Faculty of Graduate Studies
Master Program in Water and Environmental Sciences

Evaluation of the Stabilization Degree of Different Biosolids Produced from Selected Palestinian Sewage Works for Agricultural Utilization

تقييم درجة الثبات للمواد الصلبة الحيوية الناتجة من محطات فلسطينية مختارة لمعالجة مياه الصرف الصحي للاستخدام الزراعي

A Master Thesis
By:

Maisa Saleem Mohammad

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This thesis was prepared under the supervision of Dr. Rashed Al-Sa`ed and has been approved by all members of the examination Committee.

Dr. Rashed Al-Sa`ed
Chairman of committee ....

Prof. Dr. Khalid Swaileh
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Dr. Nidal Mahmoud
Member ....

DEDICATION

This research is dedicated to the spirit of my father, with sincere longing and prayer, and my wonderful, loving mother who has always encouraged me to succeed. To my loved husband and children, who motivated me throughout my study.

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TABLE OF CONTENTS

ABSTRACT

The Palestinian water strategies entail erection of new and upgrading of old wastewater treatment plants (WWTPs) to cope with increase sludge production, which is currently landfilled. Achieving a sustainable sludge management including resource recovery through sludge land application in Palestine warrants the study of the degree of sludge stabilization.

The aim of this study is to identify and analyze the sewage sludge produced from different WWTPs in view of its suitability for agricultural use in Palestine. The research focuses mainly on pathogenic and agronomic values of wastewater sludge; considering the nutrient elements and potential impacts on the soil environment. To assess pathogens and agronomic value of different types of sludge, a quantitative research methodology was adopted. Two types of sewage sludge fresh and treated sludge was analyzed and compared with characteristics of stable sludge permitted for agricultural application. In addition to selective pathogens (TC) and (FC), the agronomic parameters selected were percentage of volatile suspended solids (VSS%), totals suspended solids (TSS), total nitrogen (TN) content, total phosphorus (TP) chemical oxygen demand (COD), pH and electrical conductivity (EC). Sludge samples from different treatment processes (aerobic, anaerobic, dewatered and dried) were collected from four different WWTPs and results were assessed for compliance to limits of local and international sludge quality standards. The results will deliver scientific evidence on satisfying the needs in fertilizers and the fulfillment of both quantitative and qualitative needs of the plant, while ensuring environmental safety. This study is significant in contributing to the understanding of health and environmental impacts of using stabilized sludge for soil amendment or as fertilizer.

Findings clarify that sewage sludge (biosolids) pathogenic characteristics comply with Palestinian sludge guidelines, where the FC results were below log 6. Moreover, the sludge stability in terms of VSS% recorded values in range between 68% - 80% near to stabilized sludge criteria. On other hand, the nitrogen and phosphorus content recorded rich amounts of these nutrients in all types of sludge samples plus the N/P ratio was recorded an average of 4 which is typically describe the stabilized sludge. Moreover, the results for pH and EC comply with commercial compost characteristics. This allow stakeholders to consider biosolids land application as a good option for sludge management furthermore; this will be helpful for decision makers and farmers in view of bioresource recovery as a cost-effective recycling of sludge produced.

ملخص الدراسة

تحتوي استراتيجيات سلطة المياه الفلسطينية على خطط لبناء محطات معالجة مياه صرف صحي جديدة و تطوير و تأهيل المحطات القديمة للتعامل مع الزيادة في إنتاج الحمأة التي يتم التخلص منها حاليًا من خلال الطمر.

تحقيق إدارة حمأة مستدامة بما في ذلك استعادة الموارد من خلال تدوير الحمأة لأغراض الزراعة في فلسطين يتطلب دراسة و تحديد لدرجة الاستقرار (الثبات) في الحمأة.

