The Islamic University of Gaza
Deanery of High Studies
Faculty of Engineering
Department of Civil Engineering
Water Resources Engineering

الجامعة الإسلامية بغزة
عمادة الدراسات العليا
كلية الهندسة
قسم الهندسة المدنية

Long Term Impact of Wastewater Irrigation on Soil and Crop Quality Parameters in Gaza Strip

*(*Case Study :BeitLahya Pilot Project*)*

By

Ziyad M. Abu Nada

Supervised By

Dr. Abd El Majeed Nassar

Dr. Husam Al Najar

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering- Water Resources Engineering

1430هـ – 2009 م

ABSTRACT

The use of recycled wastewater (RWW) for irrigation is increasingly considered as an effective solution of water resources scarcity. The present study was undertaken to assess the long term impacts of wastewater irrigation on soil and crop parameters. Analysis for soil was done from the BeitLahya Pilot Project (BLPP) area where wastewater effluent from BLWWTP was used for alfalfa irrigation since 2003. Starting from the surface to a 60 cm depth, 12 boreholes were driven over the BLPP area. Each bore hole was divided into two layers each of 30 cm thickness and 12 soil samples were collected from each layer. Three alfalfa samples were being analyzed in addition to two irrigated wastewater samples. Analysis was done for soil and wastewater key chemical and physical parameters (**Ec, pH, Na, Ca, Mg, OM, P and K**). Biological (Fecal and Tot. Coliform) and heavy metal (**Cu, Pb, Zn**) parameters for soil, alfalfa and wastewater samples were also analyzed. Results revealed that BLWWTP effluent is suitable to be used for irrigation as its quality match the local and international standards for wastewater irrigation except Na, Cl and Pb. Long term wastewater irrigation increased salt, organic matter and plant nutrients in both soil layers. Soil pH was not consistently affected. Even pH values were slightly decreasing with time for both soil layers it still within permissible range (6-8.5). By the time, soil exhibited permeability and infiltration problems when RWW used. Comparison of soil properties before and six years after RWW shows soil salinity EC, SAR, and Na increased by 570, 200 and 84% in both layers respectively. Average alfalfa FC level was 3000 CFU/100ml in the first year then it decreased while TC was higher than the usual range all the time (6000no/100ml*)*. Lead was the dominant heavy metal in wastewater and alfalfa crop. Although Pb level was in the acceptable range for soil, it was noticed that Pb has higher levels in alfalfa compared with other metals all the time with irregular Pb increase noticed after Israeli aggression on Gaza as its level was 240% (7.2ppm) higher than before. 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. Estimation of WW quantities that can be used for irrigation showed that nearly about 45Mm^3/year is needed by the restricted cops over GS. Regular monitoring of site-specific water and soil and appropriate management are needed to mitigate the negative impacts of sodium and salts accumulations.

Keywords: Recycled wastewater, Irrigation, Alfalfa, Soil.

ملخــــــص الدراســــــــة

لقد أصبح استخدام المياه المعالجة لأغراض الري الزراعي واحدا من الحلول الفعالة للتغلب على مشكلة تهالك مصادر المياه. هدفت هذه الدراسة لمعرفة اثر استخدام المياه العادمة في الزراعة على خواص التربة و النبات من خلال تحليل عينات من التربة و النبات من مشروع بيت لاهيا حيث يتم استخدام الناتج من محطة معالجة بيت لاهيا في ري نبات البرسيم منذ العام **2003**. تم جمع **24** عينة تربة من كامل المنطقة و ذلك على طبقتين بسمك **30** سم لكل طبقة يدءا من سطح التربة إضافة لثلاث عينات من البرسيم و عينتين من المياه المستخدمة في الري. تمت التحاليل لجميع العناصر الأساسية للتربة و المياه العادمة مثل (الملوحة، الحامضية، الكالسيوم، المغنيسيوم، الصوديوم، المادة العضوية والفسفور..) كما تم فحص التلوث البيولوجي في كل من المياه، التربة، و النبات. بالإضافة إلى عناصر النحاس و الزنك و الرصاص. أشارت النتائج إلى أنه يمكن استخدام المياه الناتجة من محطة المعالجة من بيت لاهيا في الزراعة حيث أنها تطابق المواصفات المحلية و العالمية عدا عناصر الصوديوم والكلورايد و الرصاص. كذلك تبين أن درجة الحامضية للتربة لم تتأثر بشكل كبير حيث أنها بقيت في المعدل العام من (**6.5–8**) و أن العناصر المغذية الأخرى زاد تركيزها بزيادة استخدام المياه العادمة وأن مشاكل في النفاذية بدأت تلاحظ في طبقات التربة . أظهرت المقارنة بين خواص التربة الحالية و تلك قبل **6** سنوات أن الملوحة و معامل امتصاص الصوديوم و الصوديوم زادت بنسبة **570**، **200** و **84**% على الترتيب. كما أشارت النتائج إلى أن معدل التلوث البكتيري كان عاليا قي السنة الأولى للنبات من خلال بكتيريا الفيكال حيث كان معدلها **3000** لكل **100** مللتر في حين أن الكوليفورم الكلي كان **6000** لكل **100** مللتر طوال التجربة. أوضحت النتائج أن عنصر الرصاص كان هو الأكثر تركيزا في كل من النبات و المياه رغم أن تركيزه كان في حدود المسموح به في التربة إلا أن تركيزه في النبات كان عاليا مقارنة مع العناصر الثقيلة الأخرى كما أشارت الدراسة إلى زيادة نسبة الرصاص في النبات عن ذي قبل بحوالي **240**% لتصل إلى **7** ملجم/لتر خاصة بعد العدوان الإسرائيلي.

أشارت الدراسة إلى أن كمية المياه العادمة الممكن استخدامها في الري في قطاع غزة هي **45** مليون متر مكعب سنويا للمحاصيل الزراعية المقيد استخدامها بالري. ختاما أكدت الدراسة أن إجراءات وقائية و أخرى إدارية لمراقبة إستخدام المياه العادمة لأغراض الري يمكن لها أن تكون فعالة في الحد من الآثار السلبية لاستخدام المياه العادمة في الري.

الكلمات الأساسية: المياه العادمة ، الري، البرسيم، التربة

DEDICATIONS

To my Father Spirit, and to my sincere Mother, for her kindness,

To my wife for her Support and Encouragement

To my lovely daughters SAJA and NAJLAA and My Beloved Son AHMED

To all of my Brothers and Sisters

To my Friends, Colleagues

To the Islamic University of Gaza

And to all those who believe in the richness of Learning

ACKNOWLEDGMENT

Thanks to Allah the compassionate the merciful for giving me patience and strength to accomplish this research.

I would like to thank all those who have assisted, guided and supported me in my studies leading to this thesis.

I would like to express my gratitude to my supervisors ***Dr Abdelmajeed Nassar*** *and* ***Dr. Husam Al Najar****. Their encouraging support, valuable ideas, and the freedom they gave me in developing own ideas are highly appreciated. The combined experiences and insight of these gentlemen have greatly influenced and impacted this study.*

I would like to express my sincere appreciation to ***Mr Ihab Ashour****- Palestinian Hydrology Group- for his kind cooperation in facilitating the author access to the experimental field and providing him the needed data.*

Field sampling and testing would have been impossible without the effort of Om Al Naser municipality staff and BLPP technicians.

Special thanks to engineer ***Jamal Abed****- Ministry of Agriculture- Water and Soil lab for his sincere efforts and hard works in performing the samples analysis and tests.*

Deep thanks to ***Dr. Khalil Tubail, Dr. Said Ghabayen****, engineer* ***Jamal Al Dadah*** *PWA , engineer* ***Maha Muhaisen****- PU university, , engineer* ***Shafeeque Al Arawi*** *and engineer* ***Nizar Al Wheedy****- (MoA) who many times answered questions and gave assistance and support to the author.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS & ACRONYMS

APHA : American Public Health Agency
BLAPP : Beit Lahia Pilot Project
BOD : Bio-chemical Oxygen Demand
C^o : Degrees Celsius
CAMP : Coastal Aquifer Management Program
CFU : Colony Forming unit
CMWU : Coastal Municipalities Water Utility
COD : Chemical Oxygen Demand
CWR : Crop Water Requirements
DO : Dissolved Oxygen
DTPA : Diethylene Triamine Pentaacetic Acid
dS/m : decisiemens/ meter
EC : Electrical conductivity
EC$_w$: Water salinity
EC$_e$: Soil Salinity
EEC : European Economic Commission
Eff. :Effluent of wastewater
ESP : Exchangeable Sodium Percentage
EPA : Environment Protection Agency
EQA : Environment Quality Authority
FAO : Food & Agriculture Organization
F.C : Fecal Coliform
GS : Gaza strip
ha :10.000 m^2
ICARDA : International Center for Agriculture Research in Dry Areas
IUG : Islamic University of Gaza
K : Potassium
Kc : Crop Coefficient
LF : Leaching Fraction
LR : Leaching Requirements
m^3/d :Cubic meter per day
MCM : Million Cubic Meters
mg/L :Milligram Per Liter
microS/cm :Micro Siemens per centimeter
MoA : Ministry of Agriculture
MoH : Ministry of Health
MOPIC : Ministry of Planning and International Cooperation

NGOs : Non Governmental Organizations.
NO_3 : Nitrate
O & M : Operation and Maintenance
P : Phosphate
PHG : Palestinian Hydrology Group
ppm : Part Per Million
PWA : Palestinian Water Authority
SAR : Sodium Adsorption Ratio
SAT : Soil Aquifer Treatment
TDS : Total Dissolved Solids
TN : Total nitrogen
TSS : Total Suspended Solids
UNDP : United Nations Developing Program.
UNEP : United Nation Environmental Program
WWTPs : Wastewater Treatment Plants
WHO : World Health Organization

CHAPTER 1: INTRODUCTION

1.1. Background

Water is a vital resource but it is severely limited in most countries of the Mediterranean region such as Palestine. Many countries are struggling to balance water use among municipal, industrial, agricultural, and recreational uses. The population increase has not only increased the fresh water demand but also increased the volume of wastewater generated. Treated or recycled wastewater appears to be the only water resource that is increasing as other sources are dwindling. Reclaimed water is increasingly viewed as a valuable resource for the agricultural, industrial and municipal sectors, rather than as a waste that requires disposal (**Qian, 2005**)

Since wastewater is considered as a non-ordinary source of water, its usage in the agriculture demands a unique management, which in addition to its appropriate utilization, has to have no threat to the environment, plants, soils and surface and subsurface water resources (**Najafi, 2001**)

The Gaza Strip (GS) is one of the places where the exploitation level of recourses exceeds the carrying capacity of the environment. This is especially true for the water and land resources, which are under high pressure and subject to sever over-exploitation, pollution and degradation. The scarcity of water in the Mediterranean and Middle East countries requires endorsement of sustainable wastewater management. The wastewater related problems, which these countries are facing, are increasing yearly owing to the increasing discharge of wastewater as a result of the increasing demand of fresh water for industrial purposes, human consumption and agricultural productions.

Generally, GS is a semi arid area with an average annual rainfall ranging between 200-mm/ year in the southern part of the area and 400-mm/ year in the north. Ground water is the only source of water in GS, and many estimation of the annual groundwater recharge in the GS have been mentioned in different references. Although different values for this recharge are given, all of these references agree on one fact, that the annual recharge is less than the abstracted quantities for along time, resulting in a serious mining of the groundwater resources and a net deficit of about 30-40 Million cubic meter (MCM)/year. Figure 1.1 illustrates the water level elevations of GS groundwater (**CMWU, 2007**)

The deficit in the water balance has led to depletion and salinization of the available groundwater resources. Salinization in the coastal aquifer may be caused by a single process or a combination of different processes, including seawater intrusion, up-coning of brines from the deeper parts of the aquifer, return flow from irrigation water, and leakage of wastewater (**PWA, 2005**).

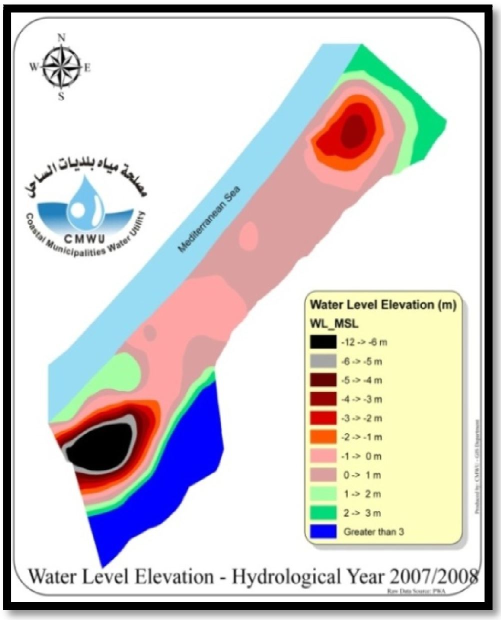


Figure 1-1: Water level elevation map in GS (CMWU, 2008)

These processes deteriorated the water quality till it reached in many areas a point that it couldn’t be used for drinking or even for irrigation. Figure 1.2 and 1.3 illustrate the development of chloride and nitrate concentrations over GS from 2002 till 2007 respectively. It is clearly noticed that the chloride concentration increases significantly over all GS especially in southern east and middle area as it exceeds the 1500 and 1000 mg/l respectively.

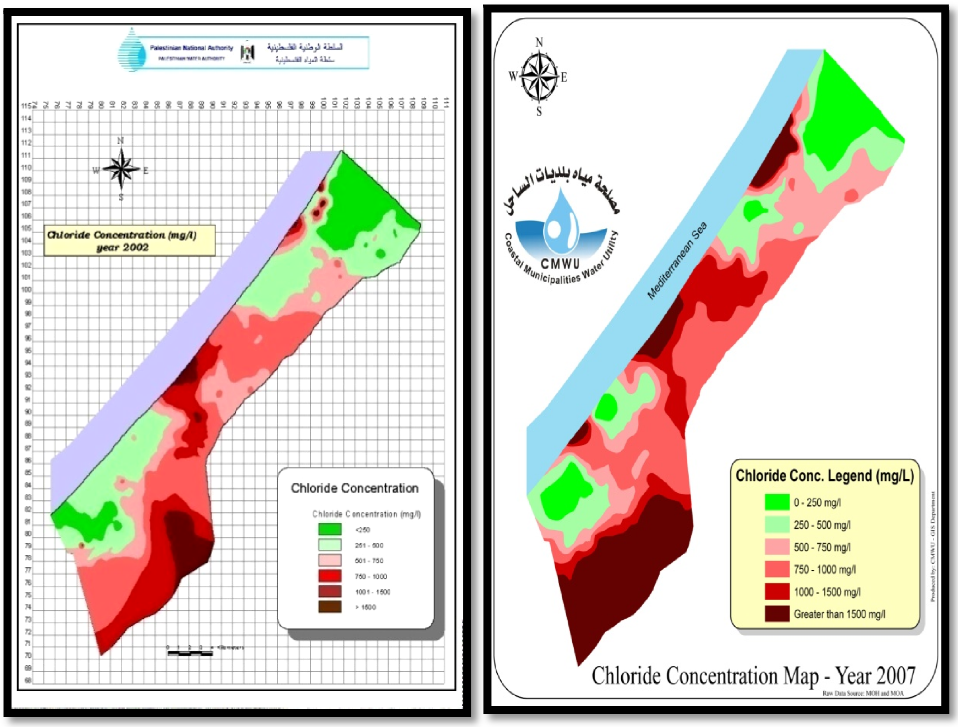


Figure 1-2: Development of chloride concentration in GS for the year 2002, 2007 (CMWU, 2008)

Nitrate level also increased significantly over all GS areas from 2002 to 2007 with the highest level (average of 200mg/l) being in northern area due to pumping the wastewater to the open sand dunes.

In GS the only resource of water for domestic, industry and agriculture use is groundwater. Surface water is not considered as a source of water because Wadi Gaza has the run-off only in winter season and the Israelis turned the direction before it reaches the Palestinian boarder. There are an estimated 4000 wells within the GS. Almost all of these are privately owned and used for agricultural purposes. Approximately 100 wells are owned and operated by individual municipalities and are used for domestic supply (**PWA, 2005**).

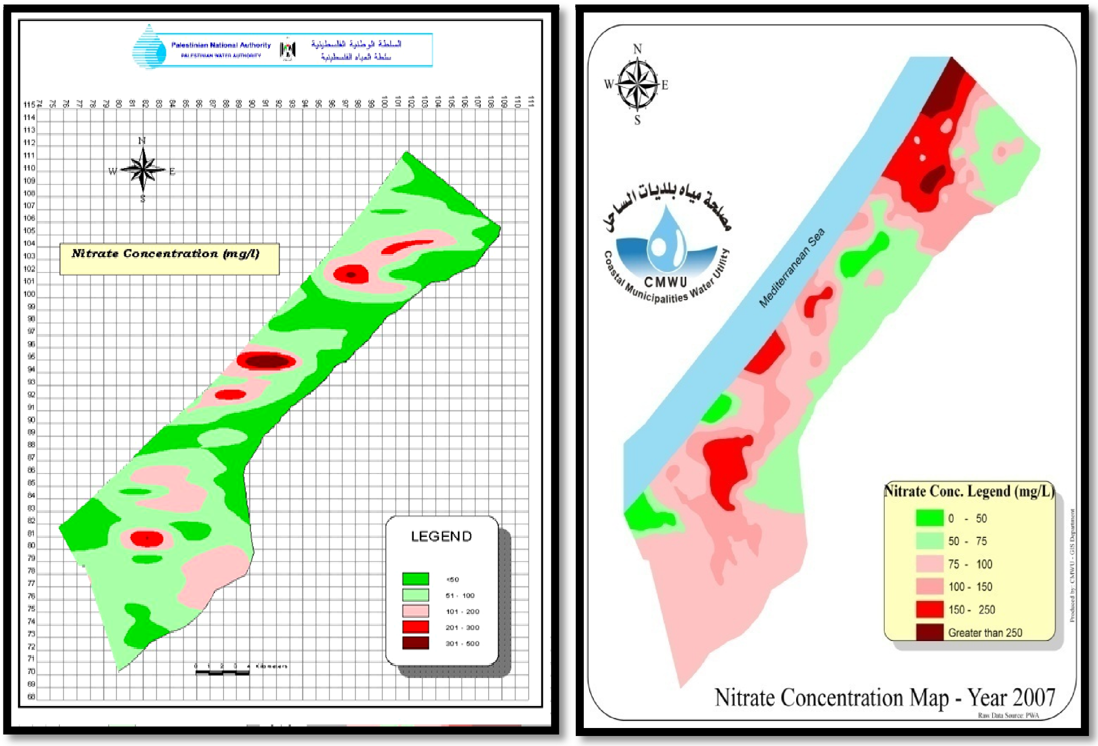


Figure 1-3: Development of nitrate concentration in GS for the years 2002, 2007 (CMWU, 2008)

According to CMWU statistics, the total groundwater abstraction in the GS in recent years estimated at 150 -170 MCM. And the supply of water from Israel has declined by approximately half from 1998 to 2004. Meanwhile the water production from authorized municipal water wells in GS in the year 2006- 2007 is 120 MMC and no available authorized data regarding to the agricultural consumption exist as most of the wells have no water flow meters (**CWMU, 2007).**

1.2. Agriculture Water Consumption

All over the world, the agricultural sector is the dominant user of water by humans, accounting for more than two-thirds of withdrawals. In developing countries agricultural use may reach 90% of total water use, with the remainder being used for domestic and industrial purposes (**FAO, 92**)

During the last fifty years there was a rapid increase in agricultural water consumption and it is expected to continue. Figure 1.4 illustrates the worldwide trend of development of agricultural water reuse. Irrigated agriculture in competition with other sectors will face increasing problems of water quantity and quality considering increasingly limited conventional water resources and growing future requirements and a decrease in the volume of fresh water available for agriculture (**Kamizoulis, 2004**).

In GS, the total water demand for agriculture and domestic use accounts for 80 and 47 MCM, respectively. The total water demand for the agricultural sector represents around 60% of total water demand. Water consumption for vegetable crops accounts for 47.7 MCM/yr which constitutes around 58% of total water demand for the agricultural sector. Citrus fruit, olives, almonds and other fruits consume around 33 MCM a year, which represents 40% of total water demand for the agriculture sector (**Al-Najar, 2007**).

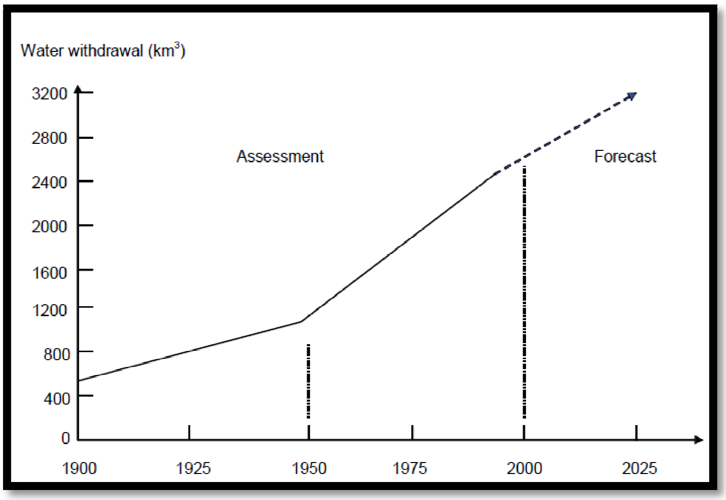


Figure 1-4: Worldwide trends in water use for agricultural purposes (Abumadi, 2004)

By 2020 the utilization of wastewater is planned to provide 78% of the total required by agriculture, with the remainder being provided by the freshwater aquifer in order to maintain the balance of salts in the soil and provide the quality necessary for certain crops (**PWA, 2000**).

1.3. Problem Definition

Gaza's wastewater treatment facilities are still vastly inadequate, with 80 % of sewage being discharged untreated into the environment. The uncontrolled discharges of untreated wastewater to the ground surface or to the sea lead to environmental and social problems. (**EQA, 2004**)

Even the use of treated wastewater to meet increasing agriculture water demand was identified as one of the main objectives of the Palestinian water sector, neither enough data nor comprehensive analysis to address the effects of using wastewater for irrigation in GS is being carried out (**PWA, 2005**).

Wastewater use for agriculture is still not practiced in the national agriculture production. The Palestinian experience in the reuse is still poor where this source can save more than two third of water consumption in GS by agriculture sector.

It is planned to have new three wastewater treatment plants in the eastern part of GS that will produce better effluent quality than current effluent. According to the Palestinian water Authority (PWA) master plan the amount of wastewater to be used for irrigation in GS will progressively increased on the coming twenty years to save more than half of groundwater needed for irrigation (**PWA, 2005**).

1.4. Study Justifications

Generally, there is a major potential use of recycled water in the GS. It is, however, essential that the development of water reuse in agriculture be based on scientific evidences of its effects on environment (soil & crops). 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**).

Afifi, 2006 stated that economical and financial feasibility of water reuse applications in GS needs to be better assessed with applied research for specific applications (**Afifi, 2006**). This reflects the need to analyze and evaluate the effects that will arise from wastewater agriculture reuse for specific reuse projects.

Moreover, while many wastewater reuse projects have been practiced in Palestine, neither of them have a comprehensive long term impact analysis on soil and crops properties. This study will carry out these analysis based on actual field analysis from BeitLahya Pilot Project (BLPP).

This study differs from previous ones as it mainly deals with treated wastewater effluent from Beit Lahia wastewater treatment Plant (BLWWTP) in GS. The quality of which varies with the time. This varying quality needs extensive monitoring and management program in order to early control undesired impacts when used for irrigation.

Moreover, in this study soil and alfalfa plant has been investigated for large scale of nutrients accumulation (Organic, inorganic and heavy metals) content after six years of wastewater use in the light of international guidelines i.e. FAO. Meanwhile, suitability of treated wastewater has been highlighted.

1.5. Goal

The main goal is to evaluate the impacts of wastewater agricultural irrigation practices in GS using the results of the northern area pilot project.

1.6. Objectives

- Investigate the suitability of current BL wastewater quality effluent to be used for agricultural irrigation based on different criteria and standards.

- Determine the direct impacts associated with BL wastewater irrigation based on nutrients found in applied wastewater on both soil and crops properties.

- Determine the potential of wastewater use and the needed quantities based on crop water demand.

- Recommend future upgrading of wastewater reuse practices in GS.

The study is expected to result in the outcome that the use of wastewater for irrigation poses definable and manageable risks as well as benefits for both soil and crops that can be overcome and developed with proper management.

1.7. Methodology

The methodology that followed to achieve the study objectives is summarized as follow:

- Pervious studies, researches, papers and journals related to wastewater reuse were reviewed and discussed.

- Historical data and results from the field of BLPP were collected

- Soil, applied irrigated wastewater and alfalfa crop samples were collected twice from BLPP field before and after 2009 rain season.

- Historical and generated soil and alfalfa results were analyzed to induce a trend of wastewater impacts on soil and alfalfa properties.

- Results of applied water quality were compared against current standards.

- Estimation of the actual wastewater quantities that can be used for irrigation
- Final conclusions and recommendations for optimum management and reuse of wastewater directed to responsible authorities and interested people were obtained.

1.10. Thesis Outline

Chapter one presents the introduction about water and wastewater situation (quantity and quality) in GS in addition agriculture water demand. It presents also the problem definition, study justification, main goal and purposes of this study. Methodology and thesis outline are stated in the last two sections.

Chapter two describes the GS area, its location, population, climate, hydrology and agriculture economy contribution in Gs. Project study area was also described with brief description about BeitLahia wastewater treatment plant where its effluent being used to irrigate the project field area.

Chapter three reviews the literature related to the wastewater treatment and reuse. The regional water recycling and potential of wastewater reuse in GS was highlighted. Existing guidelines and different standards concerning irrigated water quality were presented discussed. In the middle of that chapter it was necessary to illustrate the different impacts of wastewater agricultural reuse especially health and environmental impacts. To provide a contextual framework for the wastewater reuse impacts a brief description on impacts on soil, crops, and ground water was also presented,

Chapter four deal with the experimental program and analysis methods that have been followed in this thesis. Introduction to the BeitLahia Pilot Project BLPP with extended site description where the samples have been collected was presented. Physical, chemical and biological parameters for applied wastewater, soil, and alfalfa were illustrated. Samples collection, preservation and methods of analysis were also described. All media and equipments with analysis methods of physical, chemical and biological parameters were also explained.

Chapter five presented the results and discussion. Previous results from 2003 till 2006 with current results generated from the current study were presented and discussed. The suitability of applied wastewater in BLPP were examined and the development of soil and plant properties

Chapter six stated the conclusions and recommendations resulting from the study.

CHAPTER 2: STUDY AREA

2.1. Introduction:

The Palestinian territories consist of the West Bank with approximately 5,800 km^2 and the GS with about 365 km^2. The West Bank area is made up of a hilly region in the West and the Jordan Valley in the East. The climate in the West Bank can be characterized as hot and dry during summer and cool and wet in winter. The GS has a Mediterranean climate and consists mainly of coastal dune sands, being located between the coast and the Negev and Sinai Deserts (**MOPIC, 1998**)

2.2. Location

GS (GS) is located at the south-eastern coast of the Mediterranean Sea, on the edge of the Sinai Desert between longitudes 34° 2” and 34° 25” east, and latitudes 31° 16” and 31° 45” north. It is either located to the south west of Palestine. It has an area of about 365 km2 and its longest width is about 45 m. (**MOPIC, 1998**)

GS is bordered by the Mediterranean Sea in the west, Egypt in the south and what is called the green line from the north and east as Figure 2.1

Figure 2-1: Geographic location of GS

2.3. BeitLahia Pilot Project Study Area

Current study was carried out in GS northern area at Om Al Naser village to the north of BLWWTP where a pilot project called BeitLahia Pilot Project (BLPP) was initiated in 2003. This pilot project initiated through a French program called “Strategy of agricultural water management in the Middle East" aimed to demonstrate a good example for the Palestinian practice of treated wastewater reuse in agricultural production. The French program selected two areas for the implementation in the Palestinian Territories, BLPP in GS, and Al Bathan project in West Bank (**MoA et al., 2004).**

For BLPP, the treated wastewater coming from the Beit Lahia WWTP which is available in unlimited quantities was used to irrigate the forage alfalfa.

The project field BLPP is located to the north of BLWWTP bordered by the main lake from west and south and by Om Al Naser village from the north an east as shown in Figure 2.2.

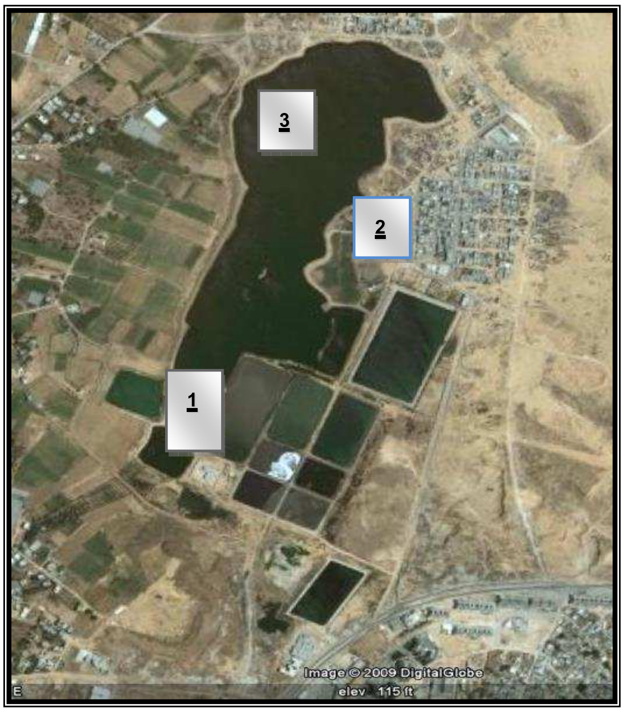


Figure 2-2: General location of BLPP (study area) (1. BLWWTP 2. BLPP1 3. Main Lake)

The existence of an important Bedouin village with many animals and big areas of sandy dunes has lead to a demonstration of fodder production of alfalfa crop. Area of BLPP is about 13 dunum (dunum=1000m^2) planted with Higazy alfalfa. Soil profile contains 76% sand, 12% clay and 12% silt so it is loamy sandy soil. Average annual rainfall is 400 mm yearly.

2.4. Population

GS is considered one of the most overpopulated areas all over the world. As it was stated, the area of GS is about 365 square kilometer with a population of 1,480,000 inhabitants most of them are refugees (**PCBS, 2007**). According to Palestinian bureau statistics council (**PBSC**) population growth rate in GS is 3.8 % which means that the available sources in GS are facing high threat. Moreover the unevenly distribution of population makes the problem of sources allocation more complicated.

Nowadays, Gaza city is the biggest population centre and has about 496,410 inhabitants. Gaza's other two main population canters are southern area (Khan younes and Rafah) with population of 270979, followed by northern area with 270245 inhabitants **(PCBS, 2007)**

2.5. Climate

GS climate is typical Eastern Mediterranean with hot dry summers and mild winters. Temperature gradually changes throughout the year, reaches it’s maximum in August (summer) and its minimum in January (winter), the average monthly maximum temperature range from about 17.6 C° for January to 29.4 °C for August while the average monthly minimum temperature for January is about 9.6 °C and 22.7 for August. Gaza Northern area has the highest rainfall rate over GS as on average it has 429mm annually.

2.6. Hydrology

Rainfall is the main source of groundwater recharge area in the GS. The Average rainfall depth over GS area in 2006-2007 is estimated about 364.7 mm with total amount 133.1 MCM received through 46 rainy days. Only 60 MCM was infiltrate into the ground aquifer while the total abstracted quantity was 166MCM (PCSB, 2007).

Despite of the small area of GS (365km^2), the level of rainfall varies significantly from one area to another with an average seasonal rainfall of 412.9mm in north area, to 225 mm in the southern area. Figure 2.3 show 2006-2007 seasonal rainfall depth contour maps.

2.7. Water supply

Water resources in GS are very limited. Over exploitation of the aquifer diminished seriously the quantity and quality of ground water badly needed for human consumption as well as for agriculture; one of the main sources of income in the GS.

The reuse of treated wastewater could be an important alternative to solve the water deficit crisis in GS (**Tubail et al, 2003**).

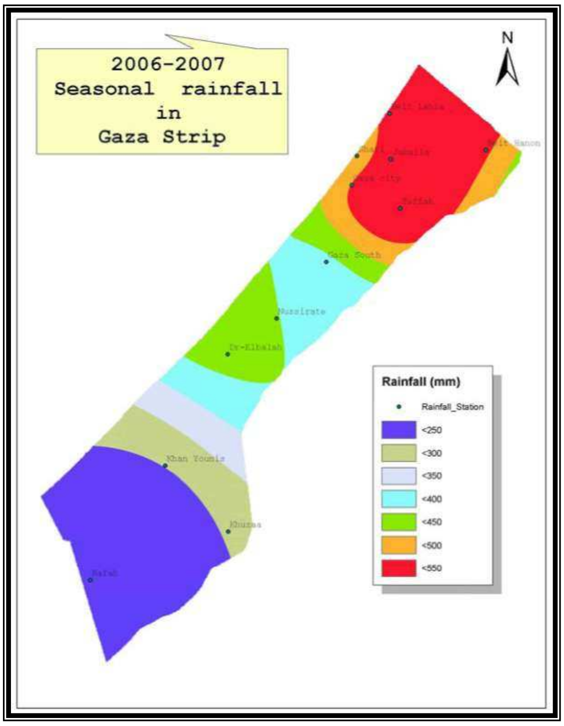


Figure 2-3: 2006-2007 seasonal rainfall depth contour map

The only source of water in GS is groundwater which is used for domestic, agricultural and agricultural consumption.

In 2007 the total production of water in GS was 173 MCM, the domestic consumption was 85 MCM while the remaining 87MCM for the agriculture sector. 97.5 % of this quantities produced by water wells while 2.5% was imported from Israel Company called Mekerot (**PCSB, 2007**).

2.8. Wastewater Quantities in GS

The wastewater collected from GS (total of 40 MCM/year) is fed into three main treatment plants; BeitLahya, Gaza and Rafah with total capacity of 20,000, 75,000 and 16,000 m^3/day by the year 2010, respectively. Currently, partially treated wastewater in GS is discharged to the sea without any significant reuse especially the effluent of Gaza wastewater treatment plant (GWWTP) (**Shomar, 2003**).

The Palestinian Water Authority estimated that at least 92 MCM of recycled wastewater would be available for agriculture reuse by the year 2020. Field measurements and future forecasting for wastewater quantities from the networks agree with these figures (**Afifi, 2006).** Table 1.1 presents the annual wastewater quantities generated in GS.

