project reuse of RWW for irrigation exist as shown in Figure 4.1.

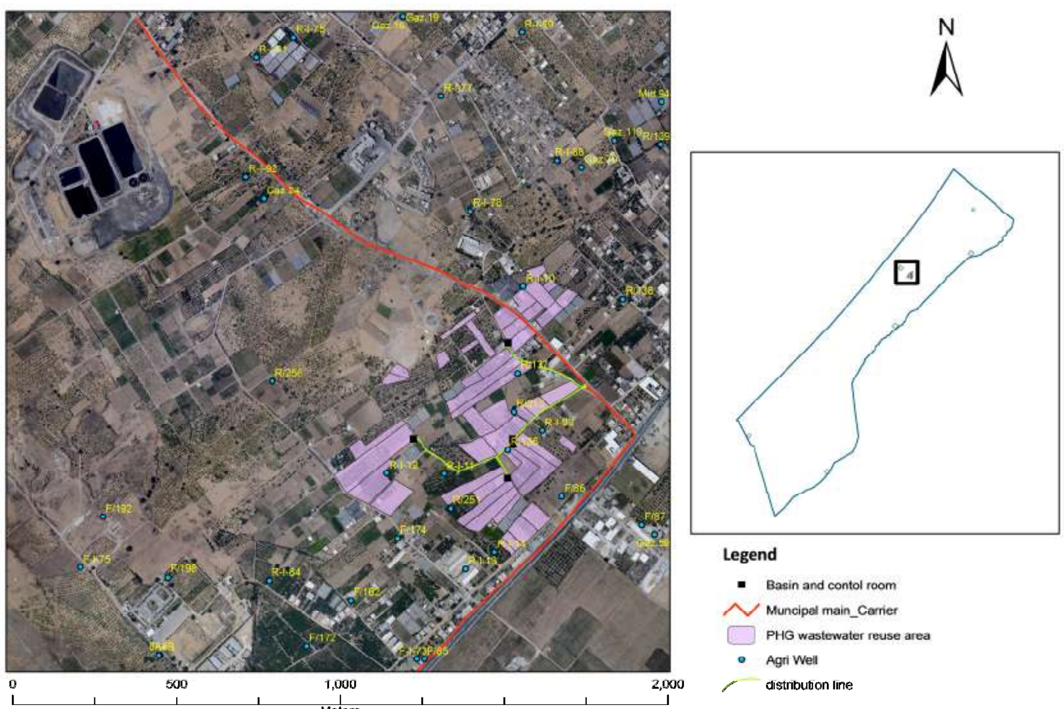

Figure 4.1: RWW reuse project in Zaiton area.

4.2 Experiment Design

Two plots (A and B) already planted with Olive and Citrus were selected, in order to investigate effects of irrigation with RWW on soil properties, groundwater quality and fruit (olive and citrus) quality. Fresh water (FW) and Reclaimed Wastewater (RWW) were used for irrigation plot A and plot B respectively. Monitoring program was conducted for soil, groundwater and fruit (Olive and Citrus) in plot A and plot B during 10 month from March to December 2011.

Sampling period includes 3 main dates:

- March 2011, Before Irrigation Season (BIS)
- August 2011, Middle of Irrigation Season (MIS)
- December 2011, End of Irrigation Season (EIS)

It is worth to be mention that the quantity of irrigation water (FW and RWW) was not taken into consideration, as the irrigation system already exists and it is difficult to control accurately, but in general the quantity of irrigation water used in both plots A and B almost equal.

4.3 RWW Irrigation System

The main pipe from the outlet of GWWTP going to the lands to be irrigated were installed, sub pipeline connected to the numbers of farms part of project ,the digging and construction of 6 accumulation basins, as shown in Figure 4.2. Each one with its own pump and filtering station (which includes sand, disc and screen filters), and the installation of pipes for drip irrigation method .which safety and very common use in Gaza strip. The area includes 6 groups, at each group of farms, a pond (100 m^3 capacity) to store the wastewater and needed for the irrigation season.

Water meter was installed at the outlet of the RWW basins to measure wastewater flow and to control the irrigation quantities supplied to the blocks based on crop water demand of plants.

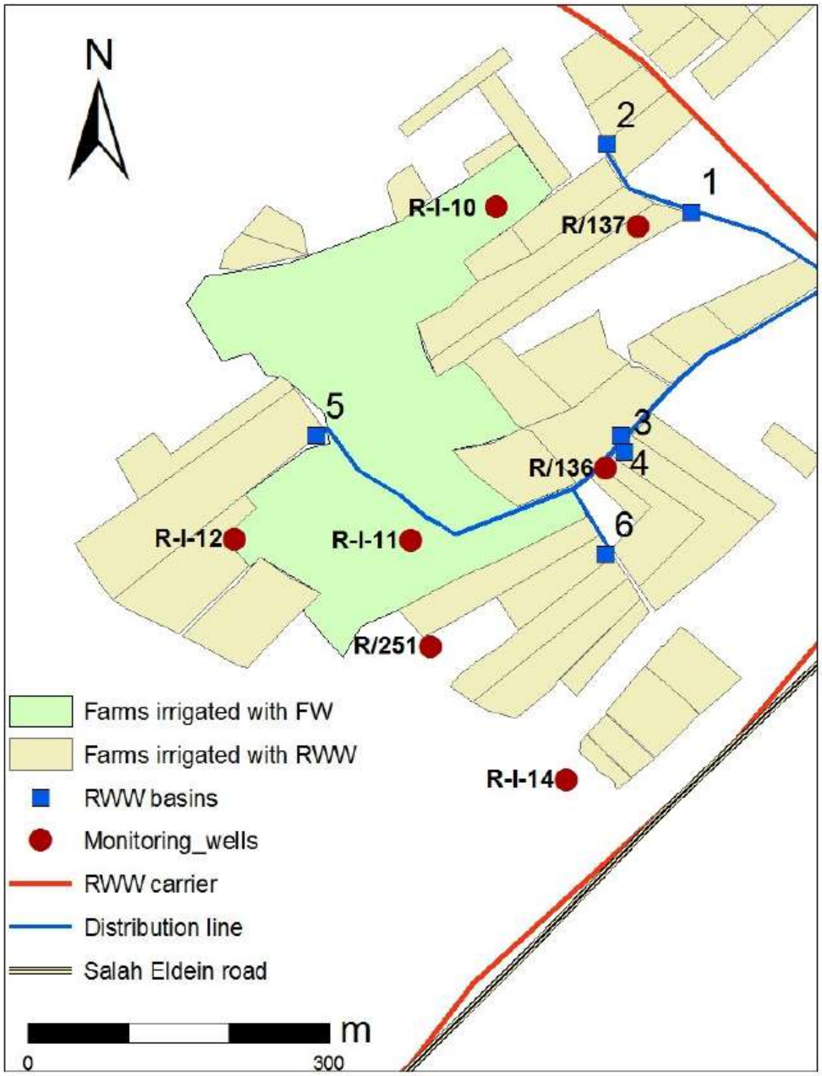

Figure 4.2: Map of RWW reuse area

4.4 Sampling

4.4.1 Soil Sampling

Zigzag soil sampling technique according to the standard method of International Center for Agriculture Research in Dry Areas (ICARDA, 2001) was used during this study. Auger method was used to collect samples from different depth. Same methodology was carried out for each plot as well as same number of samples was collected from each depth and plot, during each sample period and from each plot, samples were collected from two depths (0-30, 30-60 cm), from each depth 5 samples were collected from different location, potentially influenced by the drip emitters. Plastic bags were used to collect samples which labeled according to the specific location where it was taken, care was taken to collect samples from the same places during sampling period.

4.4.2 Soil Samples Preparation

Soil samples were dried in an air –forced oven at 30C for 24 hour, cleaned off any stones and plant residues, grounded with a porcelain mortar soil grinder and passed through a 2mm sieve. The sieved soils were collected ~500 g, and stored in plastic bags.

4.4.3 Soil Physical Analysis

According to Soil and Plant Analysis Laboratory Manual of International Center for Agriculture Research in Dry Areas (ICARDA, 2001), common soil physical measurements were conducted, include particle size distribution, texture, porosity, bulk density, particle density and infiltration rate.

The hydrometer method was used for particle size analysis (ICARDA, 2001), in order to estimate percentage of sand (0.05-2 mm), silt (0.002 – 0.05 mm), and clay (< 0.002 mm). Soil textural class assigned using United States Department of Agriculture (USDA) textural triangle.

Soil core method (USDA, 2004) was used for bulk density measurement, a metal cylinder was pressed or driven into the soil, and the cylinder was removed extracting a sample of known volume. The moist sample weight was recorded and the sample was then dried in a oven at 110 °C and weighed. The particle density test measures the mass of the soil in a specific volume, which is very similar to the bulk density test (Roots of Peace, 2008).

First a graduated glass container was taken and measured its weight. Then placed 25 g of a soil sample inside the container. Measured and registered the weight of the soil together with the container. With some water added, the mixture was boiled for 10 minutes to remove all air bubbles. Once the container has cooled, place it in a cup and let it sit for 24 hours. After 24 hours, the container was filled with water to a total volume of 100 ml and measured the weight and temperature of the mixture. Porosity was calculated from the ratio between the bulk density and the particle density and converted into into a percentage, thus:

Porosity = (1 – Bulk density / Particle density) x 100

Walklely method was used to determine soil organic matter (OM) (ICARDA, 2001). Based on (FAO, 1988), infiltration rate was measured by Double-ring infiltrometers, consisting of two concentric rings, were used (Figure 4.3); the rate of fall of water was measured in the inner ring while a pool of water was maintained at approximately the same level in the outer ring to reduce the amount of lateral flow from the inner ring.

