# إقــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

# The Potential Use of Sewage Sludge from Sheikh Ejleen TP for Agriculture

# الاستخدامات الممكنة للحمأة الناتجة من محطة معالجة المياه العادمة في الشيخ عجلين

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## DECLARATION

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification

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# The Potential Use of Sewage Sludge from Sheikh Ejleen TP for Agriculture

MSc Thesis

By

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# نتيجة الحكم على أطروحة ماجستير

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## الاستخدامات الممكنة للحمأة الناتجة من محطة معالجة المياه العادمة في الشيخ عجلين

## The potential use of sewage sludge from Sheikh Ejleen TP for agriculture

وبعد المناقشة العلنية التي تمت اليوم السبت 25 صفر 1435هـ، الموافق 2013/12/28م العاشرة صباحاً بمبنى طيبة، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/** قسم الهندسة المدنية- **هندسة مصادر المياه.**

***واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.***

والله ولي التوفيق ،،،

مساعد نائب الرئيس للبحث العلمي وللدراسات العليا

أ.د. فؤاد علي العاجز

شئون البحث العلمي والدراسات العليا
Research & Graduate Affairs

بسم الله الرحمن الرحيم

{رب أوزعني أن أشكر نعمتك التي أنعمت علي وعلى والدي وأن أعمل صالحا ترضاه
وأدخلني برحمتك في عبادك الصالحين} (النمل الآية:19)

*"O my Lord! So order me that I may be grateful for Thy favours, which Thou has bestowed on me and on my parents, and that I may work the righteousness that will please Thee: and admit me, by Thy Grace, to the ranks of Thy Righteous Servants".*

# ACKNOWLEDGMENT

First of all praise Allah for blessings and guidance in fulfilling this goal.
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**ملخص الدراسة :**

هدفت هذه الدراسة الى تحديد خواص الحمأة الناتجة من احواض المعالجة من محطة الشيخ عجلين ومدى ملائمتها وصلاحية استخدامها في الزراعة . تم اخد العينات من محطة الشيخ عجلين لمعالجة المياه العادمة ، و تجفيفها هوائيا و تنخيلها باستخدام منخل 2 مم ثم تخزينها في اكياس بلاستيكية تحت درجة حرارة الغرفة.

تم استخدام طرق التحليل المعيارية القياسية لتحديد : كثافة الحمأة ، التوزيع الحبيبي، قدرة الحمأة على الاحتفاظ بالماء، حجم الفراغات، درجة الحموضة، التوصيل الكهربائي، محتوى الحمأة من الانيونات والكاتيونات، نيتروجين Kjeldahl الكلي، الاكسجين المتسهلك حيويا، الاكسجين المستهلك كيميائيا، الكربون العضوي الكلي، درجة كره الماء، محتوى الحمأة من العناصر الثقيلة وكذلك تأثير الحمأة على الاستخدام الزراعي.

أظهرت نتائج التحاليل ان الكثافة الكلية للحمأة تساوي تقريبا 1.18 جم/سم3 بينما الكثافة الحقيقية 2.12 جم/سم3 ، نسبة الفراغات تقريبا 50%، أظهر التدرج الحبيبي ان معظم التدرج يشبه تدرج الرمل (630-200 µm) ، وتدرج قليل يشبه تدرج الطين والطمي(200-20 µm)، اما درجة الحموضة الحمأة فهي تتجه في الاتجاه الحامضي، بينما درجة التوصيل الكهربائي فتساوي 2.49 mS/cm ، احتوت الحمأة على نسبة عالية من نيتروجين كلدال الكلي (TKN) تساوي 5 جم/كجم بينما النيتروجين الذائب يساوي 61.63 جم/كجم . الصوديوم، البوتاسيوم ، الكالسيوم، الماغنسيوم يساوي 28.93 ، 2.53، 271 و 177 مجم/كجم على الترتيب اما الفوسفات، الكبريتات والكلورايد يساوي 0.434، 18.59، 0.026 جم/كجم على الترتيب. محتوى العناصر الثقيلة من الحديد، النحاس، الرصاص، الزنك، المنغنيز تساوي 125.12، 172.56، 76.88، 218.73 و 157.56 مجم/كجم على الترتيب. اما الاكسجين المستهلك كيميائيا و الاكسجين المستهلك حيويا يساوي $10^3$*(60.99) و 115 مجم على الترتيب. وبالنسبة الي (ODPT) وقت اختراق نقطة الزيت للحمأة تساوي 5.05±1.28 ثانية وكان قطر القطرة على سطح الحمأة يساوي 1.25±0.14 سم والنسبة WDPT/ODPT وقت اختراق قطرة الزيت/ وقت اختراق قطرة الماء للحمأة فهي قيمة عالية جدا تساوي 22.73 مما يدل على درجة كره للماء متطرفة جدا . لم تؤثر اضافة الحمأة الى التربة على التربة بشكل ملحوظ، حيث ان درجة حموضة التربة ودرجة التوصيل الكهربائي ومستويات النيترات لم تتغير ، في حين أثرت بشكل ملحوظ على نمو الذرة .

واظهرت النتائج ان معدل الاضافة من الحمأة للتربة 5 طن/هكتار كان الامثل من بين جميع الحالات(1طن/هكتار،5طن/هكتار،10طن/هكتار). وقد خلصت الدراسة الى ان اضافة الحمأة (المواد الصلبة الحيوية) ممكن ان تكون ذو تأثير جيد وكبير في الاستخدامات الزراعية.

وقد اقترحت الدراسة ان هذه النتائج المشجعة تعزز من استخدام الحمأة في القطاع الزراعي لتحسين النمو والانتاج الزراعي.

## Abstract

This study aimed to characterize the potential use of sewage sludge from wastewater treatment plant from Sheikh Ejleen for agricultural use. Sludge samples were collected from Sheikh Ejleen Wastewater treatment plant. Air-dried, sieved through 2mm and stored in plastic bags at room temperature. Sludge density, particle size distribution, water holding capacity, void volume, pH, EC, cations and anions contents, Total Kjeldahl Nitrogen (TKN), BOD, COD, Total organic carbon, hydrophobicity, heavy metals content, Influence of sludge on agricultural use were characterized using the standard methods of Analysis. Results showed the bulk density is about 1.18 g/cm3 whereas the real density is 2.12 and void volume is 50%; Particle size distribution showed that the major size of sludge is sand-like size (630-200 µm) and the minor size is silt and clay-like size (200-20 µm); Sludge has an acidic pH reaction with an electric conductivity equal to 2.49 mS cm$^{-1}$; sludge contained high fraction of TKN 5g/kg whereas the soluble nitrogen is 61.63mg/kg.

$Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ were 28.93, 2.53, 271 and 177 mg/kg respectively whereas PO4, SO4, Cl were 0.434, 18.59 and 0.026 g/kg respectively.

Heavy metals content such as Fe, Cu, Pb, Zn and Mn were 125.12, 172.56, 76.88, 218.73 and 157.56 mg/kg respectively. COD and BOD values were $60.99*10^3$ mg and 115mg respectively. The hydrophobicity of sludge is very high, Water Drip Penetration Time (WDPT) is 114.77±18.78 sec with a radius of 0.44±0.08 cm. In the way around, Oil Drip Penetration Time (ODPT) of sludge is 5.05±1.28 sec with a radius of 1.25±0.14 cm. The WDPT/ODPT is very high value 22.73 indicating extreme hydrophobicity. Addition of sludge to soil in the pot experiment had not a significant influence on soil nutrient status, since soil pH, EC, Nitrate levels were not changing. Whereas it significantly increased the corn growth. It appears that 5ton/ha as an addition rate was the optimum among all cases (0ton/ha, 1ton/ha, 10ton/ha). It can be concluded that Application of sludge “biosolids” could be advantageous opportunity for agricultural uses. These encouraging results may enhance the application of sludge in the agricultural sector for improving plant growth and yields.

# DEDICATION

I wish to dedicate this thesis to the souls of my mother and grandmother and grandfather and my uncle martyr Nasser who have supported me spiritually all the way since the beginning of my studies.

Also, this thesis is dedicated to my father who has been a great source of motivation and inspiration.

Finally, this thesis is dedicated to my brothers, sisters, friends, colleagues at Islamic University, and all those who believe in the richness of learning.

**Ibrahim Y. El-Nahhal**

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **°C** | Degrees Celsius. |
| **ANOVA** | Analysis of Variance |
| **APG** | A kind of non-ionic surfactants |
| **BOD** | Biological Oxygen Demand. |
| **C/N ratio** | Carbon/Nitrogen Ratio. |
| **COD** | Chemical Oxygen Demand. |
| **DOM** | Degradable Organic Matter. |
| **EC** | Electrical Conductivity. |
| **EDTA** | Ethylene Diamine Tetra Acetic Acid. |
| **EPA** | Environmental Protection Agency. |
| **EPS** | Extracellular Polymeric Substances. |
| **g** | gram |
| **g/g** | gram substance per 1 gram of Sludge |
| **g/kg** | gram substance per 1 Kilogram of Sludge |
| **g/L** | Grams per Liter. |
| **h** | Hour. |
| **ICP** | Inductively Coupled Plasma. |
| **KHP** | Potassium Hydrogen Phlalate |
| **LOI** | Loss On Ignition. |
| **mg/kg** | Milligram substance per 1 Kilogram of Sludge |
| **mg/L** | Milligrams per Liter. |
| **MM** | Mineral Matter. |
| **$mS\ m^{-1}$** | Milli Semins per meter |
| **Msl** | Mean sea level |
| **$NH_3$** | Ammonia. |
| **nH-N** | Non Hydrolysable Nitrogen. |
| **NPK** | Nitrogen Phosphorus Potassium. |
| **ODPT** | Oil Drip Penetration Time. |
| **OPEO** | A kind of non-ionic surfactants |
| **Org-N** | Organic Nitrogen. |
| **pH** | Power of Hydrogen = Degree of Acidity. |
| **rN** | Resistant Nitrogen. |
| **ROM** | Resistant Organic Matter. |
| **SALS** | Small Angle Light Scattering. |
| **SCOD** | Soluble Chemical Oxygen Demand. |
| **SD** | Stabilization degree. |
| **SRF** | Specific Resistance to Filtration. |
| **Stdev** | Standard Deviation |
| **TDS** | Total Dissolved Salts |
| **TKN** | Total Kjeldahl Nitrogen. |
| **TOC** | Total Organic Carbon. |
| **TOM** | Total Organic Matter. |
| **Ton/ha** | Ton per Hectar. |

| | |
|---|---|
| **TSS** | Total Suspended Solids. |
| **TWW** | Treated Waste Water. |
| **w/v** | Weight to volume ratio. |
| **w/w** | Weight to weight ratio. |
| **WAS** | Waste Activated Sludge. |
| **WDPT** | Water Drip Penetration Time. |
| **WR** | Water Repellency. |
| **WWTP** | Waste Water Treatment Plant. |

# Chapter 1

# Introduction

## 1.1 Background

Gaza Strip (GS) has a coastline of 40 km at the eastern extreme of the Mediterranean and on the edge of the Sinai Desert. GS has a total area of 365 square kilometers (MOPIC, 1998) and the population is estimated to be around 1,500,000 people.

Sludge (biosolids) may be defined as the matter which refers to the residual, semi-solid material left from industrial wastewater, or sewage treatment plants. It may also refer to the settled suspension obtained from conventional drinking water treatment and numerous other industrial processes. When fresh sewage or wastewater is added to a settling tank, approximately 50% of the suspended solid matter may settle out in a few hours. The collection of the above mentioned solids may be known as raw sludge (Miller 2011). Sludge may be dried and incorporated with some carbonaceous materials to produce a suitable composted material for the use in the agriculture to increase the production and improve the soil properties.

Another definition of Sewage sludge comes from (Hussien, 2009) who defined it as the insoluble residues from municipal wastewater treatment after either aerobic or anaerobic digestion processes. Increasing costs of commercial fertilizers and large amounts of sewage sludge produced worldwide have made cropland application of this residue an attractive disposal option. Chemical and biological compositions of sewage sludge depend on the wastewater composition (Melo et al., 2002). Usually, it is rich in Organic Mater (OM) and plant nutrients such as nitrogen (N), phosphorus (P) and calcium (Ca) (Hue, 1988) and can improve soil physical, chemical and biological properties, such as porosity, aggregate stability, bulk density, soil fertility, water movement and retention (Silveira et al., 2003)

## 1.2 Wastewater treatment facilities in the Gaza Strip

There are four wastewater disposal and treatment facilities in Gaza strip, Beit Lahia (BLWWTP), Gaza City (GWWTP) and Rafah (RWWTP), but none is functioning effectively (MOPIC, 1998). They are not sophisticated treatment technology, it consist of anaerobic lagoons, aerated lagoons and maturation ponds. GWWTP is the only treatment facility which has trickling filters. The effluent from Gaza and Rafah treatment plants is mostly discharged into the Mediterranean Sea. In the case of the Beit Lahia wastewater treatment plant, a substantial quantity of wastewater infiltrates into the ground, contaminating soil and groundwater in the area. High level of nitrate has recently been detected from the aquifer, and it is most likely that the excess effluent is responsible for the deterioration of the water quality of the aquifer (Abu-Jalalah, 1999). The GWWTP is located in Sheikh Ejleen Area southern Gaza city; this area is known to produce the most famous grapes in Gaza strip and may be in whole Palestine. The area, where the plant is located is owned by the MOG totaling around 120 dunums including the infiltration basins and most of this area is bought by the MOG from private owners. Before the Israeli disengagement in 12/09/05, there was an Israeli settlement just 100m from the treatment plant called Netzarim, and now after the disengagement this area is expected to be developed for the harbor stores. As the level of treatment in GWWTP continued to deteriorate, the pollution in Wadi Gaza became a problem. This was worsened by wastewater flows from the middle area. To alleviate the problem in 1994, UNRWA and the municipality of Gaza upgraded the treatment plant by removing sand and sludge from the lagoons, upgrading their physical conditions and altering the treatment process to adequately treat around 12,000m3 of influent daily. In 1998, the United State Agency for International development (USAID) upgraded GWWTP to receive influent quantity up to 32,000 m3 daily in 2005 (USAID, MOG, 1997) However, the system is overloaded and the hydraulic flows exceed the planning schedule. The GWWTP receive new an estimated effluent of more than 55,000 m3/day (DORSCH CONSULT, 2005).

The population in Gaza produces large quantities of wastewater that contains huge qualities of biosolids (sludge) in which very little information is available. The treatment system in the Gaza Strip is limited to anaerobic lagoons, aerated lagoons and facultative lagoons. Only Gaza and Rafah cities treatment plants have trickling filter system. Primary and secondary sludge are produced from Gaza 3 wastewater treatment plants. Currently the sludge disposed in the treatment plant without use.

## 1.3 Problem Statement

It is expected that, large amounts of sludge are being produced from Gaza Strip four wastewater treatment plants, but there is no exact data. Sludge constitutes a burden to the operators of the treatment plants, it is accumulated in the closest sandy dunes surrounding the treatment plant causing serious hazards to the environment and its leachate infiltrates to the ground water leading to high $NO_3$ concentration and high soluble heavy metals concentration in the groundwater aquifer. In addition, there is a lack of data about the effect of sludge on plant growth and the best applied rate to produce the highest yield and the characteristics of the soil in which it is applied. Searching the data base in the internet and websites indicated that there is lack of published works that describe the physicochemical and/or biological characteristics of sludge produced from Gaza Strip wastewater treatment plants and particularly from Gaza City Treatment plant (Sheikh Ejleen). It is planned now to have 4 central wastewater treatment plants to serve the population of Gaza Strip. The expected annual quantity of sludge is 203,137 $m^3$ as fresh sludge (12,188 tons dry). Such a high quantity of sludge requires safe disposal (PWA, 2013). Accordingly, the current thesis is designed to achieve the following objectives.

## 1.4 Thesis Aim

The main goal of this thesis is to physically and chemically characterize the sludge from the drying beds of Sheikh Ejleen Treatment plant and the extent of usability of it in agriculture.

## 1.5 The objectives of this study are to

1. Characterize the physicochemical properties of sludge produced in Sheikh-Ejleen sewage water treatment plant.
2. Assess the potential risk due to the undesirable elements (heavy metals)
3. Determine whether the sludge properties are encouraging for agricultural use
4. Determine the sludge quantity to improve corn growth.

## 1.6 Methodology

The methodology to achieve the objectives of this study is summarized in the following points:

5. Taking representative samples from Sheikh Ejleen Treatment plant
6. Air-drying of this samples using the sun rays in the month of June
7. Using mechanical plastic hammer to grind the sludge samples
8. Sieving these samples on 2mm sieve and storing them in plastic bags for further physical and chemical characterization
9. Dissolving 10 g of the air-dried sludge in 50 ml of distilled water (1w:5v ratio)
10. Measuring pH, EC and TDS in this solution
11. Using Buchner funnel to separate the solids from the liquid matter
12. Appling other chemical and physical tests on the filtrate such as total organic matter content
13. Planting corn in a pot experiment and determining the best applied rate of sludge
14. Calculating the average and standard deviation and p-value to compare between the treatments

## 1.7 Thesis Outline

**Chapter one** presents the introduction about sludge situation in Gaza Strip. 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** presents all the aspects of the study area from general information to the specific information about Gaza (Sheikh Ejleen) wastewater treatment plant , it also describes all the treatments processes that take place within the treatment plant

**Chapter three** reviews the literature related to the sludge physical and chemical characteristics and reuse.

**Chapter four** deal with the experimental program and analysis methods that have been followed in this thesis.

**Chapter five** presented the results and discussion.

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

# Chapter 2

# Study Area

## 2.1 Location and Population

The Municipality of Gaza (MOG) is located in the mid-north of Gaza strip and it is a separate Governorate as shown in map (1), with a total area of 40 square kilometers (MOPIC, 1998). The Gaza City population is estimated to be around 500,000 people, about two third of them are refugees. All governmental institutes and international organizations headquarters are located in Gaza city.