Table 2-1 Annual potential of wastewater generation in GS, (Afifi, 2006)

YEAR	2000	2005	2010	2015	2020	2025
Population in Million	1.121	1.34	1.84	2.29	2.58	2.91
Water Consumption MCM	45.02	58.81	80.65	116.89	131.87	148.72
Wastewater generation MCM	36.02	47.05	64.53	93.51	105.50	118.98
% connected to network	50.0	65.0	75.0	85.0	90.0	95.0
Treated Effluent MCM/yr.	18.01	30.58	48.39	79.48	94.95	113.03

2.9. Wastewater Quality in GS

The effluent of Gaza plants contains higher levels of N and P than the recommended levels. Although these elements are important for soil refreshment and reduce the use of fertilizers and hence saving money, their high content in wastewater may cause many problems to plants (**Pescod, 1992**).

It was indicated by Shomar, 2003 that wastewater in GS 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. However, the plants are capable to absorb the industrial effluents with no significant impact on treatment bioprocesses (**Shomar, 2003)**.

The reclaimed wastewater effluent from GWWTP will offer a better water quality when compared with water quality of existing wells in the area (Average chloride and nitrate concentrations are equal to 1125 and >100 mg/l, respectively. Salinity of the groundwater increases due to seawater intrusion and mobilization of incident deep brackish water, caused by over-abstraction of the groundwater (**Ouda and Al-Agha, 2000**).

Coliform content is higher than that recommended by World Health Organization (WHO) and Food and Agriculture Organization (FAO). This may impose some health problems to farmers whom in contact with such wastewater.

Table 1.2 illustrates the efficiency of GS wastewater treatment plants in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SS). It is noticed that the BLWWTP has the best efficiency as it has minimum BOD and COD effluent as well as SS. and this may be due to the quality of source water which is good in terms of chloride in the GS northern area. However these parameters are more than recommended for agricultural.

Table 2-2 Efficiency of GS wastewater treatment plants (CMWU, 2007)

	BOD		**COD**		**SS**	
Plant	**in**	**Eff.**	**in**	**Eff.**	**In**	**Eff.**
BLWWTP	420	40	1078	120	417	35
GWWTP	511	71	912	229	580	175
RWWTP	760	240	1237	666	622	126

2.10. Agriculture

Agriculture is the prevalent sector Gaza's economy and contributes to 32% of its economic production. In addition, it is a politically sensitive sector as all of its inputs such as, seeds, fertilizers and pesticides are imported from Israel. Therefore, any political crisis influences it directly while the agricultural sector is considered to be a main part of Palestinian life, over the last five years it's contribution to the national Gross Domestic Production (GDP) has reduced from 9.1% in 2000 to about 7.0% in 2005, the irrigated area in GS is estimated to be about 176,000 dunum and the total supply is estimated to be about 85 MCM. (**Al Najar, 2007**)

Table 2-3: Agricultural production over GS in the year 2005-2006

Crop	**Area in dunum**	**Quantity in tons**
Vegetables	55730	254883
Field crops	61740	96332
Citrus	15656	32025
Fruits	42248	16307
Flowers	730	1279

The current total amount of cultivated lands in the five Gaza Governorates observed a remarkable increase (the total cultivated was 146 and 176 km^2 in 2004 and 2005, respectively) in comparison to the areas recorded in previous years, which witnessed an observed decline since the mid 1990's, including a drastic decrease in the production of citrus fruits, which were considered to be the main consumer of water. Table 2.1 illustrates the agriculture production and the areas of each crop for the year 2005-2006 according to MOA, 2006.

2.11. BeitLahia Wastewater Treatment Plant (BLWWTP)

The WWTP of BeitLahya is constructed in a sand dunes overlies a clay layer of variable thickness. The original design of BWWTP includes seven ponds and was originally designed by Israeli civil administration in 1976 to serve a population of

50,000 inhabitants. Today the population of Gaza northern area is about 260,000 inhabitants from which about 75-80% are connected to the sewerage network (**PCBS, 2007).**

The plant was originally designed with 4 primary aerated lagoons followed by two secondary settlement/maturation lagoons and tertiary maturation/ storage lagoon provided the biological treatment, together with pathogen reduction (**Al-Khaldi, 2006**). It was planned to produce an effluent of such quality to allow for agriculture irrigation reuse as the goal was to meet BOD and suspended solids of 20 and 30 mg/l respectively as to pump the effluent to the irrigation fields at BeitLahya area.

The plant was constructed in stages, commencing in 1983 with four lagoons. In 1989 united nation development program (UNDP) supplied the effluent pump station and in December 1993, surface aerators were installed by Israel company. In 1999, rehabilitation activities of BLWWTP included construction of screen and grit removal to avoid silting of the ponds and damages for equipment as well as construction of two infiltration basin was carried out by PWA.

For the purpose of reusing water for irrigation, a pumping station was built as well as a first segment o a duct towards fields but it was never completed and up to now the effluent overflows the last pond to the surrounding sand dunes.

Today the actual BLWWTP differs from the original design as the number of ponds as well as its function differs. The plant is overloaded and ponds operating in series as 2 anaerobic lagoons, 2 actively aerated lagoons, 2 facultative lagoons followed by a maturation lagoon discharging effluent to the main lake of about 300 dunum (dunum=1000m^2) (**Al-Khaldi, 2006**)

It is wroth to mention that the current effluent from BLWWTP being pumped to the new site assigned by PWA to the eastern of GS northern area, this lead to minimizing the quantities disposed to the main lake as it just receive the effluent in nighttime..

CHAPTER 3: LITERATURE REVIEW

3.1. Introduction

Whenever good quality water is scarce, water of “marginal quality” will have to be considered for using in agriculture. Municipal wastewater is marginal quality water and using of this for irrigation can be an important consideration when its disposal is being planned in arid and semi-arid regions. (**Angelakis, 2002**).

Wastewater is used extensively for irrigation in certain countries e.g. 67% of total effluent of Israel, 25% in India and 24% in South Africa is reused for irrigation through direct planning. Clearly, agricultural and landscape irrigation represents the most important area in which this valuable resource is used (**Kamizoulis, 2004**)

Treated waste-water represents a stable and reliable source of irrigation water and often provides significant levels of required plant nutrients, such as potassium and nitrogen. It has been successful for irrigation of a wide array of crops, and increases in crop yields from 10-30% have been reported (**Asano, 1998**). In addition, the use of wastewater in agriculture is a form of nutrient and water recycling, and this often reduces downstream environmental impacts on water resources in addition to help communities to grow more food and conserve precious water and nutrient resources. (**WHO, 2006**)

On the other side, wastewater reuse in agriculture can pose some negative impacts caused by poor chemical balance and high wastewater contaminants that impacts accumulate over time.

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 (**FAO, 92**). It is agreed upon that any reuse project has to have impact assessment to account for its effects.

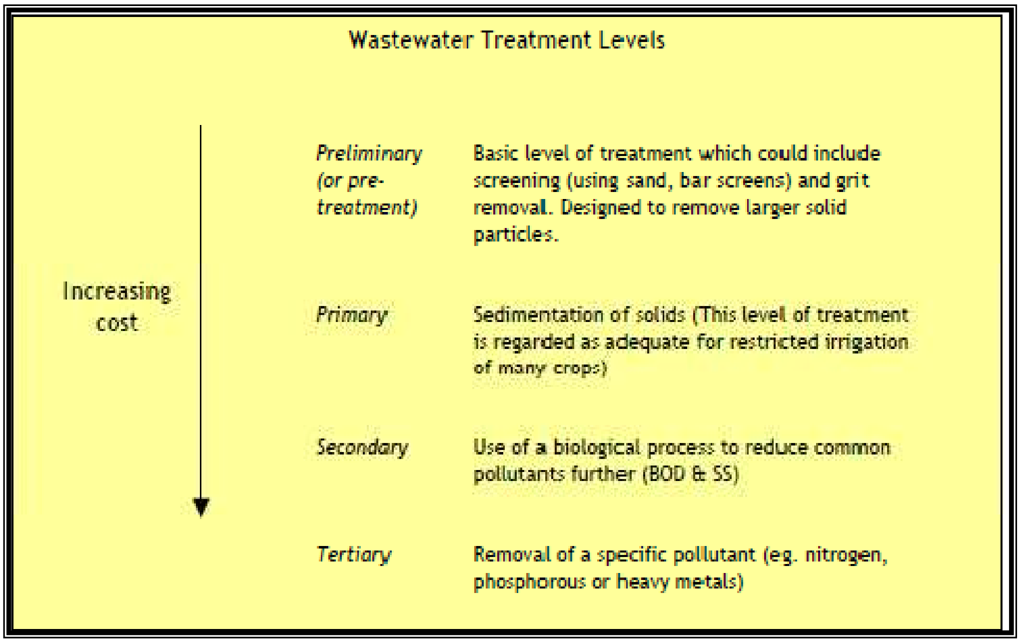
3.2. Wastewater Treatment for Reuse

Conventional 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 (Figure 3.1).

The minimum treatment required for restricted irrigation is secondary biological treatment and disinfection producing an effluent with BOD_5 and SS concentrations below 25 and 35 mg/l for 95% of the samples and a fecal coliforms concentration below

200 FC/100 ml, as a median value and not exceeding 800 FC/100 ml for 95% of the samples. (**Andreadakis, 200**1)

The minimum treatment for unrestricted irrigation is secondary biological treatment, followed by tertiary treatment (normally coagulation, flocculation, sedimentation, and filtration) and disinfection, producing an effluent with BOD_5 and SS concentrations below 10 mg /l for 80% of the samples and turbidities below 2 NTU as an average value. Fecal coliform concentrations should be below 5 FC/100 ml for 80% of the samples, below 15 FC/100 ml for 95% of the samples, and not exceeding 100 FC/100 ml in any sample.



Wastewater Treatment Levels

Preliminary (or pre-treatment)	Basic level of treatment which could include screening (using sand, bar screens) and grit removal. Designed to remove larger solid particles.
Primary	Sedimentation of solids (This level of treatment is regarded as adequate for restricted irrigation of many crops)
Secondary	Use of a biological process to reduce common pollutants further (BOD & SS)
Tertiary	Removal of a specific pollutant (eg. nitrogen, phosphorous or heavy metals)

Figure 3-1: Typology of wastewater treatment processes (AbuMadi, 2004)

Secondary treatment is determined by Victorian Environment Protection Authority (**EPA, 2003**) and FAO as the minimum standard of treatment needed for most agricultural and municipal reclaimed water use schemes.

3.3. Regional Water Recycling

Average annual per-capita availability for the Eastern Mediterranean Region (EMR) covers all human activities (domestic, industrial and agricultural) has fallen to about 1250 m^3/year today. This is the lowest in the world and it is predicted to fall to below 650 m^3 by 2025. In some countries, For example, Yemen and Palestine, the per-capita availability today is less than 180m^3 (**Tagasaki et al. 2004**).

In most of the countries of the Mediterranean region, wastewater is widely reused at different extents within planned or unplanned systems. In many cases, raw or insufficiently treated wastewater is applied.

In Tunisia, 20- 30% of the treated effluent is being reused accounted for 6.3% of available water resources in the year 2000 while in Israel, 92% of the treated effluent is being reused accounted for 15% of available water resources in the year 2000. In Jordan 85% of the treated effluent is being reused. (**Tagasaki et al. 2004**).

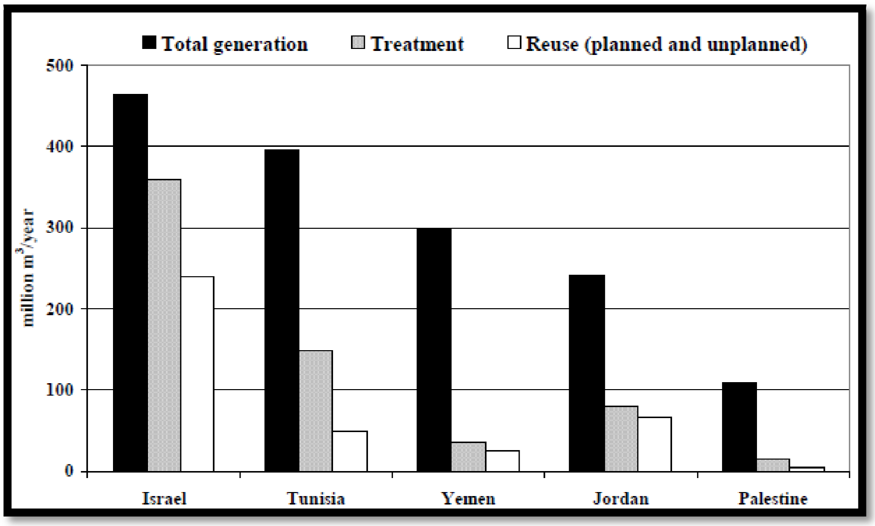


Figure 3-2: regional wastewater reuse, Source (AbuMadi, 2004)

Significance of water reuse may be evaluated through the comparison of water reuse potential with total water use which expressed by wastewater reuse index (WRI). (WRI) quantifies the total amount of reused wastewater as percentage of the total production of wastewater. It can be used to quantify the gap between achievements in wastewater reuse at different junctures; thus, highlights the way forward for improving the reuse efficiency.

3.4. Potential Wastewater Reuse in GS:

As stated in the proposed regional plan for the Gaza Strip the three main treatment plants should be transferred to the eastern border of the Gaza Strip, and should work with treatment technology to produce treated effluent of a quality fit for fruit trees irrigation, according to Ministry of Environmental Affairs (MEnA) standards (**Al Najar, 2007**). The treatment plants are planned to be connected with a main carrier that would transfer the treated effluent to where it was needed as in figure 3.3.

A consequence of transferring the wastewater treatment plants to the eastern side by the year 2010, and the availability of treated wastewater is that, around 50 km^2 of fruit trees, which are cultivated within and surrounding the residential areas could be transferred to the eastern side of the Gaza Strip if new policy to keep the production of fruits with least cost, and the re-use of treated effluent faraway from the residential areas for health and safety reasons, is put into practice.

This approach will reduce the costs of fruit production, and as a consequence will increase farm profits, considering the water resources crisis. (**Al Najar, 2007**)

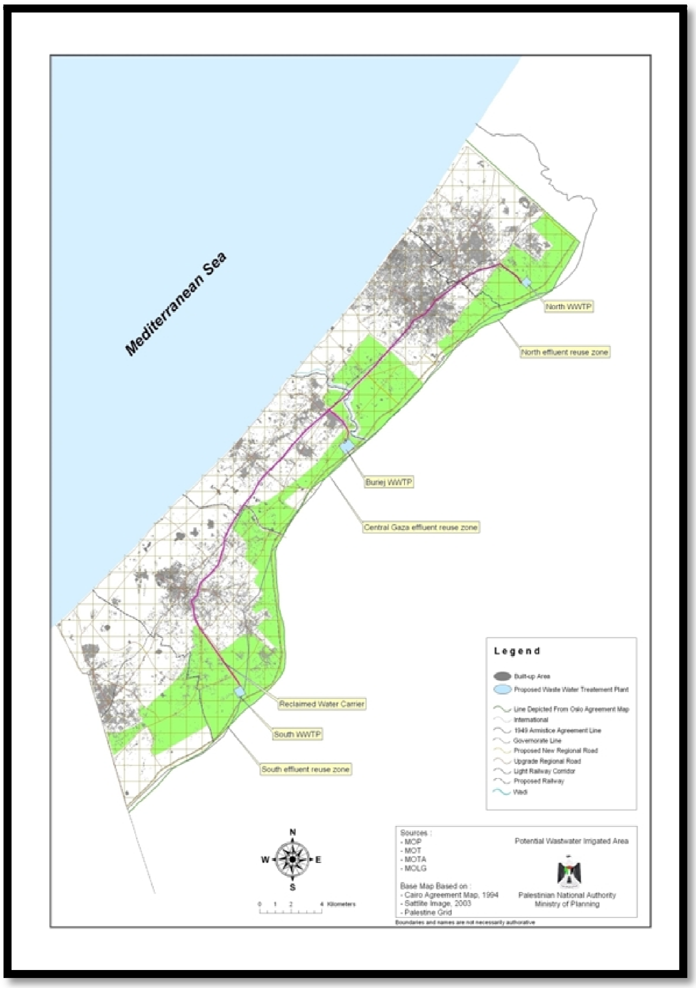


Figure 3-3: Proposed new location of the three main treatment plants with main carrier (Al Najar, 2007)

3.5. Existing Guidelines Concerning Wastewater Reuse

Most of guidelines have focused on identifying clear performance outcomes that need to be met to achieve sustainable irrigation. The risks that may associate with each potential site are assessed and the work is to minimize these risks in such away not to cause harm for human and environment.

There are many different guidelines aims at governing and controlling the impacts associated from WWR. All of it was initiated based on experimental data and results as follows:

- Australian Environmental Protection Agency (EPA 1991and 2003): Guidelines for water reuse: Beside the reclaimed water quality guidelines, recommended monitoring and setback distances are given.

- Food and Agriculture Organization (FAO 1985, 92, 97 and 2000) (Quality criteria) 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

3.6. Palestinian Standards for WWR

The draft Palestinian standard reuse mainly care of; a) Sanitary, b) Environmental and c) Agro technical quality requirements

The draft Palestinian standard principles (PS) principles for wastewater mainly envisage; a) Sanitary, b) Environmental and c) Agro technical quality requirements. Sanitary requirements centered upon the pathogens potentially present in wastewater, namely bacteria and intestinal nematodes (Ascaris and Trichuris species and hookworms) (**EQA, 2004**).

Where its recommended less than 1 intestinal nematode per liter and 200 to 1000 fecal coliform per 100 ml of wastewater depending on the reuse conditions, b) From the environmental viewpoint concentration of various heavy metals (particularly cadmium, copper, zinc), salt, nutrients (N and P) and malodors have taken into consideration, c) Agro technical requirements firstly include total salt and several anion (Cl, SO4, HCO3), cation (Ca, Mg, Na) and boron concentrations which determine traditional irrigation water quality standards depending on the plant species, soil physical and chemical properties, climate and irrigation methods. (**EQA, 2004**)

3.7. Palestinian Water Policy

The Palestinian Water Policy, as set out in the following principles is the basis decisions on the structure and tasks of water sector institutions, and the water sector legislation.

- All sources of water are public property.

- Water has a unique value for human survival and health and citizens have the right of water of good quality for personal consumption at costs they can afford

- Water supply and domestic, industrial, and agricultural development must be compatible with the available water resources and based on sustainable development.
- Water has social, environmental, and economic values
- Development of Palestinian water resources must be coordinated on the national level, and carried out on the appropriate local level.
- Public participation in water sector management should be ensured
- Water management at all levels should integrate water quality and quantity
- Water supply and wastewater management should be integrated at all administrative levels.
- Consistent water demand management must complement the optimal developme nt of water supply.
- Conservation and optimum utilization of water resources should be promote and enhanced.
- Pursue Palestinian interests in connection with obtaining the right of water resources shared by other countries on the principle of equality.
- The Government will cooperate with regional and extra regional parties to promote the optimum utilization of water resources to identify and develop new and additional supplies, and to collect and share relevant information and data

3.8. Institutional Role

The different institutions, their remit, and responsibility should be clearly defined within the legislative framework. Failure to provide this will lead to long-term problems within the sector from overlapping responsibilities, duplication of effort, unclear reporting lines, and difficulties in enforcement. During the occupation the role and responsibilities were scattered fragmented and unclear.

The organization of the Palestinian Water Sector theoretically envisages a clear separation between policy formulation, regulation, and service delivery functions. The National Water Council (NWC) establishes by By-Law No.2 (1996) is theoretically the policy making body while the Palestinian Water Authority (PWA) should only act as the regulator and the Figure 3.4 shown the PWA regulatory framework.

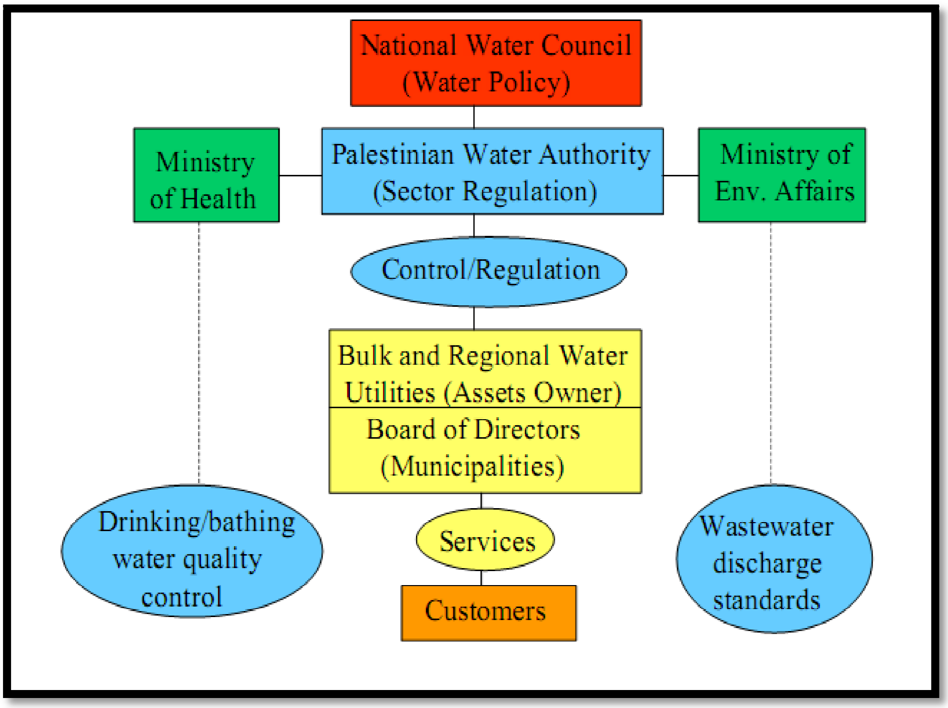


Figure 3-4: The PWA regulatory framework (Ghbn, 2003).

3.9. Palestinian Water Law

It is common to find that much of the water legislation in a country has historically been incorporated within other laws and elements of legislation, such as Public Health Laws or Natural Resources Laws. Whilst these may address water, it is limited to specific impacts and fails to provide a comprehensive framework for the sector. It is therefore desirable that all water legislation be brought under an umbrella Water Law which has an array of associated addenda, regulations, and codes of practice (**Tarazi, 2009**).

Legal Framework Governing Water and Water Institutions Various Governments ruled Palestine and imposed their legal systems, rules, and laws. Water related laws in Palestine date back to the Ottoman Empire period, followed by the British, Jordan/Egypt, Israel, and now the Palestinian Authority. Each ruling power enacted new laws and created different water related institutions.

The process of law making and governance over the sector remained a key goal of the PWA. The PWA prepared a comprehensive law on water in 2000-2001 that it was enacted by the Palestinian Legislative Council in 2002. The Law No. 3 of 2002 encompasses the whole water sector issues and it aims to develop and manage the water resources, increase capacity, improve quality, preserve and protect against pollution and depletion. The Law establishes a Water Council chaired by the President of the PA and membership of water user association, various ministries, academicians, regional utilities that it sets the policies for the water sector and ratifies PWA plans and reports (**Hussein, 2004**).

3.10. Types of Wastewater Reuse

The collected wastewater must be treated to adjust its quality to any of the following end-uses (i) agriculture irrigation, (ii) artificial recharge, (iii) potable water supply, (iv) toilet flushing, and (v) industrial water supply.

The two mostly common types of water irrigation based on water 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.

3.11. Evaluation of Water Quality

When using wastewater as a source of irrigation, factors such as contamination of plants and harvested product, farm workers, the environment, public health and salinity and toxicity hazards, need to be considered. There is considerable scope for reducing the undesirable effects of wastewater use in irrigation through selection of appropriate irrigation methods (**FAO, 1992)**.

In recent guidelines four categories namely salinity, infiltration, toxicity and "miscellaneous problems" are used for evaluating conventional sources of irrigation water as in table 3.1. The physical and chemical constituents in treated effluents need careful consideration in order to evaluate or detect possible short or long-term effects on soils and crops from salts, nutrients and trace elements (**Ayers &Westcott, 1985**).

These general water quality classification guidelines help to identify potential crop production problems associated with the use of conventional water sources in addition to soil and environmental ones.

Other criteria for evaluation of treated wastewater were developed by Kathijotes, 2006 presented in table 3.2. It was applied in the investigation of the risk of the treated sewage intended for irrigation in Cyprus during salinization risk assessment study.

Results indicated that at most time the quality of effluent in Cyprus is not suitable for irrigation use as it poses some risks for both soil and groundwater. This is interpreted as great care should be taken when using such effluents in order to minimize or eliminate possible contamination (**Kathijotes, 2006**)

Table 3-1: Guidelines for Water Quality Use for Irrigation, (Ayers &Westcott, 1985)

Parameter		**Degree of Restriction on Use**		
		None	**Slight to moderate**	**Severe**
Salinity				
ECw (dS/m)		<0.7	0.7-3.0	>3.0
TDS (mg/l)		<450	450-2000	>2000
TSS(mg/l)		<50	50-100	>100
Infiltration				
SAR (meq/l)	0-3	>0.7 EC	0.7-0.2 EC	<0.2 EC
SAR (meq/l)	3--6	>1.2 EC	1.2-0.3EC	<0.3 EC
SAR (meq/l)	6--12	>1.9 EC	1.9-0.5EC	<0.5 EC
SAR (meq/l)	12--20	>2.9 EC	2.9-1.3 EC	<1.3 EC
SAR (meq/l)	20-40	<5 EC	5-2.9 EC	<2.9 EC
Toxicity				
Sodium Na (meq/l)	Sprinkler irrigation	<3	>3	
Sodium Na (meq/l)	Surface Irrigation	<3	3--9	>9
Chloride Cl (meq/l)	Sprinkler irrigation	<4	>3	
Chloride Cl (meq/l)	Surface irrigation	<1	4--10	>10
Boron (mg/l)		<0.7	0.7-3.0	>3.0
Miscellaneous Problems				
Hydrogen Sulfate H2S		<0.5	0.5-2	>2
Iron Fe (mg/l)	Drip irrigation	<0.1	0.1-1.5	>1.5
Manganese Mn (mg/l)	Drip irrigation	<0.1	0.1-1.5	>1.5
Total Nitrogen (mg/l)		<5	5--30	>30
pH		6.5-8		

Table 3-2: Various criteria for the estimation of wastewater risk factor, (Kathijotes, 2006)

No.	**Criteria**	**Criteria Range**	**Risk Estimation**
1	$\frac{Ca + Mg}{Na + 0.23\,Ca}$	>1	Natrium
2	$\frac{100(Ca+Mg)}{Na}$	>60%	Natrium
3	$\frac{100\ Mg}{Ca + Mg}$	< 50%	Magnesium
4	$\frac{288}{5.Cl}$	>18	Chloridisation
5	$\frac{288}{Na+4Cl}$	6-18	Chloridisation
6	$\frac{288}{10Na-5Cl-9SO_4}$	1.2-6	Chloridisation
7	$\frac{6620}{Na+2.6Cl}$	<1.2	Chloridisation
8	$\frac{(Na+K)100}{Na+Ca+K+Mg}$	<66%	Alkalinisation
9	$\frac{Na}{Na+Ca+Mg}$	<0.6	Alkalinisation
10	$\frac{Na}{Ca+Mg}$	<0.7	Alkalinisation

11	$\frac{Na+K}{Ca+Mg}$	<1 NO, 1-4 possible, >4 sure	Alkalinisation
12	SAR	<10	Dangerous Level

3.12. Microbiological Quality

International guidelines for the microbiological quality of irrigation water used on a particular crop do not exist. The reason is the lack of direct epidemiological data to show any relationship between the quality of water actually applied at the field and disease transmission or infection (**Kiziloglu, 2007**).

According to EPA, 2003 the microbial criterion for reclaimed water based on the corresponding range of reuse is classified into four classes (A-D) where class A represents the tertiary treatment for unrestricted crops with high quality and class D represents the secondary treatment (minimum treatment level) for non food crops as in table 3.3 (**EPA, 2003**).

Table 3-3: Reclaimed water classes for biological and pathogen reduction and the corresponding range of reuse. (EPA, 2003)

Class	**Water quality**	**Treatment level**	**Range of use include lower class uses**
A	10 E-coli org. /100ml- 10/5 mg/LBOD/SS	Tertiary & pathogen reduction	Unrestricted, Urban (Non Potable)Industrial
B	100 E-coli org. /100ml. 20/30 mg/L BOD/SS	Secondary& pathogen reduction	Agriculture, Industrial
C	1000 E-coli org /100ml. 20/30 mg/L BOD/SS	Secondary& pathogen reduction	Agriculture: human food crops/ cocked Fodder crops
D	10000E-coliorg./100ml , 0/30 mg/L BOD/SS	Secondary	Fodder crops, Wood crops, flowers

3.13. Impacts of Wastewater Reuse (WWR)

Uncontrolled use of wastewater in agriculture and/or unmanaged one has important health implications for product consumers, farmers, and communities. Raw or partially treated wastewater has been applied in many locations all over the world not without causing serious public health consequences and negative environmental impacts. This generated the existence of endemic and quite epidemic diseases (**Kamizoulis, 2004)**

3.13.1.Health Impacts

The obvious reason that public authorities have not encouraged wastewater use is its potential negative public health impact (**Asano, 1998**). According to FAO, 92 the primary constraint to any wastewater use project is public health. Wastewater, especially domestic wastewater, contains pathogens which can cause disease spread when not managed properly. The primary objective of any wastewater use project must therefore be to minimize or eliminate potential health risks

In 1970, a cholera epidemic in Jerusalem was directly linked to vegetables irrigated with the city's wastewater. In Dakar, an outbreak of typhoid in 1987 was also linked to farmers who were using raw wastewater to irrigate their gardens. A survey of farmers in Dakar using untreated wastewater found that gastrointestinal infection rates varied between 40% and 60% (**UNEP, 2005**).

In Eritrea, research on the health impacts of untreated wastewater revealed a Guardia infection rate of 45% of farmers using wastewater. Amongst consumers of the vegetables from these same farmers, infection rates were lower at 7% (**UNEP, 2005**).

Another problem is posed when heavy metals are present from, for example, industrial wastewater. Heavy metals can have a long-term impact on human health and soil quality. Cadmium (Cd) and mercury (Hg) are metals commonly found in untreated wastewater and have been linked to kidney disease (in the case of Cd) and brain and nervous system damage in the case of Hg (**Amiri, 2008**).

More problematic is the use of sewage without any treatment. In Pikine, a region within Dakar city limits where wastewater is frequently used, 28% of farmers use untreated wastewater (**UNEP, 2005**). Often, this water is mixed with well and groundwater, however, it still poses a significant health risk. Some measures include stopping irrigation several weeks before harvest or washing and cooking produce prior to consumption.

Erfani studied the microbial contamination of tomato fruit when irrigated using different water qualities including tap and treated wastewater, Fecal coliform in different treatments were measured and the results show that there is no significant difference between the different treatments. Additionally, with regard to health problems, these treatments generated minimum contact between the effluent and the workers, that is why microbial quality and health impact is the key of success of any reuse project and should be investigated (**Erfani, 2001**)

3.13.2.Crop Yield

The economic impacts of wastewater on crops may differ widely depending upon the degree of treatment, types and nature of crops grown, and the water management practices. Generally, as wastewater is a rich source of nutrients, higher than average crop yields may be higher with wastewater irrigation (**Mara, 2006**).

A number of studies have demonstrated the positive impacts of wastewater on crop productivity due to these nutrients and organic matter. Erfani, 2001 indicated that the utilization of treated municipal wastewater has caused an increase in the yield of tomato as compared to irrigation with the well water. (**Erfani et al. 2001**).

Tomato fruit size and weight increased with increasing the percentage of treated wastewater proportion. These results agreed with Maurer et al, 1995, who reported that citrus trees receiving wastewater had significantly larger fruit (95mm) than those receiving canal water (90mm) **(Erfani, 2001)**

Najafi, 2002 found that after three times of harvesting tomatoes from various treatments, the mean yields were compared. Tap water irrigation had the least yield, while treated wastewater had the maximum yield which was about 52 tons/ha (18 tons/ha higher than the average yield of tap water). (**Najafi, 2002**)

Moreover it is reported that most crops give higher yields, when irrigated with wastewater than with fresh water and have less need for chemical fertilizers, resulting in net cost savings to farmers (**Hussain et al., 2002**).

A comparison study on the difference in crop yield when wastewater and fresh water used in India illustrated in table 3.4. It is noticed that at most time and for all tested crops the use of wastewater increases the crop yields with different ratios from crop to another (**Mara, 2006**)

Table 3-4: Yield of crops irrigated with fresh water and wastewater in India.(DDMara,2006)

Crop	Annual crop Yield (Ton/hectar)	
	Fresh Water	Wastewater
Beetroot	8.75	16.27
Carrot	9.71	11.75
Radish	7.26	8.33
Potato	6.12	9.33
Ginger	6.04	9.80
Papaya	26.72	37.00
Cabbage	9.27	12.13
Cauliflower	6.96	9.09
Okra	2.82	5.89
French beans	6.63	8.06
Tomato	10.01	13.38
Tobacco	1.12	1.25
Groundnut	2.88	3.17

3.13.3.Fertilizer Saving.

Irrigation with wastewater can, in most situations, supply all the nutrients required for crop growth. The value of these substances has long been recognized by farmers worldwide. If crops are supplied with essential plant food nutrients, wastewater irrigation will act as a supplemental source of fertilizer thus increasing crop yields especially (**WHO, 2006**).

The application of wastewater provides, in addition to nutrients, organic matter that acts as a soil conditioner, thereby increasing the capacity of the soil to store water. The increase in productivity is not the only benefit because more land can be irrigated, with the possibility of multiple planting seasons (**Christopher, 2001**).

Plants vary in its capacity to nutrient uptake. Table 3.4 shows nutrients uptake by different crops. Nitrogen can be found as total nitrogen (nitrate, ammonia, organic nitrogen and nitrite). Most plants absorb nitrate only and normally the other forms transformed into nitrate. The main problem is that nitrate solubility in water especially if it is added too long time is very high. (**WHO, 2006**)

Phosphorus can be found in low amount in wastewater this makes the use of wastewater beneficial and has positive impact even if the P concentration is too high and wastewater used for long time. WWTP needs extensive treatment to remove P, thus the use of wastewater in agriculture can save these costs and minimize the environmental impacts.