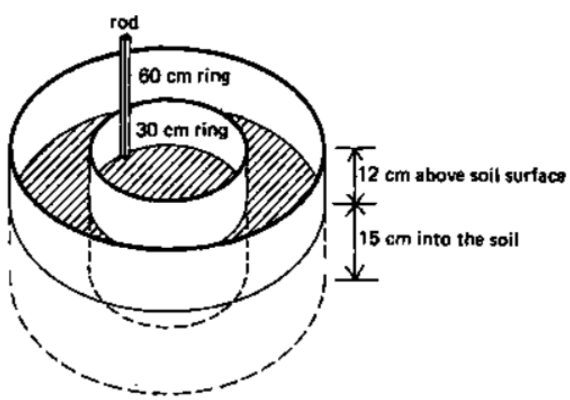

Figure 4.3: Double-ring infiltrometers (FAO, 1988)

Soil soluble salts measurements were conducted according to soil survey field and laboratory method manual (Soil Survey Staff, 2009). An aqueous soil extract solution (1:5 ratio) was prepared using 50 g of dried soil and 250 ml of distilled water. Each solution was shaken with a rotating laboratory shaker, then centrifuged and filtered (0.45 μm) into vials and analyzed to determine the chemical characteristics of the soil such as pH, EC, TDS, $CaCO_3$(Hardness), $CaCO_3$(Alkalinity) Na^+, K^+, Ca^{2+}, Cl^-, HCO_3^-, NO_3^-, SO_4^{2-} and SAR.

4.5 Irrigation Water

4.5.1 Irrigation Water Sampling

For each round of analysis, samples of FW and RWW were taken, manual grap samples were collected from selected monitoring wells and storage basins of RWW after sand filter, one liter clean acid-washed polyethylene bottles used to collect FW and RWW samples for physiochemical analysis, while 250 ml sterile bottles were used for microbiological analysis, using Gummed paper label to prevent sample misidentification.

4.5.2 Samples Storage and Preservation

After the collection of FW and RWW samples, they were stored in an ice box and transported immediately back to the Al-Azhar laboratory and public health laboratory (PHL) to retard chemical and biological changes that inevitably continue after sample collection. Samples were stored for one day at 4 ^{o}C to minimize microbial activity before usage

4.5.3 Irrigation Water Analysis

Samples of Irrigation water (FW and RWW) were analyzed for the physiochemical and biological parameters in accordance with procedures outlined in Standard Methods (APHA, 2005) Standard Methods for the Examination of Water and Wastewater. Chemical, physical and biological analysis was conducted at Al Azhar University, Institute of Water and Environment (IWE) laboratories and Ministry of Health (MOH), public health laboratory (PHL). Table 4.1 illustrate the parameters were analyzed, units used to express their concentration and the test methods.

4.6 Olive and Citrus Fruits

4.6.1 Sampling and Analysis for Olive and Citrus Fruits

Composite olive samples were collected in December from the periphery of each tree in plot A and plot B; paper bags were used to collect samples which labeled according to the type of fruits, irrigation water and sampling plot. The same technique was used with citrus fruits. Hygienic parameters such as Fecal coliform, Total cloiform, E.coli, Salmonella, Listeria were conducted these samples, in addition to heavy metal Zn, Cu and Pb parameters and fruit quality as described by (ICARDA, 2001).

Table 4.1: Analyzed parameters for irrigation water and methods were used.

Parameter	Conc. Unit	Test method
pH	-	Electrometric (pH meter)
Electrical conductivity (EC)	dS/m	Conductivity meter
Total dissolve solids (TDS)	mg/l	Dried at 180 C and Calculation
Nitrite (NO_2^-)	mg/l	Calorimetric method
Nitrate (NO_3^-)	mg/l	Ultra violet spectrophotometic
Ammonia (NH_3)	mg/l	Titrimetric
Total Kjeldahl Nitrogen (TKN)	mg/l	Macro Kjeldahl
Chloride (Cl^-)	mg/l	Titration with $AgNO_3$
Sulphate (SO_4^{2-})	mg/l	Turbidimetric method
Alkalinity as $CaCO_3$	mg/l	Titration
Hardness as $CaCO_3$	mg/l	EDTA-titration
Calcium (Ca^{2+})	mg/l	EDTA-titration
Magnesium (Mg^{2+})	mg/l	Calculation
Potassium (K^+)	mg/l	Flame photometry
Sodium (Na^+)	mg/l	Flame photometry

SAR	-	Calculation
Cadmium (Cd^{2+})	mg/l	Atomic absorption
Chromium (Cr^{2+})	mg/l	Atomic absorption
Copper (Cu^{+})	mg/l	Atomic absorption
Mercury (Hg^{+})	mg/l	Atomic absorption
Nickel (Ni^{2+})	mg/l	Atomic absorption
Lead (Pb^{2+})	mg/l	Atomic absorption
Biological oxygen demand (BOD)	mg/l	Respirometric method
Chemical oxygen demand (COD)	mg/l	Closed reflux
Total coliform (TC)	cfu/100ml	Multiple tube
Total fecal coliform (FC)	cfu/100ml	Multiple tube

4.6.2 Olive Oil Samples

Olive fruits were harvested in November sent directly to olive mill for oil extraction. Two samples of olive oil were taken, first one from reference orchard irrigated with FW (plot A) and the second from orchard irrigated with RWW (plot B).

According to International Olive Council (IOC, 2011), quality parameters for olive oil samples were characterized for refractive index, acid value, peroxide value and free acidity as oleic acid.

4.7 Water Depth Measurements

In order to identify the extent deterioration in water depth during study period, measurements of water depth were implemented from July 2011until the end of November 2011 by using portable water level meter, six of existing agriculture wells were selected as monitoring wells, which exist in the study area, as revealed in Figure4.1. Twice measurements were conducted per month.

4.8 Statistical analyses

All statistical analyses were performed with the SPSS program (Statistical Program for the Social Sciences 17.0), collected data were subjected to the analysis of variance, an ANOVA test was done with the two treatments as the independent variables. The mean values of all parameters were compared using the Tukey test. Pearson's correlation coefficients (R) were calculated to quantify the linear relationship between parameters.

Groundwater analyses were performed with Rock Ware Aq.QA 1.1.1, the spread sheet for water analyses, in order to identify groundwater deterioration during study period through Trilinear diagram and other types of analyses.

CHAPTER 5

RESULTS AND DISCUSSION

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Introduction

Analyses of irrigated water (RWW and FW), plant and soil for wastewater reuse Project in Zaiton area, from March till December 2011, was presented and discussed in this chapter in order to investigate effects on the groundwater quality as a results of short term irrigation by reclaimed wastewater, and to investigate the effect of RWW irrigation on soil physical and chemical properties and plants quality.

5.2 Characteristics of Irrigation Water

The majority of physicochemical and microbiological analyses results of irrigation water (RWW and FW) were presented in Table 5.1, where average values as well as standard deviation values from the three different sampling periods (March, August, and December period, respectively) are shown.

5.2.1 Hydrogen Ion Activity (pH)

The results show there is no significant variation between RWW and FW for pH values, average value of RWW and FW pH was 7.58 and 7.41 respectively. According to Palestinian Standards (PS) reported by The Water Studies Institute (WSI, 2005), EPA (2004) and Ayers and Westcot (1985) guidelines these values are in the normal range for irrigation water. The normal pH range for irrigation water is from 6.5 to 8.4. Within this range crops have done well. Irrigation waters having pH outside this range may still be satisfactory but other problems of nutrition or toxicity become suspect (Ayers and Westcot, 1985). For GWWTP most of the wastewater source is of domestic origin with almost the same source, therefore, the risks of pH dramatic changes are negligible due to the absence of industrial activities along with the wastewater network.

Table 5.1 Irrigation water quality for fresh water (FW) and reclaimed wastewater (RWW), average (±STDEV) Results are in mg L^{-1}unless otherwise stated

Parameter	RWW		FW		P value
	Average*	STDEV	Average	STDEV	
pH**	7.58	0.13	7.41	0.08	0.133^{ns}
EC (μS cm^{-1})	4133	523	2603	108.73	0.008^{a}
TDS	2562	324	1614	67.38	0.008^{a}
TSS	32	3.61	-	-	-
NO_2	0.38	0.09	0.07	0.10	0.024^{b}
NO_3^-	21.90	11.77	61.83	4.00	0.006^{a}
NH_3	17.53	0.70	-	-	-
TKN	63.90	5.67	-	-	-
Cl^-	882	6.13	560	18.73	0.000^{a}
SO_4^{-2}	91.71	23.37	109.63	6.09	0.274^{ns}
Alk.	928	42.11	543	2.36	0.000a
Hard.	597	66.89	595	17.10	0.968^{ns}
Ca^{+2}	105.95	28.01	102.93	5.03	0.864^{ns}
Mg^{+2}	70.23	22.72	75.90	5.06	0.698^{ns}
K^+	34.21	3.82	10.07	1.87	0.001^{a}
Na^+	653	61.10	329	10.98	0.001^{a}
SAR**	10.05	2.28	4.91	0.14	0.018^{b}
COD	136	23.44	7.00	1.63	0.001^{a}
BOD	101	11.53	<5	-	-
TC(CFU 100 mL^{-1})	8500	500	5.33	1.25	0.000^{a}
FC(CFU 100 mL^{-1})	7500	500	2.67	0.47	0.000^{a}

Cd^{+2}	0.0015	0.000	0.0012	0.000	0.016[b]
Cr^{+2}	0.0163	0.000	0.0115	0.000	0.000[a]
CU^{+}	0.007	0.001	0.006	0.001	0.251[ns]
Hg^{+}	0.001	0.001	0.001	0.001	1.000[ns]
Ni^{+2}	0.0096	0.000	0.0032	0.000	0.000[a]
Pb^{+2}	0.004	0.000	0.004	0.000	1.000[ns]

[*]There are three observations for each irrigation water, [**]Unitless parameter**,** [a] statistically significant at $P < 0.01$ level of significance. [b] Statistically significant at $P < 0.05$ level of significance. [ns] not significant

5.2.2 Salinity Hazard

Significant variations between FW and RWW salinity were detected. This variation was maximum during November period. EC was 2750 µS/cm for FW and 4620 µS/cm for RWW. However, the variation reduced during August sampling period. EC was reported to be 2570 µS/cm and 3580 µS/cm for FW and RWW, respectively, as shown by Figure 5.1.