## 2.2 Administration

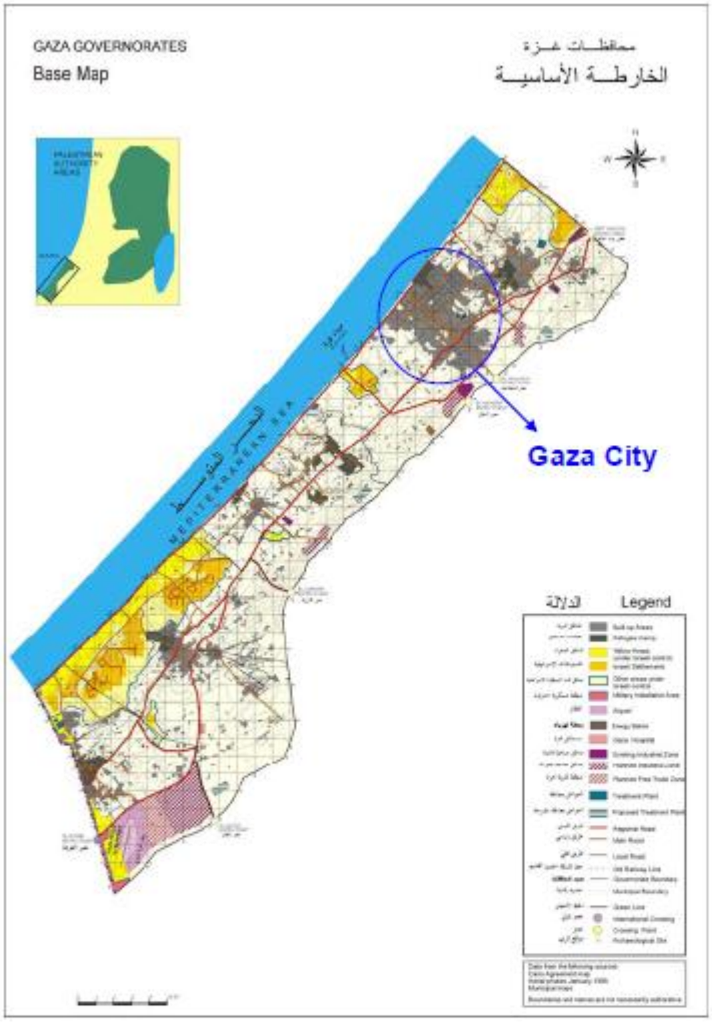
Prior to the year 1948, the MOG had a population of about 75,000 inhabitants with a limited infrastructure (USAID, 1997; Ghannam, 2006). The mass of refugees resulting from the 1948 war caused crowded housing conditions, and thus massive drainage problems to the city. After the war, the Egyptian Government Administration took responsibility for the Gaza strip, who undertook limited sewer construction activities within the area of MOG in an attempt to keep up with the rapidly growing population. The 1967 war brought Israeli occupation and control to Gaza strip. Infrastructure control, including planning and development, was under Israeli Civil Administration. The population of MOG was estimated to be about 117,000 by the year 1967. After the establishment of the Palestinian Authority in 1994, the first most accurate survey for population was performed by the Palestinian Central Bureau of Statistics (PCBS; Ghannam, 2006) which showed the population of Gaza governorate was 357,768 in mid 1994, and according to the PCBS report on December 1999 the population projection for the year 2005 is 516,882 inhabitants and it is expected to reach 650,033 by the year 2010 (PCBS, 1999; Ghannam, 2006). Nowadays, the Governorate of Gaza is divided into nine main areas: Turkman, Judeidah, Al-Daraj, Al-Sabrah, Northern Remal, Southern Remal, Tal El-hawa, al-Zaitoon, and the Beach Camp. The Ministry of Local Governorates is responsible for the administration of the local Municipalities within the territories of the Palestinian Authority (PA) which was created after Oslo Agreement in 1994, which signed between the Palestinian Liberation Organization (PLO) and Israeli. The Municipality has municipal counsels, which formed by Presidential Decrees to supervise the administration of municipalities. The municipal counsel of Gaza municipality consisted of seven members. The responsibility for the development, operation and maintenance of all wastewater and storm water drainage system within the MOG is fully under the direction of the Mayor. Similarly, the Municipality is also responsible for water supply. Operation and maintenance costs are covered by the MOG annual budget which is supplemented by user fees assessed on water use. Such fees include a surcharge for wastewater services. Funding support from donor program is being obtained directly through National Ministries and used primarily for new projects and for rehabilitation of existing works. However, some efforts are being dedicated to operations, maintenance and training activities. The department of water and wastewater in the MOG consists of four main sub-departments: Water (wells and networks), Wastewater (networks and pumping stations), Treatment (wastewater treatment plant- GWWTP) and Maintenance (electrical and mechanical). The GWWTP consists of two sections: operation and laboratory. The operation section is responsible for the daily operations of the plant and to monitor the performance of the different mechanical facilities in the plant and to record the daily activities while the laboratory is responsible for monitoring the quality of influent and effluent coming to the plant or discharging to the sea or infiltration ponds. In 2000, the MOG along with 25 Municipal Counsels signed a memorandum of understanding with the Palestinian Water Authority to consolidate the water services in all the 26 municipalities in one single water utility called Coastal Municipalities Water Utility (CMWU). The establishment of the CMWU was one of the major reforms adopted by Palestinian Water Authority (PWA) in water sector and it became a major demand from the donors to cooperate with the PA. The Board of the Utility has also been nominated. The Minister of Local Government, as part of his mandate, issued a Decree of CMWU establishment under the Local Government Law (CMWU Quarter Report, 2005; Ghannam, 2006) In April, 2005 a Management Contract was signed between CMWU and a consortium of an Austrian company and a Saudi company (joint venture) to operate the Gaza Emergency Water Project (GEWP) financed by the World Bank which will lead to the activation of the CMWU on the ground as a responsible body for the water services in all Gaza strip. Today, the Operator (Inframan) is responsible for the maintenance and operation of GWWTP (CMWU Quarter Report, 2005; Ghannam, 2006).

## 2.3 Climate

The climate in the Governorate of Gaza is typical Eastern Mediterranean with hot dry summers and mild winters. Rainfall average about 425 mm annually based on 35 years record (USAID, 1997; Ghannam, 2006). The average daily mean temperature is 25 degrees centigrade in the summer and 13 degrees centigrade in the winter (MOPIC, 1998; Ghannam, 2006). During the hot summer season, the daily maximum temperature generally exceeds 30 degrees centigrade and the maximum relative humidity exceeds 90%. Winds prevail from the northwest in the summer, with velocities up to 3.9 m/s (USAID, 1997; Ghannam, 2006). During the winter, the most frequent wind direction is southwest and average velocity is about 4.2 m/s (USAID, 1997; Ghannam, 2006).

## 2.4 Land Ownership and Land Use

Historically Gazans have generally had the freedom and opportunity to own and develop their own lands. This trend continues today and land is one of the most important commodities in Gaza with values rating from $200 to more than $1000 per square meter within the city limits. These prices are high, even by industrialized country standard, and will influence the land use in the MOG area. The development in Gaza increased after the Oslo accord by both private owners and donors. Returning residents and refugees have added to this rapid development rate. Even during the Intifada, investment in land remained high. Today growth is occurring at a rapid and uncontrolled pace. There are no planning controls in place that effectively direct growth or control the type of use. The Ministry of Planning (MOP) has developed general plans for the Gaza strip defining target uses such as agriculture, industry, and public facilities including locations of a future harbor and the regional wastewater treatment sites. This general plan assumes that growth within the city limits will continue.



**Map (1)**: Location of Gaza city and existing treatment facilities.

## 2.5 Sewerage system and coverage

The sewer system in Gaza City is reported to date back to a Roman drainage system; however, the extent and location of this early history are unknown. Such a system was probably used for the removal of both storm flows and sewage (USAID, MOG, 1996; Ghannam, 2006). Over the last 30 years, the sewage network was constructed primarily by the MOG while under various authorities and controls. Records, such as as-built drawings were not usually developed or kept, nor was maintenance undertaken except for emergencies. UNRWA addressed the need for cleaning and repairs of a key portion of the system. A critical part of this work was a detailed inspection of the network and recording of the physical as-built data of the network. These as-built conditions were combined with available city records and survey data collected for the Master Plan to create a detailed as-built record of the network. The sewer network covers around 75% of the total area of the MOG and around 90% of the population with a total number of sewage subscribers around 26,000 subscriptions in the Gaza Governorate (PWA, Fiscal Report, 2004; Ghannam, 2006).

## 2.6 The Gaza Wastewater Treatment Plant

This section describes the Gaza Wastewater Treatment Plant demonstrating the development of the original design, the existing facilities of GWWTP and the prevailing conditions of the plant. The ongoing and planned activities of GWWTP are then produced along with the environmental effects of plant on the aquifer and habitat. This section concludes with a description of the treatment process scheme.

### • Hydrogeology of Plant Location

The Gaza Strip is essentially a foreshore plain gradually sloping westwards, and underlain by a series of geological formations. The area within MOG consists mainly of sands dunes in undulating formations, interspersed with clay lenses. Some areas have relatively deep layers of clay soils (USAID, 2001; Ghannam, 2006). These are experienced mostly in Al-Zeiton and Al-Tofah catchments while the coastal zone is primarily sand. Groundwater levels in the city ranges from 1.0m to 2.0m relative to mean sea level and the fresh water aquifer under the city is reported to have thickness of up to about 90m (USAID, 1996; Ghannam, 2006) The GWWTP is situated on a hill with elevation of 44.2 msl in Sheikh Ejleen sand dune area with a percolation rates in the range of 8.6m/day (USAID, 1997; Ghannam, 2006).

### • Existing GWWTP Facilities

The existing GWWTP includes on-site treatment facilities, as well as off-site infiltration basins. All flow is pumped to the site through three force mains. An effluent pump station and pipeline are used to transport effluent from the main plant to the infiltration basins or to the Wadi Gaza. An existing force main/gravity line is also used to discharge effluent to the sea. The main plant facilities consist of three anaerobic ponds in series followed by an aerated lagoon and two bio-towers. The anaerobic lagoons are heavily loaded compared to typical design recommendations. Limited dredging is practiced in the first of the three anaerobic lagoons. The aerated lagoon is equipped with floating mechanical aerators and the bio-towers are filled with high-density plastic media. The bio-tower effluent is directed to an effluent polishing pond where solids sedimentation occurs and limited solids collection is possible. Solids are removed by a series of draft tubes. The sludge is directed to un-aerated solid holding ponds. Polishing pond effluent is pumped to the off-site infiltration basins, Wadi Gaza or to the sea. Three basins are used for infiltration. The plant has a sodium hypochlorite disinfection system used for the effluent which is directed to the sea. Solids dredged form anaerobic pond 1 and biological solids from the sludge holding pond are directed to the on-site sludge drying beds for dewatering. The following point gives short description to the main existing treatment facilities of GWWTP (CAMP,2001; Ghannam, 2006)

- **Influent Structure:** The structure consists of a side inlet structure accepting the 900mm force main from Pumping Station No.7B, and a main box inlet structure which accepts the flow from the remaining two pumping stations: Pumping Station No.1 and Pumping Station No.6A.
- **Anaerobic Ponds:** The anaerobic ponds include two initial anaerobic ponds (1 & 2) each with volume of 22,000m3. The two ponds can be operated in series or parallel. The third anaerobic pond (3) has a volume of 32,000m3.
- **Aerated Pond:** The aerated pond includes ten 25hp floating surface aerators and six 50hp units. Each of the 16 aerators is fixed in the pond by cables and anchors. The pond has the total capacity of 45,000 m3.

**Bio-Tower Feed Pump Station:** A submersible pumping station pumps aerated pond effluent plus recycle to two high-rate bio-towers. Four 60hp pumps, each rated at 667m3/hr, are available.

- **Bio-towers:** The two high rate bio-towers are 27 m in diameter with 7.3 m of media depth. The units operate in parallel and are designed for 85% BOD5 removal. Countercurrent natural ventilation openings are provided at the base of the units around the circumference on a 45-degree center. Bio-tower effluent drains to the downstream settling pond through a 1,000mm pipe.

- **Bio-Tower effluent Distribution Chamber:** This structure divides effluent flow from the bio-towers proportionally between the settling pond and recycle back to the bio-towers. It also allows bypass of bio-tower effluent to the existing effluent pump station. Stop gates provide for six recycle rates ranging from 20%-67% of the bio-tower effluent.
- **Effluent Polishing Pond:** The pond is divided by a concrete wall creating a settling pond and a chlorination contact zone. The settling pond is 13 m wide by 83 m long concrete hopper-bottom settling zone. Sludge is removed through 150 mm suction pipe draped along the existing 3:1 slope. The suction manifold is connected to a diesel pump. The pump discharges sludge into the sludge holding pond. The suction drop pipes are spaced on 4 m centers and each includes a plug valve located at the top of the beam so the suction pipes can open individually.
- **Sludge Holding Pond:** This un-aerated pond is used as an anaerobic sludge holding pond with a total capacity of 10,700m3.
- **Effluent Pump Station:** A submersible pump station is constructed in the beam of the effluent polishing pond. It consists of two wet wells, each containing two 60hp and 1,000 m3/hr submersible pumps.
- **Chlorination Facility:** Sodium hypochlorite storage and dosing equipment are provided, but are not currently in use.
- **Effluent Pipeline.** A 600mm pipeline can deliver plant effluent to the infiltration basins or to the Wadi Gaza. A separate pipeline can carry effluent to the sea.
- **Infiltration Facilities.** Effluent reuse facilities consist of three infiltration ponds with a total area of 37,000 m2, 5,000 m3 storage tank and 2,000 m3/hr booster pump station.

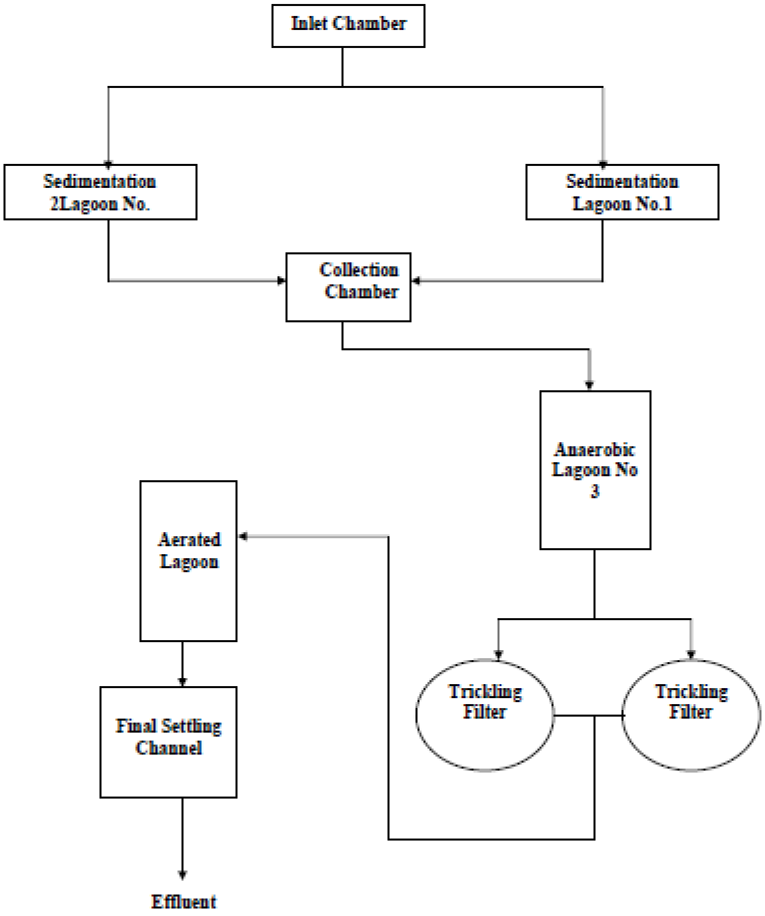


**Figure 2.1**: The Current Flow Scheme of GWWTP

## 2.7 Existing Operation Condition

The GWWTP was upgraded in 1997-1998 to receive and treat influent quantity up to 32,000 m3 daily in 2005 from Gaza City. When it was put into operation, flows were found already to exceed 30,000m3/day. The GWWTP regularly received over 50,000m3/day up to summer2004, after this time the flow meter was out of order. Based on site visit and discussions with plant operators and engineers, the following points are noted:

- The GWWTP was already over loaded since it started operation in 1998 and today the plant receives more than 55,000m3/day. The lagoons are almost full to the edges and the capacity to discharge effluent is limited to the capacity of the effluent pumping station which is less than 2000m3/ HOUR. To reduce the flows received at the GWWTP, raw sewage is being discharged direct to the sea from two locations at Gaza beach.
- The anaerobic lagoons had not been desludged (cleaned) for more than three years. As a result, the settlement lagoons are now full of grit and sludge. Since naerobic lagoon no.1 is filled with grit totally, this part of treatment plant is bypassed. The sludge layer of bond 2 is almost 20cm below the water surface. Less than one eighth of the tank volume is operating as a settling zone. Anaerobic bond 3 seems to be not significantly better than pond 2.
- The official Gaza Municipality landfill site is located on eastern Gaza near the Green Line with Israel. Access to the land fill had been frequently blocked during the past two years. During these periods, municipal garbage had been dumped in the GWWTP site as the only available alternative. It is estimated that more than 700,000m3of solid waste had been dumped at the site. Wind blown plastic bags are causing frequent blockage of the aerators and biotower distributors.
- Although the Bio-towers are damaged by Israeli actions, they are operating well and the media is in good shape. However, the surface area of the trickling filter is partly covered with solid waste (plastic bags) which influences the hydraulic flow patterns negatively. Part of the openings of the trickling filter flow distributors seem to be clogged and the first layer of the media seems to be clogged and need to be cleaned.
- In the end of October 2004, the GWWTP received more aggressions from the Israeli Army, where the administration building had been damaged, the parking shelter had been completely destroyed and one of the bio-towers has been hit by a tank gun. Moreover, the lab of plant also received its share in the damage that led to complete suspension of the monitoring program of the quality of influent and effluent, moreover, the automatic sampler for the influent was also totally damaged.

# Chapter 3

# Literature review

## 3.1 Wastewater Treatment in Gaza Strip

Wastewater management, including the collection, treatment and disposal of wastewater has been a major environmental challenge in the Gaza Strip for several decades. Recent reports indicate that 81.9 percent of the population now lives in areas with sewage networks, while the remainder uses porous cesspit or tight cesspit (PCBS, 2011; Attaallah, 2013). There are four WWTPs operating in the Gaza Strip: Beit-Lahia WWTP in the north, Gaza WWTP in the Gaza City, Khan Yunis WWTP and Rafah WWTP in the south. The type of treatment, quantity and final disposal of each plant is summarized in Table 2.1.

Table 3.1: Existing WWTPs in Gaza strip (UNEP, 2009; Attaallah, 2013)

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

## 3.2 Previous studies on the subject of the physicochemical characteristics of sludge

### 3.2.1 Local studies about the sludge physicochemical properties

Nassar et.al,(2003) studied the sludge management using reed bed system and they concluded that the wastewater and the sludge in Gaza Strip is relatively free of contamination of heavy metals and they suggested the application of sludge to agriculture would have minimal risk of heavy metals accumulation. Furthermore in advanced study (Nassar el al. 2005), the authors studied the sludge management concept in Gaza Strip and found that there is little experience of sludge use in Gaza. In addition, they reported that huge quantities of sludge (30,000 tds) produced annually and this required a minimum of 30,000 dunums for its use. However, the report mentioned the international standards for sludge use in agriculture whereas the physicochemical properties of sludge produced in Gaza were not reported.

Sludge currently generated in the Gaza Strip is difficult to quantify. No measurements are taken and there are no previous estimates of sludge quantities. Estimates suggest that around 400 m3 of sludge is produced daily from the secondary treatment facility in the Gaza treatment plant. The analyses show that sludge is almost free of heavy metals and rich in nutrients such as nitrogen and phosphorus. The quantities of sludge estimated by the year 2025 in all Gaza Strip are 55.74 thousand kilograms of dry solids daily. The sludge is expected to consist of 1–2% dry solids which mean that 3,716 m3 of sludge will be generated daily in the Gaza Strip by the year 2025 (Nassar and Afifi 2006).