Potassium either is present in soil with high concentration but it is generally bounded to other elements. So it is needs to be added to soil as fertilizer. Generally 185kg of K /hectare is required so wastewater contains low potassium level does not cover the soil demand. Usually no significant negative impacts associated with potassium (**Mikkelsen, 1995**)

However, if plant food nutrients delivered through wastewater irrigation result in an oversupply of nutrients, yields may actually be negatively influenced. Also, since wastewater contains undesirable constituents such as trace elements and heavy metals, organic compounds and salts, crop yields may be negatively affected depending upon their concentrations in the wastewater and the sensitivity of crops to these elements.

Table 3-5: Summary of crop water use (ETc), crop nutrient uptake rates, and salinity threshold for various forage crops grown in Southern California.

	Crop water Use Etc	**Crop Uptake (lb/ton)**			**Salinity Tolerance**	
Crops	Normal Year. ET_c (AC. ft)	N	P_2O_5	K_2O	Soil EC_s	water EC_w
Alfalfa	**6.65**	**56**	**15**	**60**	**2**	**1.3**
Bermud grass	4.6	50	12	47	6.9	4.6
SorghumSudan	3.3	41	16	59	2.8	1.9
Corn Silage	2.3	8.3	3.6	8.3	1.8	1.2
Winter Forage	2.4	40	-	-	6	4

3.13.4.Environmental Impacts

Major environmental issues such as dissolved oxygen depletion, Eutrophication, foaming, and fish kills are recorded. Therefore, uncontrolled wastewater contributes to water resources degradation, soil resources deterioration, reduces agricultural production and affects public health.

There have been several cases in California of improper reclaimed wastewater applications to cropland that have resulted in nitrate contamination of groundwater, Therefore it is important that reclaimed municipal wastewater be applied to cropland with careful thought given to the application site and wastewater characteristics, crop water use (ET) and nutrient use rates, and other crop production considerations to maximize yield.

On the opposite, the controlled use of wastewater, through treatment and planning, leads to water resources augmentation, in addition to environmental protection. The use of wastewater in irrigation may also improve groundwater conditions, by recharging aquifers thereby preventing seawater intrusion in coastal areas.

3.13.5.Soil Resources

Effects of WW on soil depend not only on the physical and chemical properties of soil, but also on crops type as well as quality and quantity of irrigated water. Najafi, et al. (2003) indicated that the only accurate method to determine the impact of wastewater on soil is to measure the soil characteristics and monitor them along the time and to compare the similar soil irrigated under similar condition using fresh water **(Najafi, et al. 2003)**

Soil-related impacts of wastewater can be grouped under the following

(1) Potential yield losses.

(2) Loss of soil productive capacity.

(3) Depreciation in market value of land.

(4) Cost of additional nutrients and soil enhancement measures. (**WHO, 2006**)

3.13.6.Soil Salinity

The most damaging effects of poor quality irrigation water are excessive accumulation of soluble salts in soil. Salt accumulation over time can lead to soil physical problems limiting infiltration, soil chemistry problems limiting nutrient uptake, and reduce the plants ability to osmotically absorb water, accordingly plant growth, crop yield and quality of produce are affected. Crops vary in their tolerance to salts; low quality water may be used to tolerant crops after they are established. Salt tolerance is defined as the ability of a plant to grow and complete its life cycle on saline substrates that contain high concentrations of salt (**Kathijotes, 2003**).

Soil salinity is strongly related to irrigated water salinity , Biswas et al. (2005) showed that during summer about 2 t of salt /ha would accumulate in the root zone (up to 60cm) if the irrigated water salinity is 0.8 dS/m. However, even at salinity of 0.3 dS/m, crop losses due to gradual salinity build up may be inevitable (**Biswas et al. 2005)**.

Moreover salinity has direct relation with irrigation system, soil salinity was monitored in Sunraysia regions at depths of 0.3m, 0.6m and 0.9m following each irrigation or rainfall event, it was clearly noticed the salinity of soil water (ECe) peaked at 2.0 ds/m at 90 cm root zone depth under drip irrigated vineyard, but was rarely more than 1.5 ds/m in an undercover sprinkler citrus orchard. (**Biswas, 2007**)

Kathijotes, 2003 noticed that treated wastewater demonstrated better results in comparison to fresh farm water related to salinity. He also noticed that salinity risk is less at the soil surface and the root zone (30-50cm) and increases soon after this zone. This is considered as positive as it is not expected to influence soil permeability at surface or the plant itself. (**Kathijotes, 2003**)

Salinity can also affect the crop yield based on plant salt tolerance, Alfalfa is moderately salt tolerant as maximum alfalfa yield occur when soil salinity is less or equal 2mmho/cm while its yield is reduced by 50% when soil salinity reaches 8.8. Irrigated water salinity also effect alfalfa yield where 100% yield occur at irrigated water EC equal 1.3 mmho/cm the 50% alfalfa yield occur at irrigated water EC equal 5.9 dS/m. (**Pool, 2004**)

Long-term use of wastewater could result in accelerating soil salinity, water logging, breakdown of soil structure and overall reduction in productive capacity of soil and lower crop yields. In arid and semi arid regions, salinity is mostly occurring where soil can't be washed as a result of low precipitation. The only practical way to reduce soil salinity is through leaching, that is applying water in greater amounts than crop water use to force the salts out of the root zone. The amount of water to accomplish leaching is called the leaching fraction. Leaching requirements can be calculated by comparing soil EC_e with water EC_w and are typically in the range of 10% to 20%. EC is measured in decisiemens per meter (dS/m = 1 mmho/cm) **(Biswas et al. 2005)**.

The typical range of soil ECe for forage crop production is from 0.7 to 3.0 dS/m. Soil with ECe values greater than 3.0 dS/m may take a considerable effort to produce a crop and the feasibility of farming these soils with reclaimed wastewater should be carefully considered. (**Pool, 2004**)

3.13.7.Soil Sodicity

The effect of sodium ions in irrigation water is the reduction of infiltration rate of water and air into the soil when its value is above certain threshold value, relative to the concentration of total dissolved solids. Permeability is either dependent on the sodium ion concentration relative to the concentration of calcium and magnesium ions.

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

Soil permeability hazards caused by sodium in irrigation water cannot be predicted independently of the dissolved salt content of the irrigation water or that of the surface layer of the soil. Figure 3.4 represent the relation between salinity and sodicity of soil (**FAO, 92**).

Kathijotes, 2003 noticed that the quality of soil samples irrigated using fresh water in Cyprus for eleven years demonstrated higher values of SAR and therefore poses greater salinization risks. This means that soil SAR values is mainly acquired from irrigated water sodium content (**Kathijotes, 2003**).

On the other hand, significant differences between treated wastewater and fresh water use also have been observed by SAR, and EC values by Palacios, 2000 as wastewater always higher than fresh water (**Palacios, 2000**).

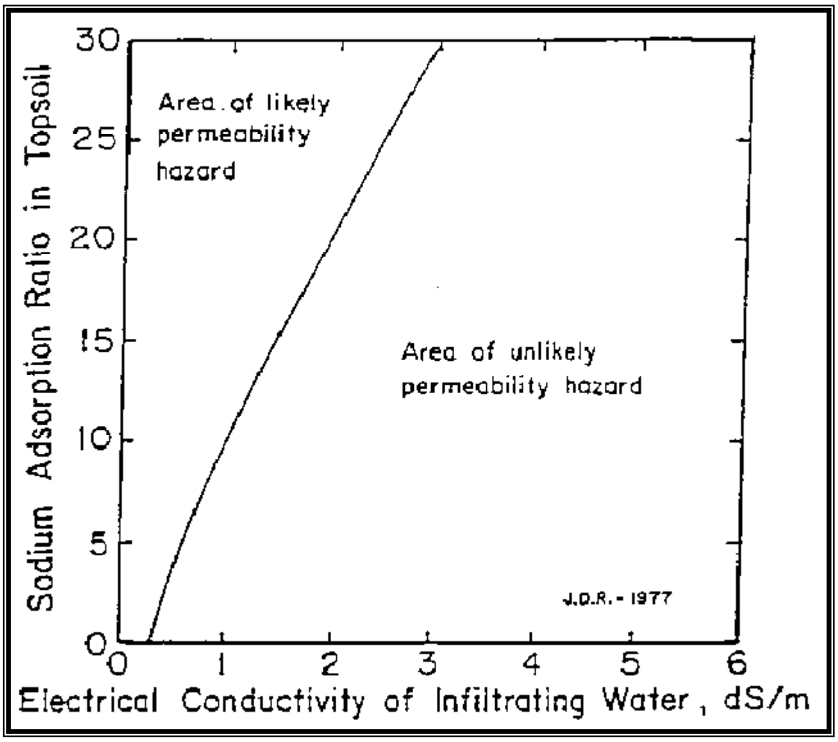


Figure 3-5: Threshold values of sodium adsorption ratio and total salt concentration on soil permeability hazard (FAO, 1992)

Using the nomogram figure 3.6, it is possible to estimate the Exchangeable Sodium Percentage (ESP) value of a soil that is at equilibrium with irrigation water of a known SAR value. Maximum permissible ESP concentration in irrigated water should not exceed 60mg/l for tolerant crops as alfalfa. (**Kathijotes, 2003**).

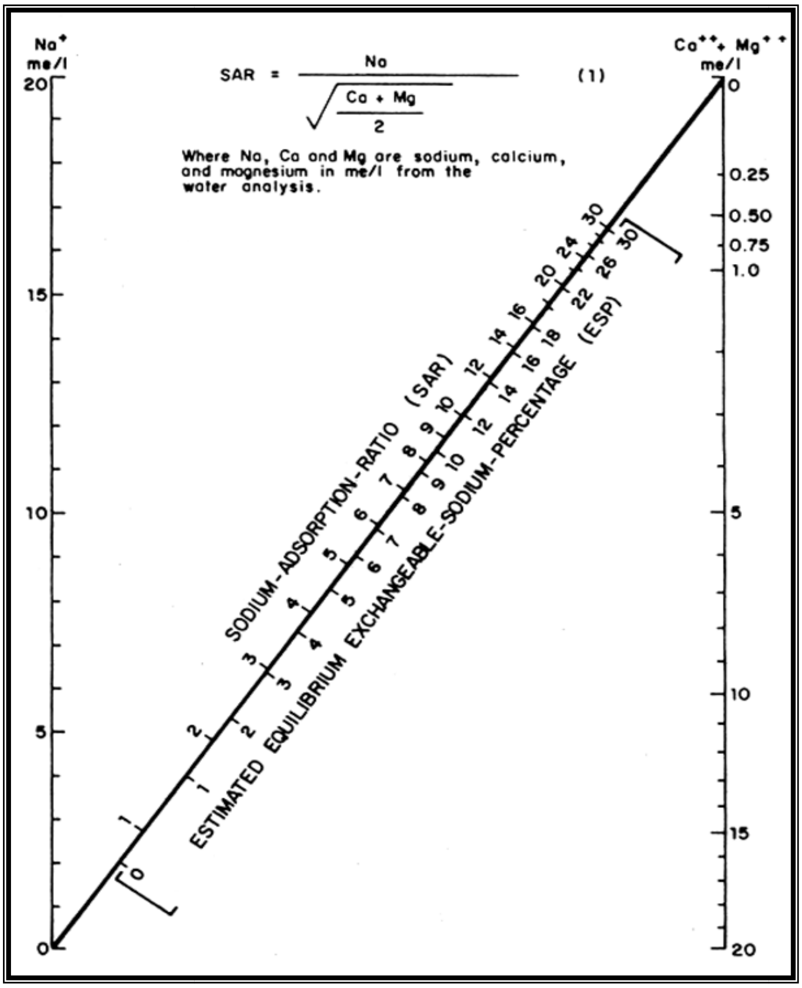


Figure 3-6: Nomogram for determining the SAR value of irrigation water and for estimating the corresponding ESP value of a soil that is at equilibrium with the water, (Richards 1954)

3.13.1.Soil Toxicity

Soil has large capacity to absorb heavy metals especially when the fresh domestic water has average concentrations (**El-Arabi, 2006**). Metals are retained in the upper soil layers bounded by the organic matter. However, the impacts and their intensity will depend on a range of factors including source, intensity of use and composition of wastewater, soil properties and characteristics of plants/crops grown

Kiziloglu, 2007 stated that the major disadvantage of the wastewater irrigation is the accumulation of immobile heavy metals in soils as he noticed an increase in Fe, Mn, Zn and B of the soil 0-30cm and 30-60cm layers from 3.9 mg/Kg to 9.13 mg/Kg when irrigated with wastewater. (**Kiziloglu, 2007**)

The relationship between different heavy metals fraction in soil and the metal uptake by alfalfa was studied from in Mexico City to evaluate the actual accumulation levels in soil. It was noticed that untreated wastewater irrigation generally increased heavy metals of soil with time and plant uptake especially of Cd and Pb also increased. (**Siebe, 1996**).

These results agree with that obtained by El-Arabi, 2006 as it was stated that the use of sewage effluent from Ismailiya treatment plant for irrigation increased the heavy metals concentration (Fe, Zn, Cu, Pb) compared with the Nile water, however the obtained level were lower than the maximum permissible limits and the normal ranges (**El-Arabi, 2006**)

3.13.2.Soil alkalinity

The normal pH range for irrigation water is from 6.5 to 8 according to EPA, 2003; pH values outside this range are a good warning that the water is abnormal in quality. Normally, the pH of a soil influences several soil characteristics: weathering processes, soil structure, mobilization of nutrients and ion exchange. Soil pH changes seasonally with the distribution of precipitation.

Generally pH values in soil irrigated with wastewater are always less than that for non wastewater irrigation due to high organic matter content. (**Kiziloglu, 2007, Oron, 1999 and Siebe, 1996**)

Plant absorption of ions from the soil to obtain essential nutrients could result in a nutrient deficiency with an increase in pH due to increased alkalinity, as some ions could be unavailable at a higher pH. Each plant has its own recommended soil pH value range. The reason for this is that soil pH affects the availability of nutrients within the soil and plants have different nutrient needs. Sodic soils have nutrient limitations and are deficient in zinc, iron, phosphorus and occasionally calcium, potassium and magnesium. The organic matter added through irrigation with wastewater could help improve soil conditions by increasing its fertility and water holing capacity. (**Bazza, 2003**)

3.13.3.Plant Toxicity

Plants also may be negatively affected through unplanned use of wastewater. Toxicity and biological contamination of plants are the most common problems encountered in such reuse projects. Care should be taken in planning and management of reuse projects as it can pose some health and environmental risks.

Irrigation water contains certain ions at concentrations above threshold values can cause soil and plant toxicity problems. Toxicity normally results in impaired growth, reduced yield, changes in the morphology of the plant and even its death. The degree of damage depends on the crop, its stage of growth, the concentration of the toxic ion, climate and soil conditions. Heavy metals (HM) included, (Cd), (Cr), (Cu), (Pb), (Hg) and (Zn) can create definite health hazards when taken up by plants.

Uptake of harmful amounts of toxic heavy metals by plants is not considered a potential risk in use of municipal wastewater, as most metals are removed from the wastewater during the primary treatment process. However, all wastewater should be initially tested for the heavy metals to ensure levels are below recommended water quality standards. (**Erfani, 2001**)

Erfani found that when five different treatments were selected for irrigation of tomato including irrigation with tap water and irrigation with treated wastewater, concentration level of Fe, Cu, Zn, Mn, Pb, and Cd have indicated that no excess accumulation of these elements was observed. (**Erfani, 2001**)

3.13.4. Ground Water

The use of wastewater has the potential both to recharge groundwater aquifer (positive externality) as well as pollute groundwater resources (negative externality). Studies indicated that if the groundwater depth is less than 1-1.5m, there are severe risks of increasing salinity thus it is restricted to use wastewater in areas where groundwater depth is less than 3m. (**Bazza, 2003**)

Recharge from wastewater irrigation to the ground water was estimated of at least 1000 mm/year, or 50-70% of the water used for agriculture. On the other hand, percolation of excess nutrients, salts and pathogens through the soil may cause degradation of groundwater. However, the actual impact will depend upon a range of factors including scale of wastewater use, quality of groundwater, depth to water table, soil drainage, and soil characteristics (porous, sandy). (**Christopher, 2001**)

Evaluation of the impact of industrial wastewater discharges on groundwater quality in Faisalabad by using groundwater samples, collected from wells located within a radius of one kilometer of industrial effluent drainage, showed very high concentrations of dissolved salts, trace elements, and heavy metals. A part of this pollution may be attributed to industrial discharges. (**Husain et al, 2002**)

Sometimes wastewater reuse may have no effects on groundwater aquifer especially if it is deep enough (more than 14 ft.). According to Harlin (1980) there were no effects from using wastewater for irrigation for 30 years on groundwater in USA.

3.13.5.Social Impacts

Social impacts can be defined as the concerns expressed by the public about their perceptions on wastewater irrigation. These concerns can be classified as follows:

- General concerns such as poor environmental quality, poor hygiene, odor etc;

- Social concerns such as food safety, health and welfare, loss of property values, and sustainability of land use.
- Natural resource concerns such as pollution of vital water resources, loss of fish, wildlife, exotic species, etc. (**Christopher, 2001**)

Tubail et al., showed that the use of wastewater for agricultural irrigation is accepted by 76% of the sample in Gaza northern area and 89% in southern area (**Tubail et al., 2003**).

3.14. Management of Wastewater Irrigation

Appropriate water management practices will have to be followed to prevent salinization, (irrespective of whether the salt content in the wastewater is high or low), irrigation method and crop selection.

It is interesting to note that even the application of a non-saline wastewater, such as one containing 200 to 500 mg/l, when applied at a rate of 20,000 m^3 per hectare, a fairly typical irrigation rate, will add between 2 and 5 tones of salt annually to the soil (**FAO, 1992).**

3.14.1. Irrigation Method

The irrigation method used, in particular, has to have specific characteristics which minimize the following risks:

- Plant toxicity due to direct contact between leaves and water;
- Salt accumulation in the root zone;
- Health hazards related to aerosol spraying and direct contact with irrigators and product consumers;
- Water body contamination due to excessive water loss by runoff and percolation

Biswas et al., 2005 found that under drip irrigation, salinity increased with depth as Ec was peaked at 20 ds/m at 90 cm root zone depth but was rarely more than 1.5ds/m under sprinkler irrigation (**Biswas et al., 2005**)

3.14.2.Leaching

To estimate the leaching requirement, both the salinity of the irrigation water (ECw) and the crop tolerance to soil salinity (ECe) must be known. Field data from conventional drip Sunraysia Regions showed that only less than 10% of applied water was found to leave the root zone during the grape growing season, which resulted in salt build up in root zone (**Biswas, 2007**)

The amount of irrigation applied must account for both the crop water use and some extra water (the leaching fraction) to flush periodically the residual salt out of the root zone. For example, when the average irrigated water salinity is about 0.4 dS/m, a 15% leaching fraction (15% more than the crop needs) should give root zone salinity around 0.6 dS/m. (**Biswas et al. 2005**)

It was found that negligible leaching is occur in summer under drip irrigation compared with that under sprinkler irrigation regardless the crop type, consequently, the general concern in drip irrigation is that in winter if no enough rainfall, then no leaching will occur under drip irrigation. (**Biswas et al., 2005**)

Oron et al. (1992) concluded that when drip irrigation system is utilized the contamination of soil surface and plants would be minimum while it would be maximum in the case of sprinkler irrigation. The results of these experiments also show that in subsurface irrigation system the amount of nitrogen in the depth of 30 to 60 cm was less than the surface drip irrigation (**Oron et al. 1999**)

The necessary leaching requirement (LR) can be estimated from figure 3.7 for general crop rotations reported by Ayers and Westcot (**Ayer, 1985**).

Biswas et al, 2005 also stated that leaching in summer time is negligible regardless of crop grown and during summer about 2 t of salt/ha will accumulate in the root zoon if the irrigated water salinity is 0.8ds/m. It is also show that the root zone salinity is often greater than 1.3 dS/m when irrigated water salinity is about 0.4 dS/m at 15% leaching fraction. The discrepancy may be due to a portion of the leaching water moving rapidly through the larger soil pores without displacing soil soluble salts from the root zone. (**Biswas et al., 2005**)

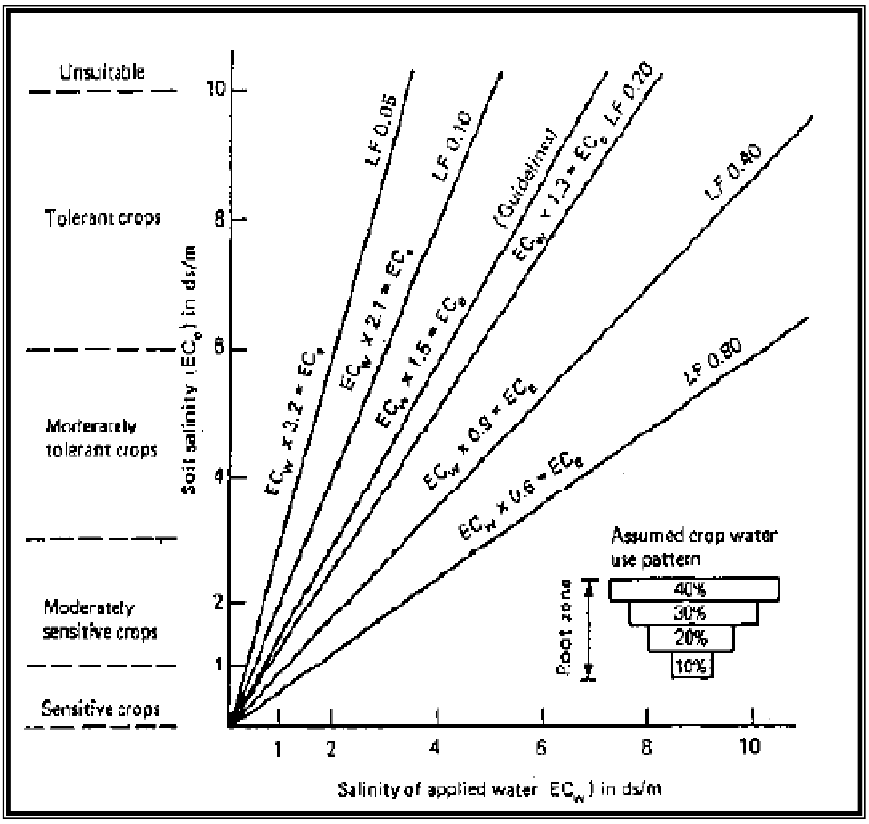


Figure 3-7The necessary leaching requirement (LR) can be estimated for general crop rotations, Ayers and Westcot (FAO, 1985)

Biswas et al, 2005 also stated that leaching in summer time is negligible regardless of crop grown and during summer about 2 t of salt/ha will accumulate in the root zoon if the irrigated water salinity is 0.8ds/m. It is also show that the root zone salinity is often greater than 1.3 dS/m when irrigated water salinity is about 0.4 dS/m at 15% leaching fraction. The discrepancy may be due to a portion of the leaching water moving rapidly through the larger soil pores without displacing soil soluble salts from the root zone. (**Biswas et al., 2005**)

A more exact estimate of the leaching requirement for a particular crop can be obtained using the following equation:

$$LR = \frac{EC_W}{5(EC_e - EC_w)}$$

Where:

LR is the minimum leaching requirement needed to control salts

EC_w = Electrical conductivity of the applied irrigation water in ds/m

EC_e = average soil salinity tolerated by the crop as measured on a soil extract. It is recommended that the EC_e value that can be expected to result in at least a 90% or greater yield be used in the calculation

The leaching requirements that keep the salinity below the crop tolerance threshold value to give 100% yield can be estimated from:

$$LR = \frac{0.0368}{3.0147F}$$

Where: F= Salt tolerance of the crop/ Electrical conductivity of irrigated water in case of drip irrigation.

3.14.3.Crop Selection

Not all plants respond to salinity in a similar manner; some crops can produce acceptable yields at much higher soil salinity than others. This is because some crops are better able to make the needed osmotic adjustments, enabling them to extract more water from a saline soil (**Ayers, 1985)**

The ability of a crop to adjust to salinity is extremely useful. In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, an alternative crop can be selected that is both more tolerant of the expected soil salinity and able to produce economic yields. There a wide range of salt tolerance of agricultural crops which allows for greater use of moderately saline water, which was previously thought to be unusable. The relative salt tolerance of most agricultural crops is known well enough to give general salt tolerance guidelines.

CHAPTER 4: EXPERIMENTAL SETUP AND ANALYSIS METHODS

4.1. Background

A French program called “Strategy of agricultural water management in the Middle East funded a project of wastewater reuse for agricultural irrigation in Palestine at the beginning of 2003. The program was coordinated by a Steering Committee (Ministry of Agriculture (MoA), Palestinian Water Authority (PWA) and French Consulate). Field works was managed by a technical committee (MoA, PWA, Palestinian Hydrology Group (PHG), and French Consulate) (**MoA et al., 2004**)

Beside Al Bathan area in West Bank, two areas in Gaza Strip were selected for the implementation of this program. The first was BeitLahia pilot project (BLPP) in northern area at OM Al Naser village where the treated wastewater (TWW) from BeitLahia wastewater treatment plant (BLWWTP) effluent is available in unlimited quantities was used to irrigate alfalfa plant of an area of about 13 dunum (dunum=0.1ha). The 2nd was Sheikh Ejleen area south west of Gaza city where TWW from the Gaza wastewater treatment plant (GWWTP) could be used to irrigate existing citrus farms of 20 dunum.

Unfortunately, Sheikh Ejleen project was stopped by 2006 due to the end of the program fund and due to the absence of follow up, so wastewater was no longer used since 2006 and farmers returned to use fresh water to irrigate their citrus farms. In the opposite side, BLPP continues working even after the fund over as it was supervised by Om Al Naser municipality. Treated wastewater from BLWWTP still used the same as during the project with same technicians that is why BLPP was chosen in this study.

4.2. BLPP Site Description

BLPP area is about 13 dunum constituted by sand dunes placed on clay layers. It is surrounded by the main collection lake with an area of about 300 dunum from the west and south. BLWWTP lays to the east of the project and OM Al Naser village to the north. The selected area was initially almost flat with very slight slopes from west to east as shown in figure 4.1.

The project area was divided into 12 main blocks according to the irrigation system each with area of about 1-1.2 dunum. A control block irrigated with fresh water was installed separately for comparison in the first year then it was irrigated with treated effluent.

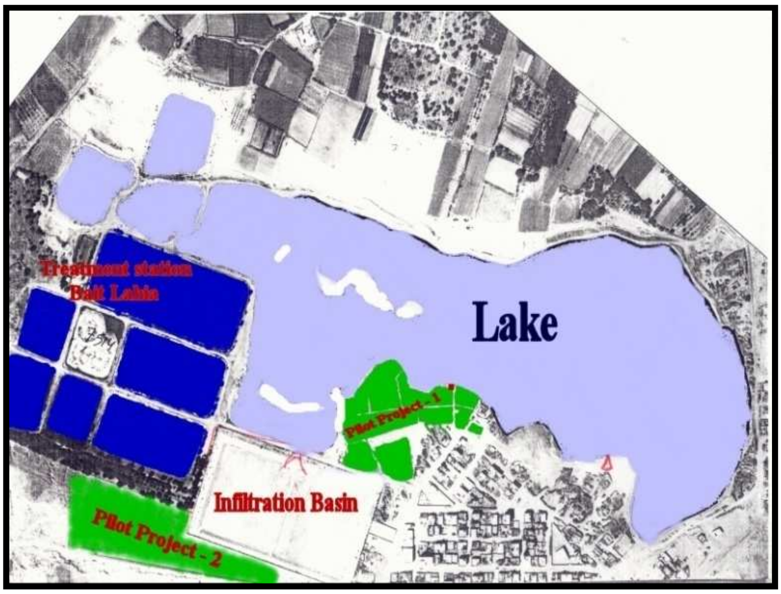


Figure 4-1: General lay out for BLPP

For BLPP the produced fodders crop (mainly Alfalfa) irrigated with TWW from BLWWTP after pumping to the main storage lake area of which is about 300 dunum. Alfalfa as presented in figure 4.2 was chosen upon farmer's interest where it could be used to feed their animals or sell when there is surplus. Between 2003 and 2006 the operation of the “farm” was organized by the project committee in order to monitor all the technical aspects (irrigation systems, fodder quality and varieties, soil and plant analysis, costs adapted techniques, etc.).

In order to improve the soil texture a 30 cm clay layer was added on the surface for the whole area. Soil texture for the top 30 cm layer is 76% sand, 16% clay and 2% silt with (loamy sand soil) while soil texture for the 30-60 cm depth is 98% sand and 2% clay (sandy soil).

Figure 4-2: Alfalfa crops in BLPP

4.3. Irrigation system

Due to its higher safety and very common use in Gaza strip a drip irrigation system was selected as illustrated in figure 4.3. Sprinkler irrigation system was excluded due to the already known risks of contamination of workers-farmers and in some case even neighbors (over head sprinklers with wind being able to spray unsafe water into inhabitant areas). The main difficulties facing the use of drip irrigation system is i) High suspended solids in the TWW requesting very efficient filtration systems, and ii)Risks of algae and bacteria populating inside the irrigation system.

To overcome these problems a sand filter (4 to 6 mm crushed silicate, allowing a 150 mesh filtration in addition to media filter was installed at the main feeding pipe line. The filter reduces the TSS level by about 48% than that in the lake. The feeding line is a polyethylene pipe of 150 mm diameter.

Water meter was installed at the inlet of the irrigation system to measure wastewater flow and to control the irrigation quantities supplied to the blocks based on crop water demand of alfalfa plant plus 20-30% extra water as leaching fraction.

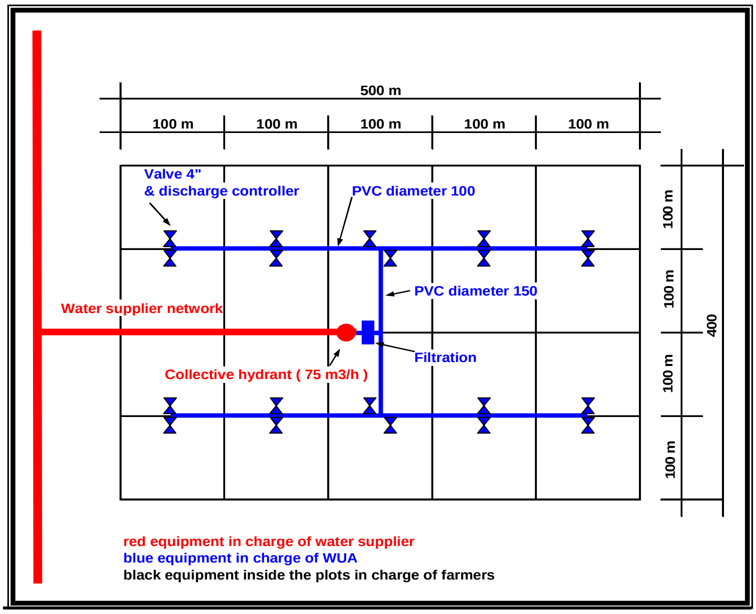


Figure 4-3: Schematic diagram of irrigated water networks in BLPP

The applied daily irrigation is eight hours with an operating pressure of 1.0 bar at the emitter; an electric pump produces 25 m^3/h at 2.5 bar was used.

The area was divided in 13 blocks of 1 to 1.2 dunum each (5000 to 6000 drippers each block supposed to receive 20- 25 m^3/h each). Wastewater application was twice a week during the summer period.

4.4. Test Program

The test program of BLPP included analysis of samples of irrigated water, plant and soil for the physiochemical and biological parameters shown in table 4.1.

Table 4-1: Parameters that had been examined through the monitoring program

	Physical parameters		Chemical Parameters (mg/l)										Biological
	pH	EC	NO_3	OM	$P_{tot.}$	K^+	Ca^{++}	Na^+	Cl^-	Cd	Cu	Pb	F.C
Waste-water	√	√	√		√	√	√	√	√	√	√	√	√
Soil	√	√	√	√	√	√	√	√	√	√	√	√	√
Plant									√	√	√	√	√

As shown in table 4.1 different parameters were tested for soil and applied wastewater through current test program conducted in IUG environmental Laboratories, MoA Soil and Water Laboratories and Al Azhar food quality laboratory.

Samples were collected twice along this study; the first was in October 2008 while the second was in March 2009. Heavy metals in wastewater were determined additionally, the uptake by the plants and the accumulation of heavy metals in the soil were also tested.

Results of microbiological analysis of irrigated water, soil and alfalfa plant were also discussed. Fecal and total coliform was tested as indicators of microbial contamination. Comparison of crop yield for the first year (2003) of BLPP with that obtained from fresh water unit for the same year was carried out.

Samples of soil and alfalfa were collected twice a year (October and March) Plant toxicity was tested through investigating the heavy metals (Zn, Cu, Pb) level in plant tissues. Similar heavy metals were also tested in applied wastewater and soil.

4.5. Materials

The main purpose of this study is to evaluate the long term impact of wastewater reuse (WWR) on soil and plant. Test program was carried out to obtain field and laboratory data needed for determining the impact of WWR on both soil and plant after six years of using treated wastewater for irrigation.

To attain perspective about WWR impact, a literature review, historical results data of soil and alfalfa analysis from 2003-2006 for the same project BLPP were reviewed and discussed in accordance with soil and alfalfa plant tests results obtained during current study to deduce the trend of WWR impact on both soil and plant based on the irrigated water quality. Wastewater quality analysis were also reviewed and discussed compared to current results from BLPP from 2003 till 2006 and current results in 2008 and 2009 from the same BLPP site through current study were analyzed and discussed.

4.6. Methods

. Soil was analyzed for NPK, Ca, Mg, Na, Ec, pH, Cl, No3, and F.C in addition to heavy metals (Cu, Pb and Zn). Alfalfa was sampled for heavy metals (Cu, Pb, and Zn) and F.C. Soil and Alfalfa analysis were carried out according to the standard method of International Center for Agriculture Research in Dry Areas (**ICARDA, 200**1) and (**Westerman, 1990**).

Wastewater samples were analyzed for the same parameters as soil while alfalfa was analyzed for heavy metals (Cu, Pb, and Zn) and F.C. Tests analysis of wastewater were conducted according to American public Health Agency (**APHA, 95**)

From 2003 till 2006, chemical, physical and biological analysis was conducted at IUG environmental and rural research center, Al Azhar University Food laboratory and Ministry of Health (MOH) public health laboratory.

In this study, the same chemical, physical and biological analysis were conducted for soil, alfalfa plant and applied treated wastewater twice for consistency, the first was in October 2008 before rainfall while the second was in March 2009 after rainfall. October samples were analyzed in laboratories of Environment and Earth Science Department at the Islamic university of Gaza while March samples were tested at MoA laboratories as the IUG labs were destroyed by Israeli plans during the Israeli aggression against Gaza Strip in 28th December last year.