In the same behavior, total dissolve solid (TDS) levels for FW and RWW have the same variation which reported at EC levels during sampling period.

Based on Ayers and Westcot (1985) guidelines for interpretation of water quality for irrigation, current EC for RWW has severe degree of restriction on use. While EC for FW has slight to moderate degree of restriction on use and it can be used for irrigation with no severe. Crops and fruits classified according to their tolerance and sensitivity to salinity (Pescod, 1992). In particular olive fruit classified as moderately tolerant EC<2.2 dS/m, while citrus fruits was sensitive EC <0.7 dS/m.

According EPA (2003) guidelines divided the applied wastewater into five main classes based on EC and TDS values. Current EC and TDS values of RWW and FW within class 4 which indicate that RWW and FW must be applied in excess for leaching, salt tolerant plant should be selected and soil must be permeable.

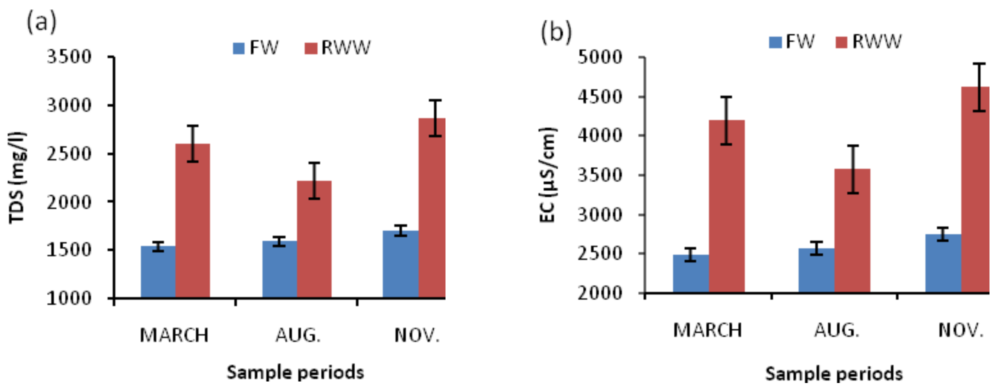

Figure 5.1: TDS (a) and EC (b), levels for FW and RWW at different sampling periods

It should be noted that, the salinity of RWW is associated with the origin water, which is mainly abstracted from ground aquifer. Where the groundwater of Gaza Strip suffered in the last years of significant increase of salinity.

5.2.3 Chloride (Cl^-) and Sodium (Na^+) Hazard

In this study the mean values of Cl^- and Na^+ are 882 and 653 mg/l for RWW, while 560 and 329 mg/l for FW receptively; significant variation ($p<0.01$) between RWW and FW for Cl^- and Na^+ concentration along sampling periods was found as shown Figure 5.2.

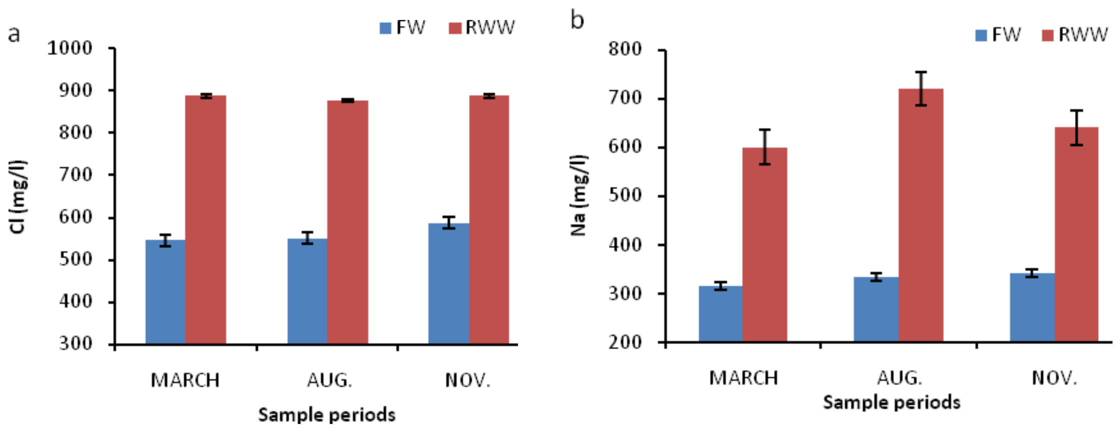

Figure 5.2: Cl^- (a) and Na^+ (b), concentration during sampling periods

High level of Cl^- in RWW was detected in this study. It was exceeded the maximum concentration of Cl^- assigned by PS and Ayers and Westcot (1985) guidelines, the maximum permissible of Cl^- without leaf injury for olive and citrus trees was 600 mg/l as reported by

Pettygrove and Asano (1984). Which make RWW is a severe restriction to be used for irrigation for sensitive crops including: deciduous fruits, nuts and citrus. It is worth to be mention; Cl^- concentration of FW is higher than recommended international guidelines, which refer to sea water intrusion in the aquifer of Gaza Strip (Al-Khatib and Al-Najar, 2011).

Also Na^+ concentration of RWW was exceeded the maximum level assigned by PS and Ayers and Westcot (1985) guidelines 200 mg/l. The average concentration of Na^+ for RWW was 653 mg/l, this high concentration may refer to the FW quality which is the main source of wastewater and the repeated irrigation using RWW. Significant correlation was found between Na^+ and Cl^- of wastewater ($R^2 = 0.94$), suggesting that the common source of these ions is salt dissolution. Sodium concentration is associated with chloride concentration which is originally high in Gaza strip groundwater due to sea water intrusion (Shomar *et al.*, 2010).

Furthermore, the most reliable index of the sodium hazard of irrigation water is the sodium adsorption ration, SAR. Calculated SAR values of RWW was 10.05, which make the water is a severe restriction to be used for irrigation according to Ayers and Westcot (1985) guidelines, while SAR values for FW was significantly varied ($p<0.05$). Its value was 4.9. This variation can be contributed due to highly content of Na^+ in RWW otherwise in FW.

5.2.4 Calcium (Ca^{+2}) and Magnesium (Mg^{+2}) Hazard

The results show that there is no significant variation between RWW and FW for Ca^{+2} and Mg^{+2} concentrations. Figure 5.3 shows values of Ca^{+2} and Mg^{+2} during sampling periods, Based on EPA (2003) and Ayers and Westcot (1985), the maximum limits were 400 mg/l and 60 mg/l for Ca^{+2} and Mg^{+2} respectively. For both RWW and FW, Ca^{+2} values were below the maximum limit, while values of Mg^{+2}slightly exceed the maximum allowable value (60 mg/l) of guidelines.

High concentration of Ca^{+2} and Mg^{+2} ions in irrigation water can increase soil pH, resulting in reducing of the availability of phosphorous PO_4^{+2} (Al-Shammiri, 2005). But they are also essential plant nutrients.

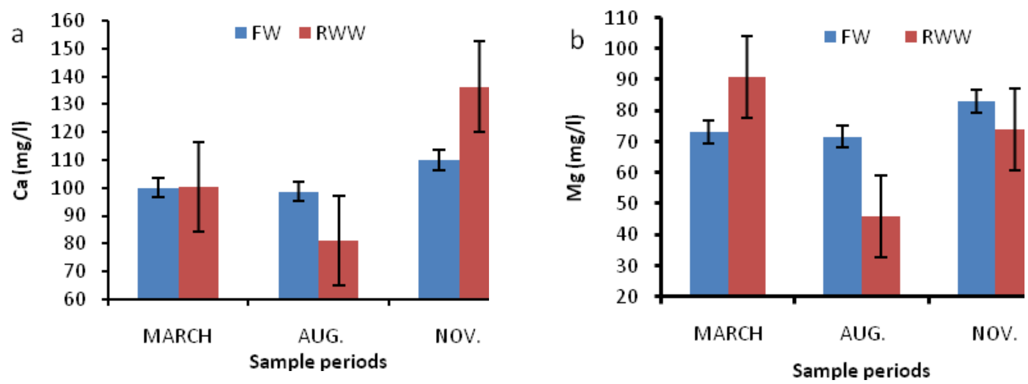

Figure.5.3: Ca^{+2} (a) and Mg^{+2} (b), concentration during sampling periods

5.2.5 Nitrogen (N) and Potassium (K)

Results indicate that Nitrate NO_3 values ranged from 8.75 to 31.45 mg/l for RWW, while it have higher values for FW ranged from 57.4 to 67.1 mg/l, as shown Figure 5.3, there is significant variation between RWW and FW ($p<0.01$). It is obvious that nitrate level of RWW varied with time and this may be due to the efficiency of GWWTP as the organic load increases with time. Moreover, as it was stated high NO_3 has no severe impact on crops but it may leachate to the ground aquifer (Abu-Nada, 2009). However, nitrate values of RWW were lower than usual limits stated by EPA (2003) and PS which is reported to be 50 mg/l.

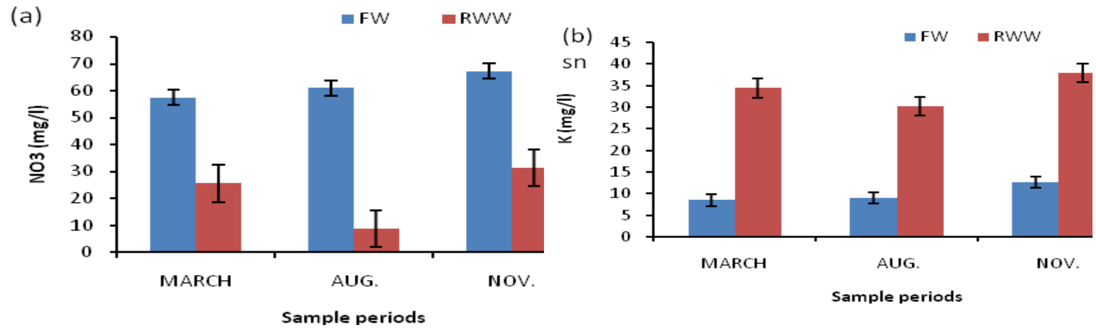

Figure.5.4: NO_3^- (a) and K^+ (b), concentration during sampling periods

The average values of Total Kjeldal Nitrogen (TKN) were 63.9 mg/l for RWW in this study. These values were higher than recommended by different standards for irrigated water quality which reported to be 50mg/l**.** Excessive Nitrogen stimulates excessive vegetative growth, and may delay maturity or reduce crop quality (Pettygrove and Asano, 1984; Ayers and Westcot, 1985).