### 3.2.2 International studies about the sludge physicochemical properties

Besides that, Ruiz et al.,(2007) investigated the influence of organic content and shrinkage of urban residual sludge under controlled atmosphere drying condition. They reported the convective drying aptitude of residual urban sludge in isothermal conditions at atmospheric pressure. They also found that the coupled analysis of the dewatering and induced shrinkage curves shows correlations between the hydric and the textural characteristics. Emphasis was placed on the influence on these correlations of the nature of the sludge, characterized by their organic matter content.

Koenig et al., (1996) studied the physical properties of dewatered wastewater sludge for landfilling to determine and evaluate dewatered wastewater sludge with regard to the following physical and geotechnical properties: (i) vane shear strength; (ii) consolidation characteristics such as compression index, compressibility factor, coefficient of consolidation and compressibility coefficient; and (iii) hydraulic characteristics such as permeability and intrinsic resistance. They found out that although dewatered sludge exhibits quite different characteristics as compared to soils, predictive logarithmic relationships may be established between various properties which are consistent with the critical state model for soils, conventional filtration and consolidation theory. Such representation provides a valuable basis for understanding the sludge characteristics and behavior to landfill design. In the same context, Mikkelsen and Keiding (2002) investigated correlations between sludge composition, structure and dewatering properties and found out that the fraction of extracellular polymeric substances (EPS) in sludges was the most important parameter with respect to sludge structure. Also they found that dewatering includes sludge expression. Taking this into account, osmosis related to EPS charges is likely to be increasingly important. (increasing the negative effect of EPS content on cake dry matter).

In a relative study, the mechanical properties of dewatered sewage sludge was previously investigated (O'Kelly 2005). He found that moderately digested sludge material has a typical specific gravity of solids value of 1.55, and loss on ignition (LOI) value of 70% dry mass, while strongly digested sludge has a lower LOI value of 55% dry mass, and a higher specific gravity of solids value of about 1.72. The shear strength values measured in triaxial compression and vane shear were consistent. The effective angle of shearing resistance ‘phi' value increased from 32 degrees for moderately digested sludge, to 37 degrees for strongly digested sludge. The effective cohesion of the sludge material remained zero throughout. Re-hydration of the dry material caused the bulk volume to double.

Furthermore, Kae-Long et al.,(2006) analyzed the effects of the heating temperature on the properties of the sintered sewage sludge ash. They found that the water absorption rate of the sintered sewage sludge ash samples decreased when the firing temperature was increased from 800 to 900 ◦C. Also they found that the bulk density of the sewage sludge ash samples increased by 2.3 g/cm$^3$ when the heating temperature was increased from 900 to 1000 ◦C, indicating that the densification was affected by heating.

In addition, Hou et al., (2012) studied the influence of non-ionic surfactants on sludge dewaterability. Two kinds of non-ionic surfactants (OPEO and APG) were studied by using two evaluation indexes, i. e., specific resistance to filtration (SRF) and dewatering efficiency. They found that the water content of dewatered cake conditioned with APG dosage of 0.05% DS was lower by about 10% than that of dewatered cake without APG, and its dewatering efficiency reached 97%. Therefore, the research provides some reference for the application of APG in sludge dewatering.

In the other hand, the effect of the substrate composition (no substrate, glucose, glucose + sulfate or glucose + sulfate + iron) on the physico-chemical characteristics of two different anaerobic granular sludge as a function of time was investigated (Eric et al., 2007). They found that the higher mineral content and the decrease of the EPS content contributed to the disintegration of iron fed granules, as shown by their lower size particles. In the way around, Yu-Chung et al. (2010) investigated the heavy metal extraction ability from PCB wastewater treatment sludge by sulfuric acid. They found out that the total and individual heavy metal removal efficiencies increased with increasing sulfuric acid concentration, but decreased with increasing solid to liquid ratio. Also they found that the trivalent heavy metal ions, iron and chromium were more difficult to be removed than the divalent ions, copper, zinc, nickel, and cadmium

Composting the sludge was also investigated by Rodríguez et al.,(2012) who published an article that concluding the influence of four process variables (turning frequency, gas-phase oxygen level, type of bulking agent and sludge/bulking agent mixing ratio) on the performance of the sewage sludge composting process using a rotary drum pilot scale reactor. They found that the right combination of having optimal process variables combined with an appropriate reactor design allowed the thermophilic stage of the composting process to be speeded up, hence obtaining a compost product.

In addition Pevere et al., (2006) investigated viscosity evolution of anaerobic granular sludge. They found out the anaerobic granular sludge has a non-Newtonian behavior. Also they found out that the total suspended solids (TSS) content of the sieved granular sludge strongly influence the limit viscosity value and an exponential relationship was found between the TSS content and this rheological parameter. They also found that significant differences in limit viscosity values were found for granular sludges of different origin. Furthermore, Bhatti et al., (1995) carried out a comparative investigation of the components and characteristics of three types of fully developed granular sludge operating in full-scale and laboratory up flow anaerobic sludge blanket reactors under different conditions. They found that feed mineral concentration had an overall effect on the mineral composition of granular sludge and that specific uptake of preferred minerals such as magnesium, iron and phosphorus occurred depending upon the operational and environmental conditions.

In a recent study, Devlin et al., (2010) investigated the effects of acid pretreatment (pH 6–1) using HCl on subsequent digestion and dewatering of waste activated sludge (WAS). They concluded that Pretreatment to pH 2 was the most effective. Also in batch digestion, this yielded the same biogas after 13 days as compared to untreated WAS at 21 days digestion. They suggested that in dewatering process the acid pretreated WAS required 40% less cationic polymer addition to achieve the same cake solid content. In a relative study, Chen et al. (2008) evaluated the bioavailability and eco-toxicity of heavy metals in municipal sludge, taking into consideration both the speciation of metals and the local environmental characteristics. They found experimentally that in general the municipal sludge collected from the five sewage plants was rich in organics, N and P. Except that the sludge from XiaWan Sewage Treatment Plant showed higher concentrations of heavy metals, the sludge from other plants all showed a low total content of heavy metals with only Cd slightly exceeding the permitted values of the national application standard of acid soil in China. The sequential extraction results showed that Cu and Zn were principally distributed in the oxidizable fraction, which meant a high potential toxicity, but the bioavailability of Zn might be overestimated to the soil of Hunan. Pb was mainly in the residual fraction. The distribution of Cd showed no obvious characteristics.

### The impact on the chemical properties of soil treated with sludge

Erdem and Ok ,(2002) evaluated the changes in chemical properties of an acid soil amended with 0, 15, 30, 60 and 120 t $ha^{-1}$ of brewery sludge (BS) for an incubation period of 120 days. And they found that by increasing BS rates and incubation time, the soluble salts of the soil increased from 0.11 to 0.80 dS $m^{-1}$, and the organic C, exchangeable cations, soluble cations and anions, $NH_4^+$–N and $NO_3^-$–N contents of the amended soil increased while the pH of the soil decreased by 0.3–0.5 unit with respect to the control . furthermore cation exchange capacity (CEC) increased slightly whereas the exchangeable acidity decreased slightly. Furthermore, Casado-Vela et al.,(2007) monitored the effect of the application of three increasing amounts of composted sewage sludge (3, 6 and 9 kg compost $m^{-2}$) on the physicochemical properties of a horticultural calcareous soil where two types of plants were grown under two exploitation regimes (one in a greenhouse and the other in open-air). They found out that the 9 kg compost m−2 application promoted the appearance of deleterious effects on the properties of soil, such as salt accumulation, a significant increase in the electrical conductivity and an input of heavy metals (Pb > Cr > Cd). The 6 kg compost m−2 application provided a supply of nutrients necessary to grow peppers plants under both exploitation regimes. The first plant biomass production under greenhouse was almost 60% higher compared to that of the open-air plot. In a recent study, Roig et al., (2012) analyzed the systematic and periodical use, for 16 years, of anaerobically digested sewage sludge as an agricultural fertilizer by assessing the effects on some soil physical–chemical, functional, and ecotoxicological properties. They found that the input of sludge enhances soil properties proportionally to the application doses and/or frequency. And the organic amendments increased the organic matter content (and its aromaticity), the soil nitrogen, and the microbial activity, improving carbon and nitrogen mineralization processes and some enzymatic functions. And they showed that the maximum dose should be (40 Mg $ha^{-1}$ $year^{-1}$) no more. In addition, the effects of organic matter, nitrogen, phosphorus and toxic elements in sewage sludges applied to agricultural land were reviewed by Sterritt and Lester (1980) and they found that the organic matter may improve the structure and water holding capacity of poor soils and the nitrogen and phosphorus in sludge have fertiliser value, and the crops can accumulate toxic elements from sludge-amended soils. Also the extent of accumulation varies considerably with plant species and cultivar; cereals and legumes accumulating lower concentrations than leafy plants.

Furthermore, the effect of sewage sludge application on biological and biochemical properties of soil in the plots maintained by the City of Winnipeg at Oak Hammock Marsh, Manitoba were examined by Banerjee et al., (1997). They found that the sludge application significantly increased the amount of microbial biomass present in the soils. Also the biomass N content was uncharacteristically low resulting in a mean microbial biomass C:N ratio of 36:1. And despite the low C:N ratio of the biomass, sludge application enhanced the N mineralization potential of the soil. Additionally they found that the sludge application somewhat increased soil enzyme activities.

In addition, Egiarte et al., (2008) examined whether the repeated application of sewage sludge to an acid forest soil (Dystric Cambisol) would lead to short-term groundwater contamination. They found that a repeated application of sludge at 60 Mg ha$^{-1}$ resulted in significantly higher concentrations of Zn, Cd, Cr and Ni in the leachates than with other treatments (other loading rates). Also, Wong et al., (2007) investigated the effects of dissolved organic matter (DOM) from anaerobically digested dewatered sludge on Cd and Zn sorption by three different soil types (calcareous clay loam, calcareous sandy loam and acidic sandy loam) of different physicochemical properties through batch studies. They found that the addition of DOM significantly reduced the Cd and Zn sorption capacity for these three soils as seen, suggesting that DOM had a stronger inhibitory effect on Zn sorption than that of Cd. They also found that the reduction in metal sorption caused by DOM was very apparent in the pH range of 5 to 8, with a maximum inhibition on metal sorption occurring at pH 7–7.5 especially for Zn but the effect was minimal at lower pH. And at each given DOM concentration, the inhibition of metal sorption of the different soil types increased in the following order: acidic sandy loam < calcareous sandy loam < calcareous clay loam.

In a different study, Criquet et al., (2007) investigated the factors regulating phosphatase activities in Mediterranean soils subjected to sewage sludge applications. The results they found showed significant effects of sewage sludge application and incubation period. The effect of sewage sludge resulted in an increase in phosphatase activities, microbial density and available P whereas the incubation period increased the available P while decreasing phosphatase activities. In addition to that they found that the origin of sludge and its chemical characteristics may show different effects on certain variables such as phosphodiesterases or bacterial density, whereas mineral parent materials of soils did not show any significant effects.

Khan and Scullion ( 2002) measured the effects of varying sludge metal (Cd, Cu, Ni, Pb and Zn) contents on respiration, biomass C and N, and N mineralization in a series of laboratory incubations of soil–sludge mixes. They found that Cd (up to 70 mg $kg^{-1}$ in soil) did not affect any microbial index. Higher concentrations of the other metals generally caused a decrease in biomass C and N, the reduction for C often being proportionally less than that for N and in most cases, higher metal concentrations increased respiration rates and microbial metabolic quotient. In addition to that soil mineral N was increased by higher inputs of all metals and the use of sludges with higher metal concentrations may lead to short-term changes in soil microbial communities and their activities, with increased loss of C to the atmosphere and N availability.

Serna and Pomares (1992) determined the N-mineralization rate of 12 sewage sludges in a given soil during a 16-week aerobic incubation by analysis of inorganic N produced by a nonleached procedure. They found that the aerobically treated sewage sludges gave higher mineralization rates than the anaerobically treated wastes and values of potentially mineralizable N (No) varied from 71 to 394 mg N $kg^{-1}$ soil, and mineralization rate constant (k) ranged from 0·089 to 0·883 week−1. In a different study, López-Valdez et al., (2010) investigated how emissions of $CO_2$, $N_2O$ and $N_2$, and dynamics of mineral N were affected when different types of N fertilizer, i.e. $NH_4^+$,

$NO_3^-$, or unsterilized or sterilized wastewater sludge, were added to the Texcoco soil. It was found that microorganisms added with the sludge accelerated organic material decomposition, increased $NH_4^+$ immobilization, and induced immobilization of $NO_3^-$ (in Texcoco soil). They suggested that wastewater sludge improves soil fertility at Otumba (an agricultural soil) and would favour the vegetation of the Texcoco soil (alkaline saline).

### The impact of sludge contained heavy metals

Fytianos and Charantoni, (1998) investigated the leaching of heavy metals from municipal sewage sludge. They found that for most values of Liquid solid ratio (L/S) the percentage of leached amounts for the examined metals followed the order Cd > Zn > Pb > Fe > Mn. As pH decreased, metal concentrations measured in the leachate increased. And in general, EDTA showed the greatest mobilization ability, followed by NaOH, acid solutions (HCl, $H_3PO_4$), and water. Particle size distribution had negligible effect on Cd, Mn, and Pb leaching from sewage sludge and a decrease in the amount of Fe, Zn, and Cu leached was observed with increasing particle size.

Moreno et al. ,(2002) investigated the effect of sewage sludge amendment of a semiarid soil, previously polluted with Cd, on the toxic effect of this heavy metal on soil microbial biomass and its activity. They found out that in general, higher ED (Ecological Dose) values were calculated for the sewage sludge amended soil than for unamended soil and thus the Cd toxicity to microbial activity of the sewage sludge amended soil can be considered lower than that of the unamended soil.

## 3.3 The Status of Wastewater Reuse Practice in The Mediterranean Basin

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

### 3.3.1 Tunisia

RWW irrigation has had Government support since 1975, and since a severe drought in 1989, RWW use in irrigation has been a part of the Government's overall water resources management and environmental pollution control (World Bank, 2010, Attaallah, 2013). It is estimated that by 2020 about 20,000-30,000 ha, or about 7-10% of total irrigated area will be using RWW. The current rate of reuse is about 29%, reused for the cultivation of fruit trees, cereals, fodder crops and industrial crops as well as for golf courses and green spaces. Wastewater is also reuse in recharges purposes and conservation of wetlands (Kamoun and Slimi, 2006, Attaallah, 2013).

### **3.3**.2 **Jordan**

Jordan is one of the most water-deprived countries of the Middle East, and has some of the highest groundwater depletion rates. To meet growing water demands, more than 70 MCM of reclaimed wastewater, around 10 percent of the total national water supply, is used either directly or indirectly each year (World Bank, 2010, Attaallah, 2013). In 1993 the quantity of reused RWW reached 50 MCM, of which 48MCM for irrigation. In 2008 the amount of RWW reached 80 MCM .the total quantity of reused RWW is expected to grow from 80 MCM in 2008 to about 237 MCM in 2020.the reused RWW in Jordan reach one of the highest levels in the world .the importance of reused wastewater is an essential element of Jordan's water strategy .(MERAP, 2010, Attaallah, 2013).

### 3.3.3 Israel

Israel was a pioneer in the development of wastewater reuse practices (Angelakis *et al*., 1999, Attaallah, 2013). It has achieved some impressive accomplishments in reclamation and reuse of wastewater, and at solving issues which arose from using RWW. The total amount of wastewater produced in Israel is approximately 500 MCM/yr including agriculture, industry, and other wastewater consumers. Almost all of the wastewater produced in Israel flows into the main sewage collection systems, while only 2.5% of the wastewater still flows into cesspits. Approximately 450 MCM/yr is being treated at 465 mechanical facilities and stabilization basins, using a variety of technologies. During

2007 total amount of RWW used for agriculture purpose was about 382 MCM. About half of the total amount has been treated to tertiary degree; the rest has been treated to a secondary degree (MERAP, 2010, Attaallah, 2013). In these countries, full fledged regulations set the basic conditions for a safe reuse of wastewater (Angelakis *et al*., 1999, Attaallah, 2013). It is therefore necessary to take precautions before reusing RWW. As a result, although the irrigation of crops or landscapes with RWW is in itself an effective wastewater treatment method, a more effective treatment is necessary for some pollutants and adequate water storage and distribution system must be provided before RWW is used for agricultural or landscape irrigation (Angelakis et al., 1999, Attaallah, 2013).

### 3.3.4 Palestine

In spite the fact that there are very limited activities in the Palestinian territories for using reclaimed wastewater due to many reasons, there is a great potential for the reuse of this water resource to meet increasing agricultural water demand as a main objective of the Palestinian water sector. The total volume of treated urban wastewater for reuse is projected to be 12.1 MCM/yr for the main Palestinian cities by the year 2010. In comparison, the total water demand is projected to increase by 50 MCM/yr over the years 2005-2010. (MERAP, 2010, Attaallah, 2013). The reuse of treated wastewater could be an important alternative to solve the water deficit crisis in Gaza Strip. According to the Water Sector Strategic Planning Study, about 20,000 dunums are to be irrigated by RWW in the year 2010 and this will increase to about 60,000 dunums in the years 2020. The existing four WWTPs ( Beit Lahia, Gaza, KhanYunis and Rafah ) are heavily overloaded as a result of the rapid population growth. Currently, most of the effluent discharged from the four existing WWTPs in Gaza Strip is disposed into the Mediterranean Sea. Although the quality of the effluent from Gaza and even Beit Lahia WWTPs would nearly meet class C standards which are progressively match irrigating citrus, fodder crops and olives (EQA, 2005, Attaallah, 2013).

# Chapter 4

# Materials and Methods

## 4.1 Sludge Sampling

A representative sludge samples with a volume of 20L each were collected from different locations from the drying beds in the Sheikh Ejleen Waste Water Treatment Plant.

The samples were air-dried in the month of June using solar radiation, crushed and mixed together to insure homogeneity of the sludge. The dried sludge samples were sieved through 2mm sieve and mixed again and kept in plastic bags for further experiment work.

Figure 4.1 The location from which the samples were taken

## 4.2 Sludge Dry Mass and Water Content

With slight modification of Wilke (2005) the sludge dry mass and water content was determined as follows. Air dried sludge samples were dried at 105 ± 5 ◦C for 24h. Then the samples were transferred to a dedicator for cooling to avoid humidity absorbance.

The samples were then weighted at room temperature to collect the dry weight.

The differences in masses before and after drying are a measure for the water content of sludge. The water content was calculated on gravimetric (*g* water /*g* sludge) or on volumetric basis ($cm^3$ water/cm3sludge). The procedure described above can be used for the determination of dry mass of sludge on a mass basis (ISO 11465 1993).

## 4.3 Water Holding Capacity

With a slight modification to the procedure described by El-Nahhal et al. (1998) columns techniques will be used. In this technique, 0.5 L of air dried sludge was transferred to small columns with 10 cm diameter. The columns were irrigated with 0.25 L with distilled water and left for 24 h to equilibrium. The sludge samples were weighted before and after irrigation to collect the water content. The leachate was collected and weighted to know the equilibrium water capacity of the columns.

## 4.4 Bulk Density

The bulk density was determined in the laboratory using the mass per unit volume technique by filling 0.5 L plastic pails previously weighed. Once filled, pails were shaked several times to insure complete filling. Between 4 and 8 measures were done on each sample to ensure repeatability. The bulk density on the dry matter basis was calculated after moisture content (Agnew and Leonard, 2003).