4.7. Samples Collection

Samples were collected from BLPP two times during the study period. These samples are applied wastewater, soil and alfalfa crops.

4.7.1. Applied Wastewater Samples Collection

As the treated effluent does not discharge continuously, time composite sample of discrete samples collected in one container at constant time intervals (10 minuets). This method is appropriate when the flow of the sampled stream is constant (flow rate does not vary more than 10 percent of the average flow rate) or when flow monitoring equipment is not available. Samples were collected from the feeding pipe over a period of 10 minutes intervals for four hours. One liter clean acid-washed polyethylene bottles were used to collect wastewater samples for chemical and bio-chemical analysis while 250 ml sterile bottles were used for microbiological analysis.

4.7.2. Soil Samples Collection

Twelve individual soil samples were collected from each 30cm soil layer using an auger starting at soil surface and ending to a depth of 60 cm from the whole area. Soil samples were collected in plastic bags and labeled according to the specific location where it was taken. The number of cores to take per composite sample does not relate to the size of the area sampled, but is related to the variability of site (**Ayer et al, 1985).**

Even of the uniformity of soil properties in the field where exist, care was taken to collect samples from the same places during French project with the guide of the project technicians. The variance in samples location was up to +/-2 m. Zigzag shape was followed to collect a representative composite soil samples.

4.7.3. Alfalfa Samples Collection

Three Alfalfa plant samples were collected using clean knife at 5-7 cm above the ground. Yellow and old grown plant was excluded. Alfalfa samples were preserved in a paper bags to allow transpiration and then moved to the lab.

4.8. Samples Preservation and Preparation

Wastewater sample bottles were sterilized by adding 20 ml of 70% ethanol and left overnight (**WHO, 1989**). The ethanol was then discarded and bottles were rinsed thoroughly with wastewater before filling the bottle with the sample. Wastewater samples bottles were closed, stored into ice box and transported immediately back to the lab. Some parameters like pH, FC and solids, were analyzed as quickly as possible where the rest was stabilized to a pH of 2 (**APHA, 1995**). Then it was placed in refrigerator at 4^0centigrade. Two duplicates were used to get the final result.

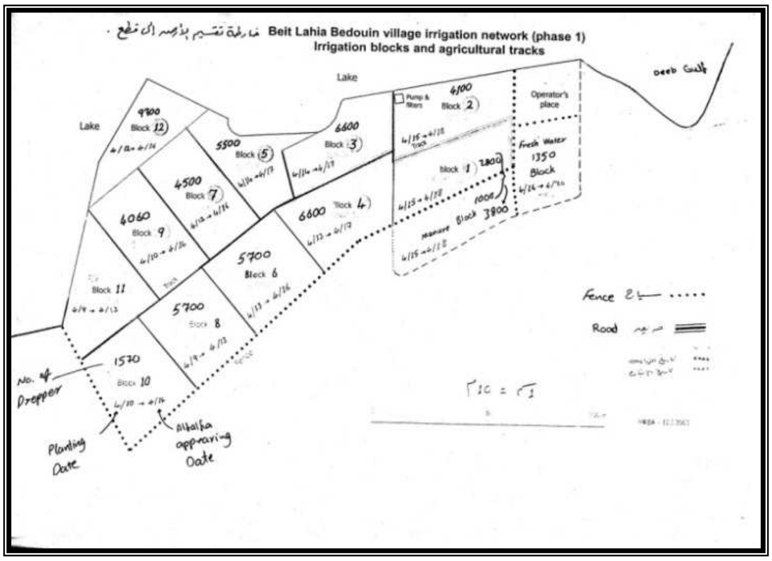


Figure 4-4 Location of soil samples in the study area in BLPP field.

As the soil samples were collected in plastic bags, it was transferred to the lab immediately and frozen in a refrigerator at four centigrade to stop microbial activities, then air dried, cleaned, root removed; mixed by hands and sieved at 2mm. Soil extraction was held by mixing 1:1 and /or 1:5 soils: distilled water using glass rod or mechanical shaker and then vacuumed by pressure pump using Whatman filter paper No. 42. The resulted filtrate was collected in a small bottle and kept to be used for soil analysis. Three duplicates were used to get the average value according to (**ICARDA, 2001)**

Alfalfa samples were cleaned and washed by distilled water and H_2O_2 to remove dust and organics, oven dried at 65 degree for 24 hours to stop enzymatic activity then mechanical grinding to produce a material suitable for analysis usually to pass 60- mesh sieve and finally oven dried at 650 c. Alfalfa analyzed for heavy metals and microbial contamination. (**ICARDA, 2001**)

4.9. Samples Analysis

Chemical and physical analyses were performed for both soil extraction and wastewater samples. Heavy metals and microbial analysis were tested in soil, wastewater and alfalfa. Soil and alfalfa samples were analyzed according to International Center for Agriculture Research in Dry Areas (ICARDA, 2001) while wastewater analyzed according to American Public Health Agency (**APHA, 1995**).

4.9.1. pH

Combined portable meter (HI 8424) was used for measuring pH, Before each sample collection process, the meter was calibrated and verified to make sure that it is in good working order. To determine the pH value, probes were immersed into the sample to be tested and the mode of pH was selected by pressing the range key until the display changes to pH. Electrode was stirred gently and stands a few minutes to adjust and stabilize. The display was showed the pH value automatically compensated for temperature.

4.9.2. Electrical Conductivity (EC)

Measuring conductivity is done by using EC meter (El-Hanna, TH-2400), that measuring the resistance occurring in an area of the test solution defined by the probe’s physical design. Voltage is applied between the two electrodes immersed in the solution, and the voltage drop caused by the resistance of the solution is used to calculate conductivity per centimeter. The display was showed the EC value automatically compensated for temperature. The basic unit of measure for conductivity is the Siemens (or mho), the reciprocal of the ohm in the resistance measurement. Because ranges normally found in aqueous solutions are small, micro Siemens/cm. EC was measured for soil and wastewater samples.

4.9.3. Total Phosphorous

Although phosphorus can be classified as orthophosphates, condensed phosphates and organically bound phosphates, there are only two common laboratory tests for the determination of phosphorus. The first is known as total phosphorus and the second is orthophosphate (also known as reactive phosphorus). The total phosphorus test consists of two steps. The first step is to prepare the sample by oxidizing organically bound phosphates and condensed phosphates to orthophosphate. The second step is to determine the total amount of phosphorus present, which is now all in the form of orthophosphate, via a colorimetric technique. If the first step is bypassed, only orthophosphate, originally present in the sample, is determined.

4.9.4. Nitrate $NO3^-$

Nitrogen in soils occurs in many forms, both organic and inorganic. The former fraction, composed mostly of plant and microbial remains, is variable in composition. With increasing aridity, however organic and total soil N tends to decrease. The inorganic phase of soil N is composed of ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) forms. The NH_4 and NO_3 forms are routinely measured in soil laboratories, as they reflect the extent of mineralization, and are the forms of N taken up by plants. Thus, Nitrate is measured by a spectro-photometric method (using chromo tropic acid). Chromotropic acid spectrophotometrically method is quite rapid, used originally for wastewater and later for soils.

4.9.5. Chloride Cl^-

10 ml of wastewater sample or a suitable portion diluted to 100ml is placed into an Erlenmeyer flask and 1ml potassium chromate solution added. The mixture is then titrated against a white back ground with silver nitrate solution until the color changes from greenish yellow to reddish brown. Blank sample with distilled water is treated in the same way as the sample. The same was performed for soil extract.

4.9.6. Sodium, Potassium, Calcium Phosphorus and Magnesium

In Wastewater, sodium was determined by flame photometer, Potassium, Ca, and Mg were determined after wet digestion of subsamples in H_2SO_4 salisilic acid mixture with three addition of H_2O_2

In the diluted digested of soil, P was measured spectrophotometrically by indophenols-blue method after reaction with ascorbic acid while Ca and K were determined by flame photometer. Soluble-salt content of soils was determined by saturation-extract method as described by Rhoades (1982). Calcium was determined titrimetrically using Diethylene Triamine Pentaacetic Acid (DTA) method and Magnesium was estimated as the difference between hardness and calcium as $CaCO_3$. Sodium Adsorption Ratio was estimated after determination of Ca, Mg and Na concentrations in the wastewater and soil samples.

4.9.7. Heavy Metal (HM)

Heavy Metals are tested based on the operating procedure for the Atomic Absorption Spectrophotometer using appropriate lamp for each element. The (DTPA) reagent should be of the acid form. The theoretical basis for the (DTPA) extraction is the equilibrium of the metals in the soil with the chelating agent. The DTPA is a multi-element soil test for alkaline soils developed by Soltanpour and Schwab (1977), and later modified by Soltanpour and Workman (1979) to omit the use of carbon black.

4.9.8. Fecal Coli form

For estimation of FC bacterial populations, The Membrane Filtration (MF) technique is performed. In the initial step, several dilutions of the sample volume is passed through a membrane filter with a pore size small enough (0.45 microns) to retain the bacteria present. The filter is placed on an absorbent pad saturated with a culture medium that is selective for coliform growth (CFU). The pad dish containing the filter and pad is incubated, upside down, for 24 hours at the appropriate temperature (44.5 ± 0.2 ̊C). After incubation, the colonies that have blue color are identified and counted using a low-power microscope. Few colonies from each plate were picked and biochemical tests were performed to confirm the identity. The same was applied for both soil and wastewater samples (**APHA, 1995**).

4.10. Data Analysis

All data (previous and obtained from test program) were entered as Microsoft Excel sheet. Results were represented on figures and curves to deduce the trend of parameters development over the desired period from 2003 till 2009.

CHAPTER 5: Results & Discussion

5.1. Introduction

The main objective of this study is to investigate the agronomic impact of wastewater reuse on the soil and on forage crops (alfalfa) when it is irrigated using partially treated effluent from BLWWTP for long-term (six years). As an approach to achieve the objectives, analyses of plant and soil for BeitLahia Pilot Project (BLPP) for the years 2003 till 2009 was presented and discussed. Moreover, the national and international reuse guidelines were reviewed and compared with the case in BLPP. Finally, regional and international experiences are highlighted to bridge the gab between the farmers and the researchers in the confidence of using the treated effluent for irrigation purposes.

5.2. Applied Wastewater Quality

In treated effluents, the physical and chemical constituents need careful consideration in order to evaluate or detect possible short or long-term effects on soils and crops from salts, nutrients and trace elements (**Kathijotes, 2006**). That is why risks that may attribute by wastewater application will be investigated based on criteria illustrated in table 3.2 developed by Kathijotes, 2006 as well as Palestinian Standards (**PS**), Environmental Protection Agency (**EPA, 2003**), and Food & Agriculture Organization (**FAO, 1985**, **1992**) as illustrated in Appendixes.

The quality of applied wastewater was tested two times during this study. The first was in October 2008 while the second was in March 2009. Time composite sample from the feeding pipe of BLPP were collected at one container at discrete intervals (10 min. each). Results from 2003 till 2006 tests were not significantly differing from that carried out during this study 2008- 2009.

5.2.1. Physical Properties

- **pH**

pH values of wastewater can be affected by the source of water, the season, type of wastewater and the treatment process (**Kiziloglu, 2007**).

For pH values, results indicate that the applied wastewater has alkaline pH values as it is **8.23, 7.98, 7.64, 7.38, 7.5**1, and **7.66** for the years 2003, 2004, 2005, 2006, 2008 and 2009 respectively as figure 5.1. According to EPA, 2003 and FAO, 1985 guidelines these values are in the usual range for wastewater pH (6.5- 8) to be used for irrigation. For BeitLahia most of the wastewater source is of domestic origin with almost the same source, therefore the risk of pH dramatic changes are negligible due to the absence of industrial activities along with the wastewater network.

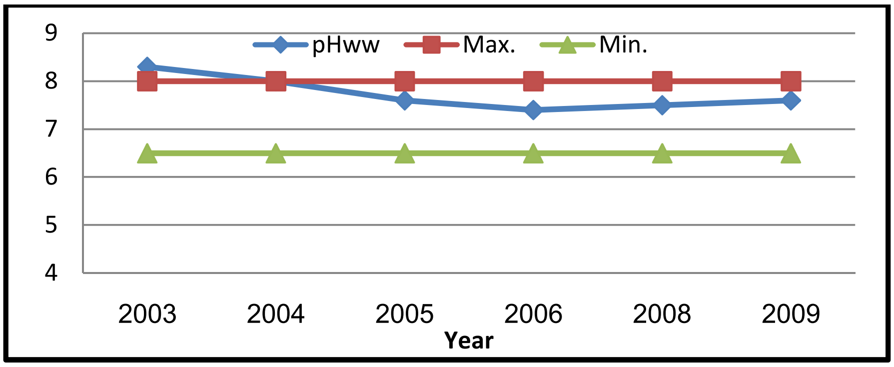


Figure 5-1: pH values for applied wastewater in BLPP

Results also indicate that pH values decrease with time, this decrease may be attributed to the increase of organic loads and decline of its removal efficiency as the treatment plant are heavily overloaded year after another (**Al Khaldi, 2006**). It may also results from the formation of volatile acids and carbon dioxide from anaerobic digestion of organic matter.

Moreover average pH in the source water was higher than that of wastewater effluent table 5.1.

Table 5-1: quality of wastewater and fresh water near the project area of BLPP

	Fresh water	Eff. Wastewater
pH	7.9	7.78
EC ds/m	1018.0	1836
TDS mg/l	678.7	1224
Cl mg/l	115.6	274
Nitrate	103.3	24
Ca mg/l	98.4	78
Mg mg/l	35.5	45
Na mg/l	87.2	236
K mg/l	8.3	23.3

- ## Electrical Conductivity (EC)

Electrical conductivity in applied wastewater was ranging from 1820-1950µs/cm (1164-1248 mg/l as TDS). Values of EC were **1.83, 1.82, 1.85, 1.95 and 1.93** dS/m for 2004, 2005, 2006, 2008, and 2009 respectively. Initial value of Ec was 1.86 dS/m. Based on FAO, 1985 guidelines for salinity concentrations EC has moderate restriction on use at current EC level and it can be used for irrigation with no severe risks in case of high drainage soil.

According to EPA, 2003 EC values are still in the usual range of salinity where the critical value of applied water should not increase 3ds/m. EPA, 2003 guidelines divided the applied wastewater into five main classes based on EC and TDS values as in table 5.2. Current values of applied wastewater lays in class 3 which indicate that the water in this class should be used for irrigation with restricted drainage. Even with adequate drainage best practice management controls for salinity may be required and plant salt tolerance must be considered.

Wastewater quality in the northern area where the experiment was conducted characterized with low salinity compared with other locations in GS. Therefore the potential use of treated effluent from BLWWTP is very high and allow to cultivate in good conditions alfalfa or others fodder (tolerance alfalfa =2-3 dS/m). The risk of soil-salt accumulation may be controlled if considerable amount of leaching is applied.

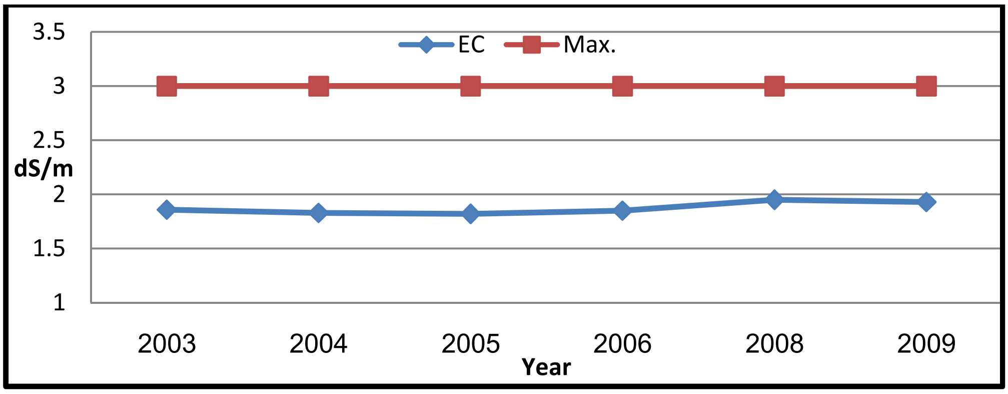


Figure 5-2: EC values in applied wastewater

As shown in figure 5.2 the salinity expressed in term of electrical conductivity is nearly constant within the 6 years of experiment. Meanwhile, the treated effluent from GWWTP shows high EC values ranging from 3 to 4 dS/m.

Al Khalid, 2006 through studying the performance of the BLWWTP found that salinity of 85% of samples of the effluent did not exceed 2dS/m and none of them reached 2.5dS/m over the monitoring program. That means high range of crops types can be cultivated and irrigated with treated effluent from BLWWTP (**Al Khalid, 2006**)

It is wroth to mention that the secondary treatment in the GS has negligible influence on the electrical conductivity; the salinity of wastewater is associated with the drinking water which is mainly abstracted from ground aquifer. Care should be taken when wastewater from different places in GS is being used as high variability in GS water quality exists even if it's small area.

Table 5-2: Salinity classes of irrigation waters and salt tolerant plants; source EPA,2003

Class	TDS(mg/l)	EC µs/cm	Comments
1	0-175	0-270	Can be used for most crops on most soils with all methods of water application with little likelihood that salinity problem will develop. Some leaching is required and this will occur under the normal irrigation.
2	175-1500	270-780	Used if moderate amount of leaching occur. Plant of moderate salt tolerance can grow, usually without salinity management. Sprinkler irrigation can cause leaf scorch on salt sensitive crops
3	500-1500	780-2340	The more saline water in this class should be used with restricted drainage. Even with adequate drainage best practice management controls for salinity may be required and plant salt tolerance must be considered
4	1500-3500	2340-5470	Soil must be permeable. Water must be applied in excess for leaching and salt tolerant plant should be selected.
5	>3500	>5470	Not suitable for irrigation except on well drain soil under good management especially in relation to leaching, restricted to salt tolerant crops or emergency use.

5.2.2. Chemical Properties

- **Calcium & Magnesium (Ca+Mg)**

Average calcium concentration in applied WW in BLPP was **77** and **85** mg/l for the years 2008 and 2009 respectively while it was **87.3, 79, 76, 83** mg/l for the years 2003, 2004, 2005 and 2006 respectively. The small variation in Ca concentration in the wastewater could refer to the test device change. Ca level is still in the acceptable range according to the EPA,2003 and FAO, 1985 guidelines as it recommends Ca values of 0-400 mg/l.

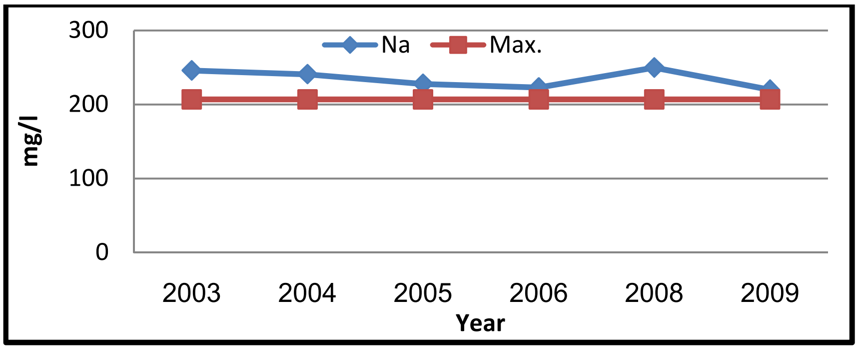


Figure 5-3: Exchangeable cations (Ca, Mg) in applied wastewater

Magnesium (Mg) level is stable for the first four years with concentrations of **54, 43, 46, 39, 34** and **46** mg/l. for the years 2003, 2004, 2005, 2006, 2008 and 2009 respectively. Generally, Mg level is decreasing with in small amount and this may be due to the increase of sodium level in wastewater as the volume of Mg was replaced by Na. Mg level still in the acceptable range according to EPA, 2003 and FAO, 1985 guidelines as the maximum allowable value is 5meq/l (60mg/l).

- **Sodium (Na)**

Results show that sodium level for the applied water make the water is of severe restriction to be used for irrigation as it exceeds the usual level assigned by FAO, 1985 guidelines (200 mg/l) as shown in figure 5.4. The Na concentration was **246, 241, 228, 223, 250,** and **220** mg/l for the years 2003, 2004, 2005, 2006 2008 and 2009 respectively. This high concentration may refer to the original water quality which is the main source of wastewater and the repeated irrigation using wastewater. Sodium concentration is associated with chloride concentration which is originally high in GS ground water due to sea water intrusion. Using treated effluent in irrigation purposes will save about 80- 100 Mm^3/year of ground water (**PWA, 2005**).

In away or another, this approach will possibly decrease sea water intrusion. It is expected to have high sodium concentration as a result of using treated effluent in irrigation. Sodium has negative effects on soil especially clay soil, this effect is minimal in case of sandy soil due to high infiltration as the case of BLPP soil.

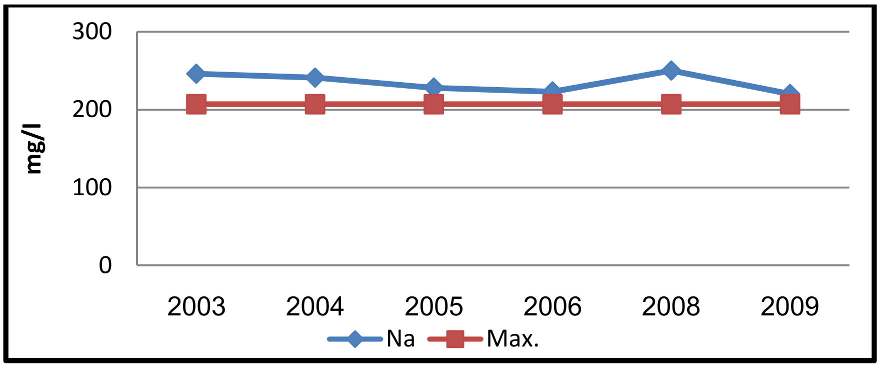


Figure 5-4: Sodium (Na) values in applied wastewater

- **Sodium Adsorption Ratio (SAR)**

SAR is the relative concentration of Na^+ to Ca^{++} and Mg^{++} levels. SAR is an important parameter because, in combination with EC, it can pose soil infiltration problems. High SAR values above 10 may result in reduction of soil permeability and aeration and a general degradation of soil structure. Even if lower EC values, sodic soils are low in total salts but high in exchangeable sodium. The combination of high levels of sodium and low total salts tends to disperse soil particles.

Calculated SAR values of BLPP applied water were **4.2, 5.3, 5.1, 5.47, 5.9** and **5.17** in 2003, 2004, 2005, 2006, 2008 and 2009 respectively. This means that the applied wastewater SAR values with the current EC are acceptable according to EPA and FAO standards. From test results it is clearly noticed that SAR value increased over the experiment years by about 30% as a result of sodium level increase. Care should be given to SAR values as not to exceed the permissible level of 10.

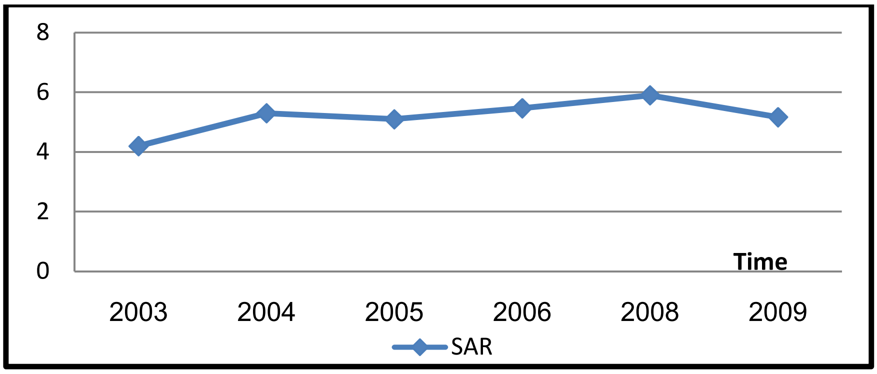


Figure 5-5: SAR values of applied wastewater in BLPP

The projection of average values of SAR and Ec of applied wastewater on figure 3.5 shows that effluent quality of BLWWTP express low salinity hazard and it can be used for agriculture irrigation for varying range of tolerant crops. This result agrees with that obtained by Al Khaldi, 2006 during the evaluation of the BLWWTP performance as he conclude that BLWWTP effluent could be used for unrestricted irrigation (**Al Khaldi, 2006**).

- **Nitrate (NO_3)**

The total nitrogen in wastewater is often referred as total kjeldahl Nitrogen (TKN). The high nitrate concentration is a well known phenomenon in Gaza northern area due to disposal of sewage to sand dunes surrounding the treatment plant, this leads to high nitrate concentration of fresh water. However nitrate values of applied water were lower than usual limits stated by EPA 2003 (**50** mg/l) all the time.

It is well known that during any biological treatment process, up to 30% of the total nitrogen is removed in cell synthesis by ammonification, in addition to that removed during the sedimentation processes. This could be the reason of which nitrate in applied water is within the permissible level and lower than source water. (**Horan,1997**)

Results indicated that NO_3 values ranged from **13** to **36** mg/l as in figure 5.6. It is noticed that nitrate level of applied wastewater increases with time and this may be due to the efficiency of treatment plant as the organic load increases with time. Results also indicated high concentration of nitrate in 2005 and 2009 as the values were **35.17** and **30.2** mg/l-NO_3 respectively which is also less than maximum permissible value.

Moreover as it was stated high NO_3 has no severe impact on crops but it may leaches to the ground aquifer.

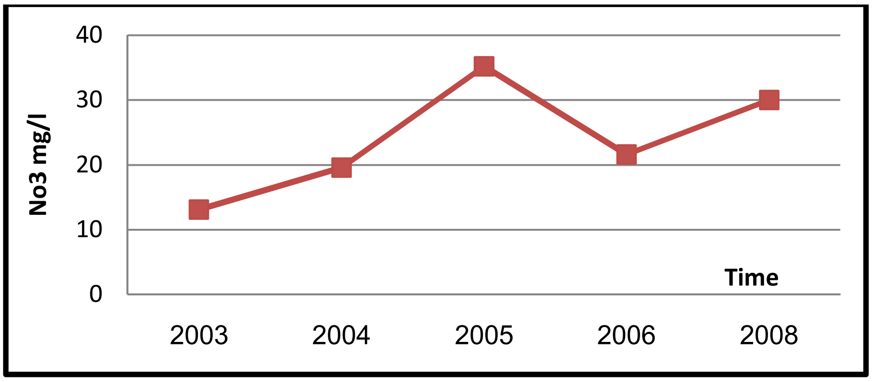


Figure 5-6: NO3 values in applied wastewater for BLPP

- **Potassium (K)**

According to EPA, 2003 the maximum permissible K level of applied wastewater is 78mg/l, this is clearly applied for our case as the maximum k level was 32 mg/l in 2003 as in figure 5.7 and it decreases to **27.9, 26, 15, 11,** and **14** mg/l for 2004, 2005, 2006, 2008, and 2009 respectively. The main reason for K decrease is the decrease of K level in the source water as K value was 16mg/l in 2003 and decreases to 8 mg/l in 2007.

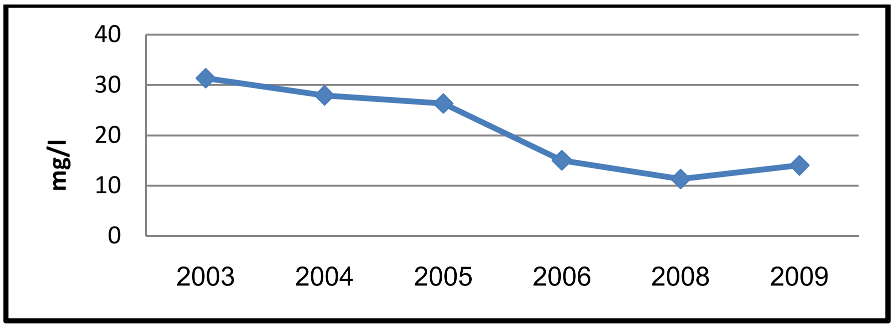


Figure 5-7: Potassium (K) level in applied wastewater for BLPP

These values were lower than recommended by different standards for irrigated water quality (40mg/l), thus fertilizer contains additional K values should be added.

- **Phosphorus (P)**

The major source of phosphorus in wastewater is from human excreta and synthetic detergent. According to EPA, 2003 **2** meq/l is the maximum range of P in applied water. Results indicated that P was higher than this level as the average level is **2.65**meq/l with the maximum level of **3** being observed in 2006 and 2008 as in figure

5.8. It is also noticed that the P level increased with time and this may be due to the aeration conditions in treatment plant. Any how **Pescode, 92** indicated that GS effluent has higher amount of P due to plants overloading.

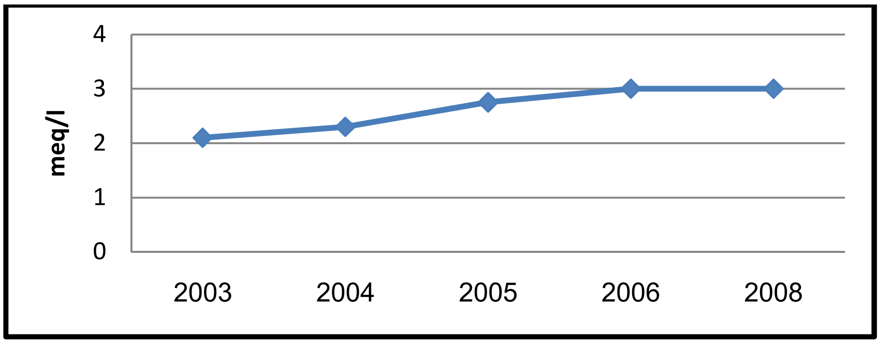


Figure 5-8: P level in applied wastewater for BLPP

- **Chloride(Cl)**

It is known that the chloride concentration all over the GS aquifer is higher than recommended by international standards except for the northern area as the chloride concentration is within the acceptable range by different standards for drinking purposes (around 250mg/l). Maximum allowable Cl level in irrigated wastewater is 1050 mg/l. It was clearly noticed that Cl values for applied wastewater is less than the maximum allowable value all the times and no risks can be generated from using this water.

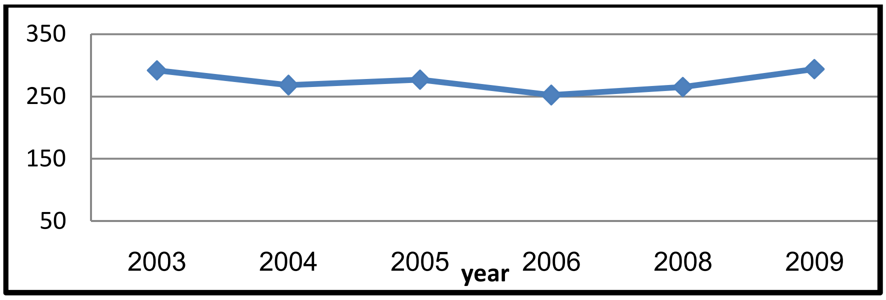


Figure 5-9: Chloride level in applied wastewater for BLPP

The values of Cl are **292, 268, 277, 252, 265** and **294** mg/l for 2003, 2004, 2005, 2006, 2008, and 2009 respectively. These value indicate that the treatment processes of BLWWTP does not affect the Cl level significantly as the values are very close to the fresh water values and low values of applied water are due to the lower chloride concentration in source water. According to EPA, 2003 water quality the chloride concentration of irrigated water that cause foliar to moderately tolerant salt crops as alfalfa is **355-710** mg/l this means that BLWWTP effluent is suitable to be used for irrigation purposes.

- **Heavy Metals (HM)**

Wastewater has wide array of heavy metals. For the reuse of wastewater in BeitLahia (Cd), (Pb), (Zn) and (Cu) were considered due to the indication of its existence in Gaza aquifer (**Shomar, 2003**) and to the historical data. Analysis shows some trace of Cd at different seasons, while in the year 2005 Pb has high concentration of about **2.86** mg/l as in table 5.3. To some extend, BLWWTP receives wastewater from GS northern area where small scale workshops such as painting and battery industries are exist. Therefore high concentrations of heavy metals are seen occasionally.

Table 5-3: Heavy metals in applied wastewater in BLPP

Parameter mg/l	**2004**	**2005**	**2006**	**2008**
Cd	**0.005**	**Free**	**Free**	**0.005**
Pb	**0.03**	**2.86**	**0.07**	**1.88**
Zn	**0.02**	**Free**	**Free**	**0.05**
Cu	**Free**	**0.001**	**0.009**	**Free**

Results also indicate that heavy metal level in the applied water varies with time. It was clearly noticed that lead (Pb) is the dominant as it ranges between **0.03** and **2.86** mg/l. while Zinc and cupper concentration levels during the experiment ranged between free and very low values. similar result were obtained by Shomar, 2003 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. Although current heavy metals level in applied wastewater is less than stated by **EPA** guidelines (**5**mg/l Pb, **0.2**mg/l Cu and **2**mg/l Zn), its level is higher than PS standards (**1**mg/l of Pb) therefore, it should be controlled in order to prevent any potential risks of pollution. Moreover, plant tissues should be analyzed to determine the level of uptake to prevent the contamination of food chain (**EPA, 2004)**.

5.2.3. Biological Quality of Wastewater

Fecal & total coliform (FC, TC) were investigated as indicator parameters for biological contamination of wastewater, soil and alfalfa. Results indicated that average values of FC in applied wastewater in BLPP were higher than PS and WHO standards (**1000 CFU/100ml**) as in table 5.4. Maximum FC value was 5500 while minimum value was 1500 CFU/100ml. Comparison of average FC values with time revealed significant increase of FC values with time.

This increase attributed to the increased organic loading as well as the inadequate design of the maturation pond in BLWWTP which could be the main reason of the high FC level. The same results was obtained by (**Khaldi. 2006**) as he concluded that the BLWWTP effluent can not be used for unrestricted crops from biological quality point view and the plant needs more disinfection units.

Table 5-4: Biological Quality of BLPP applied water

Year	F. Coliform	Tot. Coliform
2003	10-100	2500
2004	1500- 2000	2500
2005	2000- 4000	3700
2006	4000-5000	10000
2008	3500-4500	6000

5.3. BLPP applied Wastewater According to PS Standards:

According to Palestinian Standards the applied irrigated water in BLPP is within the acceptable range for most of nutrients levels. However some risks may be associated from using this water especially related to heavy metals as the average concentration of Pb is much more than the permissible by PS. Table 5.5 illustrate the acceptable range of many parameters and the existing range in the applied wastewater in PLBB.