As shown in Figure 5.2.3, significant variation of Potassium (K^+) values ($p<0.01$) for RWW and FW, the average value 34.21 and 10.07 mg/l for RWW and FW receptively, these values were lower than recommended by different standards for irrigated water quality which reported to be 40mg/l. Therefore, it is classified as a major nutrient.

5.2.6 Biochemical and chemical oxygen demands (BOD_5 and COD)

The BOD_5 values for RWW in the present study varied from 88 to 110 mg/L, while COD values ranged from 110 to 154 mg/L. With few exceptions, RWW in this study displayed higher values of BOD_5 and COD, which refer to the Over loading of GWWTP, causing decrease of the efficiency of this plant, values of BOD_5 were higher than the maximum allowable value(60 mg/l) recommended by Palestinian standards for irrigated water quality. Values of BOD_5 for FW below detection method, while the average values of COD were 7 mg/l. Results of this study show that the average COD/BOD_5 ratios for RWW are about

1.25-1.47 (average 1.35), In most municipal wastewater where organics are readily degradable, the COD/BOD_5 ratios are typically 1.25-2.5 (Metcalf and Eddy, 2004).

5.2.7 Total Suspended Solid (TSS)

In the present study TSS values for RWW varied from 28-33mg/l (average 32mg/l) ,which indicate a good sign that, TSS value is located within the guidelines and standards for irrigation with RWW(30-90) mg/l , TSS concentration is an important performance indicator of WWTPs (Abu-Madi, 2004).

It is worth mentioning, low concentration of TSS in RWW may refer to the sand filter were used before irrigation net work, and settling process occurred in the storage bond of RWW it may minimize the value of TSS.

5.2.8 Trace Elements

Results were presented in Table 5.1 indicate that, heavy metals concentrations in the irrigation water RWW and FW are very low values, they comply with the standards of reused wastewater in agriculture. Similar results were obtained by Abu Nada (2009). Revealed that domestic wastewater influent contains considerable amounts of heavy metals and the partially functional treatment plants of Gaza are able to remove 40-70% of most metals during the treatment process.

5.2.9 Microbial quality

Fecal coliform and total coliform (FC and TC) were investigated as indicator parameters for biological contamination of wastewater. Results indicated that average values of FC in RWW were higher than PS and WHO (1989) which is recommended to be 1000 CFU/100ml. As exposed in Table 5.1the maximum FC value in RWW was 9000 while minimum value was 8000 CFU/100ml.

This high value may refer to the absence of disinfection unit in GWWTP. FW have very low value of FC. Irrigation with RWW with high FC values can't be used for unrestricted crops. A different approach was adopted by WHO, which recommends the more liberal threshold of 1000 CFU/100 ml of fecal coli forms for unrestricted irrigation of crops to be eaten uncooked, sports fields and public parks (WHO, 1989). Although there are no hygienic standards concerning restricted irrigation of cereals crops, industrial and fodder crops, pasture and trees. According to the WHO (1989) guidelines, RWW could be used for fruit tree irrigation. Irrigation should be stopped 2 weeks before harvest and no fruit should be picked up off the ground.

5.3 Soil Characteristics

5.3.1 Soil physical properties

The soil texture for both experimental fields plot A (irrigated with FW) and plot B (irrigated with RWW), was classified as sandy loam according to the United States Department of Agriculture (USDA) soil texture classification. The clayey fraction varies between 16.6 and 21.4%; the Loamy fraction is between 11.7% and 14.3%; the sand fractions vary between 66.4 % and 69.2% as shown in Table 5.2. The plotting of these results on the textures triangle of the U.S.D.A shows that the soils, generally, present uniform and balanced textures.

Table 5.2: Soil physical properties at the research site

Plot	Depth (cm)	Sand %	Silt %	Clay %	Textural class	Bulk density (gm/cm3)	Particle density (g/cm3)	Porosity %	Infiltration rate (mm/min.)
A	0-30	69.2	14.2	16.6	Sandy loam	1.54	2.54	39.37	2.6
	30-60	68.5	14.3	17.2	Sandy loam	1.57	2.48	36.69	-
B	0-30	68.8	11.7	19.5	Sandy loam	1.54	2.52	38.89	2.6
	30-60	66.4	12.2	21.4	Sandy loam	1.55	2.49	37.75	-

These soils have a homogeneous composition and the sandy nature of samples will allow the infiltration of pollutants. Nevertheless, due to the relatively high percentage of clay fraction the possibility of pollutants adsorption is relatively high (Abedi-Koupai *et al*., 2006 and Klay *et al*., 2010).

Measurements of soil bulk density and particle density for both plot A and B were found no significant variation between A and B plots for these properties at the beginning of this study. However results of porosity show variation between different depth for two plot A and B, porosity at 0-30cm depth for A and B were 39.37 and 38.89 receptively, while porosity at depth 30-60 cm were 36.69 and 37.75 receptively. The average infiltration rate for plot A and B at the beginning of irrigation season were 156 mm/hr.

5.3.2 Soil chemical properties

To study the effects of irrigation with RWW on soil properties we must know the chemical properties of the soil before the irrigation. Some soil characteristics of the experimental field at the beginning of the study are listed in Table 5.3.

Table 5.3: Initial characteristics of the soil at the experimental field, results are in mg L^{-1}unless otherwise stated

Parameter	Depth (cm)			
	0-30		30-60	
	Average*	STDEV	Average	STDEV
pH**	7.16	0.80	7.24	0.12
EC(µS cm^{-1})	270.6	73.42	239.00	78.28
TDS	167.77	45.52	148.18	48.53
NO_2^-	0.82	0.79	2.53	0.83
NO_3^-	19.76	5.03	25.28	7.48
NH_3	1.08	0.37	1.30	0.40

Cl^-	37.60	9.42	36.80	21.75
Alk. $CaCO_3$	109.40	2.88	106.40	84
Hard. $CaCO_3$	20.60	2.97	23.20	9.65
Ca^{+2}	4.86	0.71	7.36	3.42
SAR**	2.98	0.78	2.17	0.93
Mg^{+2}	2.00	0.71	1.114	0.59
K^+	4.64	1.73	7.02	2.64
Na^+	39.40	9.90	30.50	11.39
OM %	1.05	0.07	0.97	0.05

*Data represent mean values for five observations, ** Unitless parameter

5.3.3 Effects of RWW irrigation on soil properties

In order to investigate the effect of irrigation with RWW on soil properties, comparison has been done between plot A and B during study period. Results of physiochemical parameters of soil are presented in Table 5.4.

5.3.3.1 Soil pH

Results showed that pH values of all soil layers were varied between 6.78 and 7.94 as shown in Table 5.4 which is the most desired range in agricultural soils, there were no significant effects on soil pH due to reclaimed wastewater application as shown in Figure 5.5, results indicated also that soil has slight alkaline pH for both plots layers over all the experiment time, pH was higher in the lower soil layer (30-60 cm) than the surface one (0-30 cm).

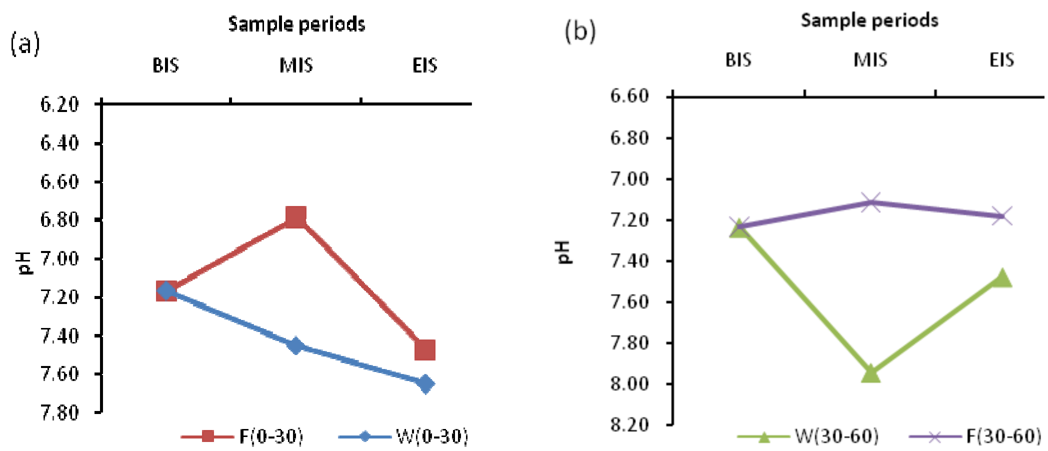

Figure 5.5: (a) 0-30cm, (b) 30-60 cm, pH of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW).

5.3.3.2 Electrical Conductivity (EC)

Soil EC is typically used to indicate soluble salt concentration in soil. Because crops only remove small amounts of salt, salt movement and distribution in soil is directly related to water movement (Heidarpour *et al*., 2007). RWW irrigation had a significant effect ($p<0.05$) on soil EC in the first (0–30 cm) and second (30–60) layers of soil as shown Figure5.6.

Soil EC was negatively affected by irrigation with RWW as compared to soil irrigated with fresh water (Al-Shdiefat *et al*., 2009). In general, soil EC increased by irrigation with RWW. The soil EC increased due to the significant chloride concentration increment observed after wastewater application. Soil EC was 451.80 µS cm^{-1} and 243 µS cm^{-1} for depths 0-30 cm and 30-60 cm, respectively for soil which received RWW, while soil EC was 326.25 µS cm^{-1} and 235 µS cm^{-1} at the same depths, respectively for soil which received fresh water.