يهدف البحث الى دراسة وتحديد ودرجة ثبات الحمأة من محطات مختلفة لمعالجة مياه الصرف الصحي (WWTPs) وتقييم مدى ملاءمتها للاستخدام الزراعي في فلسطين. يركز البحث بشكل رئيسي على القيم المسببة للأمراض والقيمة الزراعية للحمأة المثبتة مع مراعاة العناصر المغذية. لتقييم مسببات الأمراض والقيمة الزراعية من أنواع مختلفة من الحمأة، سيتم اعتماد منهجية البحث الكمي. سيتم تحليل نوعين من حمأة المجاري الطرية والحمأة المعالجة والمقارنة مع خصائص الحمأة المستقرة المسموح بها للتطبيق الزراعي. بالإضافة إلى مسببات الأمراض الانتقائية و هي (TC) و (FC)، فإن المعلمات الزراعية المختارة هي النسبة المئوية للمواد الصلبة المتطايرة (VSS)٪، والمجاميع الكلية المعلق (TSS) ، ومحتوى النيتروجين الكلي (TN) ، والفسفور الكلي (TP)، والطلب على الأكسجين الكربوني (COD) .سيتم جمع عينات من أنواع الحمأة المختلفة من أربع محطات معالجة مياه الصرف الصحي المختلفة وتقييمها للتأكد من الالتزام بالحدود المفروضة على معايير الجودة المحلية والدولية. وستقدم النتائج أدلة علمية على تلبية الاحتياجات في الأسمدة وتحقيق الاحتياجات الكمية والنوعية للنبات، مع ضمان السلامة البيئية. هذه الدراسة مهمة في المساهمة في فهم الآثار الصحية والبيئية لاستخدام الحمأة المستقرة في تعديل التربة أو كسماد.

توضح النتائج أن خصائص الحمأة من حيث مسببات الأمراض تتوافق مع إرشادات تصنيف الحمأة حيث تسجل نتائجFC دون 10^6 ، وعلاوة على ذلك ، فإن استقرار الحمأة من حيثVSS٪ سجلت قيم معقولة تتراوح بين 68٪ - 80٪ ,و هذه القيم قريبة إلى حد ما من معايير الحمأة المستقرة. من ناحية أخرى، سجل محتوى النيتروجين والفوسفور كميات غنية من هذه العناصر الغذائية موجودة في الحمأة بالإضافة إلى أن نسبة N / P في المتوسط سجلت بقيمة 4 أضعاف والتي عادة ما تصف الحمأة المثالية والمستقرة. بالإضافة إلى أن نتائج الأس الهيدروجيني والمفاصل الكهروضوئية تتوافق مع خصائص الدبال الصتجاري. وهذا يسمح لأصحاب المصلحة بالنظر في تطبيق الأراضي الحيوية كخيار جيد لإدارة الحمأة علاوة على ذلك؛ هذا سيكون مفيدا لصانعي القرار والمزارعين في ضوء استعادة الموارد البيولوجية باعتبارها إعادة التدوير فعالة من حيث التكلفة من الحمأة المنتجة.

List of Abbreviations

BOD	Biochemical oxygen demand
BZU	Birzeit University
CAS	Conventional activated sludge
CFU/g	Colony forming unit per gram
COD	Chemical oxygen demand
DS	Dry solids
EC	Electrical conductivity
EPA	Environmental Protection Agency
FC	Fecal coliform
MBR	Membrane bioreactor
ms/cm	Millisiemens / centimeter
NGOs	Non-governmental organizations
pH	Potential hydrogen
ppm	Part per million
PSI	Palestinian Standards Institute
PWA	Palestinian water authority
TC	Total coliform
T-N	Total nitrogen
TOC	Total organic carbon
T-P	Total phosphorous
TSS	Total suspended solids
VSS	Volatile suspended solids
WWTPs	Wastewater treatment plants

LIST OF TABLES

List of Figures

1 BACKGROUND

1.1 INTRODUCTION

Many developing countries face depletion in their natural resources, or they are already with limited resources. Some of these countries depend almost on agricultural production as the main available pillar of the economy. Limited natural resources in these countries raise pressure on competition and developing upraising. For improving crop production within this situation there are some creative unconventional solutions for grapping needs for good crop production. Since using treated wastewater for irrigation was accepted and regulated there is no doubt that the use of biosolids and the products of treating wastewater in plants will be accepted and regulated sooner or later. Besides, commercial fertilizers production is fossil fuel intensive so the price is therefore relatively expensive for many countries. However, recycling organic sources are good alternatives for these countries as these resources enhance biological, chemical and physical soil properties. The usual organic fertilizers such as animal manure and compost relatively consist of high plant nutrients. Sewage sludge or biosolids produced from WWTPs is another good option to be managed for agronomic uses as well as the common organic fertilizers sources. In fact, choosing organic fertilizing criteria in Palestine have to be supported and directed by all stakeholders through different levels.

A local published study *(*Harb et al., 2016*)* on 43 farms reported that there are thousands of tons of chemical agricultural fertilizers were annually applied to increase the amount of agricultural land production. This excessive use of commercial fertilizers consists of more than a hundred types and about 20% of these types are banned for health or environmental reasons like causing destruction of soil fertility or the pollution of water.