Table 5-5: Palestinian Standards for irrigated wastewater

Group	Parameter	Palestine Standards	BLPP applied WW
Sanitarian aspects	**FC (CFU/100ml)**	<1000/100ml	60 - 6000
Heavy metals	**Cd (mg/L)**	0.01	0.005
	Pb (mg/L)	1	1-4
	Hg (mg/L)	0.001	< 0.001
	Cr (mg/L)	0.1	< 0.01
	Cu (mg/L)	0.2	< 0.1
Salinity	**EC (dS/m)**	2.5	1.85-1.95
	TDS (mg/L)	1500	1236
Physical quality	**pH**	6.5-9	7.4-8.3
	SS mg/l	40 / 50	64
	BOD mg/l	45 / 60	53.6
	COD mg/l	150 / 200	105
Chemical quality	**Cl mg/l**	500	1224
	NO3mg/l	50	23.5
	Ca mg/l	400	79.2
	Mg mg/l	60	45
	Na mg/l	200	234
	TKN mg/l	50	56.6
	Total P mg/l	30	2.8
	SAR	9	5.9

It is clearly noticed that the PS has the same results as international standards guidelines regarded to the BLWWTP effluent and its possibility to be used in agricultural irrigation. Results indicated that the average FC level of applied water is much higher than recommended by PS, which means there is a great concern in using this effluent for agricultural irrigation especially in case of raw vegetables and applied water need additional disinfection unit. Results reveals that salinity of BLWWTP effluent is less than the critical limit assigned by the PS, this support the general conclusion that the water quality in GS northern area has high quality related to salinity and no risks associated from its irrigational use.. Heavy metals are also within acceptable range except Pb which is higher than recommended by PS (1ppm). More details will be presented in section 5.4.

Organic and inorganic nutrients are also having acceptable level and no risks can be generated from using the BLWWTP effluent in irrigation except sodium which is higher than the desired level by PS standards.

Generally, the effluent of BLWWTP could be used for agricultural irrigation in condition that some measures can be provided as excess water application accounting for leaching, crop selection and crop rotation.

5.4. BLPP Applied Wastewater According to Kathijotes Criteria

Table 5-6 : Kathijotes criteria for irrigation water quality standards and risks

Criteria	**Criteria Range**	**Risk Estimation**	**2003**	**2004**	**2005**	**2006**	**2008**	**2009**
$\frac{Ca + Mg}{Na + 0.23\,Ca}$	**>1**	Natrium risk	0.84	0.35	0.71	0.58	0.88	1.12
$\frac{100(Ca+Mg)}{Na}$	**>60%**	Natrium risk	93	73	77	62	100.9	140
$\frac{100\ Mg}{Ca + Mg}$	**< 50%**	Magnesium	47	51.2	50.1	39	37.32	25.3
$\frac{288}{Na+4Cl}$	**6-18**	Chloridisation	6.9	7.1	7.0	73	7.2	6.6
$\frac{6620}{Na+2.6Cl}$	**<1.2**	Chloridisation	1.38	1.64	1.61	1.68	1.66	1.54
$\frac{288}{5.Cl}$	**>18**	Chloridisation	7.0	7.68	7.38	8.1	7.78	7.02
$\frac{Na}{Na+Ca+Mg}$	**<0.6**	Alkalinisation	0.5	0.6	0.58	0.62	0.5	0.42
$\frac{Na}{Ca+Mg}$	**<0.7**	Alkalinisation	1.05	1.4	1.29	1.58	0.99	0.6
$\frac{Na+K}{Ca+Mg}$	**<1 NO**	Alkalinisation	1.15	1.52	1.4	1.7	1.02	0.6
SAR	**<10**	Dangerous	4.3	5.3	5.1	5.87	4.47	3.87

Kathijotes criteria were developed in 2006 during the conference on water observation and information systems for decision support. It was applied in the investigation of the risks of the treated sewage intended for irrigation in Cyprus during salinization risk assessment study.

Applying the criteria on BLPP irrigated water indicated that sodium risks were existed all the time and the applied water has higher sodium values than recommended by Kathijotes. Therefore Natrium risks can easily occur and this result is similar to that obtained in the previous section. It is also clear as illustrated in table 5.6 that there was no risks regarded to chloride, cations (Ca, Mg) and alkalinity as the level of these parameters are less than the threshold values assigned by Kathijotes. Generally results indicate that at most time the quality of effluent in BLWWTP is suitable for irrigation use as it does not pose risks. However, care should be taken when using such effluents based on soil and crop type in order to minimize or eliminated possible contamination (**Kathijotes, 2006**)

Generally, the characteristics of wastewater used for irrigation varied within and among the years of application. In average, the wastewater is alkaline with basic pH value of 7.73. The wastewater contains considerable amount of i.e. (nitrate, calcium) which are considered essential nutrients for improving plant growth and soil fertility and productivity level. On the other hand, the concentration of micronutrients and heavy metals in the applied wastewater are relatively low and meet the standards of wastewater agricultural use. Given the fact that these metals could be accumulated in soil and plant with continuous use of wastewater in irrigation, therefore their periodic monitoring should be an important component of wastewater management.

5.5. Soil Properties

5.5.1. Physical Soil properties

- **pH**

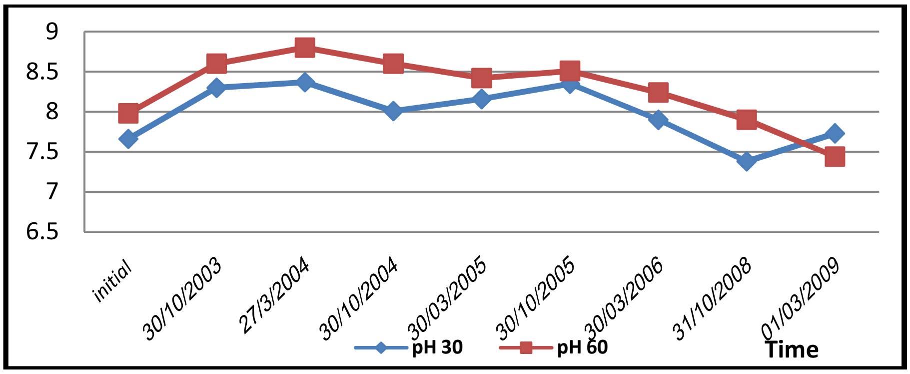


Figure 5-10: Soil pH values for both 0-30 and 30-60 cm layers.

Significance of pH lies in its influence on availability of soil nutrients, solubility of toxic nutrients elements in soil, physical breakdown of root cells, cation exchange capacity in soils whose colloids (clay/ humus). Soil pH is affected by depth as well as duration of wastewater irrigation. Many researches pointed that there is inconsistency in wastewater effect on soil pH **(Rusan et al, 2007)**

Results indicate that soil has alkaline pH for both layers over all the experiment time the same as irrigated water. pH was higher in the lower soil layer than the surface one as in figure 5.10. pH values for top soil layer ranged between 8.37 and 7.73 while pH values for lower layer ranged between 8.8 and 7.44. This variation may be due to the differences in microbial action in soil layers as it is decreasing with depth resulting in a decrease of organic acids formation. Results also indicated that long term use of wastewater application result in soil pH decrease for both soil layers. This may due to humus increment causing formation of organic acids which decrease the pH value. This result is similar with that obtained by Kiziloglu, 2007 as he found during a field experiment aims at minimizing degradation of soil irrigated with wastewater in Erzurum, Turkey that pH values increased with depth in all plots irrigated with wastewater general decrease in pH values occur after long term wastewater use (**Kiziloglu, 2007**).

However, Schipper et al., 1996 found that soil pH increased following long term wastewater irrigation and they was attributed this increase to the chemistry and high content of basic cations such as Na, Ca and Mg in the wastewater applied for a long period **(Schipper et al., 1996)**. Other researchers **(M.J, 2003)** found that soil pH decreased with wastewater irrigation due to the oxidation of organic compounds and nitrification of ammonium **(M.J, 2003)**

The end section of the curve indicates lower pH values especially for the 30-60cm layer in 2009; this was due to fully harvesting of alfalfa plant at the beginning of 2009 and no more humus consumption by plant occur.

- **Soil Salinity (EC)**

Crops are differing in its resistance to salts. Salinity is expected to cause yield reduction of crops for various levels of soil salinity under normal growing conditions. Generally forage crops are the most resistant to salinity, followed by field crops, vegetable crops, and fruit crops which are generally the most sensitive.

For all crops, soluble salts that accumulate in soils must be leached below the crop root zone to maintain productivity by leaching which is the only management tool that overcomes this problem. When salt accumulate in soil, the soil solution osmotic pressure increases. Thus, the amount of water available for plant uptake decreases and plants exhibit poor growth and wilting even though the soil isn’t dry. Figure 5.11 present the effect of different saline soil levels on availability of water at root zoon and its relation with crop growth.

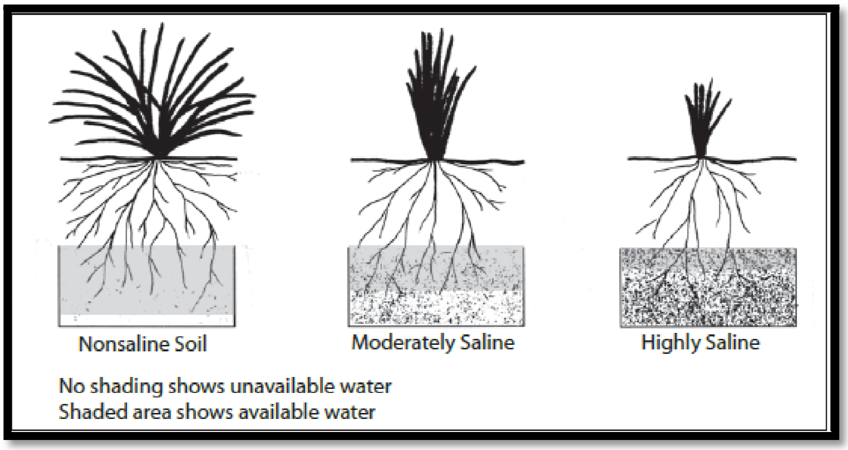


Figure 5-11: Salinity effects on water availability and crop growth (MARS, 1996)

Results indicate that salinity in soil layer increases with time with higher increase being observed in the lower 30-60 cm layer as figure 5.12. Salinity level varies significantly in the surface layer after rain seasons due to high leachate of sandy soil as it has high infiltration rate. This is expected due to precipitation as much salts leach thus water displaces soil soluble salts from the top 30 cm layer to settle in the 30-60 cm lower layer which accounts for salinity increase. This increase in soil salt content in 30-60 cm layer after six year of wastewater application attributed to the high evaporation rates and absorption by the alfalfa roots which reduce the amount of free water and therefore concentrates the salt in the soil substrata. Same results were achieved by (**Biswas et al, 2005**). However, salt leaching from the surface layer was decreasing with time as result of salt accumulation. This may be due to irrigation system efficiency at which drainage water mixes with the soil solution. Biswas, 2007 found that the average leaching efficiency in surface 30 cm soil in case of drip irrigated fields has to be **65**%. A 65% LE implies that at least one third of leachate is non-mixed irrigation water which is bypassed without removing salt from the soil (**Biswas, 2007**).

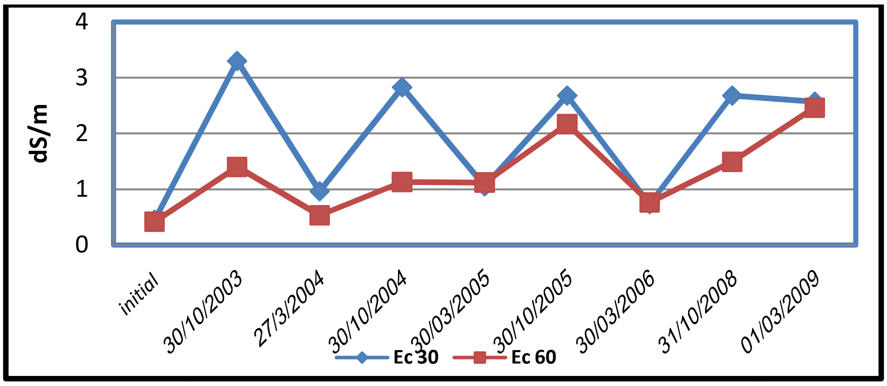


Figure 5-12: Salt contents in two soil layers.

Wastewater application increased soil salt content in the top 0-30 cm layer from **0.45** to about **3** dS/m while it increased the 30-60cm layer salt content from **0.41** to **2.50** dS/m. For both soil layers, soil salt content became more than that for irrigated wastewater as a result of long term wastewater application and salt accumulation.

Generally, plant growth becomes affected by the presence of salts and/or sodium when the sodium adsorption ratio (SAR) and electrical conductivity (EC) levels exceed critical values of 15 and 4 dS/m, respectively (**Marschner, 1986**). However, some plant species are sensitive to salinity at less than 4 dS/m. Even with adequate drainage, best practice and management controls for salinity may be required and the salt tolerance of the plants to be irrigated must be considered.

5.5.2. Chemical soil properties

It is obvious that soil chemical properties are mainly affected by the applied water properties. The level of nutrients in soil is proportionally affected by that in irrigated water and sometimes it may increase due to nutrients accumulation especially in low permeable soil and/or low leaching fraction application.

- **Exchangeable cations (Ca, Mg)**

Many minerals in soil are negatively charged and can attract or retain cations such as Potassium K^+, Calcium Ca^{++}, Sodium Na^+, Magnesium Mg^{++} etc. the exchangeable capacity is the reversible process as elements can be held in the soil and not lost through leaching and subsequently released for crop uptake. Results reveal that (Ca, Mg) level is decreasing with soil depth as well as with increased time of waste water application as in figure 5.13. This decrease resulted from the reduction of exchangeable volume occupied by Mg as it is replaced by Na cations. It is also known that high concentrations of sodium reduces the uptake of important mineral nutrients, K^+ and Ca^{++} which further reduces cell growth especially for roots.

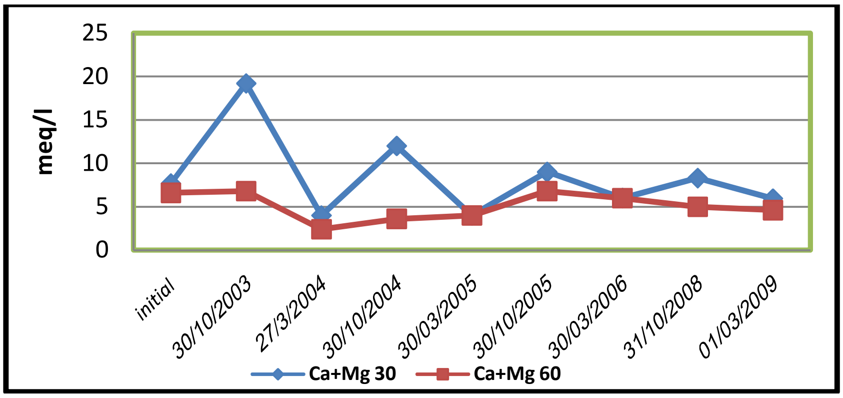
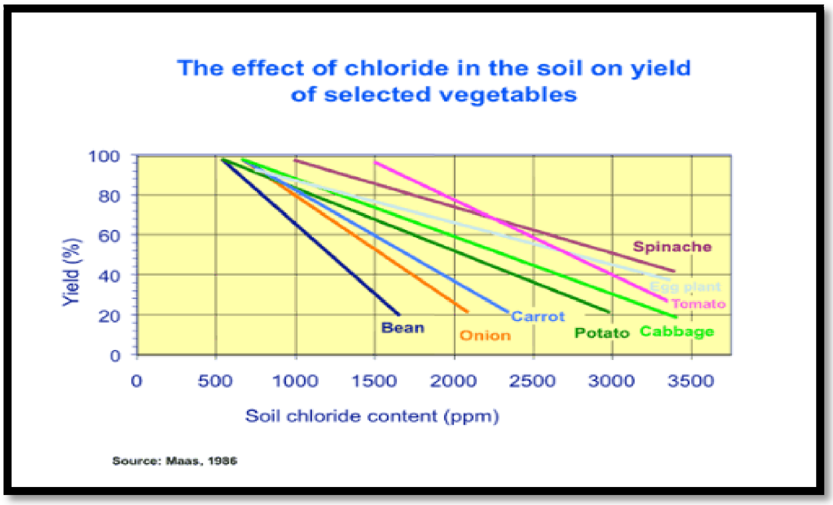


Figure 5-13: Exchangeable- cation level in soil layers

Ca, Mg level is also varies significantly within soil layer especially in the surface top layer 0- 30 cm. The variation of cations value in soil top layer is about 70% while it is 32% in 30-60cm layer. This high variation probably due to high leaching rate resulted from precipitation as the Ca, Mg level before rain fall was higher than that after rain especially in the first stages of project. Later on the variation decreases due to Ca+Mg accumulation. Similar result was obtained by **Oron et al., 1999.**

- **Chloride (Cl^-)**

Mass, 1996 illustrated the level of soil chloride content at which the crop yield of different crops began to be affected. The effects of high Cl^- concentrations in the soil solution on yields of various crops is shown figure 5.14.



Source: Maas, 1986

Figure 5-14: effect of chloride level on yield of selected vegetables

Results indicate that for both layers Cl^- level do not increase the permissible limit assigned by different standards (30meq/l) at any time as in figure 5.15. However, average Cl level was **15.4** and **9.4** meq/l for both soil surface layer and lower 30cm layer respectively which may negatively affect the yield of some certain crops other than alfalfa according to Mass, 1996. It was clearly noticed that there was great harmony in chloride level in both soil layers resulting from the same soil properties. The results indicate that leaching of Cl was occurring after rainfall seasons in the top layer especially in the first years of wastewater reuse as high variation was noticed in Cl level before and after rainfall.

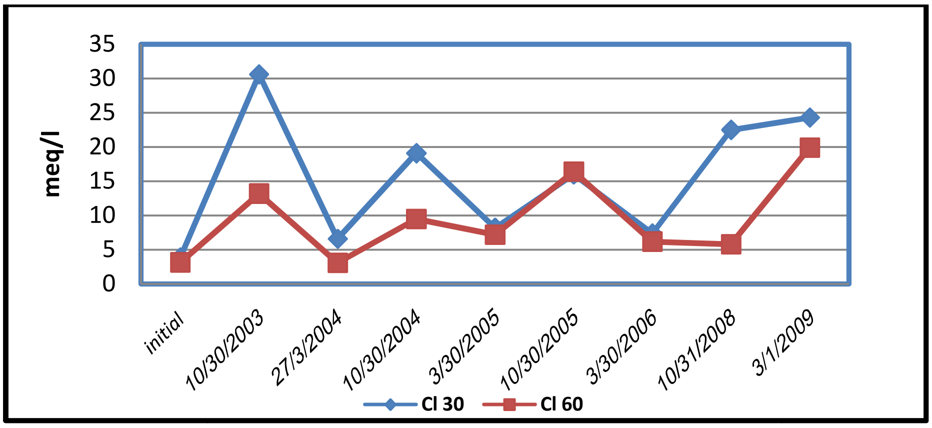


Figure 5-15: Chloride level in different soil layers of BLPP

Cl level increased with time where its level in 2009 was **24.3** and **19.9** meq/l for top and lower soil layer respectively, this increase in both layers may be due to the saturation of lower layer with Cl as in 2005 Cl level was similar in both layers was, thus no possible leaching can occur. This reveals that a mitigation measure should be at that time.

- **Sodium (Na^+)**

Na Level was increasing significantly with the time especially in the top 0-30 cm layer as illustrated in figure 5.16. Average sodium level in surface soil layer was **319**mg/l while it was **257** mg/l for the lower 30-60cm layer while the initial Na level for both layers was almost same (45 mg/l). This means that the higher increase was on the top layer due to the high TDS level in treated wastewater which allows accumulation of Na especially in the top soil layer. Average Na concentration exceeds the permissible limits stated by the EPA and FAO guidelines. It is clear that wastewater application poses a source of excess Na in the soil due its high Na level compared with other cations (Ca, K, Mg) and therefore it should be appropriately controlled. Similar results were obtained by **Kiziloglu, 2007**.

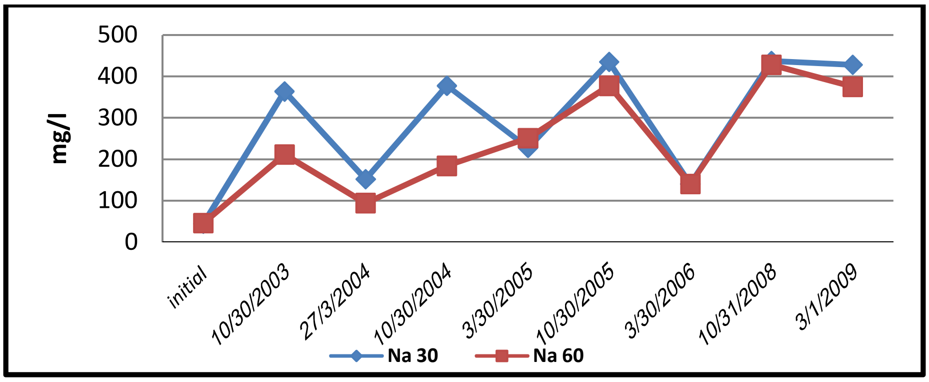


Figure 5-16: Na level in soil layers.

Leaching is clearly occur from surface to the bottom layer as indicated by the variation of sodium concentration from winter to summer time especially for the first 3 years. Pettygrove and Asano had the same indication that accumulation of sodium in the soil from effluent applications can cause soil infiltration problems and exacerbate salinity problems. (**El-Arabi, 2006**)

- **Sodium Adsorption Ratio (SAR)**

SAR is the relative concentration of Na^+ to Ca^{++} and Mg^{++}. SAR values were examined along wise with EC values to study the influence on soil permeability and infiltrate just as crops differ in tolerance to high salt concentrations; they also differ in their ability to withstand high sodium concentrations. Plants on sodic soils usually show a burning or drying of tissue at leaf edges, progressing inward between veins. Crops differ in their ability to tolerate sodic soil, but if sodium levels are high enough, all crops can be affected ion capacity as they are strongly related.

SAR values for irrigated water were ranged from **3.4 to 5.4**. Same SAR values for soil were noticed at the early start of the project in 2003 however SAR for soil was increasing with time because of sodium increase and accumulation till SAR. Average SAR value in the top soil was **7.2** with maximum value of **10.7** in 2009 while the average value for bottom layer was **7.14** with the maximum value of **10.3** also occurs in 2009 as illustrated in figure 5.17.

Kathijotes, 2003 noticed that the quality of soil samples irrigated using fresh water in Cyprus for eleven years demonstrated higher values of SAR and therefore poses greater salinization risks. This means that soil SAR values is mainly acquired from irrigated water sodium content (**Kathijotes, 2003**).

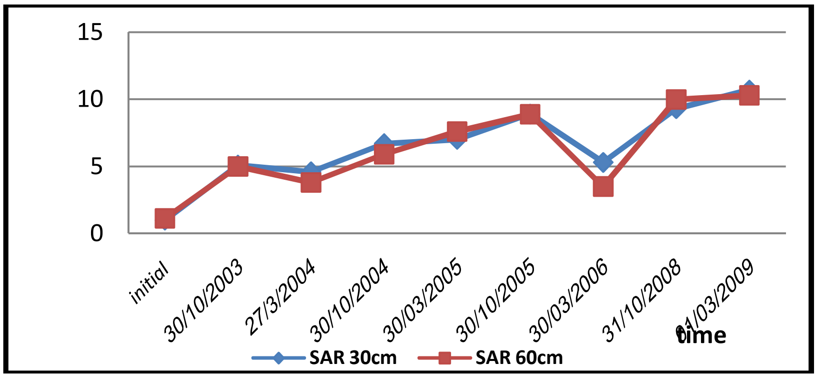


Figure 5-17: SAR values for two soil depths.

It is noticed that there is a great harmony between the Na and SAR graphs as both are increasing for both layers and it tends to increase without management and mitigation measures being applied. Qian, 2005 stated that the Long-term uses of RWW with marginal high SAR may result in reductions of soil infiltration and permeability in clayey soils and for sites with high traffic and compaction pressure. Further research is needed to monitor soil hydraulic properties for sites irrigated with RWW (**Qian, 2005**).

To determine the combined impact of SAR and Ec on soil, the salinity hazard chart mentioned in chapter 3 figure 3.3 were used. The projection of current salinity Ec (2. 5dS/m) and SAR (10- 13) showed that under these values soil lays in the area of unlikely permeability hazards and filtration and permeability problems occur. This was clearly noticed through increase salinity and sodium levels in both soil layers. This high concentration requires more leaching fraction and drainage or even soil washing using fresh water as well as crop rotation.

- **Nitrate (NO_3)**

Nitrogen applied through wastewater is either taken by the crop, leached beyond the crop zone, resides in the soil or is lost through denitrification. The two forms of nitrogen that are available to plants in the soil are nitrate (NO_3), and to a lesser degree ammonium (NH_4) (**POOL, 2004**). Results indicate that average NO_3 concentration was

243 and **173** mg/l for surface and bottom layer respectively. This means that the average NO_3 in the surface was higher than the lower layer as a result of wastewater application No data was collected for the year 2004 as in figure 5.18.

It was noticed that there was considerable variation in nitrate levels in the surface layer after each rain season. This probably due to leaching of nitrate to the lower layer, this was clearly noticed as the nitrate level in the lower layer has increasing trend. Moreover, this variation may attribute by alfalfa crop action, as alfalfa consume high quantities of nitrogen at the beginning of growth season which occur in spring, thus NO_3 concentration decreases in soil at that time and vise versa (**Pool, 2004**). Moreover alfalfa nitrate uptake is relatively high compared with other forage crops and this may lead to more yields and less NO_3 level in soil in growing season (spring to summer). Similar result was obtained by **(Angin, 2005**)

Increase of NO_3 level in summer time can also be attributed to the nitrification process at which ammonium is converted to nitrate after the mineralization of organic nitrogen. That is why ammonium can not accumulate in soil as soil temperature and moisture suitable for plant growth also are ideal for conversion the ammonium to nitrate Tamm, 2006 found that different nitrate patterns show a low concentration in top soil during the vegetation period and a much higher concentration after that (**Tamm, 2006)**.

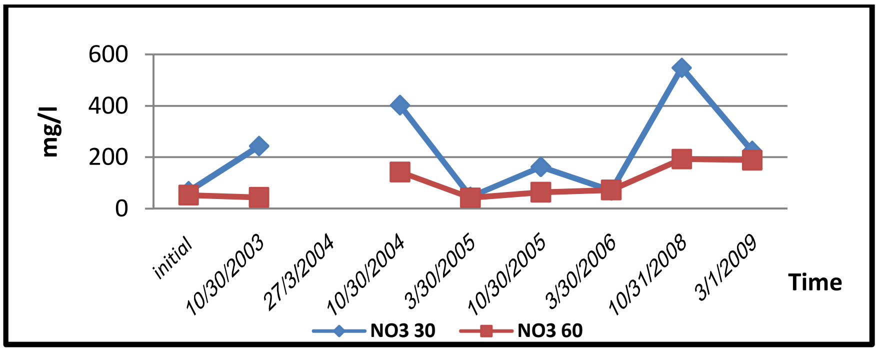


Figure 5-18: NO3 values for two soil depths

- **Phosphorus (P)**

Phosphorus is essential for alfalfa production and is one of the most common nutrient inputs for this crop. This nutrient is involved in many essential roles within the plant, and deficiencies result in slow growth, suppressed yields, and lost in yield.

There have been many reports that P nutrition have been found to improve plant disease tolerance or resistance. This nutrient response could be due to the influence of P on plant growth, leading to improved disease resistance or tolerance, or possibly due to its direct influence on pathogen activity in the soil prior to infection.

Soil phosphorus is most available for plant use at pH values of 6 to 7. When pH values exceed 7.3 as our case, phosphorus is increasingly made unavailable by fixation in calcium phosphates.

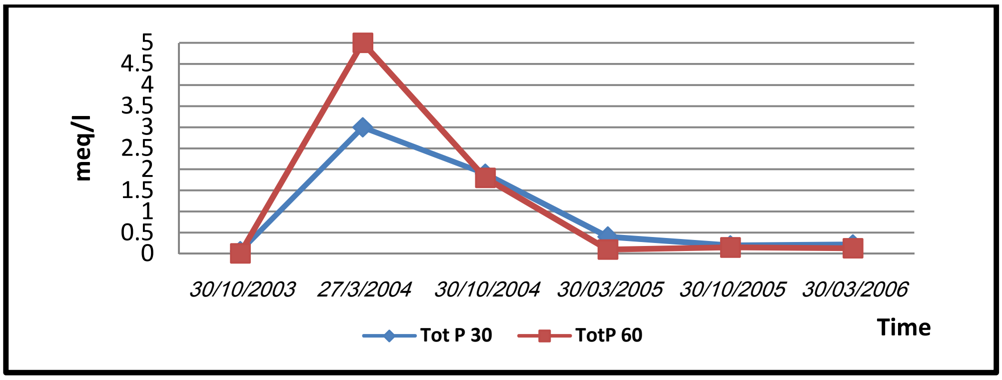


Figure 5-19: Phosphorus values for two soil layers.

Results reveal that there was great harmony in total phosphorus level for both soil layers (0-30 and30-60cm) as in figure 5.19. P in lower soil layer is higher than in top soil in the beginning of grown season in 2004 as P value was **3 and 5** for surface and lower layers respectively , this may be due to that P in the top layer interact with other organics and becomes involved in many soil reactions that tend to reduce its solubility. Moreover, maximum P value occurs in spring of 2004 where alfalfa is in the initial growth stage was probably due to that alfalfa has no enough roots that access to P and uptake it, thus high p values noticed during the growing time, P values was almost same for both soil layers and this may be due to alfalfa plant uptake of P in the lower layer while P in the top layer was converted to organics. It is obvious that high-yielding alfalfa removes large amounts of nutrients from the field in each cutting which occur in summer times. Hence P level being decreased during plant growth time as the plant consumes all P. Mikkelsen, 2004 stated that by the time remarkable decrease in P level in the soil layers occur as the roots are able to access P which includes sufficient soil moisture and other essential nutrients present in adequate wastewater supply (**Mikkelsen, 2004)**

Most of the P entering the plant rapidly becomes converted into organic compounds, where it becomes involved in a variety of essential reactions. For example, P in alfalfa is essential for formation of nucleic acids, and associated with functions such as protein formation.

- **Potassium (K)**

Excessive soil K level can result in elevated alfalfa k level which may be detrimental to animal health. Results of wastewater reveals that K level in applied water was less than recommended and it is decreasing with time. Soil results indicate that K level in both soil layers are much correlated and no considerable variation of K level in both layers was observed except in 2005 spring time as presented in figure 5.20. There was no exact interpretation of this sudden increase; however it could be related to the fact that potassium bind to negative sites on the surface of soil particles, therefore the amount of this exchangeable potassium in a soil depends on the cation exchange capacity (CEC) of the soil, and on the levels of other cations (positively charged ions) in the soil. Results of other cations revealed that there was a drop in its level at that time which allow to K level increase.

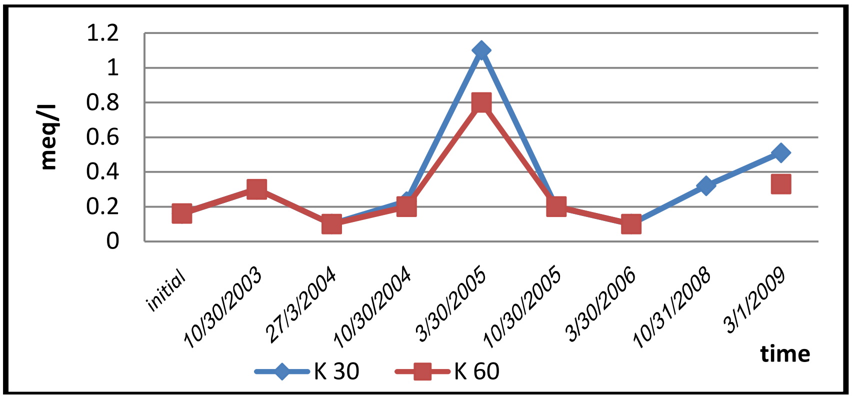


Figure 5-20: Potassium values for two soil layers

Generally results indicate that the K level in soil layers was **0.35** and **0.29** meq/l for surface and bottom layers respectively. Therefore extractable K level is low according to Marx , 1999 who indicated that K level less than **0.4 meq/100g** soil is low level . This is may be due to leaching of potassium which is common in sandy soil, with the greatest losses occurring when soils wetted by irrigation or rainfall. When this happens, drainage occurs, and potassium ions are leached out in this drainage water **(Marx, 1999)**

- **Organic Matter (OM)**

Soil organic matter consists of a variety of components. These include, in varying proportions; raw plant residues and microorganisms, active organic traction and stable organic matter also referred to as humus. Organic matter does not add any "new' plant nutrients but releases nutrients in a plant available form through the process of decomposition. Organic matter in soil is important for two main reasons. First acting as a "revolving nutrient bank account" and second, as an agent to improve soil structure and minimize erosion.

Results of OM soil content in both soil layers is presented in figure 5.21. It is noted that OM level vary highly from winter to summer and great harmony was exist for OM level in both soil layers. Organic matter varies significantly due to many reasons mainly the microbial activity, plant growth season and soil type. It was noticed that O.M level decreases in spring seasons because of alfalfa organic matter uptake is maximum at the beginning of alfalfa growing season. Meanwhile, microbial activity which consume huge amount of organic matter is in its maximum at spring and this lead to sharp decrease of soil organic matter content.

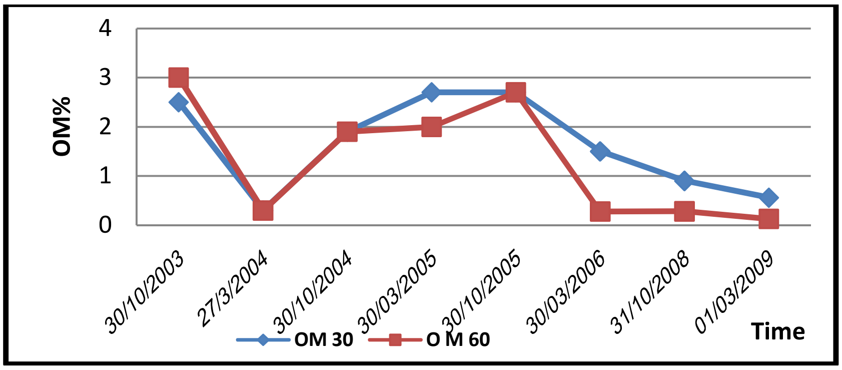


Figure 5-21: NO3 values for two soil depths.