Table5.4: Soil chemical properties for plots A and B during study period at two different depths, Results are in mg L^{-1}unless otherwise stated

Soil depth (cm)	Parameter	Initial	Plot A		Plot B	
0-30		BIS	MIS	EIS	MIS	EIS
	p H	7.164	6.78	7.47	7.45	7.64
	EC (μS cm^{-1})	270.6	162.20	326.25	313.50	451.80
	TDS	167.8	100.60	202.27	194.40	280.12
	NO_2	0.82	0.57	2.27	3.65	2.04
	NO_3	19.76	17.04	38.65	29.23	61.63
	NH_3	1.08	0.58	0.27	0.34	0.42
	Cl^-	37.6	33.40	54.07	62.25	72.32
	Alkalinity	109.4	63.80	106.33	74.25	123.47
	Hardness	20.6	30.00	76.05	30.75	60.65
	Ca^{+2}	4.86	8.88	16.31	11.10	16.03
	SAR	2.98	1.28	2.38	2.60	3.50
	Mg^{+2}	2	1.90	8.56	0.75	4.99
	K^+	4.64	3.12	5.52	6.65	6.55
	Na^+	39.4	21.20	48.25	44.75	61.60
	OM%	0.66	0.79	0.79	0.84	1.05
30-60	p H	7.24	7.11	7.18	7.94	7.48
	EC (μS cm^{-1})	239.00	215.20	235.00	329.00	243.00
	TDS	148.20	134.30	145.70	204.00	150.66
	NO_2	2.53	0.09	0.36	5.42	0.62
	NO_3	25.28	18.28	21.86	32.22	26.27
	NH_3	1.30	0.35	0.28	0.55	0.16
	Cl^-	36.80	34.80	75.16	55.20	76.58
	Alkalinity	106.40	91.80	108.40	94.60	103.54

Hardness	23.20	32.20	78.81	26.80	78.39
Ca^{+2}	7.36	9.04	17.02	7.86	14.21
SAR	2.17	1.96	1.74	3.07	1.99
Mg^{+2}	1.14	2.40	8.80	1.74	10.40
K^+	7.02	3.90	5.93	7.08	3.06
Na^+	30.50	33.60	36.00	48.80	40.90
OM%	0.69	0.70	0.75	0.92	0.91

There was an increase in EC values in the first soil layer (0-30cm) by RWW irrigation over the study period as shown by Figure5.6. However, porous pipes were placed at the surface and there was upward movement of water by evaporation and capillary rise, which resulted in the accumulation of salts at the soil surface.

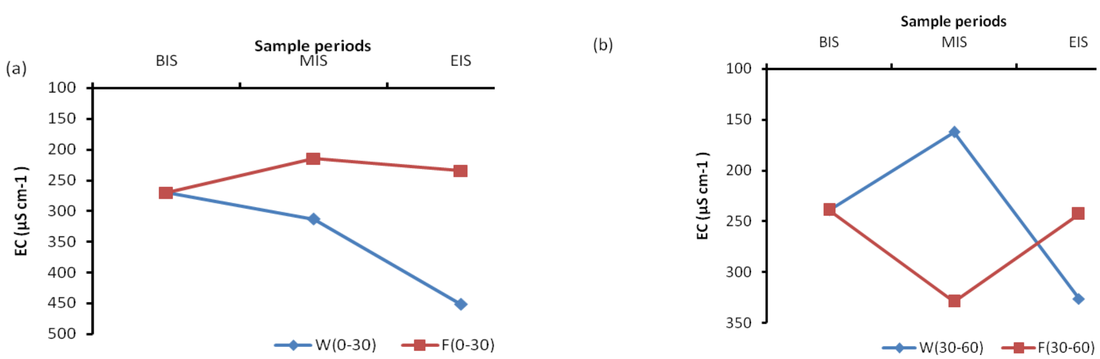

Figure 5.6: (a) 0-30cm, (b) 30-60 cm, EC of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW)

Higher EC values were found in (0-30cm) layer than in the lower layers (30-60 cm), which might be due to salts in RWW and subsequent evaporation at the soil surface. This result was expected and agrees with other researcher's results such as Heidarpour *et al*. (2007); Al-Shdiefat *et al*. (2009); Pedrero and Alarcon (2009) and Xu *et al*. (2010).

Irrigation water is the main source of adding salts to the soil (Hussain and Al-Saati, 1999). In this research the EC value of RWW was greater than FW. Therefore, the application of RWW would be expected to cause greater soil EC than FW in soil layers (Table 5.4). Mean

EC values of RWW irrigated soil were slightly greater than those of FW irrigated soil for the first layer. This result is likely due to the effect of plant uptake on the soil solution.

5.3.3.3 Nitrate (NO_3^-)

The distribution of NO_3^- in examined soil profiles was shown in Table5.4. It was observed that NO_3^- had the analogous distribution trend in soil horizons. That is, on top 0-30cm layers, NO_3^- contents in soils with RWW irrigation (plot B) were significantly ($p<0.05$) higher as compared to concentrations in soil from the control site (plot A). This increasing may refer to high content of organic nitrogen in RWW, which turn out to nitrate by nitrification process. NO_3^- concentration of RWW and FW irrigated soil at the end of the study was greater than that at the beginning (Figure 5.7). This suggests that both irrigation water contained nitrogen in excess of plant requirements. Similar results have been previously reported by several authors Heidarpour et al. (2007); Duan et al.(2010) and Xu et al. (2010).

To a lower depth of 30-60 cm, concentrations of NO_3^- in plot B were not significant different from those in control soil (plot A) at the end of irrigation season (EIS) as shown by Figure 5.7.

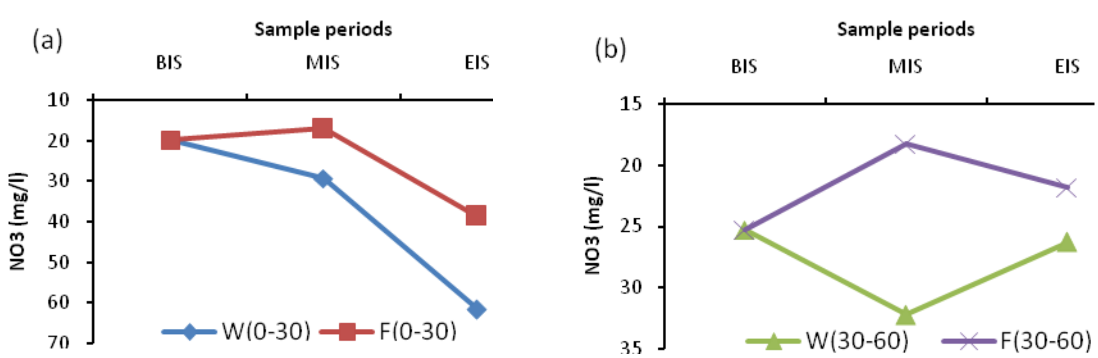

Figure 5.7: (a) 0-30cm, (b) 30-60 cm. NO3- of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW).

It was noticed that there was considerable variation in nitrate levels in this layer during study period. This probably due to leaching of nitrate to the lower layer. Moreover, this variation may attribute by olive and citrus trees action and root uptake (Quin˜ones *et al*., 2007). One of the benefits of reclaimed water irrigation is that it serves as a source of nutrients, such as nitrogen. This increase of NO_3^- in the surface soil was due to the direct input through effluent irrigation.

5.3.3.4 Potassium (K^+)

Results show in this study, unexpected behavior in the concentration of potassium in the soil layers, the differences between K^+ concentration in soils irrigated with RWW and FW were not related to K^+ concentration of the applied water as shown in Figure5.8. Based on analysis of variance, K^+ concentration in the surface layer of RWW irrigated soil was significantly lower than that with FW ($p<0.05$). The reduction in K^+ concentration may be due to plant uptake or movement of K^+ ions from this layer (Heidarpour *et al*., 2007).

Several researchers such as Rusan *et al*. (2007); Travis *et al*., (2010) and Mojiri (2011) reported accumulation of K^+ in the soil with wastewater application which was attributed to the original contents of these nutrients in the wastewater applied.

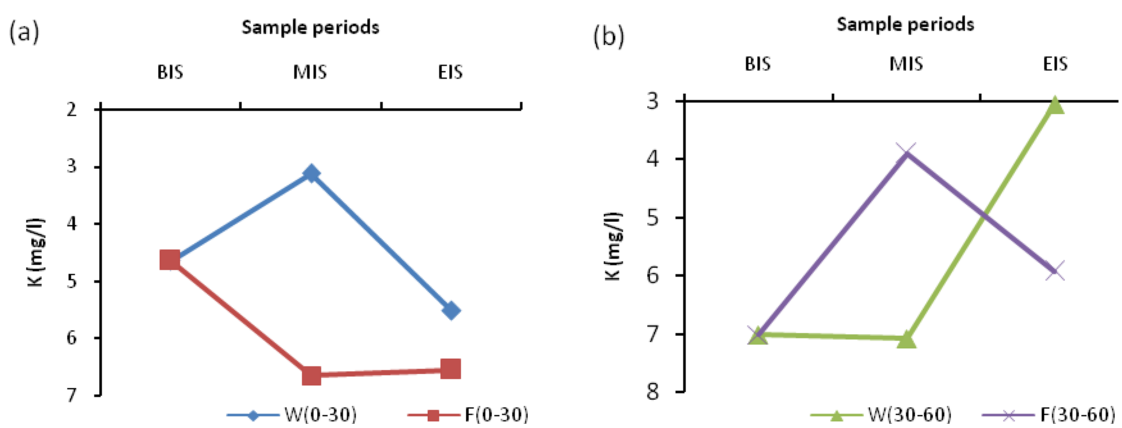

Figure 5.8: (a) 0-30cm, (b) 30-60 cm. K^+ of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW).

5.3.3.5 Sodium (Na^+)

In both soil layers, the Na^+ concentration with RWW irrigation soil was significantly greater than with FW irrigation soil as illustrated in Figure 5.9.