The reality of agricultural production sector in Palestine needs non-conventional solutions in order to increase agricultural production without influencing human or environmental health. In fact, sludge land fertilization was proven as an optimal solution globally by practicing and from scientific approvals (Project Interim Reports, 2010). On other hand, sewage sludge quantity is increasing rabidly due to increasing WWTPs establishment in Palestine (PWA, 1999; Samhan, 2012). Furthermore, the produced sludge is transferred mostly to landfills that increase cost for transportation or other dealing issues (Actual practices reported by WWTP operators). This status becomes another challenge to be solved and exploited.

The relevance of this study stems from the urgent need for securing sustainable management of municipal sludge and biosolids produced at Palestinian sewage works.

The Palestinian Water Authority Ministry of Agriculture and NGOs have set sludge management among the research priorities, where resource recovery and environmentally sound sludge disposal practices warrant further research (Palestinian Environmental Law no.7, 1999; (ARIJ), Annual Report 2015).

Utilizing the nutritional elements (carbon and nutrients) in the sludge supports agricultural sector, and is the most viable management option in Palestine. However, there is a lack of data that can help to enable determination of whether all sludge produced in Palestine is suitable for agricultural use. Therefore, developing and/or updating the current sludge guidelines for sludge management options such as landfilling and beneficial use of biosolids in agriculture as fertilizer must comply with microbial and chemical standards, to ensure wide acceptance by the farmers is secured (Suleiman et al., 2008). The Palestinian Standards Institute (PSI) formed a biosolids task group in order to develop Palestinian rules for biosolids management considering the Jordanian regulations and the Israeli standards. Sustainable management options of wastewater sludge entail bioresource recovery and are environmentally sound. Jordan has issued regulations for the beneficial use of municipal sludge in agricultural purposes (Water Authority, Jordanian Standard # 1145/1996). Several research studies (Petersen et al., 2003; Xiangsheng et al., 2011; Al-Sa`ed and Samarah, 2018) on utilization of municipal sludge in agriculture revealed an increase in soil fertility and crop production. However, other researchers underlined the environmental and health risks associated with long-term application rates of biosolids as soil amendment or fertilizer (Stasinakis et al., 2008; Galdos et al., 2009; Radjenović et al., 2009).

Urban wastewater treatment plants apply different sludge treatment technologies. The sludge line entails either aerobic or anaerobic sludge stabilization processes. Stability degree of sludge and safety are crucial criteria impacting the capital and annual running costs.

The current biosolids disposal path in Palestine is landfilling associated with huge annual financial costs for land transportation to the municipal landfill.

Increased population served by sewage works results in an increased annual amounts of biosolids to dispose safely. Researchers (Ghyoot et al., 2000; Wagner and Rosenwinkel, 2000; Weia et al., 2003; Odeh, 2016) suggested installing innovative wastewater treatment technologies as part of national strategies, where bioresource recovery, co-composting and reduced amounts of municipal sludge are achieved. According to Snyman et al., (2006), the South African Water Research Commission has initiated a long term research program to rectify previous sludge guideline shortcomings and to develop knowledge base on handling of wastewater sludge in the South African context. Intensive search on previous studies made in this field using the internet and specifically the web sites Science Direct, Cambridge Journals, Oxford Journals, SAGE, OARE and HINARI, revealed few related studies.

Variables of this study are to reveal scientific knowledge pertinent to limits and thresholds of physical-chemical and biological parameters in various types of sewage sludge. The thesis work can be considered as a technical support document that enables decision makers achieve a safe and environmentally sound disposal practices for sludge of different origins destined for diverse beneficial applications. To the best of our knowledge, there are few individual studies, which investigated one type of sludge, where only one type of technology has been applied (Mtshali,et al., 2014; Rizzardini and Goi, 2014. This research study is more comprehensive tackling two types of sludge and different treatment technologies. Most of biosolids generated by WWTPs are disposed to landfills mainly Zahret- Al Finjan at Jenin district which is about 90 km away from some WWTPs. Recent studies indicate that the biosolids are equivalent in metal and pathogen loads to that of Class B biosolids in the United States (EPA 503). Changes in Palestinian regulations create the opportunity for beneficial use of these biosolids through agricultural application.

1.2 REGULATORY AND PUBLIC HEALTH SIGNIFICANCE

Disposal of sewage sludge is becoming challenge in Palestine and all over the world. The presence of chemical contaminants and pathogens in sewage sludge are potential health risk as a consequence of recycling biosolids for land application (Stasinakis et al., 2008; Galdos et al., 2009; Radjenović et al., 2009). In Palestine about 1.5 million of three million urban populations have access to central sewer network. However, there is about eight large urban WWTPs and about 300 onsite treatment plants (Al-Sa'ed et al. 2010).