## 4.5 Particle size distribution

Particle size distribution was obtained using the hydrometer method of analysis according to Standards Association of Australia (1976) .The samples passed through the 2 mm sieve to insure that no aggregates were retained on the sieve. Fifty grams of air-dried sludge were transferred to a 500mL beaker containing 50 ml Kalgon solution and 250mL distilled using a milkshake mixer. The suspensions were homogenized for 5 min. The volume of the suspension was completed to 1L with distilled water and transferred to the sedimentation cylinder. A plunger was used to stir the suspension for 2 minutes then the hydrometer was gently immersed in the cylinder and allowed for stabilization. The hydrometer readings were collected after 40 seconds, and again after 2 hours. The temperature of the suspension was also recorded at each reading for correction factors. Sand fraction-like particle size was calculated according to the equation used for hydrometer and likewise Silt fraction-like particle size and clay fraction-like particle size.

### 4.6 Sludge hydrophobicity

The water drip penetration time (WDPT) method (Letey, 1969) was used to quantify the degree of water repellency (WR) of the sludge. This procedure involved placing a drop of water on the sludge surface and measuring the time needed for its penetration. The degree of hydrophobicity was evaluated from the WDPT results according to Bauters et al. (1998). An amount of sludge was put on a big dish and distilled water drops (50 µm) were taken by the Jencons Sealpette instrument and put on the surface of the sludge. Photos for the water drips were taken. Oil drip penetration time was taken as a standard deviation of hydrophobicity.

### 4.7 EC and pH measurements

EC (mS $m^{-1}$) and pH values were measured from water extract (1:5 w/v) on wet samples, using a electrical conductivity probe and a pH electrode, respectively.

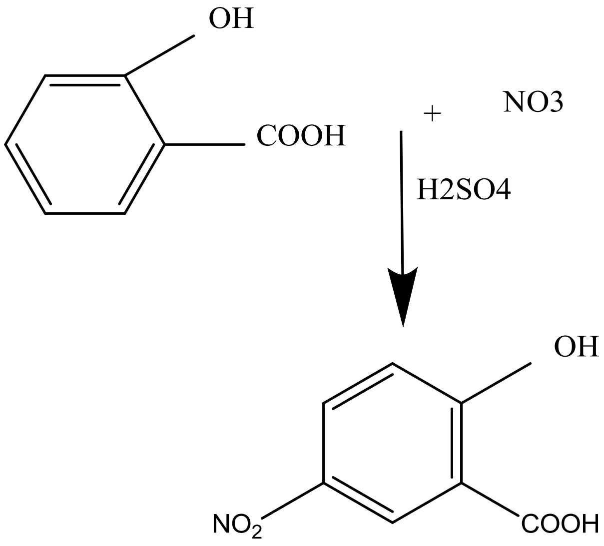
### 4.8 Determination of Total organic matter

Total organic matter (TOM) was determined by weight loss on ignition heating for 4 h in a muffle furnace at 560°C after heating at 250ºC 30 min. Mineral matter (%MM) is %MM=100-%TOM.

### 4.9 Determination of water soluble nitrogen fractions

#### 4.9.1 Nitrate fraction

Nitrate levels in the sludge was deformed according to the salicylic acid method (Cataldo et al. 1975) and which converts the nitrate concentration under acidic media to the corresponding nitrosalicylic acid with yellow color according to the following chemical reactions shown in Figure 4.2.



Nitro salicylic acid (yellow color)

Figure 4.2 Nitro-salicylic acid produced as yellow color during determination of nitrate level in sludge samples.

The intensity of the yellow color represent the nitrate concentration and it was determined using a spectrophotometer. After making a standard curve of nitrosalicylic acid , the same procedure was done to the filtrate from 10 g of sludge in 50ml of water. Results were expressed in g kg-1 dry weight basis.

### 4.9.2 Ammonium fraction

Ammonium was determined using Kjeldahl method without the digestion step. Ten ml of the filtrate of 10g of sludge in 50ml of water after shaking overnight were taken to the distillation step of Kjeldahl and then to the back titration step to determine the ammonium fraction using hydrochloric acid. Results were expressed in g kg-1 dry weight basis.

## 4.10 Determination of total organic nitrogen fraction

Organic nitrogen (org-N) was determined using Kjeldahl digestion. C/N was calculated using Equation 3 (Zucconi and de Bertoldi, 1987; Saña et al., 1989):

$$"C/N" = \frac{TOM/2}{Org - N} \quad (1)$$

Parameters relating to organic matter and nitrogen stabilisation were conducted according to Klason method and Saña et al. (1989): resistant organic matter (ROM) and non-hydrolysable nitrogen (nH-N) was determined as TOM and org-N in the dried residue obtained after two successive sulphuric acid hydrolyses (one in a cool for 3 hours with 72% $H_2SO_4$ followed by a second boiling hydrolysis under reflux for 5 hours in $H_2SO_4$ 0,7N). The reactions based on the following equations

$$\text{Org-N} + H_2SO_4 \longrightarrow (NH_4)_2SO_4 + CO_2 + SO_2 + H_2O \quad (2)$$

$$(NH_4)_2\,SO_4 + NaOH \longrightarrow Na_2\,SO_4 + 2NH_3\,(g) + 2\,H_2O\,(\,l) \quad (3)$$

$$H_2O + NH_3 + B(OH)_3 \longrightarrow NH_4^{\,+} + (BO_4)^- \quad (4)$$

## 4.11 Determination of Nutrient content

### 4.11.1 Determination of Cations

Ten g of sludge samples were suspended in 25 ml distilled water form a ratio of 1:2.5 w/w and shaken over night the pH and EC and TDS were measured to each sample. Then additional 25 ml water were added to form a ratio 1:5 w/w. Nutrient content (K, Ca, Mg, and Na, expressed as g kg-1 dry weight basis) were determined by atomic absorption spectrometry (Ca, Mg), flame photometry (K, Na) (Saña et al., 1989).

### 4.11.2 Determination of Anions

The sulphate (SO4) was determined using the turbidity method and in this procedure sulfate ion is converted to a barium sulfate suspension under controlled conditions. The resulting turbidity is determined by spectrophotometer at 420 nm and compared with a curve prepared from standard sulfate solution.

While the orthophosphate was determined using ascorbic acid method.

The chloride was determined using the titrimetric method by titrating it with silver nitrate ($AgNo_3$) in the presence of potassium chromate as indicator

### 4.12 Determination of the undesirable material such as heavy metals

Following the procedure described by Bashour and Sayegh (2007) the heavy metal concentration in sludge samples will be described. In this procedure, 0.5-2 g air dried sludge were digested in 10 ml of nitric acid 78% and kept under heating with flux at 65 $^oC$ for 24h. Then the system was heated up to 120 $^oC$ for another 24h. After complete digestion (nearly clear solution appeared). The system was left for cooling at the room temperature. The digested sludge was filtered through whattman scale 43, filter paper ashless. The collected filtrate was completed to the mark of volumetric flask capacity 25 ml with the same acid solution. Then the heavy metals were analyzed using inductive coupled plasma analyzer (ICP) at the Rural and Environmental Study Center, Faculty of Science, The Islamic University-Gaza.

### 4.13 Biological investigation

BOD and COD of the sludge samples were measured according to the standard method.

### 4.13.1 COD Determination:

Following the procedure described by ASTM 1995, Chemical Oxygen Demand was determined. Ten grams air-dried sludge were added to erlenmeyer flask containing 50 ml water and kept under magnetic shaking for 48h. Then supernatant was removed by using Buchner funnel. 2 ml of the supernatant was transferred to the COD digestion tube. 2.8 ml, potassium dichromate reagent (Sulfuric acid + silver sulfate + 10g potassium dichromate) was added to the tube in addition, 40mg mercuric sulfate. The tubes were heated up to 160 $^oC$ for 2h in the digestion block of COD. Standard Solution of potassium hydrogen phthalate (KHP) ranged from 0-2000 mg/l COD. The developed blue color was determined at 620 nm using spectrophotometer. Calculation of COD in sludge samples was obtained using regression equation of the standard curve. The results of sludge samples were made and obtained. Average and standard curve were calculated. Low value of standard deviation indicates homogeneity and precision of results.

### 4.13.2 BOD determination:

Ten grams of air-dried sludge were transferred to erlenmeyer flask containing 50ml of distilled water and kept under magnetic shaking for 48h. The supernatant was collected by Buchner funnel. 43ml was transferred to an OxiTop dark brown gloss tube. The consumed $O_2$ after 5days was regarded automatically by machine and the reading was adjusted to the results according the dilution factor. For every dose the dilution factor was 3. Three replicates were made for BOD determination. Average and standard deviation were calculated.

### 4.14 Effect on agricultural growth

Amounts equivalent to 0, 1, 5, and 10 ton sludge/ha were tested in pot experiments using corn as test plant and these equivalent amounts were respectively 0g/pot surface area , 4.2g/pot, 21g/pot, 4.2g/pot. In this experiments, the above mentioned rates of sludge were mixed with sandy soil collected from an agricultural area using 5 replicates for each equivalent amount. The pot volume was 8.8L and the average soil amount volume was 6.5L with an average surface area of 0.0415 $m^2$. Five corn seeds were sown in each pot and irrigated with regular water free from fertilization. Corn plants were harvested after 90-100 day after planting. Plant height and/or fresh biomass were taken as an indicator of plant response to sludge addition to soil.

### 4.15 Plant Harvesting

With slight modification of previous calculations (El-Nahhal et al., 1998) and recent updates by El-Nahhal et al. 2013, % growth was calculated according to the following equation

$$\% \, growth = \frac{(PWt - PWc)}{PWc} \qquad (5)$$

Whereas PWt and PWc are plant weight (g) in the treatment and control sample respectively.

### 4.16 Statistical analysis

The statistical analysis of data was performed with ANOVA test using Excel program

The samples were in three replicates; Mean and standard deviation were calculated.

Analysis of variance among treatment was performed using t-test, p-values below 0.05 indicate significant differences.

# Chapter 5

# Results and Discussion

## 5.1 Physical Properties of sludge

### 5.1.1 Density and void volume

The bulk density of sludge is measured according to the mass per unit volume technique mentioned in chapter 3.

The bulk density of sludge is about 1.18 ± 0.04 g/cm3 which is nearly half the real density. The explanation of these data is that bulk density includes void volume, some water vapor and other gases which contribute to decreasing the density. These results agree with O'kelly (2005) who found that moderately digested sludge material has a typical specific gravity of solids value of 1.55. The similarly of densities of sludge and soil samples suggest that sludge sample contained high fraction of solid materials which may be sand. Furthermore, the void volume of sludge is about 50% of the total volume as shown in Table 5.1.

Table 5.1 Bulk and true density and void volume

| item | value |
|---|---|
| Bulk Density | 1.18±0.04 |
| Real Density | 2.13±0.15 |
| Void volume | 50%±3.6 |

This may indicate high porosity of sludge, in addition this could contribute to the aeration of sludge. This is in agreement with O'kelly (2005) who found that re-hydration of dry sludge caused the bulk density to double. As the bulk density indicates the solid material volume. The presented results agree with Ruan and Liu (2013) who analyzed the fractal structure of activated sludge and found that the sludge was constituted by a series of clusters with different sizes and has various holes and gaps that formed a range of pore structures the enable sludge to have a high void volume. Such a fact makes the sludge to be used in agriculture to store irrigation water and keep good aeration to the soil. Thus, it improves the soil texture. Our result agree with Hu et al., (2012) who found similar bulk density of sludge (1.05 g/cm$^3$).

### 5.1.2 Water holding capacity

Water holding capacity or water retaining capacity is one of the main parameters to determine the suitability of sludge to agricultural lands. The average moisture content of sludge at air dry basis is about 1.81+0.06% which is several times higher than sand (0.14+0.02%). In addition water holding capacity of sludge is about 54.45±1.1%. This indicates that water holding capacity of sludge is nearly 2 times higher than soil water holding capacity as shown in Table 5.2.

Table 5.2 Water holding capacity and moisture content for sludge.

| sample | Water content (%) | Water holding capacity (%) |
|---|---|---|
| Sludge | 1.81+0.06 | 54.45±1.1 |
| sand | 0.14+0.02 | 32.05±2 |

These results lead to the conclusion that if the sludge is used as a conditioner for any soil, it will increase the water holding capacity. Consequently, a reduction of irrigation water in agriculture may occur. The explanation of these results is that the sludge has more porosity because of its fine particles and less permeability that is the continuity and connection of voids between its particles. These results are in accord with the data in Table 4.1.

### 5.1.3 Hydrophobicity of Sludge Samples

It has been reported that the sludge water drip penetration time (WDPT) was 114.77±16.76 seconds and the average wetted radius was 0.44±0.09 cm. Meanwhile, sludge oil drip penetration time (ODPT) was 5.05±1.26 seconds and the average wetted radius was 1.25±0.14 cm. On the contrary, the WDPT of sand was 0.86±0.22 sec(s) and the average wetted radius was 1.167±0.164 cm whereas the sand ODPT was 10.11±2.02 sec(s) and the average wetted radius for the oil drops on sand was 1.07±0.14. In addition, the ratio WDPT/ODPT of sludge is 22.73 which is higher than 1 and the ratio WDPT/ODPT of sand is 0.08 sec(s) which is much lower than 1 as shown in Table 5.3.

Table 5.3 Average water and oil drop penetration time ± standard deviation

| Sample type | WDPT (sec) | Radius (cm) | ODPT (sec) | Radius (cm) | WDPT/ODPT |
|---|---|---|---|---|---|
| Sludge | 114.77±16.76 | 0.44±0.09 | 5.05±1.26 | 1.25±0.14 | 22.73 |
| Sand | 0.86±0.22 | 1.167±0.164 | 10.11±2.02 | 1.07±0.14 | 0.08 |

This means that the water drop needs more time than the time needed for an oil drop to penetrate the sludge surface. This leads to the conclusion that the sludge is a hydrophobic more than sand indicating that there may be retardation and/or reduction in the infiltration rates of rainfall to the aquifer if applied in agriculture (Letey,1969; Wallis et al., 1991;Feng et al., 2001; Arye et al. 2011) .This in turn, may lead to increased surface runoff (Burch et al., 1989; Arye et al. 2011), soil erosion (Shakesby et al. 2000; Arye et al. 2011), which may cause inhomogeneous distribution of water and nutrients in the root zone of crop plants and may accelerate pollutant transport to the ground water (Hendrickx et al., 1993; Wang et al., 1998; Carrillo et al., 2000a,b; Arye et al. 2011). Our results agree with previous reports (Bauters et al.,1998) who found similar results in drop penetration for TWW in agricultural irrigation. Furthermore, sand WDPT was 0.86±0.22 seconds and sand ODPT was 10.11±2.02 seconds and the ratio WDPT/0DPT was 0.08 which is less than 1 meaning that the WDPT is less than the ODPT for sand. This indicates that sand has hydrophilic surfaces. The photos of water drop before and after penetration on the sludge surface are shown in Figure 5.1.

Figure 5.1 Water drop penetration, upper photo shows water drop at time zero, down photo shows penetrated drop.

It is obvious from Figure 5.1 that water drop is stayed on the surface of the sludge for longer time due to the water repellency with the sludge surface. It was not possible to get a photo for water drop in sand because it disappeared immediately from surface as shown from the presented results in Table 5.3.

A comparison between water drop and oil drop sludge aggregates is shown in Figure 5.2.

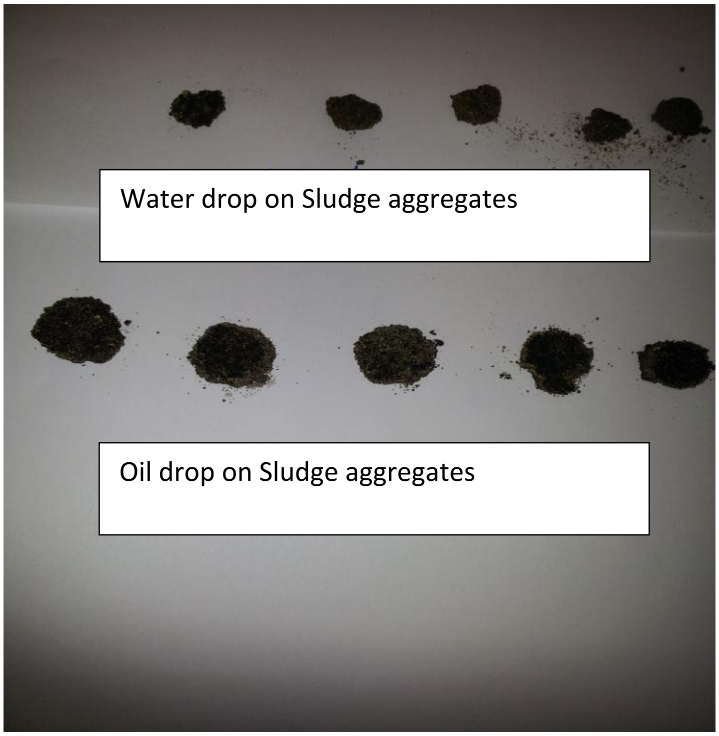


Figure 5.2 Water and oil drop on sludge aggregates.

It is obvious from Figure 5.2 that sludge water aggregates are smaller than oil sludge aggregates due to the hydrophobicity of sludge surface, water diffusion diameter in sludge is smaller that oil diffusion diameter as shown in Table 5.3. Accordingly, the aggregates size of the oil drop is larger than in sand. The explanation of these results is that sludge samples contain high fraction of organic matter that make a layer that prevents water penetration due to the hydrophobicity of water. Furthermore, in chemistry, the like dissolve like. This means that hydrophobic solvent dissolve hydrophobic (organic) materials. And hydrophilic solvent (water) dissolve hydrophilic materials (e.g. NaCl). Due to surface tension and bi-bonds and hydrogen bond interactions, it is hardly to dissolve organic material or NaCl in organic solvent. For water and sludge this is like two different solvents in the interphase. Accordingly, the values of WDPT were very high due to high fraction of organic carbon. Similar results were observed when TWW was used for irrigation (Wallach et al. 2005). The low value of ODPT is due to possible dissolving of oil drop in the organic in sludge.

### 5.1.4 Particles size distribution of sludge samples

Particle size distribution of sludge samples was determined using the hydrometer method explained in chapter 4.

As shown in Figure 5.3, the large size particles (630-200 µm) have the highest percent size fraction which is nearly equal to 90% while the medium size particles (200-20 µm) have percent size fraction which is nearly equal to 10% and the fine size particles (<20 µm) have percent size fraction which nearly is equal to 3%. The medium size particles are nearly similar.