Organic matter is then begins to increase as the first cut of alfalfa occur in June, this results in more organic matter soil content to occur till the second growing season in next spring. Moreover as the temperature increases the microbial activities decreases thus free more organic matter. The same results were obtained by **Kiziloglu, 2007** as he found that OM content varies with cabbage growing season (**Kiziloglu, 2007)**

Generally it is clearly noticed that applied wastewater increase the OM soil content considerably and this was obtained by **Kiziloglu, 2007** and **Angin et al, 2005**. Insofar as organic matter contributes to improved soil physical properties (e.g., moisture holding capacity and resistance to erosion) increasing soil organic matter will generally result in increased soil productivity. On many soils, suitable soil physical properties occur at relatively low levels of organic matter (2-4 per cent) (**M.J, 2003)**

- **Soil Heavy Metals Content**

Heavy metals contribute to environmental pollution mainly because they are non biodegradable and generally do not leach from top soil layers. Even if metals added with small concentrations, they find specific adsorption sites in soil where they are retained very strongly. (**Amiri, 2008**)

HM often occur as cations which strongly interact with the soil matrix, consequently, heavy metals in soils can become mobile as a result of changing environmental conditions. This situation is known as “Chemical timing bomb” (**Afshin, 2007**)

Data given in table 5.7 show the total amount of Pb, Zn and Cu in both soil layers of the investigated soil profile. Results revealed that the total content of these elements differed according to the soil depth as it's higher in the top soil especially after six years of application. These results agree with that obtained by **El Arabi, 2006** as he found that after 6 years of continually applying sludge at a cropland disposal site over 90 % of the applied heavy metals were found in the 0 to 15 cm soil depth. He also noticed that the heavy metals in a specific soil layer are due to repeated irrigation with wastewater. He also stated that the high permeability of sandy soil beside the colloidal state of the suspended matter facilitate the downward movement of heavy metals (**El Arabi, 2006**)

Table 5-7: Heavy metal concentration in BLPP soil layers

	Mar-04	Oct-04	Mar-05	Oct-05	Mar-05	Oct-08
0-30 cm						
Zn mg/l	<0.01	0.4	<0.01	< 0.01	0.128	0.164
Pb mg/l	<0.01	0.5	0.3	< 0.01	<0.1	0.008
Cu mg/l	1.5	0.5	<0.01	< 0.01	0.749	0.051
30-60 cm						
Zn mg/l	<0.01	0.5	<0.01	<0.01	0.48	0.078
Pb mg/l	<0.01	0.4	0.2	<0.01	<0.1	0.006
Cu mg/l	0.8	0.4	<0.01	<0.01	0.789	0.018

From the above mentioned results, it can be seen that, although the treated water contained high level of heavy metals especially Pb according to PS standards, the magnitude of increase in such metals in the soil irrigated with treated water was not high. Referring to the permissible limits of HM values in agricultural soil, considered by the European Economic Commission (**EEC**); total Zn (150-300ppm), Cu (50-100ppm), and Pb (50-100ppm), the present results in both soil layers show that the different HM level do not exceed this permissible limits, however the problem is that HM level increases with time and may pose severe risks as its level may be accumulate even after hundreds of years (**Amiri, 2008**).

Generally HM data revealed that more investigations should be performed to study the HM concentration in both wastewater and soil in case of using the effluent of BLWWTP for irrigational use compared with fresh water use.

5.5.3. Soil Biological Quality

Fecal and total coliform was the main tested indicators to investigate the biological contamination in soil. Results reveal that even there was noticeable biological contamination in applied wastewater; soil was free from the biological contamination in both layers. Neither the surface soil (0-30cm) nor the lower (30-60cm) contains biological indicators. This result may refer due to the type of soil as it is loamy sand which has high capability to leach the microbial contamination beyond the root zone. Moreover because of the open field conditions which is subjected to the sun lights that penetrates and disinfect the soil layers, natural disinfection has been occurred.

5.6. Alfalfa Quality

5.6.1. *Biological Quality of alfalfa*

The WHO, 2004 has recommended that crops to be eaten raw should be irrigated only with biologically treated effluent that has been disinfected to achieve a coliform level of not more than 100 coliform per 100 ml in 80% of the samples **(WHO, 2004)**

Results for alfalfa microbial analysis show that there was biological contamination in terms of fecal and total coliform in both alfalfa irrigated water (Wastewater and well water). As it was stated earlier, a control unit irrigated with well water was initiated in the fist year of the BLPP and biological analysis of alfalfa crops there indicated that maximum FC in alfalfa was **$20*10^3$** CFU/100ml occurred at the third cut which is similar to maximum alfalfa FC with wastewater irrigation.

Generally, FC level in both irrigated water was decreasing with time till it was minimized to the acceptable level for both fields (control and wastewater irrigation). Total coliform level for alfalfa irrigated with wastewater still have higher values than the acceptable range by PS standards all the times (**1000** CFU/100ml and 10,000TC./100ml**)** as illustrated in table 5.8. This reveals that biological contamination resulting from WWR is manageable and can be controlled. Similar results were obtained by Palacios as he found that wastewater irrigation could be used to irrigate fodder and forage crops in order to produce bulk feed for livestock with out sever biological contamination (**Palacios, 2000**).

Table 5-8 Biological contamination of alfalfa in BLPP using different water qualities

	Wastewater		**Fresh Water**	
Parameter	Fecal Col. 10^3/100ml	Total Col. 10^3/100ml	Fecal Col. 10^3/100ml	Total Col. 10^3/100ml
2nd cut 2003	2	40	1.8	9
3rd cut 2003	20	40	20	25
4th cut 2003	0	3	10	20
5th cut 2003	1.2	3	0	2
2nd cut 2004	0	2	0	3
3rd cut 2004	4	20	NA	NA
4th cut 2004	0	10	NA	NA
1th cut 2005	0	40	NA	NA

NA= Not Available

5.6.2. *Chemical Quality of Alfalfa*

Results of alfalfa heavy metals analysis indicated that alfalfa plant was free form HM during the past six year of experiment except for the lead content which was occasionally occur in alfalfa as its level was **2.78** ppm at the second and third year of wastewater irrigation. This level matches with the low HM level in soil and wastewater.

This is probably due to the high Pb uptake level of alfalfa crop relative to other forage crops (**EPA, 2003**).

Current guidelines do not specify the types of soil, plant, and other factors that have a bearing on how much metal a plant can uptake. Local conditions as climate, soil, plant characteristics affect the uptake of metals **(Kiziloglu, 2007).**

What is of most concern is the irregular increase of HM level in alfalfa samples in March, 2009 where results reveal that the lead level was **7.2**ppm. This sudden increase was observed in two different alfalfa samples analyzed at Al Azhar food lab.

Really there was no exact interpretation for these data as there was no possibility to verify these results where the lab atomic absorption device used for HM analysis was broken down and no other devices in GS can be used. The author reveal this data to the Israeli aggression against GS in January 2009 as reports talked on about **7000** Kg of toxic and destructive materials being thrown over limited are of GS. More investigation and studies should be conducted in this field to verify this result.

5.7. Estimating WW Agricultural Irrigation Demands in GS

To assess the feasibility of wastewater reuse, the reclaimed water supplier must be able to reasonably estimate irrigation demands and reclaimed water supplies. To make this assessment in the absence of actual water use data, evapotranspiration, percolation and runoff losses, and net irrigation must be estimated, often through the use of predictive equations (**EPA, 2004**).

Because crop water requirements vary with climatic conditions, the need for supplemental irrigation will vary from month to month throughout the year. This seasonal variation is a function of many factors; rainfall, temperature, crop type, stage of plant growth, and other factors, depending on the method of irrigation being used.

The supplier of reclaimed water must be able to quantify these seasonal demands, as well as any fluctuation in the reclaimed water supply, to assure that the demand for irrigation water can be met. Unfortunately, many agricultural users are unable to provide sufficient detail about irrigation demands for design purposes. This is because the user’s seasonal or annual water use is seldom measured and recorded. However, expert guidance is usually available through state colleges and universities and the local soil conservation service office.

Depending on these equations and generated results from current study, it was necessary to estimate the actual quantities of wastewater that could be used for agricultural irrigation under GS soil type, crops type and available areas. This was investigated regardless the water quality variation in GS.

Three different options were generated, the first was DORCH study which was conducted at 2005 as it accounts for the locations of proposed treatment plants and available area to be irrigated with wastewater (fruit crops) regardless the soil type.

In the second option, current crops areas excluding vegetables over all GS was considered and water quota for each crop was estimated based on results of CROPWAT model for crop water demand .

Finally based on study results, areas of crops over GS excluding the reddish soil and vegetable crops were estimated and then the crop water demand was calculated.

5.7.1. *Irrigation Water Demand Based on DORCH Study*

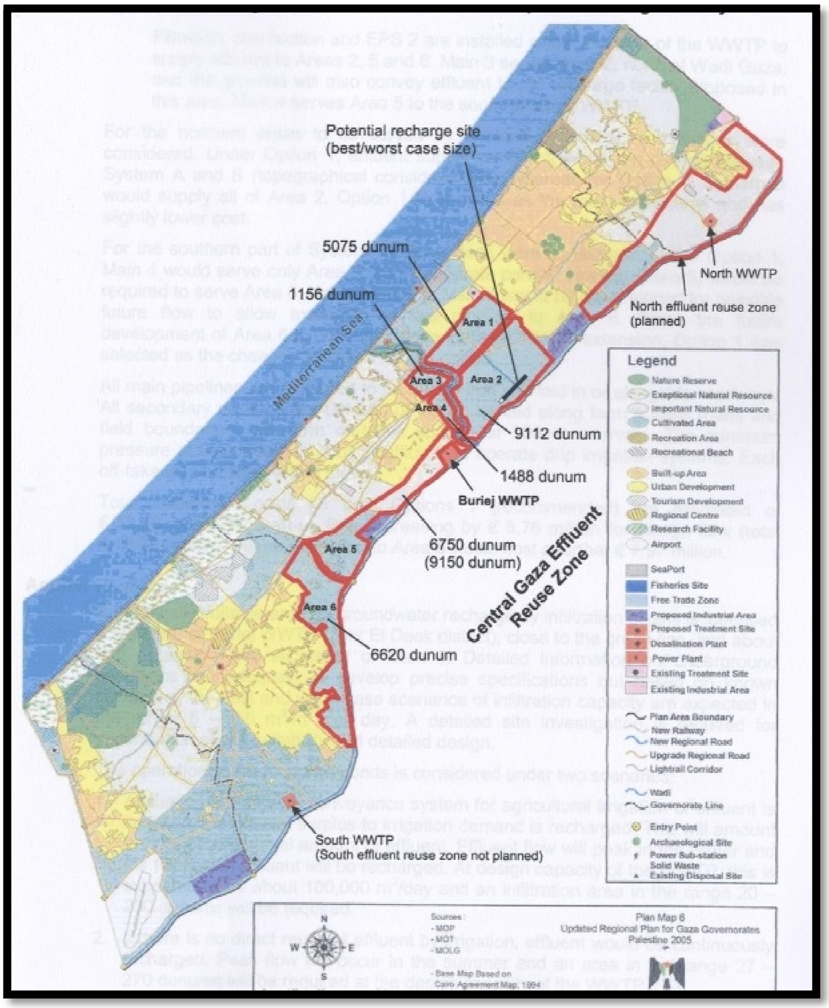


Figure 5-22: Proposed Irrigated areas using reclaimed wastewater in GS; (DORCH,2005)

In 2005, DORCH study suggested the areas to be irrigated with proposed effluent from the planned three treatment plants. The total area was estimated by about 60,000-80,000 dunum. As presented in figure 5.20 these areas located in the eastern half of Gaza Strip along the Israeli border where the new wastewater treatment plant will be located. The agricultural area is bounded from the west by the main median road (Salah El-Dein).These areas were considered because there is little ongoing urban development and none planned in the future.

Moreover, farming activity is widespread but access to water is often difficult, the quality of groundwater is mediocre (salinity, nitrates) and not used for producing drinking water (**OTUI, 1998**).

The problem with that plan is the soil type of these areas which is mostly reddish brown with low infiltration capacity. This will lead to salts and nutrients accumulation thus specific salt tolerant crops could be cultivated in those areas. Considering the DORCH plan, the quantity of wastewater that can be used for irrigation is ranged between **32.24 – 120 Mm^3/year** according to the selected crops type as the minimum and maximum water quota per crop is **400 and 1500m^3/year** respectively.

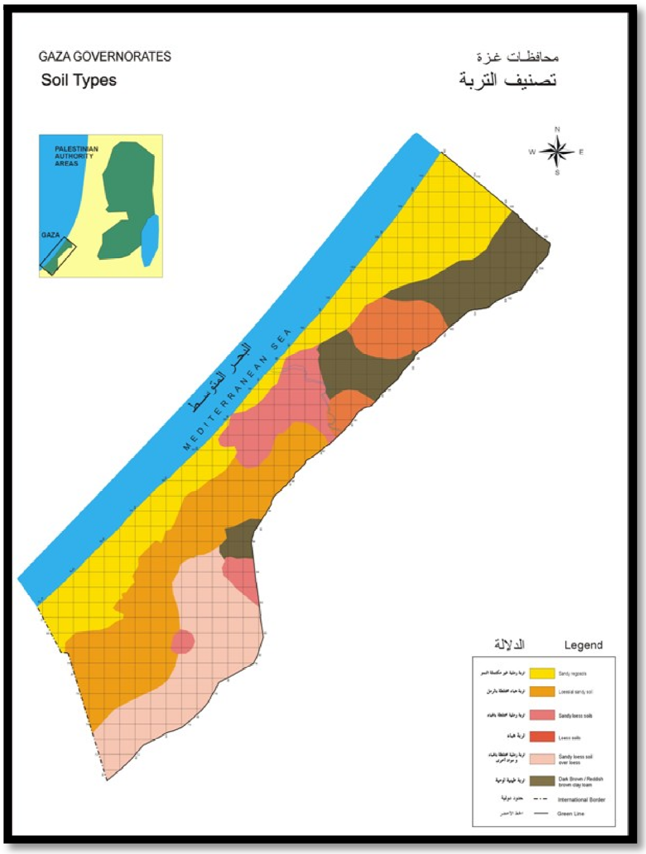


Figure 5-23: Soil type over GS (MOPIC, 1998)

5.7.2. Irrigation Water Demand Based on Current Crops Area

Agricultural water demand was also estimated based on the current cultivated areas and crops type according to MOA, 2006 report. The water quota allowed for each crop was calculated using the CROPWAT model by Al Najar, 2007. Table 5.10 presents the crops types and areas for the current crops and the total water quantity required by these crops. These results was driven based on the crops distribution over GS excluding the vegetable regardless the soil type as shown in figure 5.21. Results indicated that the total water required for the listed is **43.646Mm^3/year** under current option.

Table 5-9: Water Requirements for Certain Crops in GS; Source: (MOA, 2006)

Crop type	Area cultivated (dunum)	Water requirement (m^3/dunum)	Total water requirement (10^6 m^3/yr)
Almond	2570	400	1.028
Fruits	12520	400	5.008
Citrus	15656	900	14.0904
Dates	4020	400	1.608
Flowers/ Forage	455	1500	0.6825
Ornamental	294	500	0.147
Olives	25708	700	17.9956
Field crops	61740	50	3.087
Total	**122943**		**43.6465**

5.7.3. Irrigation Water Demand Based on Soil Type

Through this option, care was given to the soil type as it excludes the clayey soil for its low permeability and infiltration capacity.

This may be harm from groundwater point view but its matching the results obtained during this study as the higher the permeability of the soil, the lesser the salts and nutrients accumulation.

Using GIS 9.2 arc view software, the area of each crops was determined based on GS crops map distribution as in figure 5.21 excluding areas of vegetables. This map was overlaid by the soil type map of GS to exclude the reddish brown soil. The resulted crops areas illustrated in table 5.11. Water requirements per each crop lead that the total quantity of wastewater that can be used for irrigation is **57.72Mm^3 /year**

Table 5-10: Crops Distribution in GS over Sandy Soil

Crop type	Total Area (dunum)	Water requirement (m^3/dunum)	Total water requirement (10^6 m^3/yr)
Almond	6,272.10	400	2.50884
Citrus	39,090.10	900	35.18109
Dates	7,939.10	900	7.14519
Hori-culture	21,887.50	400	8.755
Grapes	5,503.60	500	2.7518
Olives	1,979.70	700	1.38579
Total	**82672.10**	**--**	**57.72Mm^3**

Generally, the estimation of proposed water quantity required for irrigation in GS differs according to the crops selection due to the high variation of water requirements per each crop and the crop pattern. It was noticed that the average water quantities that can be used in GS under different options is about **45.00 Mm^3/year.** This figure is a rough estimation regardless the quality of irrigated water and its impact.

Where the total generated quantities of wastewater in GS is expected to be about **48 Mm^3** as was calculated by Afifi ,2006, all of these quantities can be used for irrigation purposes if storage facilities being provided for the winter time or recharging into the aquifer.

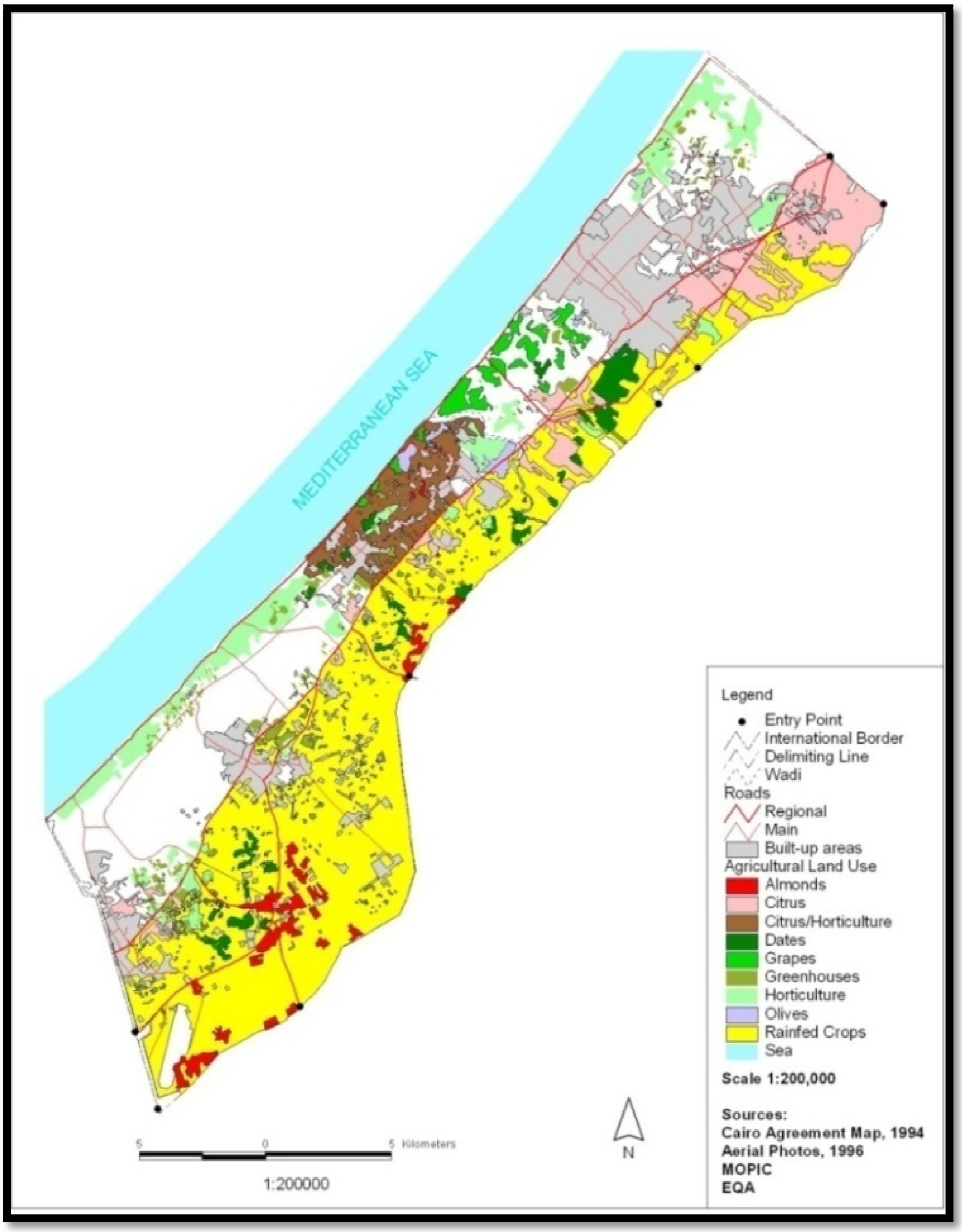


Figure 5-24: Crops distribution over Gaza Strip, Source (MOA, 2006)

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

6.1. Conclusions

The main objective of this study is to investigate the impacts of long term use of wastewater irrigation on soil and crop properties. Results obtained from field measurements and historical data induce a meaningful trend for development of soil and plant properties.

Generally, both opportunities and problems exist in using recycled wastewater (RWW) for irrigation. Recycled wastewater irrigation is a powerful means of water conservation and nutrient recycling, thereby reducing the demands of freshwater and mitigating pollution of surface and ground water. It also increases the crop yield and gives higher production. However, potential problems associated with recycled wastewater irrigation do exist.

1) Current wastewater effluent from BLWWTP is suitable to irrigate salt tolerant and moderately tolerant crops as its salinity level matching the different international standards (EC<3 dS/m), however BLWWTP effluent has high level of sodium than recommended (average of 240mg/l); therefore continuous irrigation with wastewater leads to high Na accumulation in the soil which negatively affects the soil infiltration and plant nutrients uptake.

2) Current wastewater of BLWWTP could be used for irrigating salt sensitive crops under extended management practices. Management practices, such as applications of soil amendments that provide Ca to replace Na; periodic leaching to reduce salt accumulation; frequent aerifications to maintain infiltration, percolation, crop rotation, drainage and regular soil and plant monitoring will be helpful in mitigating the negative impact and ensuring continued success in using RWW for irrigation.

3) Salt and sodium was leached out of the root zone at the early start for the first three years because of sandy soil, and then it accumulates on the top soil layer as its level increases significantly under repeated wastewater irrigation. Even there were problems associated from wastewater reuse, yet it could be managed by different ways including irrigation pattern, nutrients load, soil enhancement and crop selection.

4) Where more wastewater generates and the plans of PWA is to limit the use of ground water for agricultural irrigation by replacing it with RWW, and as there is development cultivated areas plan to switch to recycled wastewater irrigation, water resources managers must be prepared to face new challenges associated

with the use of recycled wastewater and to mitigate the negative effects and ensuring continued success in using RWW for irrigation.

5) Despite of the high level of FC in applied wastewater in PLBB there was no biological contamination of soil and alfalfa as its FC was in acceptable range (<1000CFU/100ml) except for the first year. Moreover no health risks or outbreaks were encountered along the six year experiment. This means that irrigated water biological contamination can be managed by and controlled.

6) Heavy metals especially Lead (Pb) varies significantly with time in both wastewater and soil. Pb level in Alfalfa was extremely high and it increases as long as the period of wastewater irrigation increase. Alfalfa plant lead level increased irregularly by about 265% (7.2 ppm) after the Israeli aggression against Gaza Strip in BLPP field and this could be a proof on the existence of toxic elements used during the aggression. More investigation is a must.

7) Despite the remarkable level of Lead in wastewater and alfalfa plant it was noticed that the lead level in soil was negligible and lower than expected, this may be due to the high uptake level of alfalfa plant to the lead element

8) Lack of qualified laboratories in the GS and shortage of atomic adsorption devices especially after destruction of IUG labs prohibit the verification of results especially plant heavy metals content.

9) The water Effluent quantities from treatment plants meet the required quantities for agriculture irrigation under different scenarios of wastewater reuse plans. Currently most of treated effluent quantities of GS treatment plants (about 43 Mm^3) are required by current crops to be used for irrigation based on crops areas in GS. This means that treated effluent in winter time should be stored or recharged.

6.2. Recommendations:

1) Whenever wastewater intended to be used for irrigation, a control unit should be initiated along side with the reuse project for scientific purposes and comparisons.

2) Whenever wastewater being used for irrigation in other places in GS more care should be given as the water quality especially salinity as it dominates GS aquifer, thus more control measures should be taken as crops selection and leaching fraction.

3) Planned areas of wastewater irrigations suggested by DORCH, 2005 study should be reviewed and extended according to soil and crops types. Crops with high water requirements may be preferred.

4) Rehabilitation and construction of environmental labs should be carried out immediately providing all necessary apparatuses especially those used for testing heavy metals and main nutrients.

5) Great care should be exercised to sodicity which increased after six years to higher levels than recommended by different standards. The high SAR of soil with current salinity values are expected to have negative effect on plants regarded to its yield. In managing these soils when irrigated with saline or semi saline waters, the salt added to them by the irrigation effluent should be equal to the salt removed by plants and by leaching. Therefore leaching requirements should be recalculated based on the current soil and applied wastewater salinity.

6) WWR irrigation needs higher concern about possible long-term reductions in soil hydraulic conductivity and infiltration rate in soil especially soils with high clay content, although these levels were not high enough to result in our case as the soil is loamy sand, but it could result with clayey soils.

7) Even the level of heavy metals was matching the international standards in both soil and applied wastewater, it increases as long as the period of wastewater irrigation increase, more concern and protection measures should be given with time to predict the time of outbreaks occurrence.

REFERENCES

1) Abu Madi, M. O. (2004). Incentive Systems for Wastewater Treatment and Reuse in Irrigated Agriculture in the MENA Region: Evidence from Jordan and Tunisia. *Dissetation for the Doctorate* . Netherland: Delft University of Technology and the Academic Board of the UNESCO-IHE Institute for Water Education.

2) Abu Zaid, K. (1998). recent trends and development:reuse of wastewater in agriculture. *Cairo, Environmental Mgmnt. and health , 9* (2).

3) Afifi, S. (2006). Wastewater Reuse Status in Gaza Strip, Palestine. *International J. Environment and Pollution,* , Vol. 28, Nos. 1/2.

4) Afshin, Q., & Moor, F. (2007). Statistical Analysis of Accumulation and Sources of Heavy Metals Occurrence in Agricultural Soils of Khoshk River Banks. *American-Eurasian J. Agric. & Environ. Science , 2* (5), 565-573.

5) Al Najar, H. (2007). Urban agriculturand eco-sanitation: the strategic potential toward poverty alleviation in the Gaza strip. *7* (1).

6) Al-Khaldi, R. (2006). Performance Evaluation of Beit-Lahia Wastewater Treatment Plant in the Northern Gaza Strip. *Master Thesiss* , Islamic University of Gaza.

7) Amiri, S. S., H., M., & A., A. (2008). Heavy Metals Accumulation in Melilotus Officinalis Under Crown Olea Europaea L Forest Irrigated With Wastewater. *African Journal of Biotechnology , 7* (21), 3912-3916.

8) Andereadakis, A., Gavalaki, E., Mamaisa, D., & Tzimas, A. (2001). wastewater Reuse Criteria in Greece.

9) Angelakis, T. (2002). Management of wastewater by natural treatment systems with emphasis on land-based systems. . *In: Decentralised Sanitation and Reuse* , 252-258.

10) Angine, I., Yaganoglu, A., & Turam, M. (2005). Effects of Long Term Wastewater Irrigation on Soil Properties. *J. Sus. Agriculture. , 26* (3), 31-42.

11) APHA, A. P. (1995). *StandardsMethods for the Examination of Water and Wastewater.* USA, America: 20th Washington D.C.

12) Asano, T. (1998). Evaluation of Tertiary Treatment Requirements in California. *Water Environ. Technol.,* , 4 :37-41.

13) Ayers, R., & Westcot, D. (1985). Water Quality for Irrigation.FAO Irrigation and Drainage paper. *Food & Agriculture Organization of the United Nation , Paper NO.29*, Rome.

14) Bazza, M. (Greece, 26-29 September 2002). Wastewater Recycling and Reuse in the Near East Region: Experience and Issues. *Int. Proc. of IWA-Regional Symposium on,Water Recycling in Mediterranean Region. Iraklion, ,* 43-60.

15) Biswas, T., Gerrit, S., Rob, S., Graem, S., John, B., & Geoff, M. (2007). *Final Report: Salinity Impact on Lower Murry Horticulture (DEP-15 PROJECT).* Murry, Australia: Australian Research and Development Institute.

16) Biswas, T., Stevens, R., & Schrale, G. (2005). Root Zoon Salinity in the Lower Murray Districts. *ANCID Confrence 2005. 23-26 oct. VIC 3051*. Melbourne: www.lmw.vic.gov.au.

17) Blummenthal, Peasey, Mara D; Palacios. (2000). *Guidelines for wastewater reuse in agriculture and aquaculture: recommevded revisions based on new resaerch evidence.* Newyourk: Work press.

18) Christopher, S. A., Antonio, Z., & Gilbert, L. (2001). *Urban-Wastewater Reuse for Crop Production in the Water-Short Guanajuato River Basin, Mexico.* Colombo, Sri Lanka.: International Water Management Institute.

19) CMWU. (2007). *Annual Report of Wastewater Quality in Gaza Strip for years 2007 and 2008.* Gaza: Coastal Municipality Water Utility.

20) ElArabi, A., & ElBordiny, M. (2006). Impact ofReused Wastewater for Irrigation on Availability of Heavy Metals in Sandy Soil and Their Uptake by Plant. *Journal of Applied Science Research* , 106-111.

21) EPA. (June 2003). *Guidelines For Environmental Management Use Of Reclaimed Water, Victoria40 City Road, Southbank Victoria 3006.* Sydney: Australia Publication 464.2 ,ISBN 0 7306 7622 6 © EPA Victoria,.

22) EQA. (2005). *Development of tools and guidelines for promotion of the sustainable urban wastewater treatment and reuse in the agricultural production in the Miditerranean Countries (EQA).* Gaza Strip: EQA.

23) EQA. (2004). Strngthening the Palestinian Environmental Action Program, Life Project. *Environmenta Qua;lity Authority , Phase 4* .

24) Erfani, A., Haghnia, G. H., & Alizadeh, A. (2001). Effect of irrigation by treated wastewaterr on the yield and quality of tomato. *Agricultural Sci. and Technol.* , 15(1): 65-7.

25) FAO. (1992). "Treatment of wastewater used for irrigation" ,. *The Food & Agriculture Organization of the United Nations,Regional Office for the Near East, Cairo, Egypt.* , Technical Bulletin Series No. 2.

26) FAO. (1997). Quality control of wastewater for irrigated crop production. *Food and Agriculture organization (Water reports - 10)* (1020-1203), Rome.

27) Genius, M., & K.P., T. (2006). Waster shortages and implied water quality: A contingent valuation study. *42* (doi:10-1029).

28) Horan, N. (1997). *Biological Wastewater Treatment Systems 'Theory & Operations'.* England: British Library Cataloguing ISBN 0471 92258.

29) Hussain, I. e. (2002). Wastewater Use in Agriculture: Review of Impacts and Methodological Issues in Valuing Impacts. *International Water Management Institute, Colombo: useful review of wastewater irrigation which contains an excellent extended list of bibliographical references on wastewater irrigation , (Working Paper 37).*

30) Jahantigh, M. (2008). Impacts of Recycled Wastewater Irrigation on Soil Chemical properties in an Arid regions. *11* (18).

31) Kamizoulis, G., Bahri, A., Brissaud, F., & A.N. (2007). Wastewater recycling and reuse practices in Mediterranean region:Recommended Guidelines.

32) Kathijotes, N. (2006). wastewater for Irrigation:An Acceptable Soil Conditioner. *Conference on Water Observation and Information Systems for decision Support. 2.* Ohird: FYROM.

33) Kathijotes, N., & Marinova, N. (22-23 Oct 2003,). Wastewater Reuse for Irrigation: Evaluation of Salinisation Risk.National Conference with International Participation, Ministry of Agriculture and Forestry,. *Sofia, BG and "Ecology And Future" Bulgarian Journal of Ecological Science* , Vol.II No.1,.

34) Kiziloglu, F., Turan, M., Sahin, U., Angin, I., Anapali, O., & Okuroglu, M. (2007). Effects of wastewater on soil and cabbage-plant(brassica olerecea) chemical properties. *J. Plant Nutr. Soil Sci , 10* (20061917), 170, 166-172.

35) Laura, A., Gidon, O., Yossi, M., Leonid, G., & Miquel, S. (2000). *Wastewater Reclamation and reuse for agricultural irrigation in Arid Regions: Experience of the city fo Arad, Israel.* Haifa, Israel: The Grand Water Research Institute.

36) Mara, D. (2001). Appropriate wasewater collection, treatment,and reuse. *Instituation of Civil Engineers Municipal Engineers* , 299-303.

37) Mara, D. (2006). *Wastewater Treatment for Wastewater Reuse: Required Effluent Qualities and How to Acheive Them at reasonable Cost.* Amman.

38) Mara, D., Blumenthal, U., & Carr, R. (2006). Health risks in wastewater irrigation: comparing estimates from quantitative micropbial risk analysis and epidemiological studies. *4* (3).

39) Marx, E., j., H., & R.G., s. (1999). *Soil tests Interpretation Guide, Soil Test manual.* USA: oregon State Uuniversity.

40) Miller, M. (2000). The Phosphorus (P) and Potassium (K) Soil Testing and Fertilizer Recommendation System in Ontario . ISSN 1198-712.

41) MOA. (2006). *The Value of Agricultural Production in Gaza Strip Governorates.* Gaza: Ministry of Agriculture, Department of planning and policies, Statistical and information unit.

42) MOA, PHG, EQA, & Project, F. (2004). *Technical Report and Partial results for the 2003 season of Agricultural Monitoring Development Support Program (Beit Lahia Site).* Gaza: Ministry Of Agriculture.

43) MOPIC. (1998). Master Plan for Sewage and Stormwater Drainage in the Gaza governorate- Final Master Plan report. *Main Report, Palestinian National Authority* , Ministry of Planning and International Cooperation.

44) Najaf, S., Mousavi, F., & Feizi, M. (2003). Effects Of Using Treated Municipal Wastewater In Irrigation Of Tomatop. . *Isfahan Soil and Water Research Center* , 1-8.

45) Najafi, P. (2002). Assessment of optimum model of using treated wastewater in irrigation ofSome Crops. *Ph. D. Thesis, Khorasgan Azad University, Isfahan, Iran* , 304 p.

46) Oron, G., & Campos, G. S. (1999). *Wastewater treatment, renovation and reuse for agricultural irrigation in small communities.* Mixico: Agr. Water Man.

47) OTUI. (1998). *Feasibility Study of the Reuse of Treated Wastewater for the Entire Gaza Agglomeration.* Phase 3, Draft Final Report. MOPIC. .