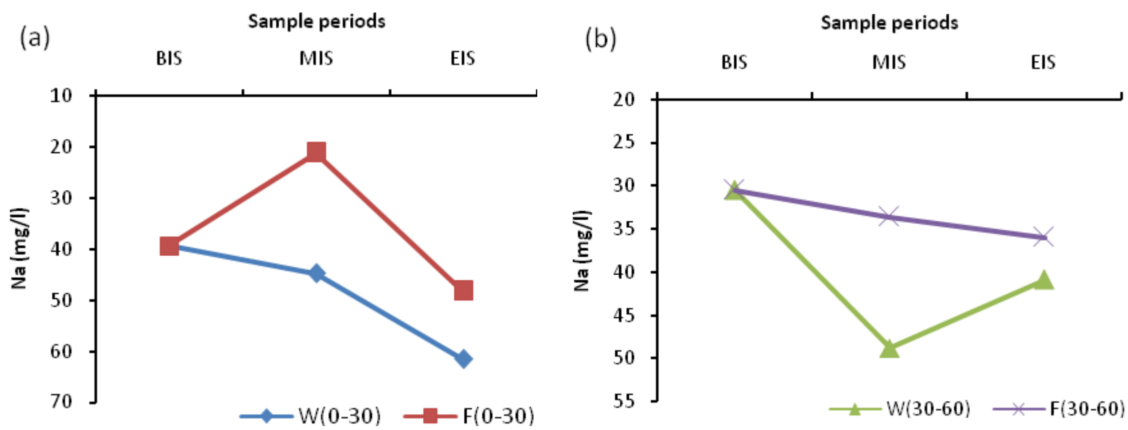

Figure 5.9: (a) 0-30cm, (b) 30-60 cm. Na^+ **of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW).**

High Na^+ concentration in the soil may cause clay particle swelling and dispersion, resulting in the deterioration of soil physical conductivity. However, the influence of Na^+ on soil particle depends on the total electrolyte concentration in the soil solution (Heidarpour *et al.*, 2007). As noted earlier, soil EC in the first layer increased with RWW irrigation, therefore, increased salinity of this soil layer reduces the potential for soil dispersion due to increased sodicity.

The increase in sodium level gives cause for concern due to the negative effects, albeit related to the surface layer. Degradation of the structural stability of the surface layer may lead, irrespective of the behavior of the deeper layers, to generally unfavorable agronomic conditions, such as a reduction in soil permeability and the consequent reduction in infiltration rate, lower water storage capacity, higher risks of water ponding and possible surface crusting, with ensuing problems for plant growth and soil use, and greater probabilities of erosion (Tedeshi and Aquila, 2005).

In relation to soil structural stability, SAR is an expression of the balance between the concentration of an undesirable cation (Na^{+}) and those of more desirable ones (Ca^{+2}, Mg^{+2}). The highest SAR was reported for surface layer, SAR values were 3.5 and 2.38 for RWW and FW respectively at EIS.

There was no significant variation found between RWW and FW irrigated soils in the two layers as presented in Table5.4. The larger SAR in the RWW irrigated soils than in the FW irrigated soils was a result of increased adsorption of the Na^{+} from the effluent, on the exchangeable complex in the soil (Lado and Ben-Hur, 2009).

Generally, soils irrigated with water of high SAR become progressively more sodic, this process is accelerated if the water is also saline (Murray and Grant, 2007).

5.3.3.6 Exchangeable cations Calcium (Ca^{+2}) and Magnesium (Mg^{+2})

Results revealed that $Ca^{+2}$and Mg^{+2} level were increased in both plots A and B at the both layers 0-30 and 30-60 cm as shown in Figure5.10, There was a significant difference ($p<0.01$) between BIS and EIS for values of Ca^{+2} and Mg^{+2} concentration in the soil. Increasing in the surface layer was about 70% while in the bottom layer was about 50%. Variations of the exchangeable cations with time are explained by the combined effects of supply from irrigation, aerosols, rains or fertilizers, supply by capillary transfers, leaching after heavy rains and root uptake (Tarchouna *et al*., 2010).

The calcium concentration in the soil profile is expected to increase in a sound wastewater land application system since this increase can potentially decrease the damage due to soil sodium increases.

Calcium can be removed by deep percolation of water, plant uptake, and precipitation in the form of calcite in alkaline soil (Pettygrove and Asano, 1984). It is also known that high concentrations of sodium reduces the uptake of important mineral nutrients, K^{+} and Ca^{+2} which further reduces cell growth especially for roots.

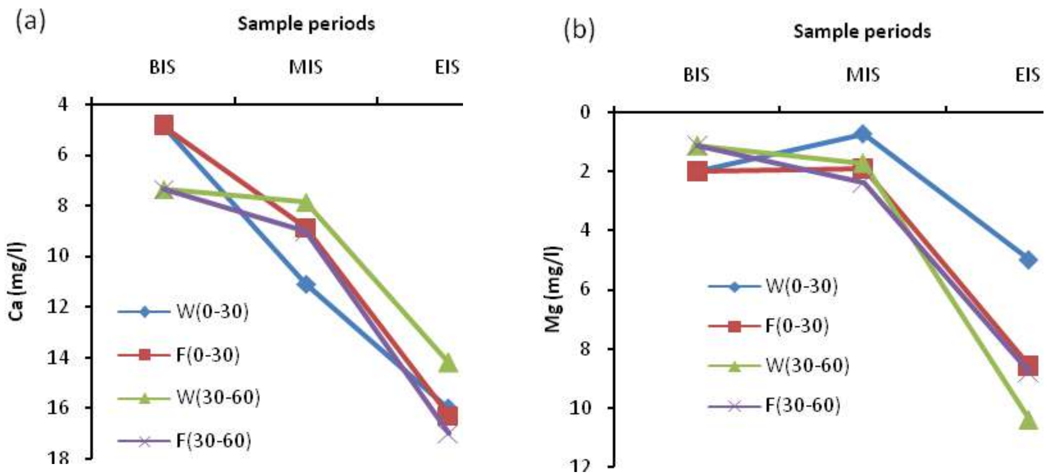

Figure 5.10: (a) $Ca+^{2}$, (b) $Mg+^{2}$. of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW).

It is noted that the study soils, because of their low clay content, have a low buffering capacity with regard to adsorbed species. This helps to explain the higher values for exchangeable $Ca^{2+}$and Mg^{2+} with regard to Na^{+} , despite the higher irrigation water supply for this latter cation. During evaporation, the more soluble Na^{+} cations can remain in solution when Ca^{2+} and Mg^{2+} precipitate as labile minerals such as calcite, magnesite or mixed carbonates or even magnesium chloride (Tarchouna *et al*., 2010).

5.3.3.7 Chloride Cl^{-}

Results indicate that Cl^{-} concentration for both soil layers in A and B plots were increased during study period as shown in Figure 5.11. Guohua et al., (2000) reported that Cl^{-} content of the soil is not an intrinsic property of the soil but is a result of soil management, because of its mobility in the soil and the fact that it moves with the water in the soil.

At EIS Cl^{-} concentration increasing in surface layer was 48% and 30% for RWW and FW irrigated soils respectively , this difference may be related to the variation of Cl^{-} concentration of RWW and FW , where was RWW has higher value of Cl^{-} than FW as illustrated in Table 5.1.

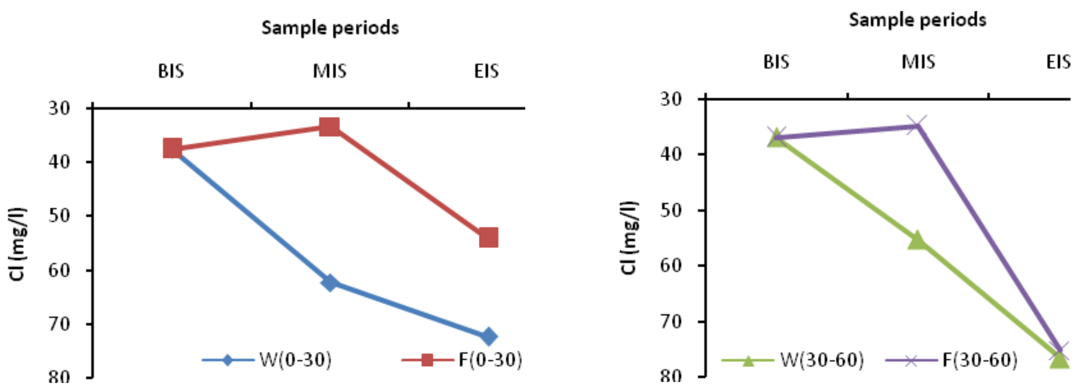

Figure 5.11: (a) 0-30cm, (b) 30-60 cm. Cl- of soil layers for different irrigation water RWW and FW, (F= FW) and (W = RWW).

It is worth to mention that the increasing of Cl^- concentration in the bottom layer 30-60cm was similar 52% and 51% for RWW and FW irrigated soils respectively, this increasing may refers to the behavior of Cl^- anion, which is not adsorbed on soil particle at neutral and basic pH values and therefore leached easily (Guohua *et al*., 2000).

According to Ayers and Westcot, (1985) Sensitivity to high Cl^- concentration varies widely between plant species and cultivars, generally, the toxicity symptom for Cl^- are the leaf burn or drying of leaf tissues typically occurs first at the extreme leaf tip of older leaves. The critical toxicity concentration is about 4-7 and 15-50 mg/g for Cl^- sensitive and Cl^- tolerant plant species respectively.

5.3.3.8 Infiltration Rate (IR)

Infiltration is the entry water into the soil. It is a dynamic process, and is one of the most important factors in the soil phase of the hydrological cycle, since infiltration determines the amount of runoff as well as the supply of water to the soil profile (Lado and Ben-Hur, 2009).

Results showed that there is no significant variation between plot A and B for infiltration rate measurements at the end of irrigation season EIS, the average values of infiltration rate at EIS for plot A and B were 156 and 159 mm/h respectively, as shown in Figure 5.12.