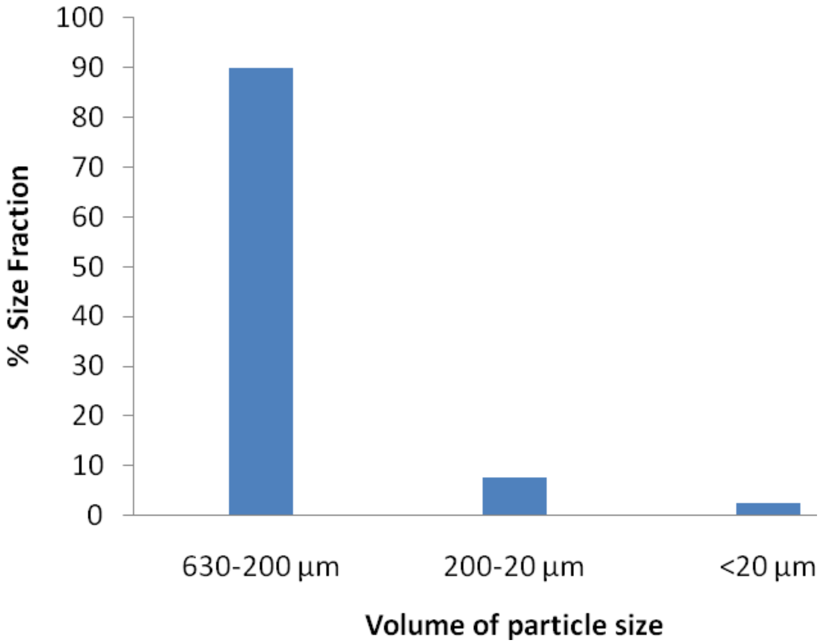


Figure 5.3 Particle Size distribution of sludge samples as percent fraction.

These results can be attributed to the fact that large size particles may be sand small gravels or other aggregates. The explanation of these results is that the large size fraction may be consisting of small size particles that aggregate together throughout cementing materials make them stable against fractionation. The presented results agree with Verawaty et al. (2013) who studied the particle size growth in aerobic granular sludge systems and revealed that granules in the reactors did equilibrate towards a common critical size of around 600-800 µm. Further supports to the presented results come from the results of Ruan and Liu (2013) who analyzed the fractal structure of activated sludge flocs using the small-angle light scattering (SALS) experiment and revealed that the sludge floc was constituted by a series of clusters with different sizes and has various holes and gaps and there were a range of pore structures within the sludge floc.

## 5.2 Chemical properties of sludge

### 5.2.1 pH and EC and TDS values

#### 5.2.1.1 pH value of sludge samples

As shown in Table 5.4, the sludge samples have an average value of pH equals to 6.78 with a standard deviation of 0.02. This value is approximately in the acidic range of pH.

Table 5.4 pH and EC values of sludge samples

| Property | Value |
|---|---|
| pH | 6.78±0.02 |
| EC (mS cm$^{-1}$) | 2.49±0.04 |
| TDS (mg/l) | 256.4±47.05 |

This result can be explained by the fact that sludge samples contain large fraction of total kjeldahl Nitrogen (Table 5.5) which may be decomposed into amino acids that maybe ionized and produced hydrogen ion that is responsible of the acidity. However, this value of pH indicates that the sludge acidity is not so severe and it is in the acceptable range in term of agricultural use (Sial et al., 2006).

These results are in accordance with (Sial et al 2006) who found acidic pH values of sludge samples. The importance of pH value of sludge emerges from the fact that the solubility of heavy metals in sludge samples is pH-dependent. Accordingly, acidic media may enhance the solubility of heavy metals in sludge samples and make them dynamically toxic. Thus, high risk may be associated with acidic pH range and the opposite is true for alkaline pH.

### 5.2.1.2 EC value of sludge samples

It is obvious that EC value of the sludge samples is 2.49±0.04 mS $cm^{-1}$ as shown in Table 5.4. This may be due to the accumulation of high soluble salts in the sludge samples which comes from the nature of the treated waste water, where Gaza is known for its high saline wastewater (PWA,2012). This EC value indicates a high salinity and also indicates that a large fraction of natural salts are available in sludge. This value of EC indicates that the sludge can not be applied in all agricultural crops due to this high salinity. Moreover, the importance of EC value emerges from the fact that it represents all soluble salts in sludge at dry conditions as in Gaza this may enhance the accumulation of salts on the surface of sludge samples or soil treated with sludge. This situation may lead to the loss of soil productivity. Our explanation is supported by the results of (Novak and Trapp 2005) who found rather saline EC (14 mS $cm^{-1}$) of the saturated paste extract.

### 5.2.1.3 TDS value of sludge samples

It can be seen from table 5.4 that the Total Dissolved Salts value of the sludge samples is 256.4±47.05 mg/l. This value of TDS is not so high

### 5.2.2Nitrate, ammonium and TKN Concentrations

The importance of nitrate levels in sludge samples emerged from the fact that sludge can be used as an alternative source of nitrate instead of NPK application in agriculture.

According to the methods described above, we generated a standard nitrate curve by converting the nitrate into the corresponding nitro-salicylic acid and created the relationship between the optical density and concentration relationship. Optical density nitrate concentration relationship is shown in Figure 5.4.

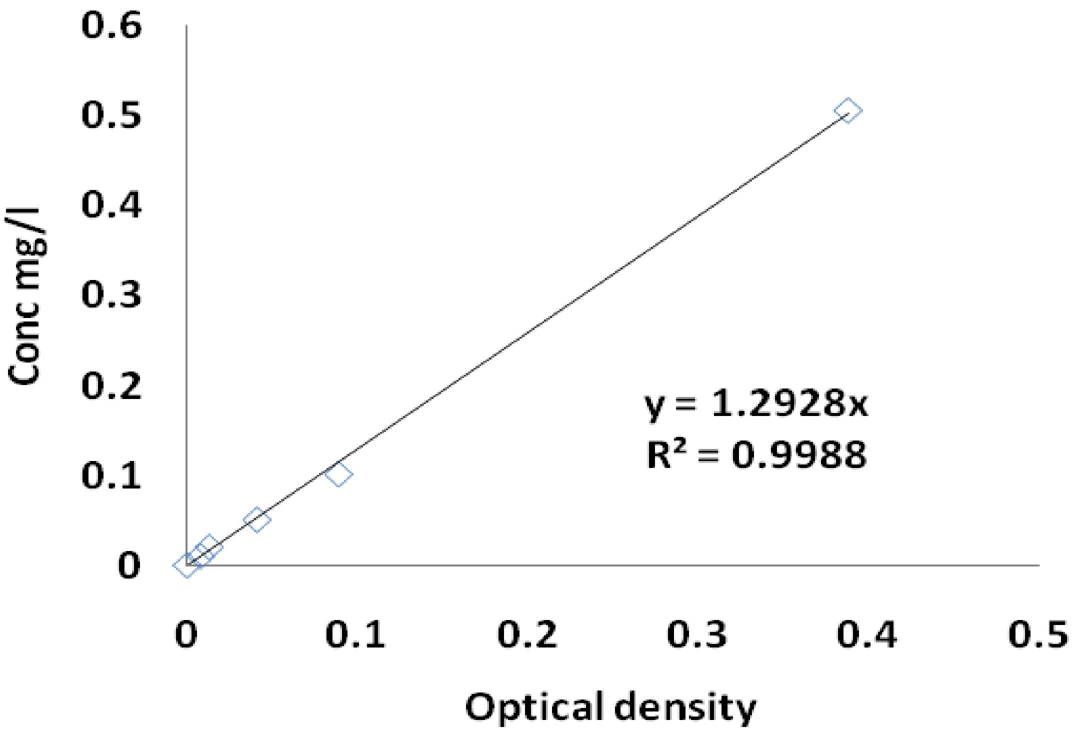


Figure 5.4 Optical density nitrate concentration relationship. Standard curve.

It can be seen that the intensity of the yellow color (nitro-salicylic acid) and the optical density relationship are linear up to the concentration below 1mg/l. We worked in a very dilute solution to all nitrate concentrations. As obvious a linear relationship was observed with a value of $R^2 = 0.9988$ indicating a strong positive association.

Accordingly, the linear relationship is expressed by the equation Y=1.2928X with $R^2$ value of 0.9988 which indicate a strong positive association. Thus, this equation was used to determine the nitrogen concentration in the sludge samples. The value of nitrate level in sludge equals to 18.03±2.8 mg/kg sludge as shown in Table 5.5. The nitrate level tends to be low but it is nearly large due to the anaerobic condition of sludge. The explanation of low level nitrate in sludge samples is probably due to the anaerobic conditions of sludge. This anaerobic condition reduced the nitrate into ammonium hydroxide due to denitrification process. This explanation is supported by the results of Dvořák et al., (2013) who investigated the nitrification performance in a membrane bioreactor treating industrial wastewater and concluded that mixing the municipal waste water with industrial waste water in the level up to 50% resulted in a breakdown of nitrification process. Furthermore, the nitrate level in treated wastewater does not exceed 5 mg/l due to anaerobic condition in the treatment plant (El-Nahhal et al., 2013). However, this level of nitrate can be sufficient for plant nutrition. In contrast, Total kjeldahl Nitrogen (TKN) is nearly high and equals to 5000.04±757.5 mg/kg sludge (Table 5.5). This high value presents all fractions of organic nitrogen as shown in Table 4.5. Our results agree with Sreesai et al. (2013) who indicated that digested sewage sludge had high value of total nitrogen (2.17 ± 0.07%).

Table 5.5 Nitrogen levels in sludge. Values represent average and standard deviation.

| | Sludge |
|---|---|
| TKN mg/kg | 5000.04±757.5 |
| Total Soluble N mg/l | 61.63±31.69 |
| nitrate mg/kg | 18.03±2.8 |

The value of Total Kjeldahl Nitrogen (TKN) of the sludge is 5000.04±757.5 mg/kg, whereas the value of the Total Soluble Nitrogen is 61.63±31.69 mg/l which includes ammonium hydroxides and probably amino acids. These results are in agreement with Zuo et al., (2013) who evaluated the heterocyclic nitrogenated compounds in sewage sludge and revealed that heterocyclic nitrogenated compounds made up 38.5-61.21%.

This value of total soluble N is considered moderate level. However, the explanation of this result is that all nitrogen fractions in wastewater or sludge are present in the form of organic nitrogen or in the reduced form ($NH_3$, $NH_4OH$) due to the anaerobic condition of TWW or sludge. Accordingly, moderate to low values of soluble N may be found. Our result are also supported by the previous work of EL-Nahhal et al. (2013) who found low nitrate concentration in the treated wastewater .

Furthermore, it is obvious that (TKN) is high 5000.04±757.5 mg/kg. This indicates a high fraction of TKN, the explanation of this result is that sludge originated from human feces which contain a high fraction of protein due to high consumption of protein. It has been shown that the protein consumption per capita per day is 40g/capita/day. High fraction of this protein goes to the wastewater treatment plant and end up by sludge samples. Accordingly, high fraction of total Nitrogen was observed in sludge samples. Moreover, the total soluble nitrogen is 61.63±31.69 mg/l, regardless of the high value of standard deviation; the total soluble nitrogen is nearly in the expected range. This includes ammonia, amines and amino-acids. Recent papers showed similar results (Sheng Y, Xing L. 2013).

### 5.2.3 Concentrations of Anions

#### 5.2.3.1 Chloride concentration

Chloride concentration in sludge samples were determined according to the data of standard curves presented in Figure 5.5, and the result is shown in Table 5.6.

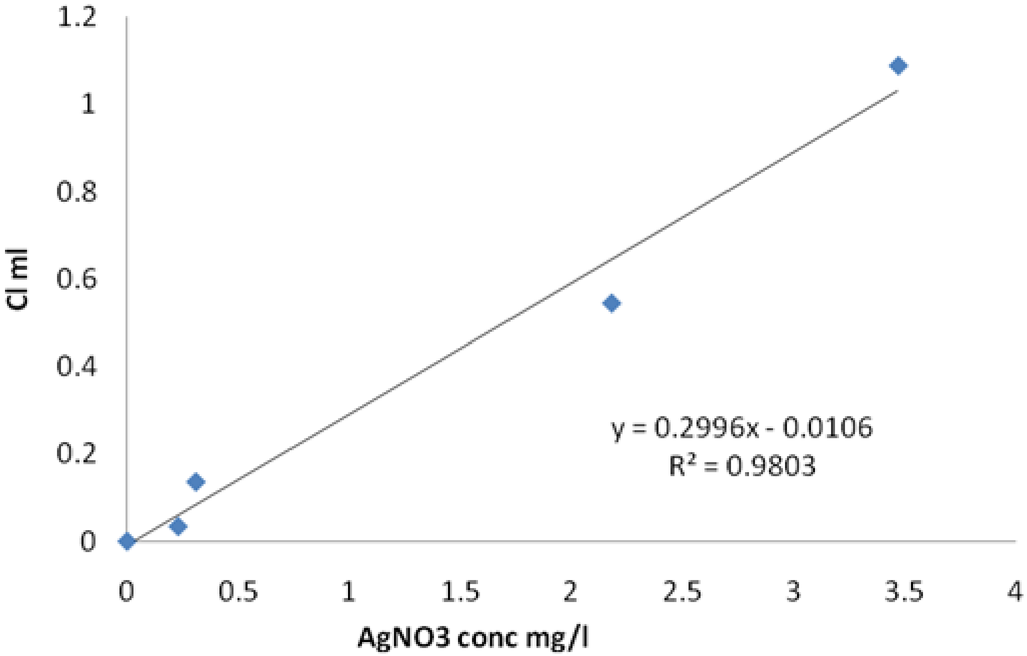


Figure 5.5 Standard curve of chloride determination in sludge samples.

It is obvious that a linear relationship is shown in concentration at AgNO3 below 4 mg/l with an equation of y =0.2996x-0.0106 with a value of $R^2$=0.9803 indicating a strong positive association between the Cl (ml) and Na concentration mg/l. Accordingly, in the range of 0-4 mg/l, concentration of Cl may be determined. However, concentration above this range may need several dilutions. Nevertheless, within the range, a strong positive association was observed R2=0.9803. This relationship allows us to determine Cl concentration in the sludge sample. However, Cl concentration is 25.84±4.26 mg/kg (Table 5.6) which is in the acceptable levels of Cl standards (EPA 2005)

### 5.2.3.2 Sulfate concentration

The relationship between the optical density and sulfate concentration are linear below 60 mg/l as shown in Figure 5.6.

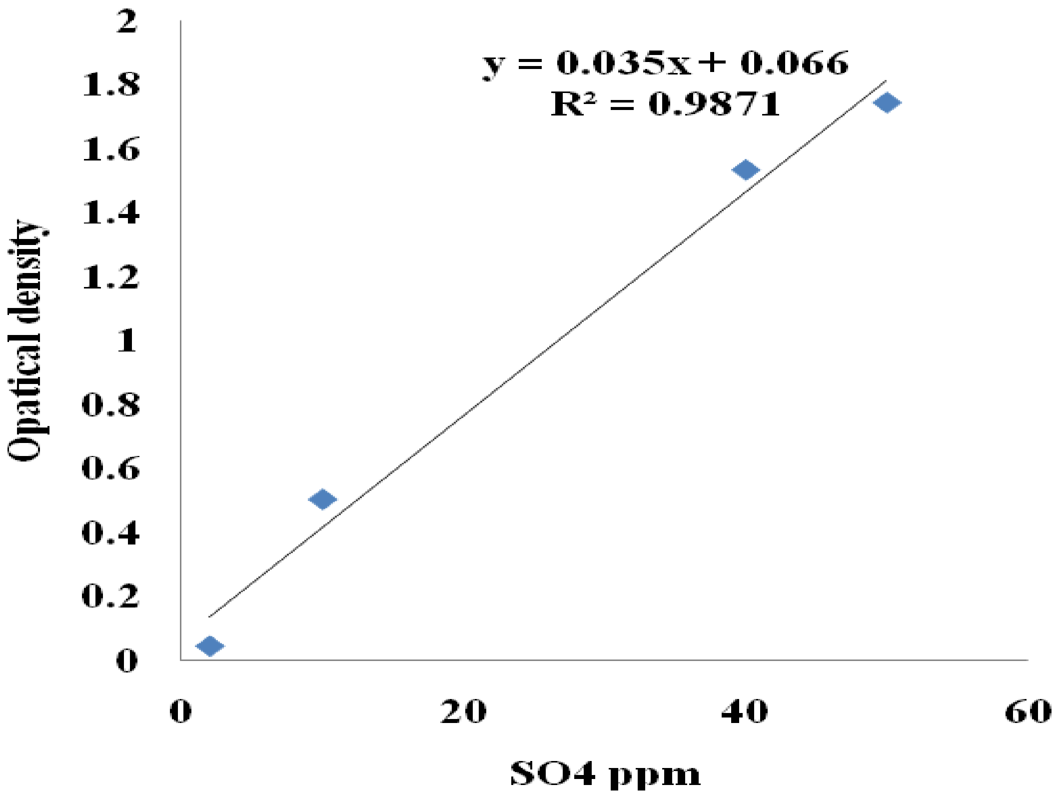


Figure 5.6 Standard curve of sulfate concentration.

It can be seen that the relationship is a linear relationship expressed by the equation Y=0.035X+0.066 with $R^2$ value of 0.9971 which indicate a strong positive association. Accordingly, this equation enabled us to determine the sulfate concentration in the sludge samples. According to the present equation, sulfate concentration in sludge is 18.59±2.44 g/kg. This value nearly looks high but in fact sulfur containing protein is a high fraction in nature. Sulfate level is nearly high due to the high solubility in water and its solubility is not pH-dependent. Similar results were recently obtained by Jing et al.,(2013).

### 5.2.3.3 Phosphate concentration

The optical density and phosphate concentrations relationship are shown in Figure 5.7.

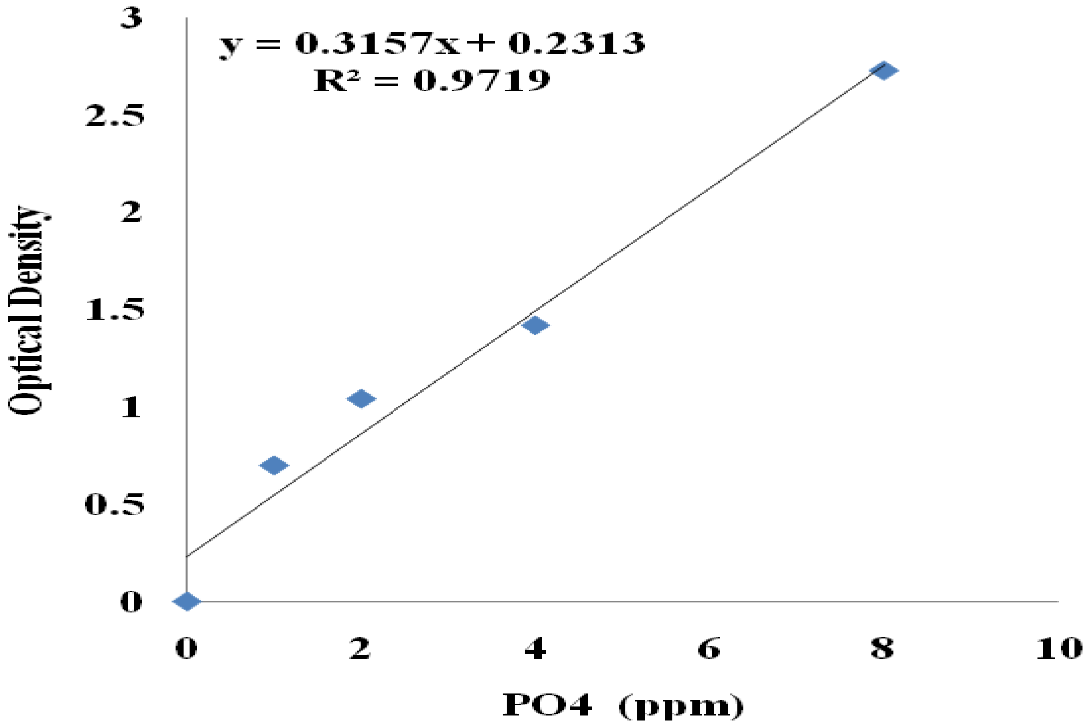


Figure 5.7 Standard curve of Phosphate determination in sludge samples.