48) Ouda, O., & Al-Agha, M. (2000). Treated wastewater use in Gaza District: The question of public acceptance. *Fifth International Water Technology Conference* , Alexandria, Egypt 471-481.

49) P.L, W., & Martin, A. R. (1994). The Importance and Management of Soil Organic matter in Tropics. *3* (12).

50) Palacios, M., Pardo, A., Del-Nero, E., & Rodriguez, F. (2000). *Alfalfa production irrigated with treated effluentin Canary Islands.* Canary Islands, Spain: CIHEAM - Options Mediterraneennes.

51) PCBS, P. C. (2007). Preliminary Results for the Census of Population and Inhabitants.Palestinian Central Beurou of Statistics, Ramallh

52) Pescode, M. (1992). Wastewater treatment and use in agriculture. *FAO Irrigation Drainage* , Paper 47 Rome.

53) Pool. (2004). Water and crop production consideration in Municipal wastewater application to forage crops: Results of Nitrate National Alfalfa symposium. San Diego: UC Cooperative Extension.

54) PWA, P. W. (2000). Water Sector Strategic Planning Study, Final Report,. *Specialist studies, Part B: Focal areas.* , Volume III.

55) Qian, Y., & B., M. (2005). Long Term effects of Recycled Wastewater Irrigation on Soil Chemical Properties on Golf Course Fairways. *97*.

56) Rusan, M. M., Hinnawi, S., & Rusan, L. (2006). Long Term Effects of wastewater Irrigation of Forage Crops on soil and Plant Quality Parameters. *215*.

57) Ryan, J., George, E., & Rashid, A. (2001). Soil and Plant Analysis Laboratory Manual.

58) Seibe, C. (1996). Effects of long term irrigation with untreated sewage effleuent on soil properties and heavy metal adsorbtion of Leptosol and vertisol in Central Mexico. *Bodenkd , 8* (7), 357-364.

59) Shoamr, B., Müller, G., & Yahya, A. (2003). Wastewater Of Gaza, Chemistry And Management Approach. *Institute of Environmental Geochemistry, University of Heidelberg,* , Feld 236, 69120 Heidelberg, Germany.

60) Standen, R. (2000). Developing Irrigation Guidelines for Wastewater irrigation. *Annual Water Industry Engineers and operators Confrence . 63rd.* Warrnambool: Brauer College.

61) Tamm, T., A., M., J., S., K., D., & T., T. (2006). *Distribution of Nitrogen in Soil When Irrigating Short rotation Forest With Pretreated wastewater.* NJF-Seminar 373.

62) Tsagarakis, P. K., G., D. E., & A.N., A. (2003). water Resources Management in Crete and Proposed Quality Criteria for Use of Recycled water in The Mediterranean Region. *48* (4).

63) Tsagarakis, P. K., P., T., K., C., & A.N., A. (2001). Water Resources Status Including Wastewater Treatment and Reuse in Greece, Related Problems and Prespectives. *26* (2).

64) Tubail, K., Dadah, J., & Yassin, M. (2003). Present and Prospect Situation of Wastewater and its Possible Reuse in the Gaza Strip.

65) UNEP, U. N. (2005). Environmental Impact of Wastewater Use Practices. *MED-WG* , 1-83.

66) Westerman, R. (1990). Soil Testing and Plant Analysis,3rd edition. *Soil Sci.Soci.Am,WI* , Madison, USA.

67) World Health Organization, WHO. (2006). *Guidelines for the safe use of wastewater, excreta and grey water*. Geneva: Policy and regulatory aspects, ISBN 92 4 154682 4 (v. 1).

68) World Health Organization, WHO. (1989). *Health Guidelines for Wastewater Use in Agriculture and Aquaculture.* Geneva: Technical Report Series No. 778.

APPENDIXES

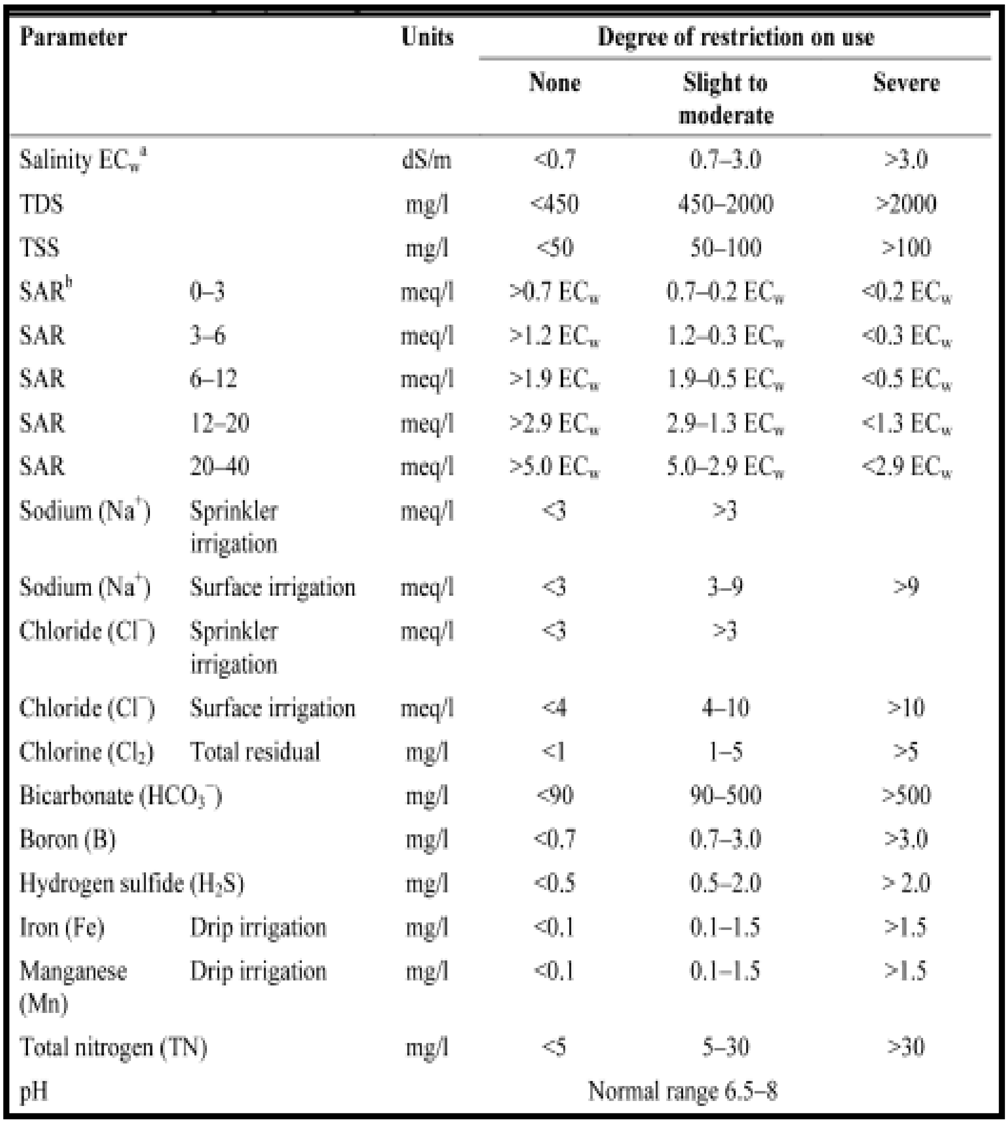
APPENDIX 1:

INTERNATIONAL GUIDELINES OF IRRIGATION WATER QUALITY

GUIDELINES FOR IRRIGATION WATER QUALITY (FAO, 1992)

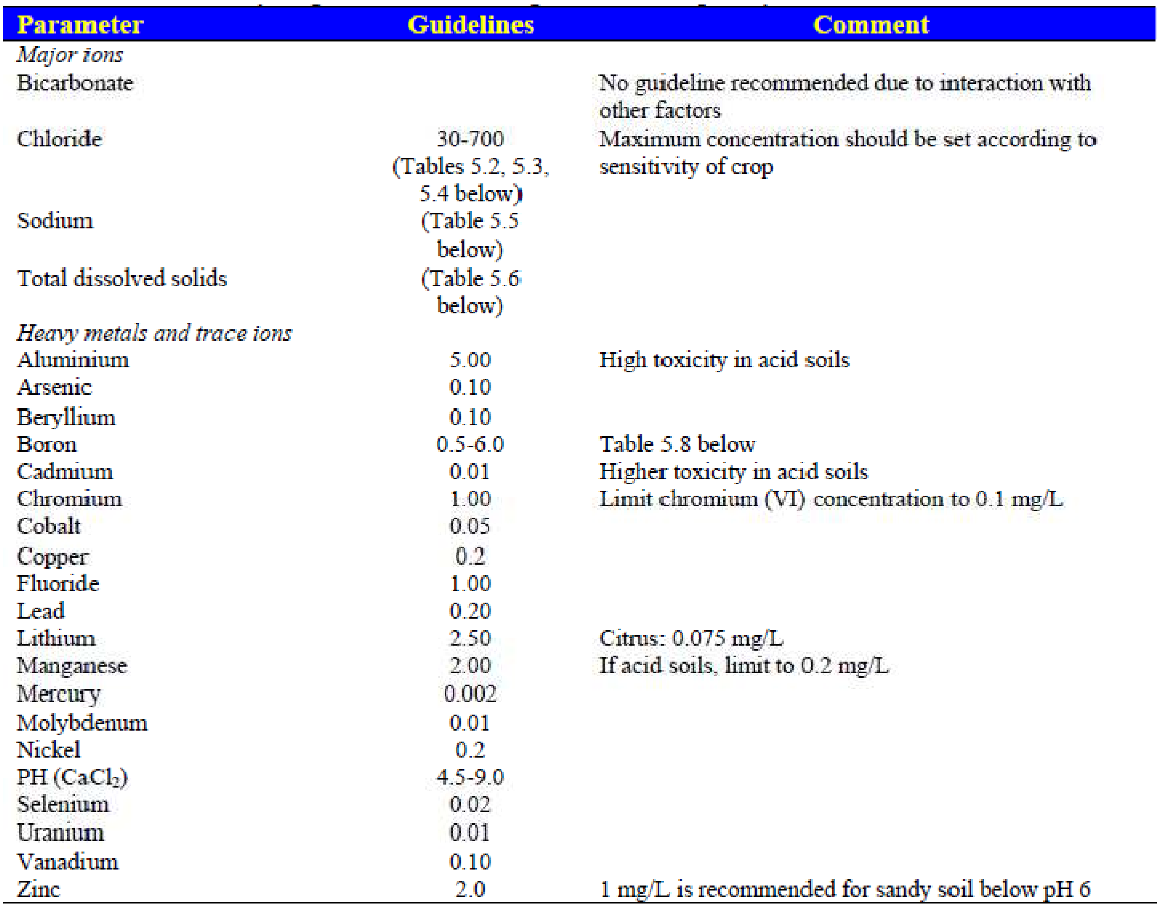
Water parameter	**Symbol**	**Unit**[1]	
SALINITY			
Salt Content			
Electrical Conductivity	EC_w	dS/m	0 – 3
(or)			
Total Dissolved Solids	TDS	mg/l	0 – 2000
Cations and Anions			
Calcium	Ca^{++}	me/l	0 – 20
Magnesium	Mg^{++}	me/l	0 – 5
Sodium	Na^{+}	me/l	0 – 40
Carbonate	CO^{--}_3	me/l	0 – .1
Bicarbonate	HCO_3^-	me/l	0 – 10
Chloride	Cl^-	me/l	0 – 30
Sulphate	SO_4^{--}	me/l	0 – 20
NUTRIENTS2			
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2
Potassium	K^+	mg/l	0 – 2
MISCELLANEOUS			
Boron	B	mg/l	0 – 2
Acid/Basicity	pH	1–14	6.0 – 8.5
Sodium Adsorption Ratio[3]	SAR	(me/l)[1], [2]	0 – 15

FAO Guidelines for interpretation of Water Quality for Irrigation, Ayers and Westcott, 1985,



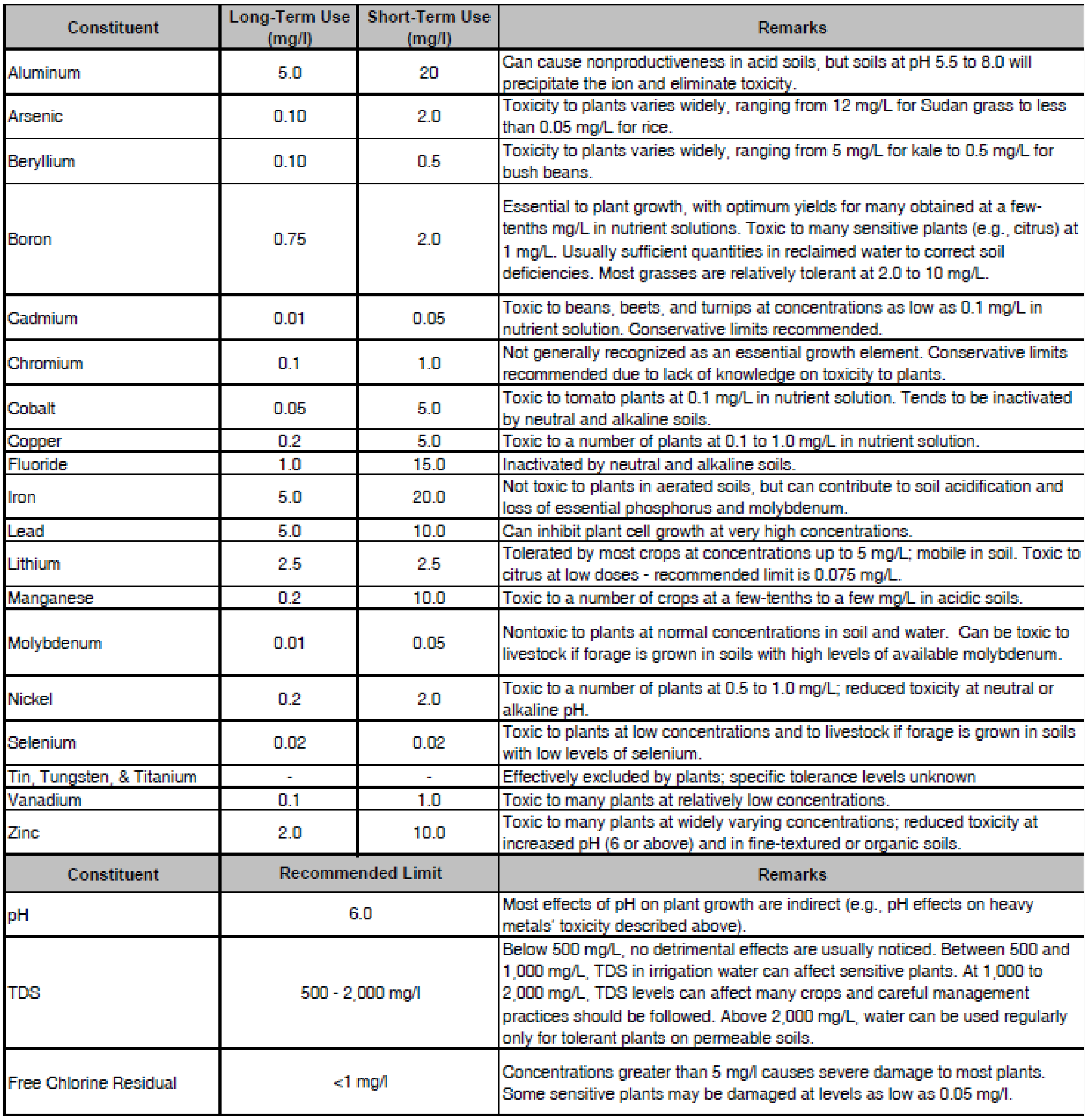
Parameter		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Salinity EC_w[a]		dS/m	<0.7	0.7–3.0	>3.0
TDS		mg/l	<450	450–2000	>2000
TSS		mg/l	<50	50–100	>100
SAR[b]	0–3	meq/l	>0.7 EC_w	0.7–0.2 EC_w	<0.2 EC_w
SAR	3–6	meq/l	>1.2 EC_w	1.2–0.3 EC_w	<0.3 EC_w
SAR	6–12	meq/l	>1.9 EC_w	1.9–0.5 EC_w	<0.5 EC_w
SAR	12–20	meq/l	>2.9 EC_w	2.9–1.3 EC_w	<1.3 EC_w
SAR	20–40	meq/l	>5.0 EC_w	5.0–2.9 EC_w	<2.9 EC_w
Sodium (Na^+)	Sprinkler irrigation	meq/l	<3	>3	
Sodium (Na^+)	Surface irrigation	meq/l	<3	3–9	>9
Chloride (Cl^-)	Sprinkler irrigation	meq/l	<3	>3	
Chloride (Cl^-)	Surface irrigation	meq/l	<4	4–10	>10
Chlorine (Cl_2)	Total residual	mg/l	<1	1–5	>5
Bicarbonate (HCO_3^-)		mg/l	<90	90–500	>500
Boron (B)		mg/l	<0.7	0.7–3.0	>3.0
Hydrogen sulfide (H_2S)		mg/l	<0.5	0.5–2.0	> 2.0
Iron (Fe)	Drip irrigation	mg/l	<0.1	0.1–1.5	>1.5
Manganese (Mn)	Drip irrigation	mg/l	<0.1	0.1–1.5	>1.5
Total nitrogen (TN)		mg/l	<5	5–30	>30
pH			Normal range 6.5–8		

SUMMARY FOR IRRIGATION WATER QUALITY (MG/L AUSTRALIAN WATER QUALITY GUIDELINES, 1992)



Parameter	Guidelines	Comment
Major ions		
Bicarbonate		No guideline recommended due to interaction with other factors
Chloride	30-700 (Tables 5.2, 5.3, 5.4 below)	Maximum concentration should be set according to sensitivity of crop
Sodium	(Table 5.5 below)	
Total dissolved solids	(Table 5.6 below)	
Heavy metals and trace ions		
Aluminium	5.00	High toxicity in acid soils
Arsenic	0.10	
Beryllium	0.10	
Boron	0.5-6.0	Table 5.8 below
Cadmium	0.01	Higher toxicity in acid soils
Chromium	1.00	Limit chromium (VI) concentration to 0.1 mg/L
Cobalt	0.05	
Copper	0.2	
Fluoride	1.00	
Lead	0.20	
Lithium	2.50	Citrus: 0.075 mg/L
Manganese	2.00	If acid soils, limit to 0.2 mg/L
Mercury	0.002	
Molybdenum	0.01	
Nickel	0.2	
PH ($CaCl_2$)	4.5-9.0	
Selenium	0.02	
Uranium	0.01	
Vanadium	0.10	
Zinc	2.0	1 mg/L is recommended for sandy soil below pH 6

RECOMMENDED LIMITS FOR CONSTITUENTS IN RECLAIMED WATER FOR IRRIGATION (US EPA, 2004)



Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Remarks
Aluminum	5.0	20	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at concentrations up to 5 mg/L; mobile in soil. Toxic to citrus at low doses - recommended limit is 0.075 mg/L.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/L in acidic soils.
Molybdenum	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium.
Tin, Tungsten, & Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

Constituent	Recommended Limit	Remarks
pH	6.0	Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
TDS	500 - 2,000 mg/l	Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine Residual	<1 mg/l	Concentrations greater than 5 mg/l causes severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/l.

Australian EPA, 2003 guidelines for wastewater irrigation Quality Parameters

Water parameter	**Usual Range of WW**
SALINITY	
Electrical Conductivity EC_w dS/m	**0 – 3**
Total Dissolved Solids TDS mg/l	**0 – 2000**
CATIONS AND ANIONS	
Calcium Ca^{++} meq/l	**0 – 20**
Magnesium Mg^{++} meq/l	**0 – 5**
Sodium Na^{+} meq/l	**0 – 40**
Carbonate CO^{--}_3 meq/l	**0 – 0.1**
Bicarbonate HCO_3^- meq/l	**0 – 10**
Chloride Cl^- meq/l	**0 – 30**
Sulphate SO_4^{--} meq/l	**0 – 20**
NUTRIENTS	
Nitrate-Nitrogen NO_3-N meq/l	**0 – 10**
Ammonium-Nitrogen NH_4-N meq/l	**0 – 5**
Phosphate-Phosphorus PO_4-P meq/l	**0 – 2**
Potassium K^+ meq/l	**0 – 2**
MISCELLANEOUS	
Boron B meq/l	**0 – 2**
Acid/Basicity pH	**6.5 – 8**
Sodium Adsorption Ratio SAR meq/l	**0 – 15**

SUMMARY OF BLPP WATER QUALITY COMPARED WITH DIFFERENT STANDARDS

Parameter	**PS**	**FAO**	**Aus. EPA**	**BLPP applied WW**
F.C CFU/100 mL)	<1000/100ml	<1000/100 ml	<1000/100ml	60 - 6000
Cd (mg/L)	0.01	0.01	0.01	0.005
Pb (mg/L)	1	5	5	1-4
Hg (mg/L)	0.001	0.001	0.001	< 0.001
Cr (mg/L)	0.1	0.2	0.1	< 0.01
Cu (mg/L)	0.2	0.2	0.1	< 0.1
EC (dS/m)	2.5	0-3	0-3	1.85-1.95
TDS (mg/L)	1500	500-2000	0-2000	1236
pH	6.5-9	6-8.5	6.5-8	7.4-8.3
SS mg/l	40 / 50	50	50	64
BOD mg/l	45 / 60	20-30	20-30	53.6
COD mg/l	150 / 200	50-60	50-60	105
Cl mg/l	500	1000	1000	1224
NO3mg/l	50	50	50	23.5
Ca mg/l	400	400	400	79.2
Mg mg/l	60	60	60	45
Na mg/l	460	900	900	234
TKN mg/l	50	NA	NA	56.6
Total P mg/l	30	30	30	2.8
SAR	9	0-15	0-15	5.9

.

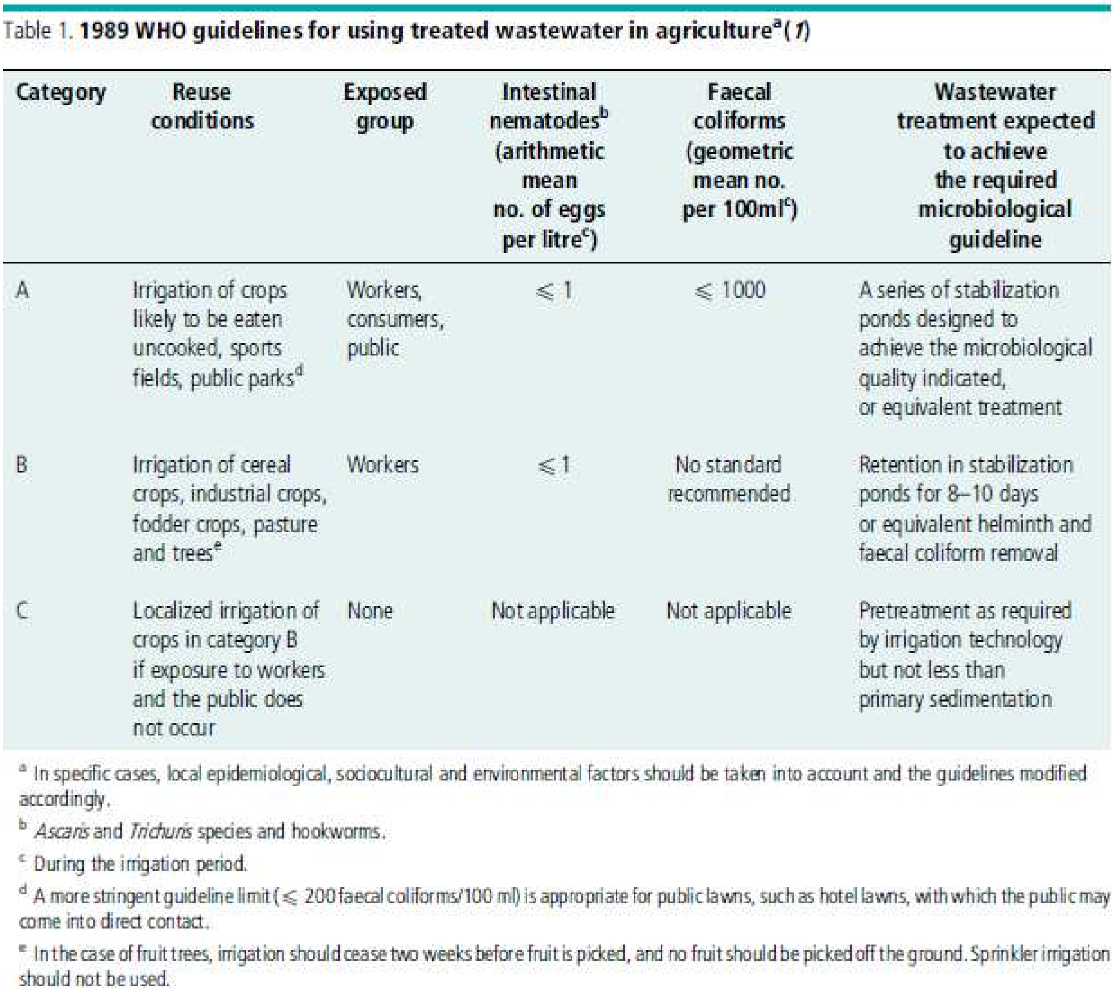


Table 1. **1989 WHO guidelines for using treated wastewater in agriculture[a] (*1*)**

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100ml[c])	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	⩽ 1	⩽ 1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	⩽ 1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by irrigation technology but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms.

[c] During the irrigation period.

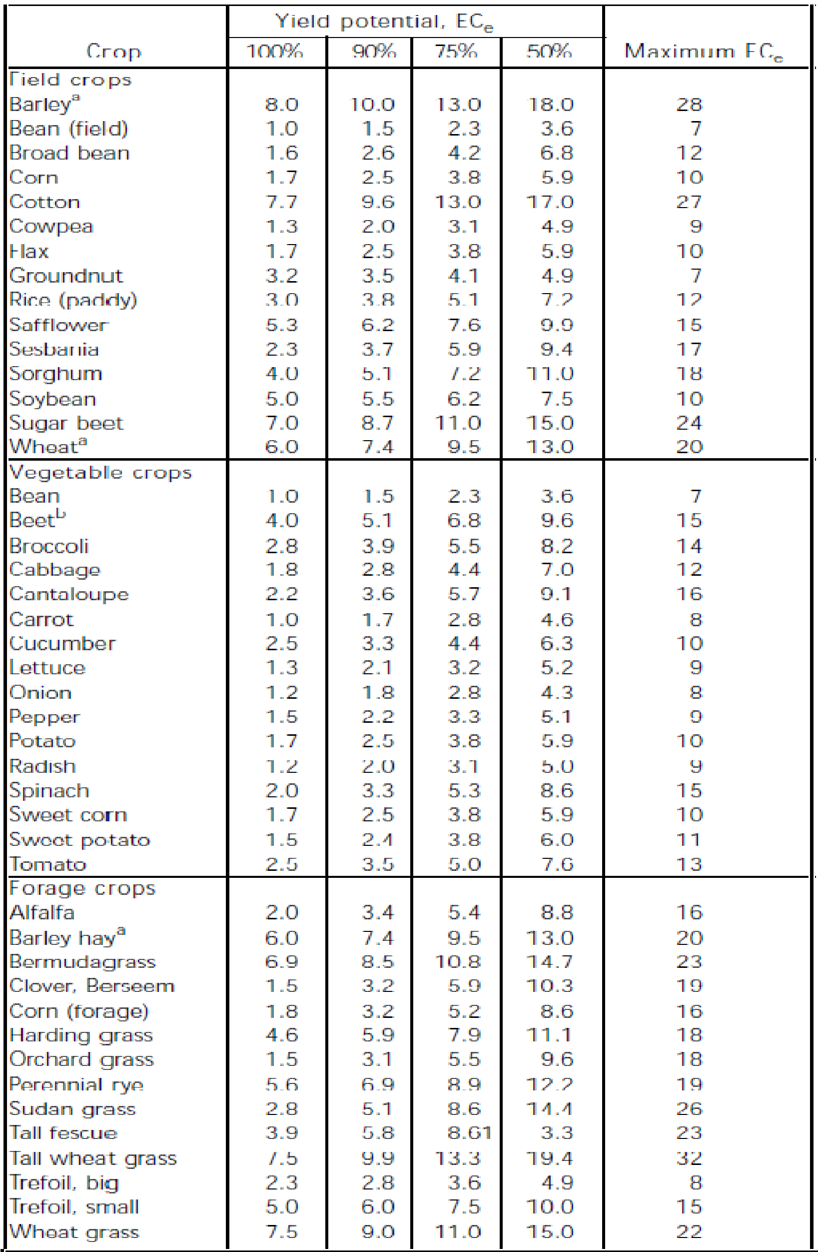
[d] A more stringent guideline limit (⩽ 200 faecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

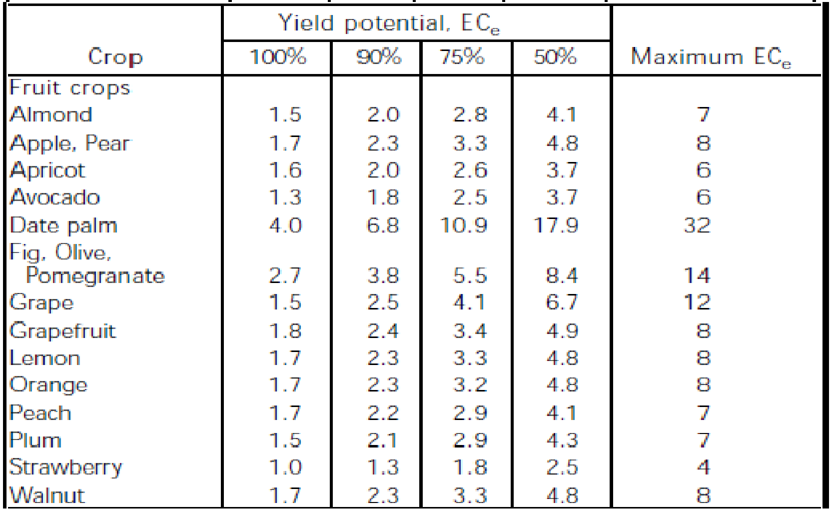
APPENDIX 2:

SOIL SALINITY TOLERANCE LEVELS FOR DIFFERENT CROPS

SOIL SALINITY TOLERANCES LEVELS FOR DIFFERENT CROPS



Crop	Yield potential, EC_e				Maximum EC_e
	100%	90%	75%	50%	
Field crops					
Barley^a	8.0	10.0	13.0	18.0	28
Bean (field)	1.0	1.5	2.3	3.6	7
Broad bean	1.6	2.6	4.2	6.8	12
Corn	1.7	2.5	3.8	5.9	10
Cotton	7.7	9.6	13.0	17.0	27
Cowpea	1.3	2.0	3.1	4.9	9
Flax	1.7	2.5	3.8	5.9	10
Groundnut	3.2	3.5	4.1	4.9	7
Rice (paddy)	3.0	3.8	5.1	7.2	12
Safflower	5.3	6.2	7.6	9.9	15
Sesbania	2.3	3.7	5.9	9.4	17
Sorghum	4.0	5.1	7.2	11.0	18
Soybean	5.0	5.5	6.2	7.5	10
Sugar beet	7.0	8.7	11.0	15.0	24
Wheat^a	6.0	7.4	9.5	13.0	20
Vegetable crops					
Bean	1.0	1.5	2.3	3.6	7
Beet^b	4.0	5.1	6.8	9.6	15
Broccoli	2.8	3.9	5.5	8.2	14
Cabbage	1.8	2.8	4.4	7.0	12
Cantaloupe	2.2	3.6	5.7	9.1	16
Carrot	1.0	1.7	2.8	4.6	8
Cucumber	2.5	3.3	4.4	6.3	10
Lettuce	1.3	2.1	3.2	5.2	9
Onion	1.2	1.8	2.8	4.3	8
Pepper	1.5	2.2	3.3	5.1	9
Potato	1.7	2.5	3.8	5.9	10
Radish	1.2	2.0	3.1	5.0	9
Spinach	2.0	3.3	5.3	8.6	15
Sweet corn	1.7	2.5	3.8	5.9	10
Sweet potato	1.5	2.4	3.8	6.0	11
Tomato	2.5	3.5	5.0	7.6	13
Forage crops					
Alfalfa	2.0	3.4	5.4	8.8	16
Barley hay^a	6.0	7.4	9.5	13.0	20
Bermudagrass	6.9	8.5	10.8	14.7	23
Clover, Berseem	1.5	3.2	5.9	10.3	19
Corn (forage)	1.8	3.2	5.2	8.6	16
Harding grass	4.6	5.9	7.9	11.1	18
Orchard grass	1.5	3.1	5.5	9.6	18
Perennial rye	5.6	6.9	8.9	12.2	19
Sudan grass	2.8	5.1	8.6	14.4	26
Tall fescue	3.9	5.8	8.61	3.3	23
Tall wheat grass	7.5	9.9	13.3	19.4	32
Trefoil, big	2.3	2.8	3.6	4.9	8
Trefoil, small	5.0	6.0	7.5	10.0	15
Wheat grass	7.5	9.0	11.0	15.0	22