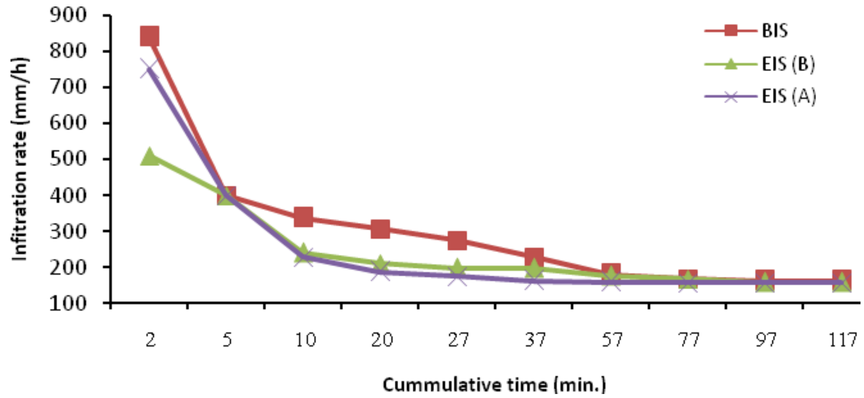

Figure 5.12: Infiltration rate curve for plot A and plot B at BIS and EIS.

This result indicate that the irrigation with RWW did not reduce the infiltrability of examined soils, Although the characteristics of RWW which used for irrigation, indicate that there are relatively high concentrations of different parameters like TSS, BOD and Na^+, these parameters play a significant role in reducing the rate of infiltration in the soil.

The findings of Lado and Ben-Hur, (2009) show that, the IR was significantly lower in the effluent than in the freshwater irrigated soil for long term application >10 years. This decrease of the IR in the effluent irrigated soil was mainly a result of seal formation.

5.3.3.9 Organic Matter (OM)

The OM contents in examined soil profiles ranged between 1.05% and 0.66% from (0-30cm) to (30-60 cm). In comparison with percentage in the control soil profiles, results showed that RWW application caused increased soil organic matter to the depths of 0-30cm, and to the depths of 30-60cm on plot B. Compared to its pristine content, soil OM in the top (0-30cm) layer was increased by 37% in soils with RWW irrigation. The increase was only significant ($p<0.05$) at top 0-30cm soil layer, and no significant difference was found in lower layers as shown in Table5.4. This is most likely due to the higher OM content of RWW. This is in line with findings of Kiziloglu *et al*. (2008); Lado and Ben-Hur (2009) and Mojiri (2011).

The accumulation of OM in effluent irrigated fields could increase soil fertility and crop production. Soil organic matter also improves soil structural properties, acts as a nutrient reserve and counteracts the effects of salinity (Ayers and Westcot, 1985).

Soil OM was reported to be able to sequester trace metals and reduce their mobility and risk of leaching (Klay *et al*., 2010). No doubt, long term reclaimed wastewater application caused appreciable increased OM in soils, which may improve the soil quality.

5.4 Impact of Short Term RWW Irrigation on Groundwater Quality

The values for the different measured parameters for groundwater during the time of the study are listed in Table 5.5.

Wastewater irrigation can add excess salts and nutrients to the soil and these have the potential to affect groundwater quality through leaching below the root zone. The actual impact depends on a host of factors including depth to water table, quality of ground water, soil drainage, hydraulic conductivity, scale of wastewater irrigation, and agronomic practices.

It could be argued that, there is no significant variation on the examined parameters during the short term study for all selected monitoring wells. The chloride concentrations in the monitoring wells range from 368 to 587 mg/l. Results revealed that, over 500 mg/l CL concentration recorded in wells R137, R I 10 which are the closest to GWWTP (about1 km east of the GWWTP), and also in well R I 14 which is located about 1.4 km east of the GWWTP. While wells R136, R251and R I 12 have lower than 500mg/l concentration of Cl, which located as previous others wells.

Table 5.5: water quality of agricultural monitoring wells during study period.

Sample period	Well ID	pH	Ec µS/cm	TDS mg/l	NO_3^- mg/l	Cl^- mg/l	SO_4^{-2} mg/l	Alk. mg/l	Har. mg/l	Ca^{+2} mg/l	Mg^{+2+} mg/l	K^+ mg/l	Na^+ mg/l	SAR
MAY	**R 136**	7.90	1740	1078	110	368.7	44	310	420	66.9	50.4	2.5	250	5.62
AUG.		7.63	1790	1135	113.1	370	44.3	320	439	64.3	58	2.6	260	5.66
NOV.		7.23	1836	1149	113.1	394	44.5	332	449	71	62	2.6	265	5.54
DEC.		7.30	1860	1153	117	408	44.7	344	468	75	68	2.8	270	5.44
MAY	**R 137**	7.50	2490	1544	57.4	545	102	541.8	578.7	100.1	73.1	8.5	314	5.82
AUG.		7.42	2570	1593	61	550	110	546.9	589	98.7	71.6	9.0	333	6.23
NOV.		7.20	2700	1674	61.5	580	116	542	615	106	85	8.6	337	5.91
DEC.		7.30	2750	1705	67.1	587	116.9	542	619	110	83	12.7	340	5.96
MAY	**R 251**	7.6	2293	1423	105	455	81.3	433.5	567.2	91.1	89.2	5.2	307	5.48
AUG.		7.37	2280	1413	111.3	452	88.7	425.3	542.4	82.8	86.4	4.99	305	5.60
NOV.		7.05	2320	1438	110	465	93.5	427	572	92	90.0	5.5	310	5.51
DEC.		7.09	2384	1478	120	480	96	431	585	97.5	94.0	5.3	300	5.20
MAY	**R I 12**	7.6	2095	1298	95.8	434.7	86.6	419.5	643	99.3	92.8	7.5	258	4.47
AUG.		7.15	2130	1320	96.5	448.6	87.4	428	648	98.7	95.2	6.59	260	4.48
NOV.		7.08	2260	1401	97.2	472	90.6	433	663	100	100	6.7	260	4.40

DEC.		7.12	2210	1370	107	465	89.2	429.4	667	106	100	6.6	268	4.48
MAY	**R I 14**	7.46	2590	1608	91.68	528.7	69.9	404.6	426.1	79.4	80.2	5.0	370	7.00
AUG.		7.27	2604	1614	92.56	530.8	69.11	401	431.8	78.54	81.11	5.18	374	7.07
NOV.		7.14	2615	1621	92.2	532.6	69.5	405.2	435.2	81.7	80.23	5.21	374	7.04
DEC.		7.23	2684	1664	93.84	546.2	70.8	408.2	432.6	84.56	82.14	5.33	380	7.05
MAY	**R I 10**	7.25	2496	1548	44.23	506.8	112.4	432.6	512.8	89.6	71.2	6.8	285	5.45
AUG.		7.58	2490	1543	44.52	502.7	110	430.8	504.2	87.81	70.84	6.32	280	5.39
NOV.		7.42	2532	1552	46.82	514.5	113.8	468.2	512.5	90.12	72.35	8.75	310	5.90
DEC.		7.26	2538	1560	50.64	517.6	115.5	493.4	517	91.54	73.54	9.09	310	5.85

According to unpublished data from (MOH) for year 2011, most of municipal wells in Gaza Strip have a chloride level over 500 mg/l. Consequently, RWW has naturally almost the same chloride level as this is not affected by the treatment processes in the wastewater treatment plant.

As shown Table5.5, the spatial distribution of NO_3^- in monitoring wells show that high NO_3^- concentrations exist mainly in wells R251, R136, RI12 and RI14, which above the values recommended by PS standard(50mg/l). While RI10 and R137 have lower NO_3^- concentration reflecting the integrative effects of groundwater flow, water exploitation, RWW irrigation and GWWTP.

5.4.1 Hydrogeochemical Facies

The concentrations of major ionic constituents of ground water samples were plotted in The Piper-Trilinear diagram to determine the water type. The classification for cation and anion facies, in terms of major ion percentages and water types, is according to the domain in which they occur on the diagram segments. Figure.5.11 reveals that majority of groundwater samples fall in.

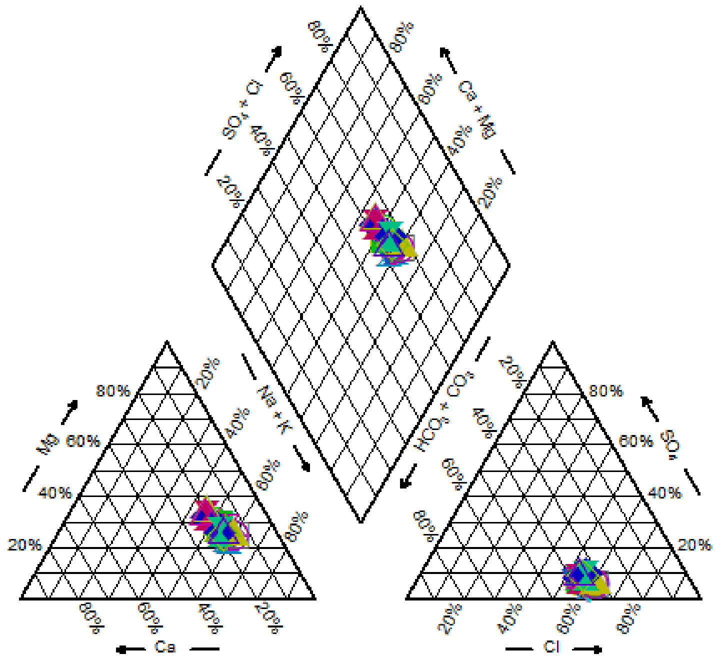

Figure 5.13: Piper-Trilinear diagram for monitoring wells.

It clearly explains the variations or domination of cation and anion concentrations during study period. Na-Cl-type of water was predominated during study period. The percentage of samples falling under Na-Cl-type was 83%, while 17% falling under mixed type (No cation-anion exceed 50%). There is no significant change in the hydro-chemical facies noticed during the study period, which indicates that short term irrigation by RWW for citrus and olive trees does not affect clearly on the groundwater quality.