The relationship is linear and expressed by the equation Y=0.3157X+0.2313 with $R^2$ value of 0.9719 which indicate a strong positive association. Accordingly, this equation enabled us to determine the phosphate concentration in the sludge samples

It is obvious that chloride concentration is the lowest one among all cases and sulfate is the highest level among the measured anions followed by phosphate as shown in Table 5.6.

Table 5.6 Chloride, sulfate and phosphate concentrations. Values represent average and standard deviation

| Anion | average |
|---|---|
| $Cl^-$ (mg/kg) | 25.84±4.26 |
| $SO4^{-2}$ (g/kg) | 18.59±2.44 |
| $PO4^{-3}$ (g/kg) | 0.434±0.023 |

The explanation of these results is that these values represent the soluble fraction of $Cl^-$, $SO_4^{-2}$, and $PO_4^{-3}$ in sludge samples. The low value of phosphate concentrations in sludge samples is due to the fact that, phosphate solubility is pH-dependent. Accordingly, at low pH value high phosphate levels may be found in sludge. However, at the current pH value of sludge (Table 5.2) low fraction of phosphate was found due to low acidity of sludge. This value is supported by the fact that phosphoric acid is a weak acid and has 3 dissociation constants. We gave explanation at the current sludge pH value, phosphate is not high because phosphoric is a weak acid and has thee dissociation constants. This indicates that phosphate solubility is pH-dependent, whereas sulfate and chloride are not pH-dependent. Accordingly, high level of sulfate ion was detected which is normal. It is obvious that the phosphate level is 0.434±0.023 g/kg in the sludge. In addition, the sulfate level is 18.59±2.44 g/kg. As obvious, nearly low values of $PO_4^{-3}$ are available in sludge samples. This value represent only the soluble fraction of phosphate not all phosphate. Under pH value 6.78, phosphate ion tends to precipitate from the solution. Similar observations were given recently by Luan et al., (2013).

### 5.2.4 Determination of sodium, potassium, calcium and magnesium:

### 5.2.4.1 Determination of sodium

The relationship between flame-photometer readings and Na+ concentrations is curvatures at the tested concentrations.

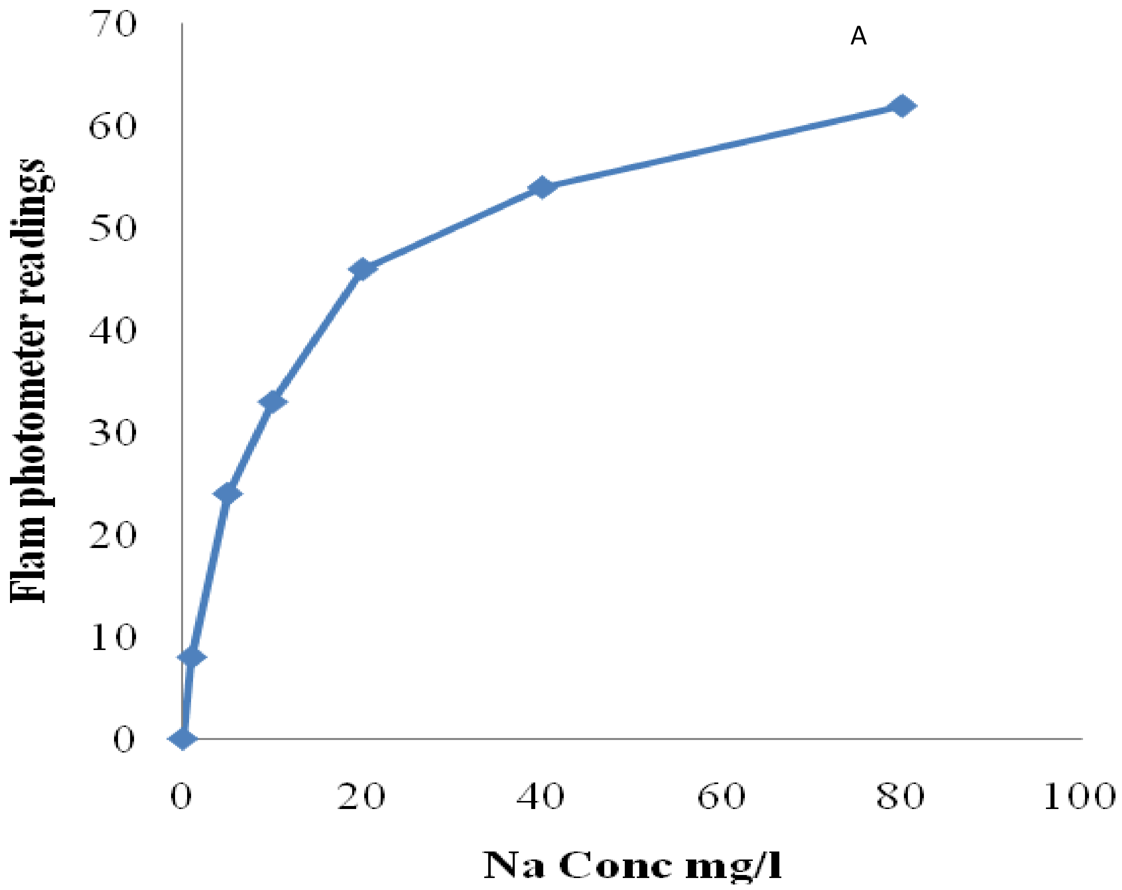


Figure 5.8a Standard curve of sodium determination in sludge sample. Real readings

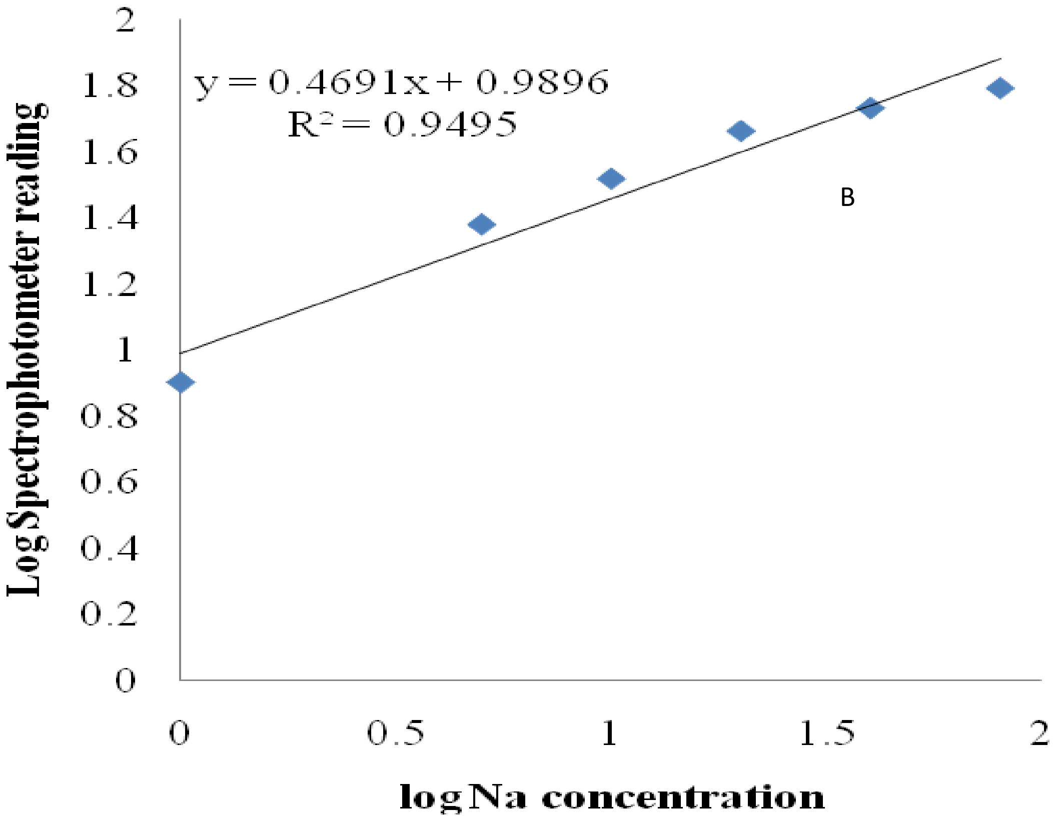


Figure 5.8b Standard curve of sodium determination in sludge sample. Log scale readings

It is obvious that at low Na concentrations, a linear relationship was observed. These relationships were converted to logarithmic scale to both variables (log-log relationship). It can be seen that these relationships are best expressed by the equation y = 0.4691x + 0.9896 and the R2 value is 0.9495 which suggests a positive strong association between the log Na concentration and the log spectrophotometer readings Figure 5.8b. Accordingly, this equation is used to determine the sodium concentration in the sludge samples. It can be seen that the relationship of both curves are curvatures and looks like Sigmoid curves.

Similarly to Figure 5.8a, we got a Sigmoid curve for flame-photometer readings and potassium concentration. We converted this relationship (Figure 5.9a) into a log scale, we got Figure 5.9b.

#### 5.2.4.2 Determination of potassium

The relationship between flame-photometer readings and K+ concentrations is a curvature at the tested concentrations. It is obvious that the relationship curve in Figure 5.9a is not a linear relationship, this relationship was converted to a linear one by using the logarithmic scale to both variables (log-log relationship) in Figure 5.9b and it can be seen that the relationship is best expressed by the equation $y = 0.5263x + 1.5373$ and the $R^2$ value is 0.9521 which suggests a positive strong association between the log K concentration and the log spectrophotometer readings.

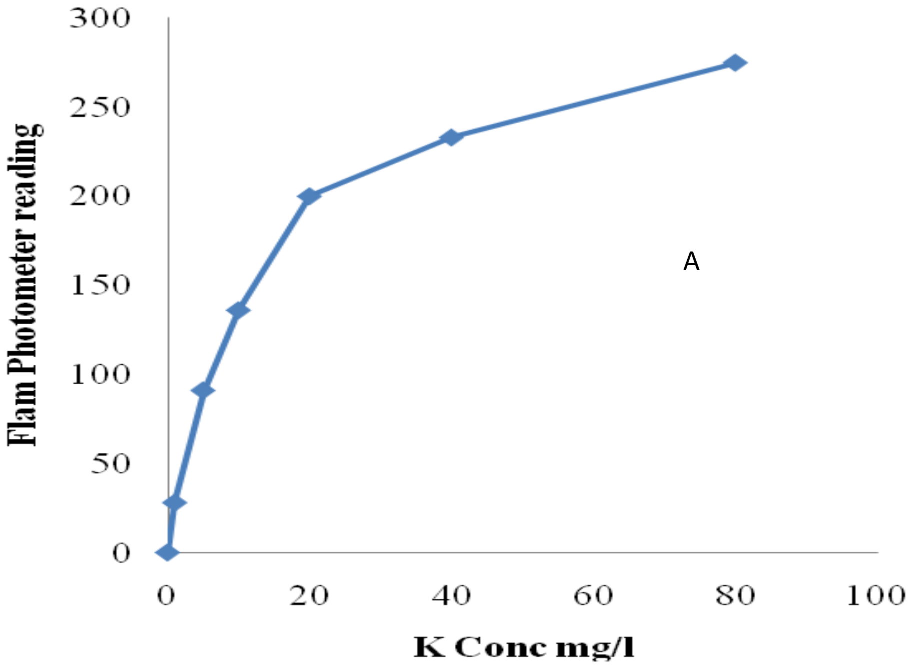


Figure 5.9a Standard curve of Potassium determination in sludge sample. Real readings

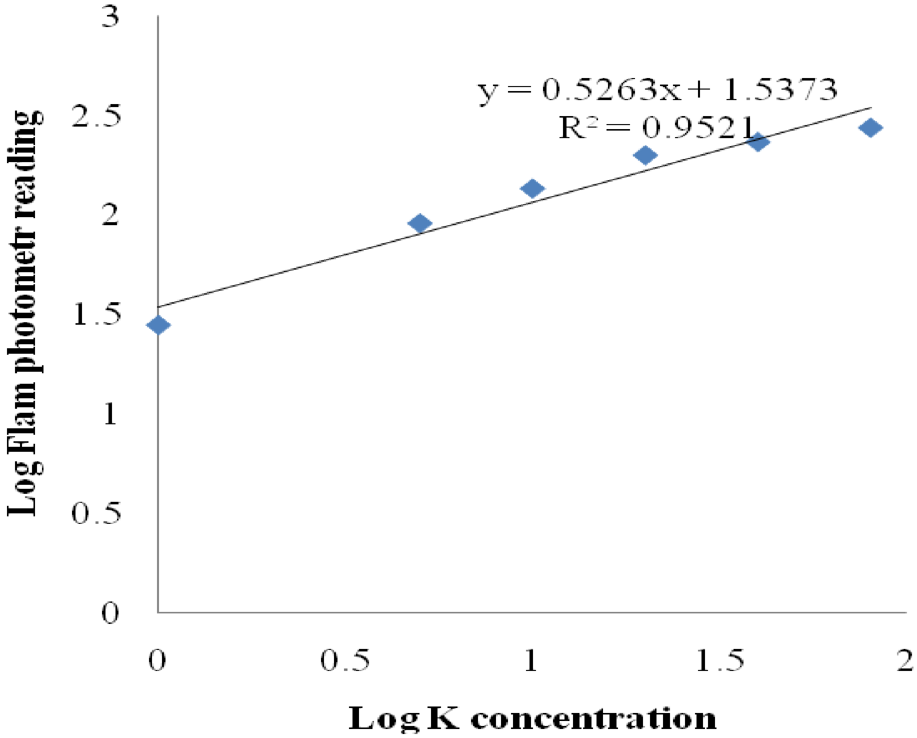


Figure 5.9b Standard curve of Potassium determination in sludge sample. Log scale readings.

Accordingly, this equation was used to determine the potassium concentration in the sludge samples. Thus, we used the log scale equations to determine Na and K ions in the sludge samples. However, the determined Na and K concentrations are shown in Table 5.7.

### 5.2.4.3 Determination of calcium and magnesium

Calcium and Magnesium concentrations in the sludge samples were determined using EDTA Titration using plank and sample readings. It can be seen from table 5.7 that the sodium concentration is 28.93 ± 6.85 mg/kg. In addition to that the potassium concentration is 2.53 ± 0.43 mg/kg. Moreover, the calcium concentration is 271 ± 38.74 mg/kg and the Magnesium concentration is 177 ± 67 mg/kg. Furthermore, Fe concentration is 125.12±13.65 mg/kg. As obvious from the table, K is the lowest concentration among all of the cations and Ca is the highest concentration among all cases.

Table 5.7 Sodium, potassium, calcium and Magnesium concentrations in sludge samples

| Cations | Concentration mg/kg |
|---|---|
| Na | 28.93 ± 6.85 |
| K | 2.53 ± 0.43 |
| Ca | 271 ± 38.74 |
| Mg | 177 ± 67 |
| Fe | 125.12±13.65 |

The high concentration of sodium or potassium ion in sludge samples may be attributed to the fact that a lot of surfactants, cosmetics, and soups are containing sodium or potassium in their chemical structure. These materials are exposed to biodegradation during sludge formation resulting in transferring sodium or potassium into inorganic form (e.g NaCl). Our discussion is supported by Ambily and Jisha (2012) who found that surfactant, cosmetic product formulations, contributes significantly to the pollution profile of sewage and wastewater with various compounds including cations. Further supports to our results comes from El-Nahhal (2006) who reported high concentration of cations in treated sewage water. Further support for our discussion may come from the results of Zheng et al. (2013) who correlated the high concentrations of cations in aerobic granular sludge with the low concentration of $Cu^{++}$ in sludge. In contrast they reported decreased cation concentration with the increased concentration of cupper ion.

### 5.2.5 Concentration of heavy metals

It can be seen from Table 5.8 that Fe concentration is 125.12±13.65 mg/kg. In addition, the cupper concentration is 172.56±61.53 mg/kg. Moreover, lead concentration is 75.86±1.63 mg/kg. Furthermore, the zinc concentration is 218.73±8.35 mg/kg. The manganese concentration is 157.96±21.67 mg/kg. It is obvious that Zn concentration is the highest one among all cases followed by cupper and manganese. Moreover, lead concentration is the lowest one among all.

Table 5.8 Heavy metals levels in sludge. Values represent average and standard deviation (mg/kg)

| Heavy metals | average± stdev (mg/kg) | USEPA standards (mg/kg)[a] |
|---|---|---|
| Cu | 172.56±61.53 | 4300 |
| Pb | 75.86±1.63 | 840 |
| Zn | 218.73±8.35 | 7500 |
| Mn | 157.96±21.67 | |

a: Dry weight basis

The high levels of heavy metals can be explained by the fact that industrial wastewater network is connected with the domestic wastewater network. Both wastewaters come together to wastewater treatment plant. The mixing of industrial wastewater with domestic wastewater allows heavy metals to precipitate due to the changes of pH values from acidic range in the industrial wastewater to alkaline range in the domestic wastewater. The precipitated heavy metals react with organic acid that generated from the biodegradation of the organic wastes in the treatment plant and with inorganic acid.

This process makes an accumulation of heavy metals in sludge. Our explanation is supported by the results of Zhang et al. (2013) who investigated the distribution and variation trend of heavy metals in sludge samples collected from different wastewater treatment plants in China and showed that contents of heavy metals in sludge varied significantly, and the average contents exhibited an order of Cr > Zn > Cu > Pb > As > Hg > Cd. However, the presence of heavy metal in sludge sample may move to the plant during the agricultural process (El-Nahhal et al., 2013). Furthermore, the presence of heavy metals in sludge may become toxic to soil nitrifying or denitrifying bacteria that benefit the plant growth. This explanation is supported by the results of Feng et al. (2013) who studied the effects of heavy metals in wastewater on anoxic/aerobic-membrane bioreactors performance and revealed that the nitrification/ denitrification rates were dramatically decreased in different percentages based on the concentration of heavy metals in wastewater. Accordingly, it may be necessary and recommended to removal heavy metals from sludge samples before agricultural application. Our recommendation is supported by the work of de la Varga et al. (2013) who investigated the long-term removal of heavy metals in a combined up-flow anaerobic sludge bed system treating municipal wastewater and revealed that High removal efficiencies were found for some metals in the following order: Sn>Cr>Cu>Pb>Zn>Fe (63-94%) and medium removal efficiencies for Ni (49%), Hg (42%), and Ag (40%), and finally Mn and As showed negative percentage removals. Further support come from the results of Wojciechowska and Gajewska (2013) who studied the retention of heavy metals at two pilot-scale treatment wetlands, consisting of two vertical flow beds followed by a horizontal flow bed and revealed that a major removal pathway was sedimentation and adsorption onto soil substrate as well as precipitation and co-precipitation. It has been shown (Kaschel et al. 2002) that application of compost containing high fraction of heavy metals expose plant and ground water to contamination of heavy metals. In addition, El-Nahhal (2006) found heavy metals in the drinking water collected from different sources and attributed this to possible contamination from industrial wastewater out house. In comparison with USEPA 1994 standards, the heavy metals concentrations in the sludge are found to be many times lower than USEPA 1994 standards. Accordingly, the sludge can be used in agriculture. More details are shown in the Annex.