The technology type implemented for treatment processes is using activated sludge system with selected modifications. This status created a significant increase in the amount of sludge being generated. Biosolids term in this research refers to the sewage sludge that is treated by any level at the WWTP. Although a Palestinian mandatory technical instructions standard (PS:59/2015) was issued to regulate the production and use of sewage sludge treated for agriculture in ways that limit harmful environmental damage to soil, vegetation, animals and humans to encourage the proper use of the biosolids, there is lack in quality and quantities of biosolids data generated. Actually documenting characteristics of sludge treated is not in general well practiced. Table 1 displays the thresholds of heavy metals in sludge treated for agricultural use *(PS: 59/2015)*

Table 1 : Metals thresholds in treated sludge for agricultural use

metal	**concentration (mg/kg on dry basis)**
Cd	20
Cu	1000
Ni	300
Pb	750
Zn	2500
Hg	16
Cr	400
All precautions must be taken into consideration by analyzing the soil before applying the sludge	

The thresholds of heavy metals accumulation rate that can be applied to agricultural land are very restricted values, shown at Appendix 1.

The only solid instructions that can be monitored in Palestinian legislation are the inorganic matter concentration for only seven heavy metals. The scope of the legislation is only limited of defining the sludge and identifying the thresholds of the seven heavy metals that may exist in the soil, the sludge and also the annual maximum quantities for each metal that can be provided to soil prepared for agriculture. Another gap in the legislation that can be clearly noticed the lack of any classification of sludge types according to its pathogen density content and this closes the door for the exploitation of sludge for many agricultural uses. Thus, the problem of sludge management remains unresolved. Although a safe and sustainable solution is possible by choosing land application option as a monitored solution.

1.3 Sludge Production Quantity Predicted from WWTPs in Palestine

There is a clear lack of data for sludge production from existing central WWTPs and also from non-governmental WWTPs. It can be said that these quantities can be estimated through some relevant data, knowing that there are projects for constructing new WWTPs that will contribute to increasing the production of sludge, which must have a plan for proper management. According to national policy for sludge task number 58, the estimated sludge quantities in the Gaza Strip only would be about 55, 74 ton / day of dry solids by 2025, where the population there is estimated to be a total of 2,910,428 persons with predicted 325,968 m^3/day wastewater produce (PWA, 2011). However, the performance status of the large and small scale of WWTPs is difficult to report due to efficiency status, operation maintenance complication as a result, it is difficult to calculate sludge production. In fact, surveys done by PWA through the Austrian project in 2011 assured this situation.

Other readings could be taken into consideration is from a study made by Yerousis (2011). The author calculated the sludge production at Al-Bireh WWTP based on data monthly reports. Considering the population served (4043218 people) and a population growth rate (2.25%), Yerousis (2011) reported an annual sludge amount produced at Al-Bireh WWTP of 8200 tons (22.8 ton/day). This quantity matches with the number provided by Al-Bireh operator that the sludge production quantity ranged between 20 to 25 ton/d. Through research on topics related to the production of sludge in Palestine, the findings as mentioned previously, that there is scarcity of data, in reporting, monitoring sludge characteristics and even sludge quantities, as a result the efficient use of sludge is delayed in Palestine.

Annual water status report 2011 that was accomplished by Palestinian Water Authority (PWA) showed documentation for quantities and qualities of selected parameters at WWTPs in WB and Gaza, for governmental and non-governmental WWTPs. But a clear solid percent of the treated wastewater to untreated wastewater in Palestine is not defined yet. A reason for this data gaps could be due to the WWTPs status of performance, that many need rehabilitation or some is not operated yet. However, the treated wastewater produced is considered as negligible compared to the total generated WW. In fact, the majority of untreated WW generated is disposed into several streams and valleys in addition to disposal into sea and that situation subsequently reflects on sludge production and utilization options (Figure 1).

Figure (1) illustrates percent of traditional systems of wastewater collection exist in Palestine according to PWA, 2011, annual report.