Table 5.6 illustrates the historical data for three of the monitoring wells in the study area, demonstrate that the quality of groundwater in the region is deteriorated, especially the increase of salinity in particular the increase in chloride, well R137 which has two times value of Cl over the past ten years.

Table 5.6: Comparison of water quality for selected monitoring wells across different time periods

Parameter	Unit	R137			R I 12		R I 10	
		2001*	2005*	2011	2005	2011	2005	2011
pH	-	7.78	7.2	7.41	7.4	7.2	7.4	7.4
TDS	mg/l	1247.6	1860	1614.00	1560	1347	1360	1550
NO3	mg/l	126.51	55	61.83	60	99	101	112
Cl^-	mg/l	298.49	535	560.67	454	455	384	456
Ca^{+2}	mg/l	88.18	104	102.93	80	101	86	89
Mg^{+2}	mg/l	45.52	79	75.90	101	97	73	71
K^+	mg/l	3	8	10.07	6	6.8	3.8	7.7
Na^+	mg/l	243.36	350	329.00	250	261	227	296

Source:*Ministry of agriculture (MOA) unpublished report.

5.4.2 Water Depth Measurements

Reductions in groundwater storage have major implications for water quality because the salinity of the extracted water frequently increases as the volume of the reservoir decreases. To monitor changes that happen to the water depth in the study area as a result of the intensive agricultural activities, seven wells were selected to measure the water depth during the period between July and November.

Results shows in Figure 5.12, that there is slightly increase of water depth for all selected wells at the period July to November, as a result of continuous pumping from the aquifer during the summer months without a compensation for these quantities. Although infiltration basins are close to study area, but did not affect on water depth during study period, while at the beginning of the raining season water depth start to slightly decrease.

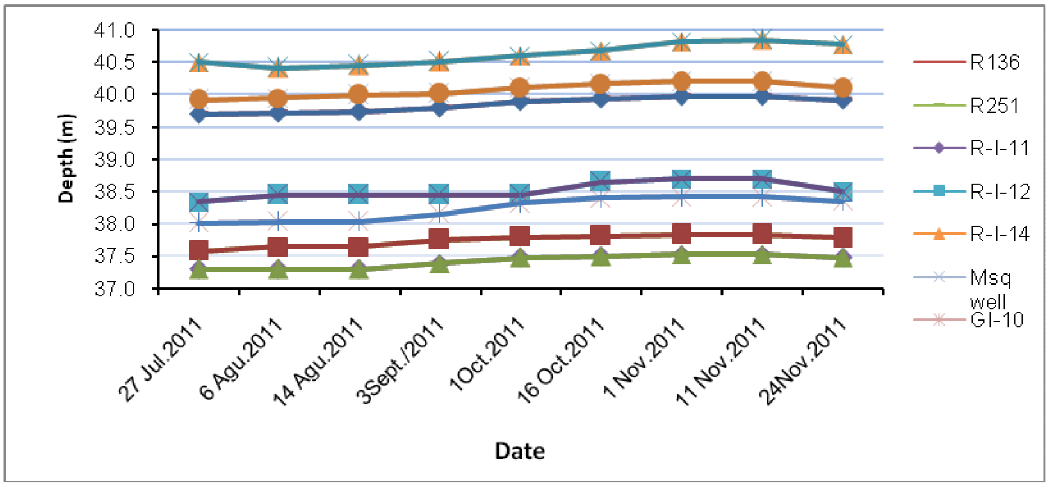

Figure 5.14: Water depth measurement for selected wells

5.5 Effect of RWW on Olive and Citrus fruits Quality Parameters

5.5.1 Hygienic Quality of Olive and Citrus fruits

Results of microbial analyses for Olive and Citrus fruits show that no surface contamination was recorded on the fruits collected at the end of the irrigation season from the irrigated treatment, where a very low concentration of Escherichia coli (E. coli) and Total coliform (TC) was recorded (Table 5.7). It is not easy to determine if this contamination was due to the fruits'contact with the wastewater, to an environmental pollution or to an accidental contamination occurring during sampling. The former possibility could be realistic because operated in the worst case condition (drupe sampled from the part of the crown placed near the drippers).

On the other hand drip irrigation, especially when utilized on fruit trees, avoids aerosol spraying and contact among wastewater, fruits and leaves thus reducing or eliminating contamination. According to WHO guidelines (1989), in case of fruit tree irrigation with reclaimed wastewater, fruits should be not harvested from the ground.

Similar results were obtained by Palese *et al*., (2009) study, which concluded no significant microbial contamination was recorded on fruit harvested directly from the canopy of the wastewater-irrigated trees. While EL Hamouri et al.,(1996) found that cucumber (ground contact) was much more contaminated than tomatoes (grown using stakes), although both crops received the same volumes of irrigation with treated wastewater.

Table 5.7:Quality characteristics of Olive and Citrus fruits grown at plot A and plot B for the season 2011.

Parameter	Unit	Citrus		Olive	
		FW	RWW	FW	RWW
Fecal coliform	CFU/100ml	0	0	0	0
Total coliform	CFU/100ml	0	0	0	280
E. coli	CFU/100ml	0	0	0	240
Listeria	CFU/100ml	0	0	0	0
Salmonella	CFU/100ml	0	0	0	0
Cu	mg/l	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	0.02	0.02	0.01	0.12
Pb	mg/l	<0.01	<0.01	<0.01	<0.01

In addition, El Hamouri *et al*., (1996) and Minhas *et al*., (2006) stressed the importance of the exposure of the edible parts of the plants to solar radiation and dessication to reduce possible contamination especially for pathogen bacteria less resistant to environmental conditions.

5.5.2 Chemical Quality of Olive and Citrus Fruits

Results of heavy metals analysis for Olive and Citrus fruits, indicated that Olive and Citrus fruits were the similar for plot A and plot B at the end of irrigation season, as illusrated in Table 5.7. It is worth mentioning that,low concentration of heavy metals were found in both fruits types,which related to low concentration of heavy metals in both types of irrigation water. This is in line with findings of Al-Shdiefat *et al*., (2009), Therefore, irrigation with wastewater increases the amount of uptake and accumulation of heavy metals in plant. Many investigations, including long and short term studies Mojiri, (2011) and Rusan *et al*., (2007) showed that the accumulation of heavy metals in plants increased as a consequence of the application of wastes such as wastewater, sewage sludge.

5.5.3 Olive Oil Quality

all olive oil quality parameters fall within the standard limit values according to IOC, (2011) as shown Table 5.8. Results showed that refractive index, free acidity, acid value and peroxide value for olive oil extracted from fruits of the plot B were not significantly different from those in the reference orchard plot A. However, peroxide value,free acidity and acid value were higher for olive oil extracted from fruits of the reference orchard, even though its value remains below the standard limit. This is in line with findings of Al-Shdiefat *et al*., (2009).

Table 5.8:Quality characteristics of olive oil extracted from fruit cultivar grown at plot A and plot B for the season 2011.

Parameter	Unit	Plot A FW	Plot B RWW	Limit value*
Refractive index at 20° C	-	1.4685	1.4686	1.467- 1.470
Free acidity as oleic acid	%	1.2	1.1	Max 3.3
Acid value	mg g^{-1}	2.5	2.1	-
Peroxide value	meqO_2 kg^{-1} oil	12.9	11.9	Max 20

*Source:(IOC, 2011)

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

In this work, Effects of irrigation with reclaimed wastewater on soil properties and groundwater quality in Zaiton area, Gaza, Palestine, was studied and evaluated. The study concentrated on characterization and assessment of RWW, which used for irrigation during study period; physiochemical properties of two layers of soils irrigated by RWW and FW were carried out; comparison quality of olive and citrus fruits irrigated with RWW and FW was implemented. The results show a number of important conclusions.

6.1. The main conclusions drawn from the present study are summarized below:

1- RWW used for irrigation in this study have very high salinity hazard, this is limiting factor for using this type of water for irrigation wide range of plant types

2- Microbial content of the investigated RWW had high value of FC and TC above the value recommended by PS and WHO standards, working on reduces safety in the application and plant quality.

3- In the case of the salts and the resulting sodium adsorption ratio tested, there were no significant differences ($p<0.05$) in the concentrations found between soil samples collected at the beginning of irrigation season and those collected after irrigation season.

4- In spite of the chemical contrast between irrigation waters, no obvious differences in soil inorganic composition were observed as a result of the short term irrigation period.

5- Results of the current study indicated that there were no residual effects of RWW irrigation on the concentration of heavy metals in olive and citrus fruits during the short term study period.

6- It can be concluded, that based on these results proper management of wastewater irrigation and periodic monitoring of soil fertility and quality parameters are required to ensure successful, safe and long term reuse of wastewater for irrigation.

7-In spite of using RWW as alternative source of irrigation water for olive and citrus trees, depth of groundwater in the selected monitoring wells was negatively influenced by intensive pumping for irrigation large areas planted with vegetables and crops, which not permitted to irrigation under current characterization of RWW.

8- The final conclusion that can be made from this research is that land application of RWW can be designed and operated in a way such that to minimize negative effects on the environment. To further prove this more completely, this research should be collected over a period of 10 years to truly evaluate long-term effects of RWW application.

6.2. Recommendations

The following are the recommendations:

1-More efforts are needed to improve the characteristics of RWW from GWWTP, especially salinity parameters, BOD5, TSS and fecal coliform. In order to expand the application of reuse RWW in agriculture sector.

3-It is necessary to establish research laboratory near agricultural areas, which apply the projects reuse of RWW, to monitor and evaluate the negative effects on soil properties and groundwater quality and monitoring of the quality of plant.

4-Needs for a survey of the agricultural areas in the Gaza Strip, that suitable for the application of reuse of wastewater in terms of soil type and the type of trees planted and the quality of ground water.

5-It is of great importance to implement long term studies in the areas of the Gaza strip that irrigated by RWW, to find out the most important environmental problems associated with RWW reuse.

6-It is necessary to promote and develop the relationship between institutions and agencies that implement RWW reuse projects in Gaza strip and relevant government institutions to ensure the sustainability and success of these projects.

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