### 5.2.6 Determination of COD and BOD

The optical density of various concentrations of potassium hydrogen phthalate KHP was measured at 620 nm and used as a standard curve for measuring the COD value of the sludge. It can be seen from Figure 5.10 that the relationship is a linear one and expressed by the equation y = 0.0003x with an $R^2$ value of 0.997. This indicates a strong positive association.

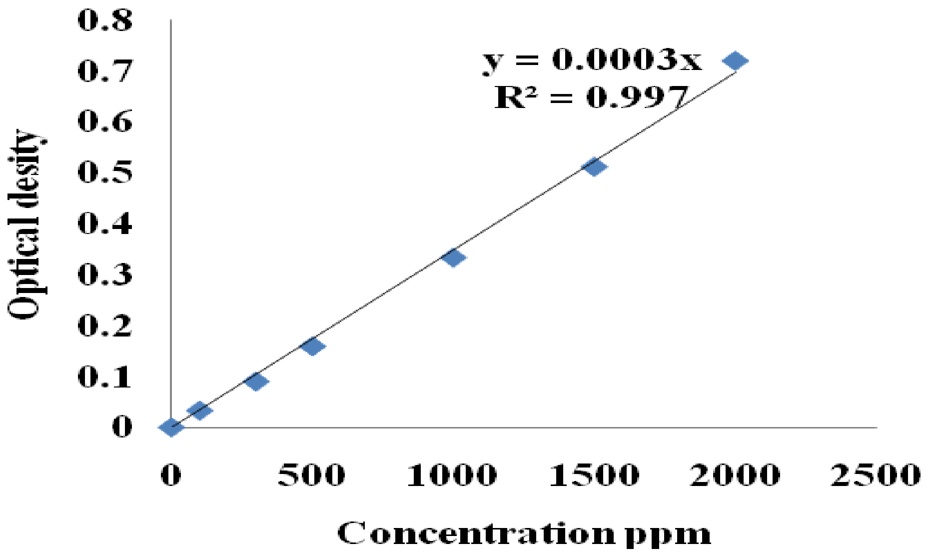


Figure 5.10 COD measurements, optical density of phosphate concentration relationship. Standard curve.

Accordingly, this equation enabled us to determine the COD in the sludge samples. The determined value is presented in Table 5.9. Furthermore, BOD value is also determined according to the described method above.

Table 5.9 BOD and COD values of Sludge. Values represent average and standard deviation (mg/kg)

| Item | average |
|---|---|
| COD | $(60.9 \pm 6.7)*10^3$ mg |
| BOD | 115 ±28.87 mg |

It can be seen that the COD is very high value (60.9 ±6.7)*$10^3$ mg indicating variety of chemical pollution. Our results are nearly different from the results produced by Lu et al., (2013) who investigate the effects of anaerobic fermentation on sludge properties and showed that the soluble chemical oxygen demand (SCOD) of sludge containing 50 g/L total suspended solids was 16.53 g/L, much higher than that from the sludge containing 20g/L total suspended solids. The SCOD/total nitrogen ratio of sludge containing high valued L total suspended solids, varied from 8 to 14.29 g/g, indicating that the sludge could serve as a carbon source for biological denitrification. The value of BOD is several times lower indicating low biological contamination in the sludge samples. The explanation of these results is that the drying process under direct sunlight in June-July could dramatically reduce the potential contamination as shown by low BOD value (115 ±28.87mg).But this treatment (sludge drying) did not reduce the chemical contamination. Accordingly, high COD value was observed. Our results agree with Mungray AK and Kumar P (2008) who found similar results.

### 5.2.7 Organic Fraction of Sludge

As shown in table 5.10, the percent organic fraction is about 89.53±0.92% and ash% is about 10.47±0.93%. The high fraction of organic matters in sludge is responsible for the high values of WDPT. This may enhance water repellency and water runoff (Table 5.3). Furthermore, this high fraction of organic matters is in accord with the fraction of Total Kjeldahl Nitrogen (TKN) (Table 5.5).

Table 5.10 Total organic carbon and ash percents.

| | |
|---|---|
| %TOC | 89.53±0.92 |
| %Ash | 10.47±0.93 |

Our results agree with the report of Malamis et al (2013) who evaluated the nutrients removal from the supernatant originating from the anaerobic digestion of the organic fraction of municipal solid waste using biological means. They reported that such effluents are characterized by high nutrient content, because organic and particulate nitrogen and phosphorus are hydrolyzed in the anaerobic digestion process and needs adequate post-treatment such as physicochemical and biological processes.

Calculating C/N ratio according to Eq(3) in section 3.9 of this thesis showed a value of 1:0.88 which indicates the importance of C/N ratio for plants and agriculture.

### 5.2.8 Influence of sludge on Soil properties

#### 5.2.8.1 Influence on Soil pH

It can be seen from figure 5.11 that the pH value of the control sample (0 ton/ha) is 8.38±0.06 and in the (1 ton/ha) treatment is 8.55±0.04 whereas, in the (5 ton/ha) treatment is 8.6±0.01, furthermore, in the (10 ton/ha) treatment is 8.48±0.05.

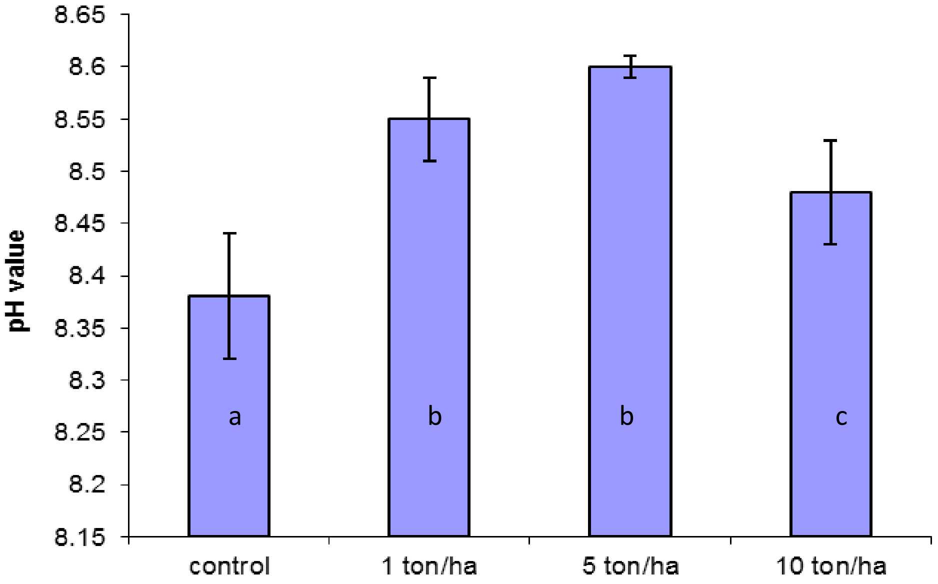


Figure 5.11 pH values in soil treated with sludge at 0, 1, 5 and 10 ton/ha. Error bars indicate standard deviation. Columns that have the same letter are not significantly different at p-value =0.05

The pH values of all soil treated sludge samples are above the pH=7 which may suggest that the effect of sludge on these samples was to make all of them to be alkali-oriented. However, the pH value in the control sample (soil +0ton/ha) is nearly similar in all cases. An explanation of this result is given above in section 5.2.1.1 of this thesis. Statistical analysis of pH values indicate significant difference between the control sample and 1 ton, p-value = 0.04. Whereas, p-value between 1 ton and 5 ton is equal to 0.09, indicating no difference. Furthermore, significant difference was detected between 5 ton and 10 ton, p-value equals to 0.038.

### 5.2.8.2 Influence on Soil EC

It can be seen from figure 5.12 that the EC value of the control sample (0 ton/ha) is 533±31.1µS $cm^{-1}$ and in the (1ton/ha) treatment is 547.5±12.021µS $cm^{-1}$ whereas in the (5ton/ha) treatment it is 506.5±28.99 µS $cm^{-1}$, furthermore, in the (10ton/ha) is 504±11.31 µS $cm^{-1}$.

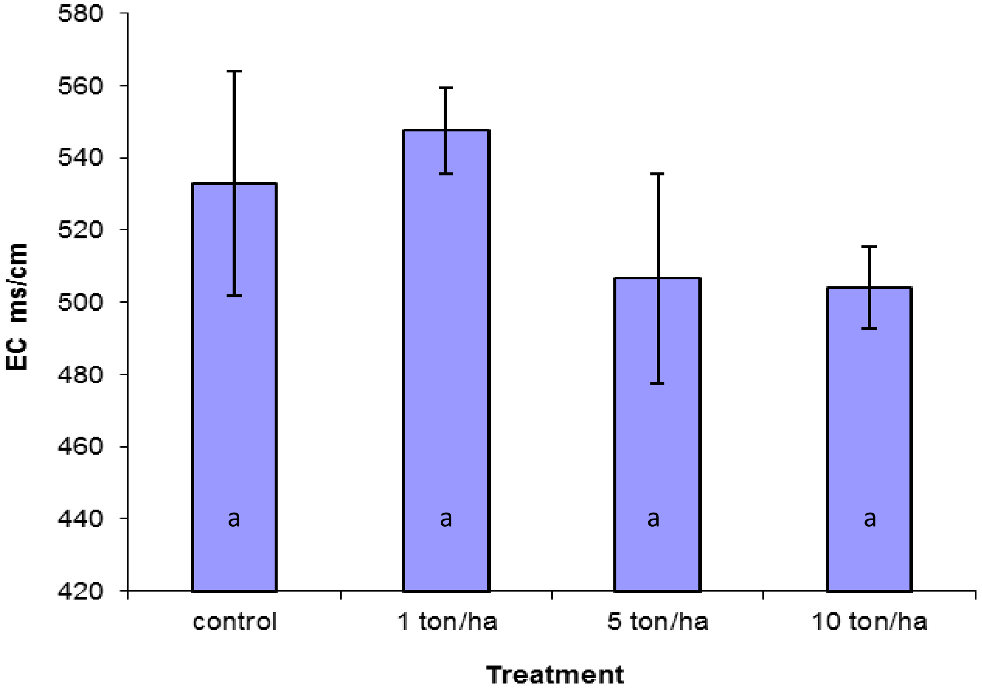


Figure 5.12 EC values in soil treated sludge with sludge at 0, 1, 5 and 10 ton/ha. Error bars indicate standard deviation. Columns that have the same letter are not significantly different at p-value =0.05

The EC values are almost very high values indicating that there are many soluble salts in these samples as a result of this treatment with sludge. However the values of EC are similar as well regardless to the value of standard deviation. Regardless to the values of standard deviation, statistical analysis does not discriminate any difference among treatments. The calculated p-value ranged between 0.1-0.46 indicating no difference.

### 5.2.8.3 Influence on Soil Nitrate

As shown in figure 5.13 that the Nitrate concentration in the control sample is 3.94±0.46 mg/kg, and in the (1ton/ha) treatment is 5.11±1.55 mg/kg, whereas in the (5ton/ha) treatment it is 4.59±1.01 mg/kg, furthermore, in the (10ton/ha) it is 4.5±2.48 mg/kg

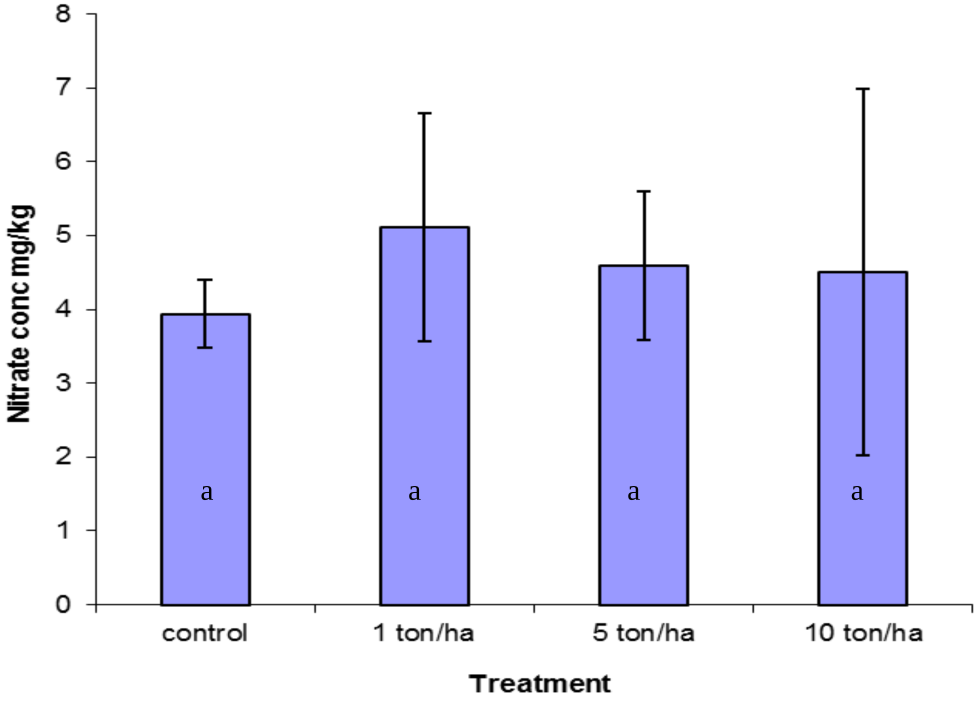


Figure 5.13 Nitrate values in soil treated sludge with sludge at 0, 1, 5 and 10 ton/ha. Error bars indicate standard deviation. Columns that have the same letter are not significantly different at p-value =0.05

The values of nitrate are similar in all cases regardless to the value of standard deviation. Inspite of nearly large error bars, statistical analysis does not discriminate difference at p-value equal to 0.05. The calculated p-value ranged between 0.22-0.36, indicating no difference. Application of sludge in soil may increase the concentration of nitrate in the top soil layer due to possible degradation of organic nitrogen containing compounds. The presented results showed high organic nitrogen content in sludge (Table 5.5). This organic nitrogen compound may be degraded in soil to nitrate due to the high fraction of organic carbon of sludge (Table 5.10) and high oxygen content of top soil layer which enhance the oxidation of ammonium compounds to corresponding nitrate. This suggestion is strongly supported by the results of Husserl and Hughes (2013) who found that nitroglycerin, a contaminant of soil and groundwater, was completely mineralized in soil and mineralization was faster in soil containing Arthrobacter sp. strain JBH1.

### 5.2.9 Influence of sludge on corn growth

It is obvious from figure 5.14 that application of sludge in field experiment did increase the yield of corn. The increase in corn yield was optimum at the applied rate 5 ton/ha. Whereas 10ton/ha resulted in a slight reduction in the growth rate of corn.

It can be seen that the (5 ton/ha) treatment yielded the highest average weight(kg) of corn which was 0.85kg. Meanwhile, the (1 ton/ha) yield is in the second rank regarding the average weight of corn and that was 0.799 Kg. Furthermore, the (10 ton/ha) effect on corn resulted in the least amount of average weight of corn which was 0.748Kg.

The optimum yield was observed with a sludge at 5 ton/ha application. The highest application rate (10 ton/ha) did not produce high yield.

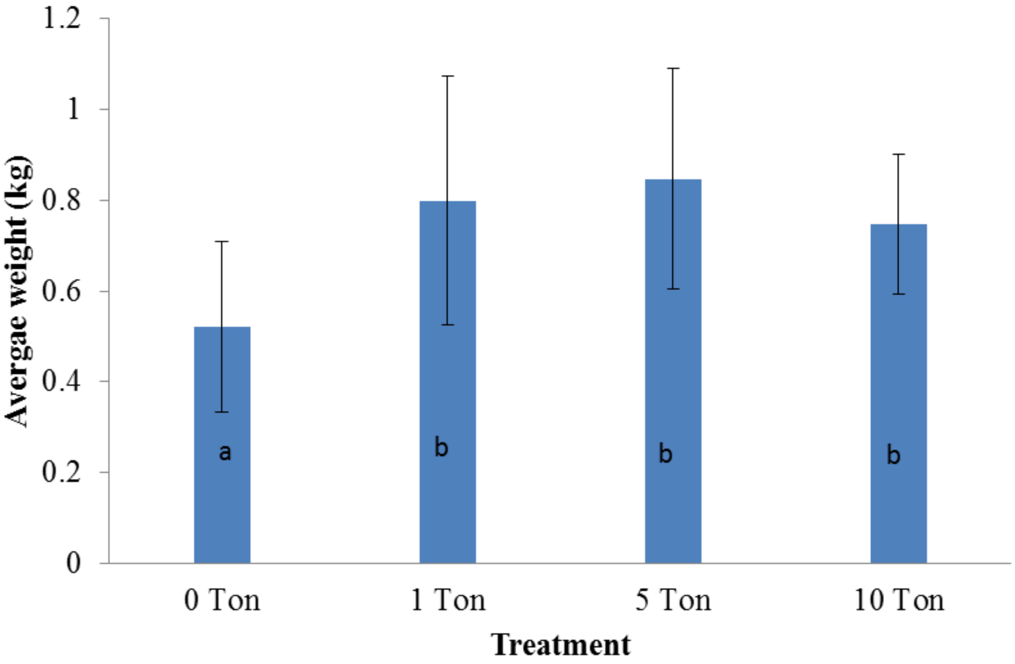


Figure 5.14 Effect of sludge treatments on corn growth. Error bars indicate standard deviation. Columns that have the same letter are not significantly different at p-value

The % growth calculation indicated 10% difference between 1 ton and 10 ton whereas, the values is less than 10% between 1 ton and 5 ton, this suggest that 1ton and 5 ton treatments are the best among all the treatments. Statistical analysis detected significant differences between the control sample (0 ton/ha) and all other treatments, p-value equals 0.049, whereas p-value among sludge treatments ranged between 0.23-0.38.

The explanation of these results is that 5 ton/ha could be the optimum application rate. Our results are supported by the work of Sreesai et al. (2013) studied the potential agricultural application of Bangkok-digested sewage sludge and finished compost products and indicated that digested sewage sludge had high fertilizing values for organic matter (19.01 ± 0.09%), total nitrogen (2.17 ± 0.07%), total phosphorus (2.06 ± 0.06%) and total potassium (1.16 ± 0.22%). The reduction of the yield at the highest application rate may be due to the possible eco-toxicity of the heavy metals that is present in sludge samples to some soil bacteria that is responsible for degrading organic nitrogen into inorganic nitrogen. This suggestion is supported by the results of Feng et al. (2013) who revealed that the nitrification/ denitrification rates were dramatically decreased in different percentages based on the concentration of heavy metals in wastewater. Furthermore, the high fraction of heavy metals may have a toxic effect on soil cyanobacteria bacteria that have a rule in nitrogen fixation in soil. However, application of sludge or compost in soil needs long time for biodegradation and to be available for plant uptake. Previous studies (Kaschel et al., 2002) reported the importance of long term application of compost. Furthermore, Ali et al., (2011) found that the effects of sludge or sewage effluent on growth parameters and elements content in plant parts and treated soil were more pronounced as water treatments were used for long period. The results suggested that the use of sewage effluent in irrigating mahogany trees grown on calcareous sandy loam soil was an important agriculture practice for improving soil properties, increasing fuel and timber production, and is an economic and safe way to dispose wastewaters. More supports to our results come from the work of Mahdy et al. (2009) who found soils treated with 1% sludge (biosolids) along with water treatment residuals rates from 0 to 3% (w/w), the corn yield increased significantly ($P < 0.01$) but decreased at 4% application rate.