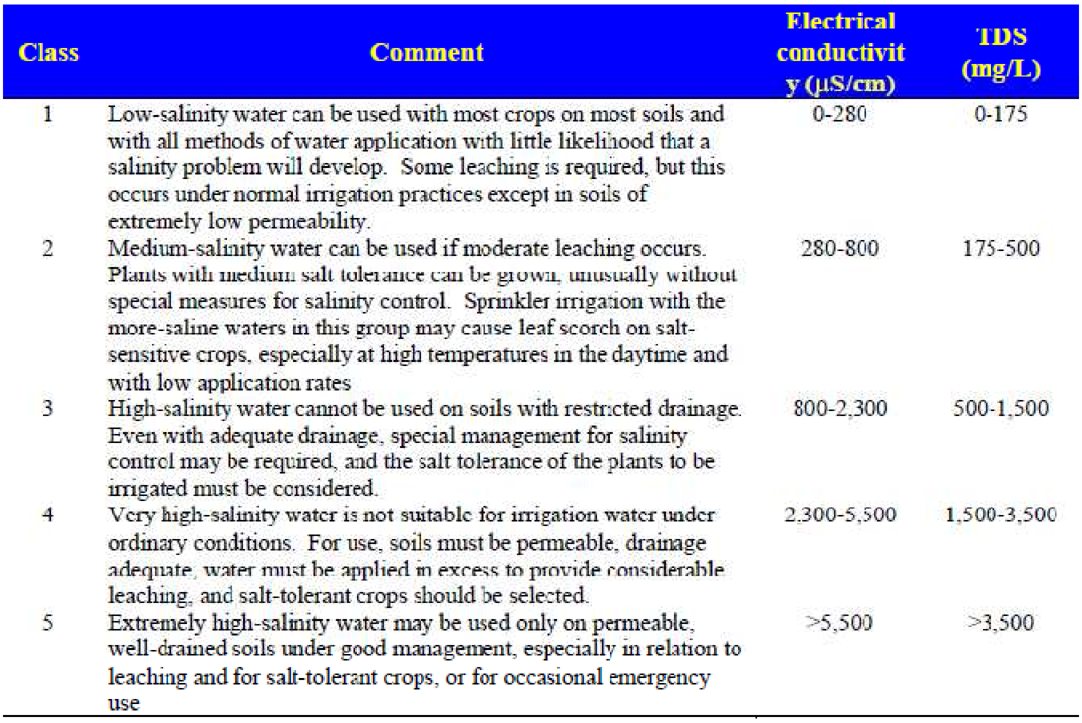


Crop	Yield potential, EC_e				Maximum EC_e
	100%	90%	75%	50%	
Fruit crops					
Almond	1.5	2.0	2.8	4.1	7
Apple, Pear	1.7	2.3	3.3	4.8	8
Apricot	1.6	2.0	2.6	3.7	6
Avocado	1.3	1.8	2.5	3.7	6
Date palm	4.0	6.8	10.9	17.9	32
Fig, Olive, Pomegranate	2.7	3.8	5.5	8.4	14
Grape	1.5	2.5	4.1	6.7	12
Grapefruit	1.8	2.4	3.4	4.9	8
Lemon	1.7	2.3	3.3	4.8	8
Orange	1.7	2.3	3.2	4.8	8
Peach	1.7	2.2	2.9	4.1	7
Plum	1.5	2.1	2.9	4.3	7
Strawberry	1.0	1.3	1.8	2.5	4
Walnut	1.7	2.3	3.3	4.8	8

APPENDIX 3:

IRRIGATED WATER SALINITY TOLERANCE LEVELS FOR DIFFERENT CROPS

GENERAL GUIDELINES OF SALINITY OF IRRIGATION WATER



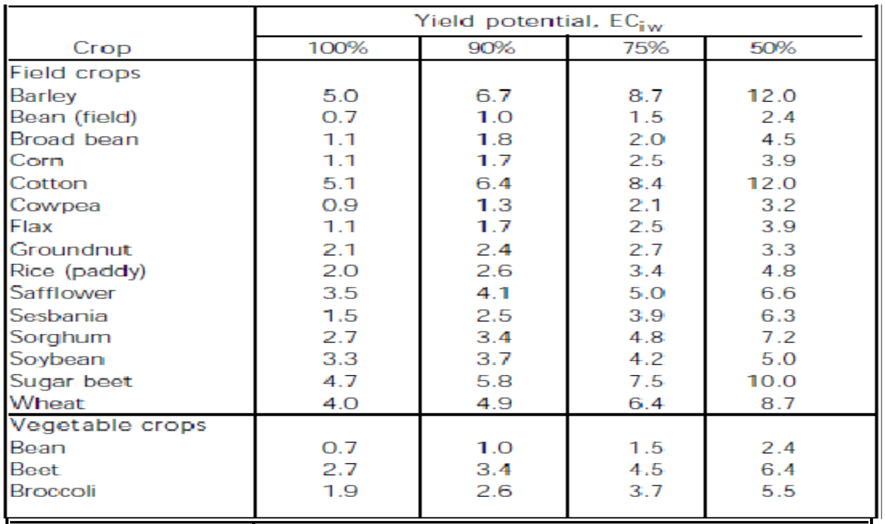
Class	Comment	Electrical conductivity (µS/cm)	TDS (mg/L)
1	Low-salinity water can be used with most crops on most soils and with all methods of water application with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.	0-280	0-175
2	Medium-salinity water can be used if moderate leaching occurs. Plants with medium salt tolerance can be grown, unusually without special measures for salinity control. Sprinkler irrigation with the more-saline waters in this group may cause leaf scorch on salt-sensitive crops, especially at high temperatures in the daytime and with low application rates	280-800	175-500
3	High-salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and the salt tolerance of the plants to be irrigated must be considered.	800-2,300	500-1,500
4	Very high-salinity water is not suitable for irrigation water under ordinary conditions. For use, soils must be permeable, drainage adequate, water must be applied in excess to provide considerable leaching, and salt-tolerant crops should be selected.	2,300-5,500	1,500-3,500
5	Extremely high-salinity water may be used only on permeable, well-drained soils under good management, especially in relation to leaching and for salt-tolerant crops, or for occasional emergency use	>5,500	>3,500

RELATIVE SALT TOLERANCE OF AGRICULTURAL CROPS

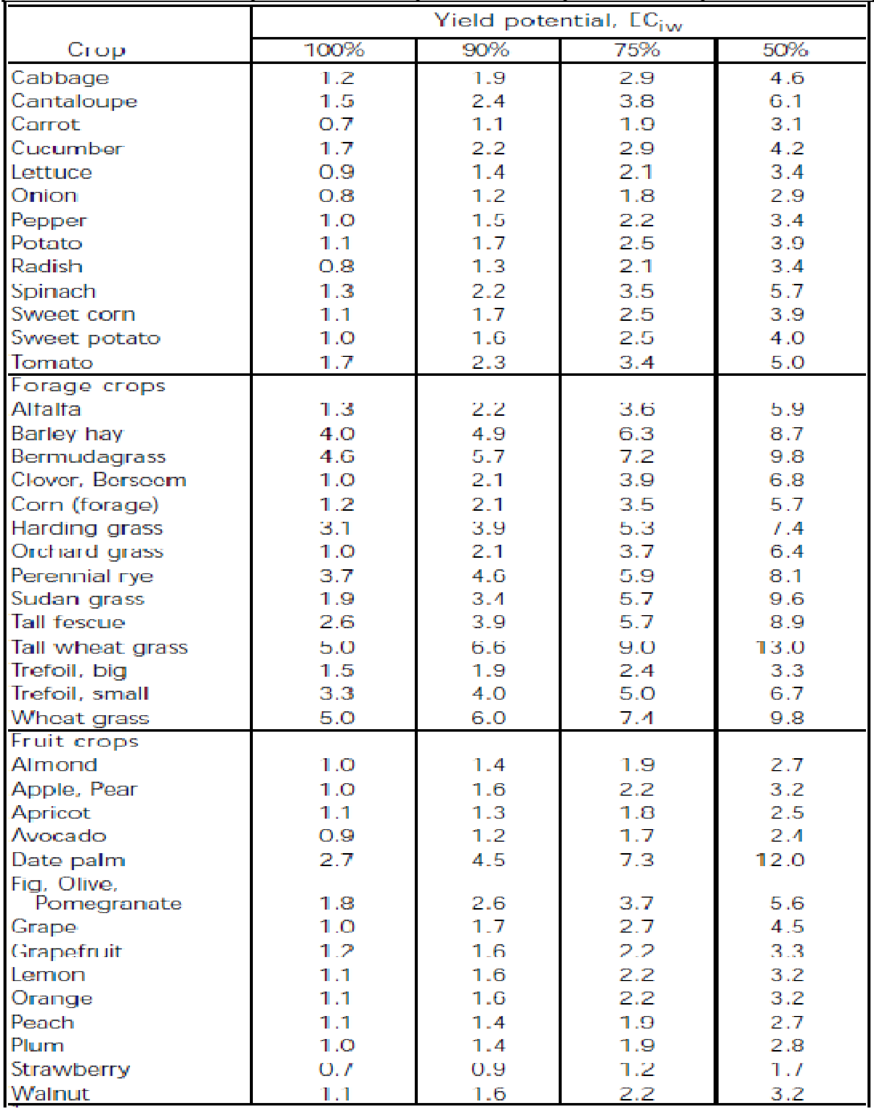
TOLERANT	**MODERATELY TOLERANT**	**MODERATELY SENSITIVE**	**SENSITIVE**
Cotton	Soybean	Alfalfa	Bean
Barley	Triticale	Corn (forage) (maize)	Carrot
Oats	Wheat	Cabbage	Okra
	Sudan grass	Corn, sweet	Onion
	Olive	Cucumber	Parsnip
		Pepper	Almond
		Eggplant	Apple
		Potato	Apricot
		Squash, scallop	Avocado
		Sweet potato	Grapefruit
		Tomato	Lemon
		Watermelon	Lime
		Grape	Mango
			Orange
			Strawberry

Source: FAO (1985)

IRRIGATION WATER SALINITY TOLERANCE FOR DIFFERENT CROPS



Crop	Yield potential, EC_{iw} 100%	90%	75%	50%
Field crops				
Barley	5.0	6.7	8.7	12.0
Bean (field)	0.7	1.0	1.5	2.4
Broad bean	1.1	1.8	2.0	4.5
Corn	1.1	1.7	2.5	3.9
Cotton	5.1	6.4	8.4	12.0
Cowpea	0.9	1.3	2.1	3.2
Flax	1.1	1.7	2.5	3.9
Groundnut	2.1	2.4	2.7	3.3
Rice (paddy)	2.0	2.6	3.4	4.8
Safflower	3.5	4.1	5.0	6.6
Sesbania	1.5	2.5	3.9	6.3
Sorghum	2.7	3.4	4.8	7.2
Soybean	3.3	3.7	4.2	5.0
Sugar beet	4.7	5.8	7.5	10.0
Wheat	4.0	4.9	6.4	8.7
Vegetable crops				
Bean	0.7	1.0	1.5	2.4
Beet	2.7	3.4	4.5	6.4
Broccoli	1.9	2.6	3.7	5.5

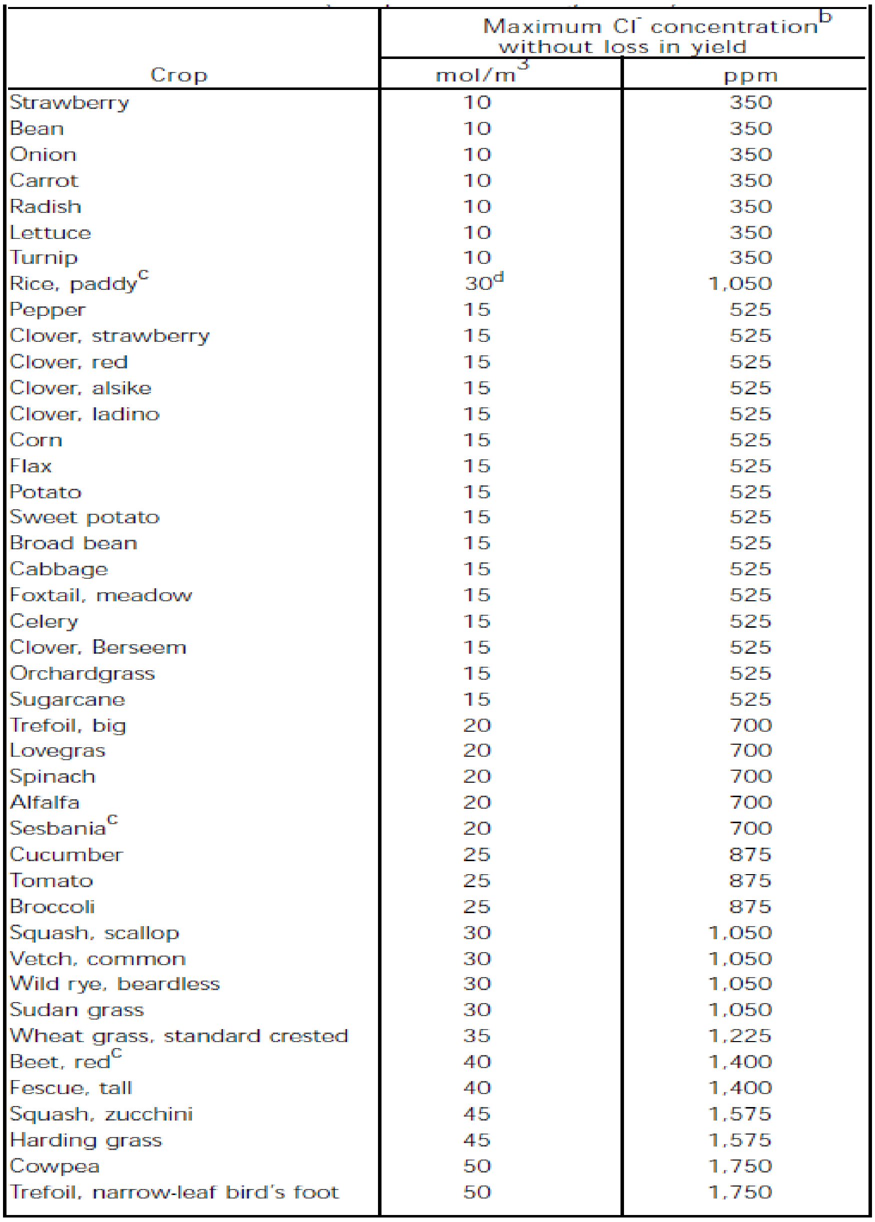


Crop	Yield potential, EC_{iw} 100%	90%	75%	50%
Cabbage	1.2	1.9	2.9	4.6
Cantaloupe	1.5	2.4	3.8	6.1
Carrot	0.7	1.1	1.9	3.1
Cucumber	1.7	2.2	2.9	4.2
Lettuce	0.9	1.4	2.1	3.4
Onion	0.8	1.2	1.8	2.9
Pepper	1.0	1.5	2.2	3.4
Potato	1.1	1.7	2.5	3.9
Radish	0.8	1.3	2.1	3.4
Spinach	1.3	2.2	3.5	5.7
Sweet corn	1.1	1.7	2.5	3.9
Sweet potato	1.0	1.6	2.5	4.0
Tomato	1.7	2.3	3.4	5.0
Forage crops				
Alfalfa	1.3	2.2	3.6	5.9
Barley hay	4.0	4.9	6.3	8.7
Bermudagrass	4.6	5.7	7.2	9.8
Clover, Berseem	1.0	2.1	3.9	6.8
Corn (forage)	1.2	2.1	3.5	5.7
Harding grass	3.1	3.9	5.3	7.4
Orchard grass	1.0	2.1	3.7	6.4
Perennial rye	3.7	4.6	5.9	8.1
Sudan grass	1.9	3.4	5.7	9.6
Tall fescue	2.6	3.9	5.7	8.9
Tall wheat grass	5.0	6.6	9.0	13.0
Trefoil, big	1.5	1.9	2.4	3.3
Trefoil, small	3.3	4.0	5.0	6.7
Wheat grass	5.0	6.0	7.4	9.8
Fruit crops				
Almond	1.0	1.4	1.9	2.7
Apple, Pear	1.0	1.6	2.2	3.2
Apricot	1.1	1.3	1.8	2.5
Avocado	0.9	1.2	1.7	2.4
Date palm	2.7	4.5	7.3	12.0
Fig, Olive, Pomegranate	1.8	2.6	3.7	5.6
Grape	1.0	1.7	2.7	4.5
Grapefruit	1.2	1.6	2.2	3.3
Lemon	1.1	1.6	2.2	3.2
Orange	1.1	1.6	2.2	3.2
Peach	1.1	1.4	1.9	2.7
Plum	1.0	1.4	1.9	2.8
Strawberry	0.7	0.9	1.2	1.7
Walnut	1.1	1.6	2.2	3.2

APPENDIX 4:

NUTRIENTS TOLERANCE LEVELS FOR DIFFERENT CROPS

CHLORIDE TOLERANCE OF AGRICULTURE CROPS LISTED IN ORDER OF TOLERANCE

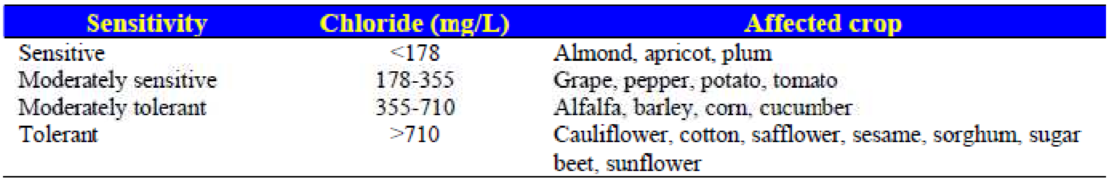


Crop	Maximum Cl^- concentration[b] without loss in yield	
	mol/m^3	ppm
Strawberry	10	350
Bean	10	350
Onion	10	350
Carrot	10	350
Radish	10	350
Lettuce	10	350
Turnip	10	350
Rice, paddy[c]	30[d]	1,050
Pepper	15	525
Clover, strawberry	15	525
Clover, red	15	525
Clover, alsike	15	525
Clover, ladino	15	525
Corn	15	525
Flax	15	525
Potato	15	525
Sweet potato	15	525
Broad bean	15	525
Cabbage	15	525
Foxtail, meadow	15	525
Celery	15	525
Clover, Berseem	15	525
Orchardgrass	15	525
Sugarcane	15	525
Trefoil, big	20	700
Lovegras	20	700
Spinach	20	700
Alfalfa	20	700
Sesbania[c]	20	700
Cucumber	25	875
Tomato	25	875
Broccoli	25	875
Squash, scallop	30	1,050
Vetch, common	30	1,050
Wild rye, beardless	30	1,050
Sudan grass	30	1,050
Wheat grass, standard crested	35	1,225
Beet, red[c]	40	1,400
Fescue, tall	40	1,400
Squash, zucchini	45	1,575
Harding grass	45	1,575
Cowpea	50	1,750
Trefoil, narrow-leaf bird's foot	50	1,750

CHLORIDE TOLERANCE OF FRUIT AND WOODY CROPS BY ROOT UPTAKE

Rootstocks	**Chloride in irrigation water (mg/L)**	**Cultivars**	**Chloride in irrigation water (mg/L)**
Grapes	710-960	Boysenberry	250
Stone-fruits (peaches, plums etc)	180-600	Blackberry, Raspberry	
Strawberries	110-180		

Chloride concentration in irrigated water causing foliar damage



Sensitivity	Chloride (mg/L)	Affected crop
Sensitive	<178	Almond, apricot, plum
Moderately sensitive	178-355	Grape, pepper, potato, tomato
Moderately tolerant	355-710	Alfalfa, barley, corn, cucumber
Tolerant	>710	Cauliflower, cotton, safflower, sesame, sorghum, sugar beet, sunflower

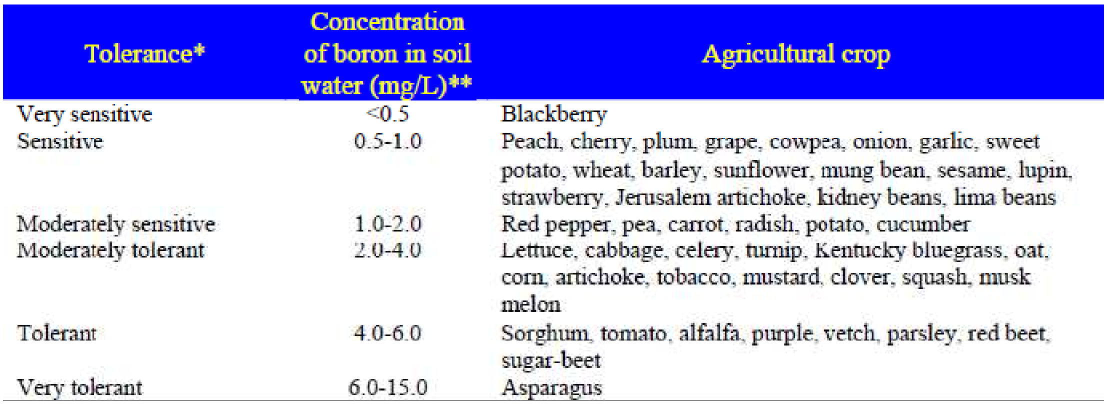
THRESHOLD LEVELS OF TRACE ELEMENTS FOR CROP PRODUCTION

	Element	Recommended maximum concentration (mg/l)	Remarks
Al	(aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As	(arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Cd	(cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cu	(copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Fe	(iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li	(lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn	(manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Ni	(nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd	(lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Zn	(zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

[1] The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

Source: Adapted from National Academy of Sciences (1972) and Pratt (1972))

TOLERANCE OF CROPS TO BORON



Tolerance*	Concentration of boron in soil water (mg/L)**	Agricultural crop
Very sensitive	<0.5	Blackberry
Sensitive	0.5-1.0	Peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney beans, lima beans
Moderately sensitive	1.0-2.0	Red pepper, pea, carrot, radish, potato, cucumber
Moderately tolerant	2.0-4.0	Lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, musk melon
Tolerant	4.0-6.0	Sorghum, tomato, alfalfa, purple, vetch, parsley, red beet, sugar-beet
Very tolerant	6.0-15.0	Asparagus

Australian water quality guidelines, 1992

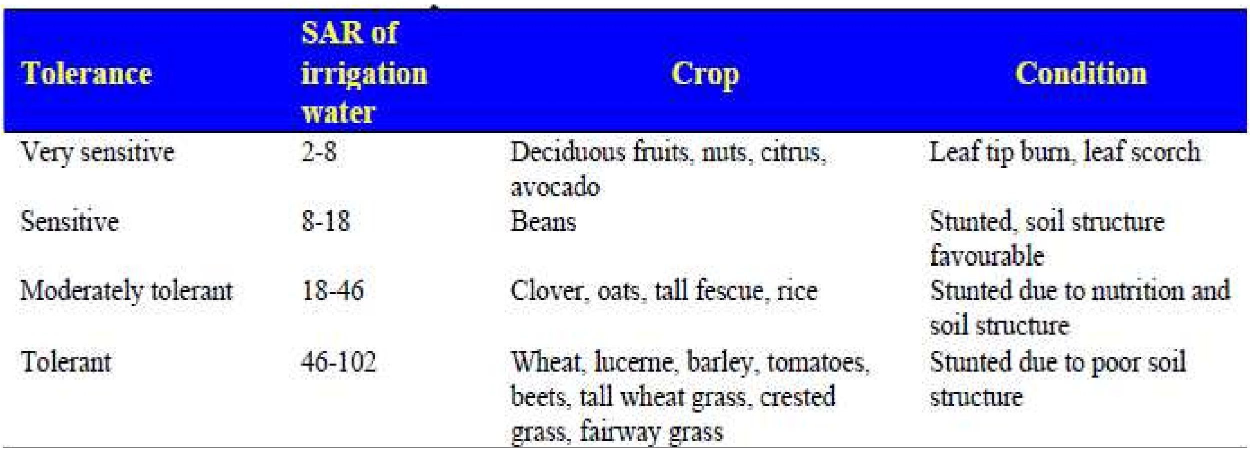
RELATIVE BORON (B) TOLERANCE OF AGRICULTURAL CROPS1

VERY SENSITIVE (<0.5 mg/l)	**SENSITIVE (0.5-0.75 mg/l)**	**SENSITIVE (0.75-1.0 mg/l)**	**MODERATELY SENSITIVE (1.0-2.0 mg/l)**	**MODERATELY TOLERANT (2.0-4.0 mg/l)**	**TOLERANT (4.0-6.0 mg/l)**	**VERY TOLERANT (6.0-15.0 mg/l)**
Lemon	Avocado	Garlic	Pepper, red	Lettuce	Sorghum	Cotton
Blackberry	Grapefruit	Sweet potato	Pea	Cabbage	Tomato	Asparagus
	Orange	Wheat	Carrot	Celery	**Alfalfa**	
	Apricot	Barley	Radish	Turnip	Vetch, purple	
	Peach	Sunflower	Potato	Bluegrass, Kentucky	Parsley	
	Cherry	Bean, mung	Cucumber	Oats	Beet, red	
	Plum	Sesame		Maize	Sugarbeet	
	Persimmon	Lupine		Artichoke		
	Fig, kadota	Strawberry		Tobacco		
	Grape	Artichoke, Jerusalem		Mustard		
	Walnut	Bean, kidney		Clover, sweet		
	Pecan	Bean, lima		Squash		
	Cowpea	Groundnut/Peanut		Muskmelon		
	Onion					

[1] Maximum concentrations tolerated in soil water without yield or vegetative growth reductions. Boron tolerances vary depending upon climate, soil conditions and crop varieties. Maximum concentrations in the irrigation water are approximately equal to these values or slightly less.

Source: Maas (1984)

TOLERANCE OF CROPS TO SODIUM



Tolerance	SAR of irrigation water	Crop	Condition
Very sensitive	2-8	Deciduous fruits, nuts, citrus, avocado	Leaf tip burn, leaf scorch
Sensitive	8-18	Beans	Stunted, soil structure favourable
Moderately tolerant	18-46	Clover, oats, tall fescue, rice	Stunted due to nutrition and soil structure
Tolerant	46-102	Wheat, lucerne, barley, tomatoes, beets, tall wheat grass, crested grass, fairway grass	Stunted due to poor soil structure

RELATIVE TOLERANCE OF SELECTED CROPS TO EXCHANGEABLE SODIUM

Sensitive	Semi-tolerant	Tolerant
Avocado	Carrot	**Alfalfa**
Deciduous Fruits	Clover, Ladino	Barley
Bean, green	Dallisgrass	Beet, garden
Cotton (at germination)	Fescue, tall	Beet, sugar
Maize	Lettuce	Bermuda grass
Peas	Bajara	Cotton
Grapefruit	Sugarcane	Paragrass
Orange	Berseem	Rhodes grass
Peach	Benji	Wheatgrass, crested
Tangerine	Raya	Wheatgrass, fairway
Mung	Oat	Wheatgrass, tall
Mash	Onion	Karnal grass
Lentil	Radish	
Groundnut (peanut)	Rice	
Gram	Rye	
Cowpeas	Ryegrass, Italian	

Source: Adapted from data of FAO-Unesco (1973); Pearson (1960); and Abrol (1982).

APPENDIX 5:

WATER & NUTRIENTS DEMAND OF DIFFERENT CROPS

WATER REQUIREMENTS, SENSITIVITY TO WATER SUPPLY AND WATER UTILIZATION OF SOME SELECTED CROPS

Crop	**Water requirements (mm/growing period)**	**Sensitivity to water supply (ky)**	**Water utilization efficiency for harvested yield, Ey, kg/m^3 (% moisture)**
Alfalfa	**800-1600**	**low to medium-high (0.7-1.1)**	**1.5-2.0 hay (10-15%)**
Banana	1200-2200	high (1.2-1.35)	plant crop: 2.5-4 ratoon: 3.5-6 fruit (70%)
Bean	300-500	medium-high (1.15)	lush: 1.5-2.0 (80-90%) dry: 0.3-0.6 (10%)
Cabbage	380-500	medium-low (0.95)	12-20 head (90-95%)
Citrus	900-1200	low to medium-high (0.8-1.1)	2-5 fruit (85%, lime: 70%)
Cotton	700-1300	medium-low (0.85)	0.4-0.6 seed cotton (10%)
Groundnut	500-700	low (0.7)	0.6-0.8 unshelled dry nut (15%)
Potato	500-700	medium-high (1.1)	4-7 fresh tuber (70-75%)
Rice	350-700	high	0.7-1.1 paddy (15-20%)
Sorghum	450-650	medium-low (0.9)	0.6-1.0 grain (12-15%)
Wheat	450-650	medium high (spring: 1.15; winter: 1.0)	0.8-1.0 grain (12-15%)

Source: FAO (1979)

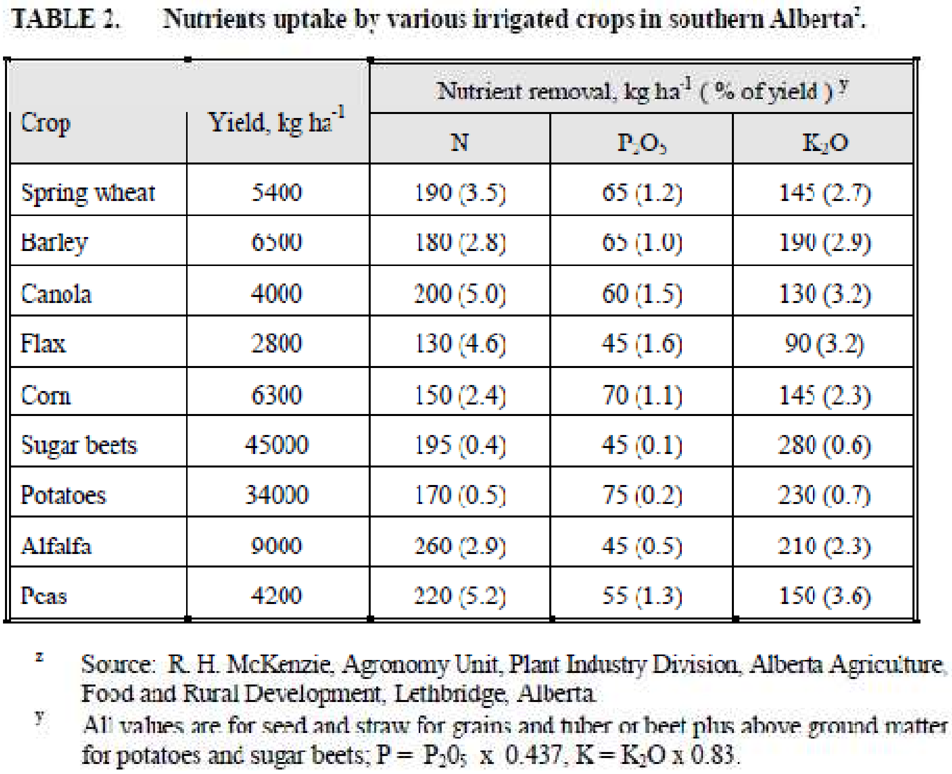


TABLE 2. Nutrients uptake by various irrigated crops in southern Alberta[z].

Crop	Yield, kg ha^{-1}	Nutrient removal, kg ha^{-1} (% of yield)[y]		
		N	P_2O_5	K_2O
Spring wheat	5400	190 (3.5)	65 (1.2)	145 (2.7)
Barley	6500	180 (2.8)	65 (1.0)	190 (2.9)
Canola	4000	200 (5.0)	60 (1.5)	130 (3.2)
Flax	2800	130 (4.6)	45 (1.6)	90 (3.2)
Corn	6300	150 (2.4)	70 (1.1)	145 (2.3)
Sugar beets	45000	195 (0.4)	45 (0.1)	280 (0.6)
Potatoes	34000	170 (0.5)	75 (0.2)	230 (0.7)
Alfalfa	9000	260 (2.9)	45 (0.5)	210 (2.3)
Peas	4200	220 (5.2)	55 (1.3)	150 (3.6)

[z] Source: R. H. McKenzie, Agronomy Unit, Plant Industry Division, Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta

[y] All values are for seed and straw for grains and tuber or beet plus above ground matter for potatoes and sugar beets; P = P_20_5 x 0.437, K = K_2O x 0.83.

NUTRIENT UPTAKE FOR SELECTED CROPS

Forage Crops

	Nitrogen	Phosphorous	Potassium
Alfalfa	201–482	20–31	156–200
Brome Grass	116–201	36–49	219
Coastal Bermuda Grass	357–602	31–40	20
Kentucky Blue Grass	178–241	40	178
Quack Grass	210–250	27–40	245
Reed Canary Grass	299–401	36–40	281
Ryegrass	178–250	54–76	241–290
Sweet Clover	156	18	89
Tall Fescue	133–290	27	268
Orchard Grass	233–312	18–45	201–281

Field Crops

	Nitrogen	Phosphorous	Potassium
Barley	112	13	18
Corn	156–178	18–27	98
Cotton	67–98	13	36
Grain Sorghum	120	13	62
Potatoes	205	18	219–290
Soybeansa	223	9–18	27–49
Wheat	143	13	18–40

Source: United States EPA 1981 Process Design Manual, Land Treatment of Municipal Wastewater.

Crops salt sensitive

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Bean	Broad Bean	Cowpea	Barley
Paddy Rice	Corn	Kenaf	Cotton
Sesame	Flax	Oats	Guar
Carrot	Millet	Safflower	Rye
Okra	Peanut	Sorghum	Sugar Beet
Onion	Sugarcane	Soybean	Triticale
Parsnip	Sunflower	Wheat	Semi-dwarf Wheat
Pea	Alfalfa	Barley (forage)	Durum Wheat
Strawberry	Bentgrass	Grass Canary	Alkali Grass
Almond	Angleton Bluestem	Hubam Clover	Nuttail Alkali
Apple	Smooth Brome	Sweet Clover	Bermuda Grass
Apricot	Buffelgrass	Tall Fescue	Kallar Grass
Avocado	Burnet	Meadow Fescue	Desert Salt Grass
Blackberry	Alsike Clover	Harding Grass	Wheat Grass
Boysenberry	Ladino Clover	Blue Panic Grass	Fairway Wheat
Cherimoya	Red Clover	Rape	Crested Wheat
Sweet Cherry	Strawberry Clover	Rescue Grass	Tall Wheat Grass
Sand Cherry	White Dutch Clover	Rhodes Grass	Altai Wild Rye
Currant	Corn (forage)	Italian Ryegrass	Russian Wild Rye
Gooseberry	Cowpea (forage)	Perennial Ryegrass	Asparagus
Grapefruit	Grass dallis	Sundan Grass	Guayule
Lemon	Meadow Foxtail	Narrowleaf Trefoil	Jojoba
Lime	Blue Grama	Broadleaf Trefoil	
Loquat	Love Grass	Wheat (forage)	
Mango	Cicer Milkvetch	Durum Wheat (forage)	
Orange	Tall Oat Grass	Standard Crested Wheat Grass	
Passion Fruit	Oats (forage)	Intermediate Wheat Grass	
Peach	Orchard Grass	Slender Wheat Grass	
Pear	Rye (forage)	Beardless Wild Rye	
Persimmon	Sesbania	Canadian Wild Rye	
Plum; Prune	Sirato	Artichoke	
Pummelo	Sphaerophysa	Red Beet	
Raspberry	Timothy	Zucchini Squash	
Rose Apple	Big Trefoil	Fig	
White Sapote	Common Vetch	Jujube	
Tangerine	Broccoli	Papaya	
	Brussel Sprouts	Pomegranate	
	Cabbage		
	Cauliflower		
	Celery		
	Sweet Corn		
	Cucumber		
	Eggplant		
	Kale		
	Kohlrabi		
	Lettuce		
	Muskmelon		
	Pepper		
	Potato		
	Pumpkin		
	Radish		
	Spinach		
	Scallop Squash		
	Sweet Potato		
	Tomato		
	Turnip		
	Watermelon		
	Castorbean		
	Grape		

Source: Tanji (1990)