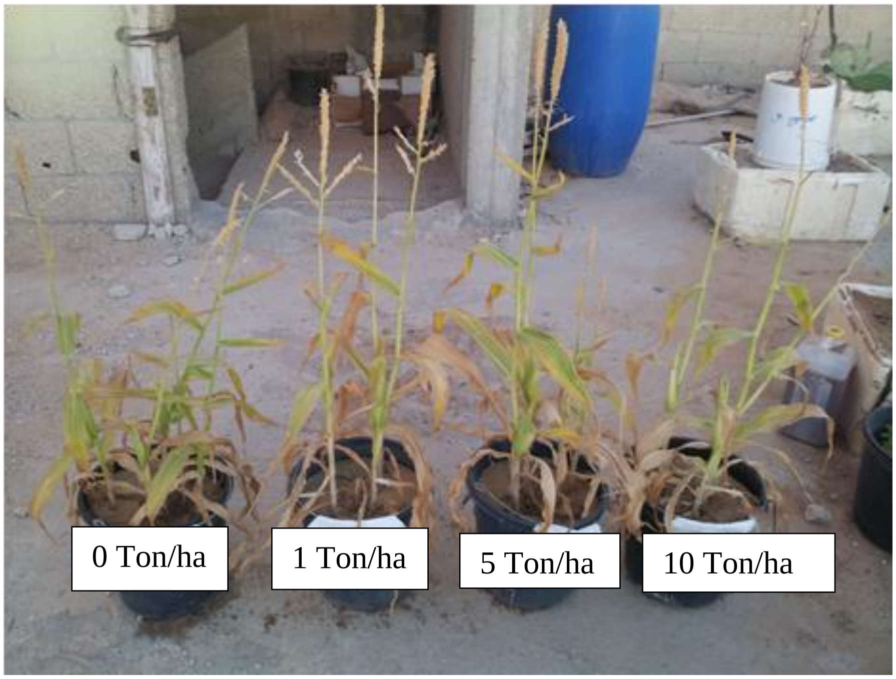


Figure 5.15 Effect of different quantities of sewage sludge (0, 1, 5 and 10 ton/ha) on the corn growth at pot experiment.

# Chapter 6

# Conclusions and Recommendation

## 6.1 Conclusions:

The rationale of this work emerges from the fact that these biosolids are of great importance for agricultural use. Our approach based on determination of physical, chemical and biological properties of sludge. We took a representative samples from different locations from Sheikh Ejleen WWTP. It can be seen that the bulk density of sludge is nearly low 1.18±0.04 g/cm$^3$ (Table 5.1) with a high fraction of organic carbon which is 89.53±0.92 (Table 5.10) and organic Nitrogen which is 61.63±31.69 mg/l (Table 5.5). The water holding capacity of sludge samples was high (54.45±1.1) and the hydrophobicity as well by the WDPT indicator which equals 114.77±16.76 sec.

The pH value of sludge is slightly in the acidic range which equals 6.78±0.02 (Table 5.4) but its application in soil does not make significant changes in soil pH (Figure 5.11).

Sludge samples contain high fraction of anions PO4$^{-3}$, SO4$^{-2}$, Cl- which are respectively 25.84±4.26 mg/kg, 18.59±2.44g/kg and 0.434±0.023g/kg (Table 4.6) and cations Na, K, Ca, Mg, Fe which are in respective manner 28.93±6.85, 2.53±0.43, 271±38.74, 177±67 and 125.12±13.65 mg/kg (Table 5.7) that enable plant growth.

The COD and BOD of sludge samples were high but in the acceptable range which were (60.09±6.7)*10$^3$ and 115±28.87 mg respectively.

Sludge samples contained high fraction of heavy metals (Cu, Pb, Zn, Mn) where Cu concentration was 172.56±61.53mg/kg (USEPA 4300 mg/kg), Pb was 75.86±1.63 mg/kg (USEPA 840 mg/kg), Zn was 218.73±8.35 mg/kg (USEPA 7500 mg/kg) and Mn was 157.96±21.67 mg/kg. Application of sludge in agriculture did improve the yield of corn plant and the optimum applied rate is 5 ton/ha.

It is advantageous to use sludge for agricultural application. However, these studies are needed to evaluate the effect of sludge on the growth of the plants that the community used in Gaza agricultural sector.

## 6.2 Recommendations :

- Further studies should be done on large scale application of the pot experiment for a long period of time and using representative land areas
- The influence of sludge on other types of plants should be studied
- Using plant-selection strategy according to the sludge characteristics which should be further studied.
- Further studies should be done on the characteristics of the sludge from the other WWTP(s) in order to have a bigger picture of the sludge status in Gaza Strip
- The influence of sludge on other types of plants should be studied

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# Annex

# Sludge Reuse Standards

# 1 INTERNATIONAL STANDARDS

Unlike effluent reuse, there are no broadly accepted international standards or guidelines for sludge, although many countries base national standards on those adopted in the US (Rule 503) or in the European Union (under Directive 86/278/EEC). A comparison of US and EU practices and standards is summarised in Annex 3 of the Phase 1 report.

The philosophies behind the controls adopted in these two regions are often considered to represent the extremes of approaches, with the US adopting a risk assessment approach to derive scientifically based environmental and health quality standards, whereas in Europe, a much more precautionary approach has been adopted, that has become progressively more restrictive as public awareness and perception of certain issues has increased. In reality, the approach to the management of sludge depends on many factors beyond the basic scientific principles. National standards also tend to reflect:

- Pressures on land use and quality (particularly to protect limited land resources and to avoid ‘waste tourism’, i.e. the transport of sludge to a neighborouring country where the controls on sludge are less stringent);
- Public, political and food retailer perceptions (the latter is a particular issue in Europe); and
- Pressures from the disposal of other wastes (particularly from the livestock industry which compete for land for spreading of manures).

In the US, sludge for use on land must be treated to meet either Class A or B standards for pathogen reduction. Class A sludge, provided in also meets with the more stringent of two heavy metal limit values, can be used without restriction (including use for vegetables and domestic gardens). Class B sludge can only be used on permitted land and its use controlled. The process requirements are given in Table 1, and the hygiene limits are as follows:

Class A: Faecal coliform <1,000 MPN per g ds

Salmonella <3 MPN per 4 g ds

Enteric viruses <1 plaque-forming unit per 4 g ds

Helminth ova <1 viable per 4 g ds

Class B: Faecal coliform 2 x $10^6$ MPN per g ds.

In the EC Directive, sludge treatment requirements are only generally defined as "*sludge which has undergone biological, chemical or heat treatment, long term storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use*". However, many countries have specified treatment processes to achieve specific levels of treatment. In Table 1, the current UK process descriptions are given, although new draft regulations will bring treatment standards more in line with the US approach, with a new category of ‘advanced treatment’ which would allow unrestricted use of sludge. Such processes entail either high temperature or high pH (lime addition).

Limit values for pathogens and parasites are not set in Europe as this is not considered necessary based on the assumption that if a treatment process meets the correct process conditions, the reduction in pathogen numbers can be predicted. Potential transmission of disease is further controlled by the adoption of restrictions on use, for instance: crops eaten uncooked cannot be grown for a period of 10 months after application; animals cannot graze pasture for three weeks after application.

**Table 1 Comparison of US (USEPA 1993) and UK Criteria (DoE 1996)**

| Process | US Regulations | UK Code of Practice |
|---|---|---|
| **A. Processes to significantly reduce pathogens:** | | |
| Aerobic digestion | 40 d-20 °C to 60 d-15 °C | Not recognised |
| Drying beds, dewatering and storage | 3 months<br>(or 2 months above 0°C) | 3 months;<br>if anaerobically digested 14 d |
| Composting | 40 °C or higher for 5 d<br>(over 4 h exceeding 55 °C) | 40 °C or higher for 5 d<br>(over 4 h exceeding 55 °C) |
| Anaerobic digestion | 15 d MRT/35-55 °C,<br>or 60 d/20 °C | 12 d MRT/35 ± 3 °C; or 20 d/25 °C ± 3 °C; both followed by secondary digestion, 14 d MRT |
| Liquid storage | Not recognised | 3 months |
| **B. Processes to further reduce pathogens:** | | |
| Composting | Within vessel, 55 °C/3 d;<br>windrows, 55 °C/15 d | 40 °C or higher/5 d<br>(over 4 h exceeding 55 °C) |
| Drying | 80 °C in sludge<br>or exhaust gas | Not recognised |
| Heat | 180 °C for 30 min | Not recognised |
| Thermophilic aerobic digestion | 55 °C/10 d MRT | 7 d MRT,<br>with at least 55 °C for 4 h. |
| Pasteurisation | 70 °C for 30 min | 30 min/70 °C or 4 h/55 °C |
| Lime stabilisation | pH 12 for 2 h | pH exceeding 12 for 2 h |

Note: Times are for batch treatment or plug-flow conditions unless mean residence time (MRT) is specified for continuous processes with mixing of the contents of the vessel.

The heavy metal limit values for sludge quality and rates of addition (annual loading limit) adopted in the US were derived from risk assessment, and this has resulted generally higher values than the equivalent EC limits (Tables 2 and 3), but some are considerably lower, for instance lead, based on risk analysis of unrestricted use (in this case, children eaten sludge-treated garden soil).

The other fundamental difference is that soil limit values are not set and soil quality is not monitored in the US, as such control is considered unnecessary, based on risk assessment and assumed ‘life-time’ additions of sludge. In the EC, permitted rates of addition of heavy metals are more restrictive and soils receiving sludge must to monitored at intervals to ensure that soil concentrations remain below specified limit values. These values are much smaller than the implied maximum soil concentrations that would be achieved under the US approach.

In practice, heavy metals are rarely a constraint as the rate of sludge application is limited by the nutrient requirements of the crop. In Europe this generally limits sludge application to 250 kg N/ha, although in areas vulnerable to water pollution by nitrate, a lower maximum limit of 170 kg N/ha is set.

**Table 2** **Comparison of Sludge Quality Limits in USEPA 40 CFR Part 503 and EC Directive 86/278/EEC (mg/kg ds)**

| **PTE** | **USEPA Part 503** | | **EC Directive 86/278/EEC(1)** | |
|---|---|---|---|---|
| | **Ceiling concentration** | **“Exceptional quality”** | **Recommended** | **Mandatory** |
| Zinc | 7500 | 2800 | 2500 | 4000 |
| Copper | 4300 | 1500 | 1000 | 1750 |
| Nickel | 420 | 420 | 300 | 400 |
| Cadmium | 85 | 39 | 20 | 40 |
| Lead | 840 | 300(2) | 750 | 1200 |
| Mercury | 57 | 17 | 16 | 25 |
| Chromium | 3000 | 1200 | - | - |
| Molybdenum | 75 | 18 | - | - |
| Selenium | 100 | 36 | - | - |
| Arsenic | 75 | 41 | - | - |

Note: (1) Most countries in the European Union have chosen low limit values than these maxima
(2) To protect children who eat 0.2 g per day sludge used in gardens for the first 5 years of life

**Table 3** **Comparison of Loading and Soil Quality Limits in USEPA 40 CFR Part 503 and EC Directive 86/278/EEC**

| **PTE** | **Loading limit (kg/ha per y)** | | **Soil concentration (mg/kg ds)** | |
|---|---|---|---|---|
| | **USEPA** | **EC(1)** | **USEPA(2)** | **EC** |
| Zinc | 140 | 30 | 1,460 | 150 to 450(3) |
| Copper | 75 | 12 | 770 | 50 to 210(3) |
| Nickel | 21 | 3 | 230 | 30 to 112(3) |
| Cadmium | 1.9 | 0.15 | 20(4) | 1-3 |
| Lead | 15(4) | 15 | 180(4) | 50-300 |

| | | | | |
|---|---|---|---|---|
| Mercury | 0.85 | 0.1 | 8.5(4) | 1-1.5 |
| Chromium | 150 | - | 1,530 | - |
| Molybdenum | 0.9(5) | - | 9.5(5) | - |
| Selenium | 5 | - | 50(4) | - |
| Arsenic | 2 | - | 21(4) | - |

Note: (1) The loading rate is averaged over 10 years in the EU
(2) Calculated values as Part 503 does not set soil limits for PTEs
(3) Higher values are permitted for calcareous soils containing >5% calcium carbonate
(4) To protect children who eat 0.2 g per day sludge used in gardens for the first 5 years of life
(5) This has been withdrawn for re-evaluation

## 2 ISRAELI–PALESTINIAN JOINT WATER COMMITTEE

The requirements of the MOU for sludge management relate only to sludge treatment, and no chemical quality standards or application controls are described.

All sludge shall be stabilised and dewatered prior to disposal at agreed disposal sites or reused. Schedule 3 of the MOU requires that:

- Treated sludge contains <2 million MPN bacteria/g ds, calculated a geometric mean of a minimum of seven grab samples;
- Sludge is stabilised by anaerobic digestion, aerobic digestion or lime treatment, or an equivalent process, such as composting, thermophilic aerobic or anaerobic digestion, heat treatment and thermal drying.

Stabilisation is interpreted as processes that reduce volatile solids to 38%, or by lime addition (pH >12 for 2 h and >11.5 for 22 h).

## 3 STANDARDS OF NEIGHBOURING COUNTRIES

### 3.1 Israel

Until recently, Israel had no specific regulation on sludge use, and a significant quantity (from Tel Aviv) was discharged to sea. The Water Regulation (Prevention of Water Pollution) (Usage of Sludge), 2004 has now been adopted and aims at preventing water source pollution and environmental degradation as a result of improper disposal of sludge originating from municipal wastewater treatment plants. These regulations require wastewater treatment plants to stabilise and treat sludge intended for agricultural use or soil improvement. They also establish:

- Maximum permitted levels for heavy metal (Table 4) and pathogen concentrations and odour limits in sludge designated for agricultural use;
- Sets recording and laboratory testing requirements;
- Defines specific uses for different types of sludge (A and B). Requirements for Class A sludge, which is virtually pasteurised and highly stabilised, will come into force three years after the regulations come into force;
- Sets limitations on areas of sludge use; and
- Prescribes requirements for warning signs, transport and storage.

**Table 4 Maximum Permitted Heavy Metal Concentrations in Sludge in Israel**

| Parameter | Maximum permitted concentration (mg/kg ds) |
|---|---|
| Cadmium | 20 |
| Copper | 600 |
| Nickel | 90 |
| Lead | 200 |

| | |
|---|---|
| Zinc | 2500 |
| Mercury | 5 |
| Chromium | 400 |

### 3.2 Egypt

Standards for sludge use were first introduced in Egypt in 1997 through the Decree of the Minister of Housing, Utilities and Urban Communities No. 214 for the year 1997 Concerning Processing and Safe Use of Sludge. This has been subsequently revised (Decree 276/2003) to introduce penalties for non-compliance but the technical requirements remained the same.

The standards are derived from US EPA Rule 503 and require all sludge used in agriculture to be Class A. Heavy metals concentrations in sludge should not exceed the values given in Table 5. Sludge should be stabilising by one of the following methods: aerobic digestion, anaerobic digestion, thermal treatment, lime addition or composting. The content of pathogens should not exceed the following limits:

- Faecal coliform <1000 MPN per 1 g ds
- Salmonella <3 MPN per 100 ml at a sludge concentration of 4% ds
- Virus (intestinal) <1 unit per 100 ml at a sludge concentration of 5% ds
- Nematode ova <1 ovum per 100 ml at a sludge concentration of 5% ds and no more than 3 species allowed.

**Table 5 Maximum Permitted Heavy Metal Concentrations in Sludge in Egypt (Decree 214/1997)**

| **Parameter** | **Maximum permitted concentration (mg/kg ds)** |
|---|---|
| Zinc | 2800 |
| Copper | 1500 |
| Nickel | 420 |
| Cadmium | 39 |
| Lead | 300 |
| Mercury | 17 |
| Chromium | 1200 |
| Molybdenum | 18 |
| Selenium | 36 |
| Arsenic | 41 |

In addition, the Decree requires the following to be taken into consideration when using the sludge as a soil conditioner:

- Nitrogen added by the sludge should not exceed crop requirement and the C:N ratio should be within the range 18:1 - 22:1.
- Annual addition rate of sludge should be as follows:
  - For heavy textured soils: 8-14 $m^3$ per feddan (1 fd = 4.2 dunums)
  - For medium textured soils: 10-16 $m^3$/fd
  - For light textured soils: 12-20 $m^3$/fd
- Sludge should not be used on land for growing vegetables eaten uncooked.
- Soil fertilised with sludge should not be used for grazing for 2 months after addition sludge.
- Ministry of Heath should follow-up the health of the farmers.
- Sludge should not be applied under windy conditions and in public gardens or playgrounds.

## 3.3 Jordan

The Jordanian Standard (JISM 1145/1996) sets standards for sludge reuse at similar levels as the USEPA Rule 503.

The standards contain two levels for sludge reuse that specify sludge application times and procedures as well as the crops that can be cultivated in the lands where sludge is applied. Each level can be achieved by different methods of treatment to comply with requirements of its application in accordance with the Standards. The use of untreated sludge for agricultural purposes is prohibited.

The Standards have also specified the amount of treated sludge that may be applied to land depending on the elements that have the least allowable concentration. The maximum allowable concentration of the heavy metals should not exceed the values listed in Table 12 below.

**Table 6 Heavy Metal Limit Concentrations, Application Rates and Permissible Accumulation Rate (JISM 1145/1996)**

| Element | Concentration in sludge (mg/kg ds) | Maximum addition rate (kg/ha/year) | Maximum permitted accumulation (kg/ha) |
|---|---|---|---|
| As | 75 | 2 | 41 |
| Cd | 85 | 1.9 | 39 |
| Cr | 3000 | 150 | 3000 |
| Cu | 4300 | 75 | 1500 |
| Pb | 840 | 15 | 300 |
| Hg | 57 | 0.85 | 17 |
| Mo | 75 | 0.9 | 18 |

| | | | |
|---|---|---|---|
| Ni | 420 | 21 | 420 |
| Se | 100 | 5 | 100 |
| Zn | 7500 | 140 | 2800 |
| Co | 150 | 1.8 | 36 |

The Standards specify the allowable concentrations of micro-organisms in sludge used for agricultural purposes (Table 6) as Level 1 and 2 (equivalent to Class A and B in USEPA Rule 503).

## Table 13 Limits on Microbial Content of Sludge Used in Agriculture (JISM 1145/1996)

| Micro-organism | Level 1 | Level 2 |
|---|---|---|
| Faecal coliform (MPN) | 2 x $10^6$ per g ds | 1000 per g ds |
| Salmonella (MPN) | - | <3 per 4 g ds |
| Viable nematode eggs | - | <1 per 4 g ds |
| Intestinal viruses | - | <1 per 4 g ds |