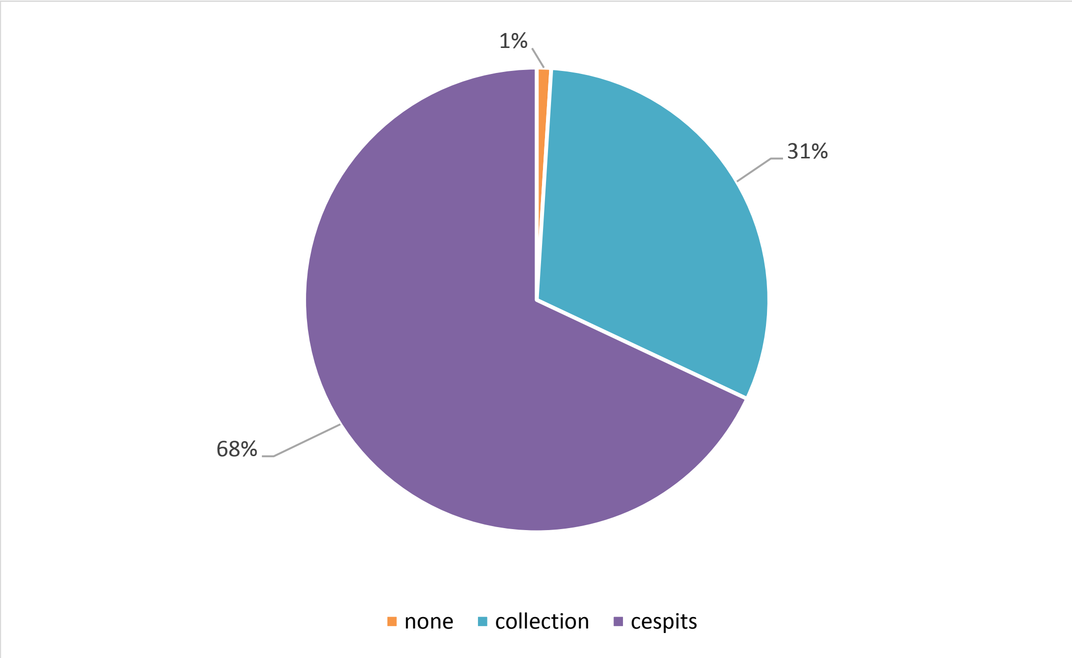

Figure 1: Wastewater collection in Palestine (PWA, 2011).

Table 2 shows daily sludge production for four WWTPs within the analysis research period. The fate of the sludge treated in Palestine according to the survey of the four sewage treatment plants that were in research scope was landfill disposal option which named as Zahret Al-Finjan landfill near Jenin city, except for the Jericho wastewater treatment plant where sludge is treated and stored on site.

Table 2 : Main characteristics for influent and effluent produced from WWTPs in West Bank, (Mar.-Jun, 2017) and daily sludge production.

WWTP name	Population served (capita)	wastewater influent (m^3/day)	Technology type	COD_{inf} (mg/l)	COD_{eff} (mg/l)	BOD_{inf} (mg/l)	BOD_{eff} (mg/l)	Sludge quantity (Ton/day)
Al-Bireh	50,000	5000	EA	1243	93	610	7.8	20-25*
Jericho	36,000	9800	EA	-	-	500	20	12 **
Al-Tireh	25,000	2000	MBR	1200*	20*	600*	10*	3-4*
Nablus west	150,000	10500	CAS	1000	36	-	7	15

* data given by the WWTP chief operators.
** data taken from monthly report for Jericho WWTP, 2015.
(-) no data available
EA: extended aeration; MBR: membrane bioreactor; CAS: conventional activated sludge system

Sludge treatment by thickening is mainly by gravity thickeners with addition of polymers where the solids concentration reach 4-6% of sludge weigh. Another sludge treatment option was applied in Jericho and Nablus west WWTPs is by implantation of natural dewatering technique (drying beds) for increasing solids concentration up to 40 to 50% of dry solids. It is noted that the sludge production volume represents about 1% to 2% of the treated wastewater volume however; sewage sludge management option that mostly implemented in Palestine has higher cost comparative to the whole total operation. Usually sludge management costs ranging from 20% to 60% of the total costs in WWTPs (Marcos, 2005).

1.4 Relationship Between Produced Sludge Characteristics and Suitable Management

Historically, sludge production has been disposed by sea or disposed to landfills or in worst case it is applied on the site of WWTPs in Palestine. There are several factors limit the potential of beneficial use of treated sludge. The major limitation that can be noticed is the WWTPs performance and its status. Furthermore, most of the WWTPs in Palestine are not built in suitable locations for beneficial use which is advised to be built near agricultural land. Other factors that have negative impact on recycling sewage sludge are known causes taken from different earlier experiences for example: public acceptance, concerns of farmers, suitable local legislations and feasible sludge management implementation that are suitable for the quantity and quality of produced sludge.

Options of sewage sludge recycling in Palestine are limited to sludge characteristics and sludge quantities as well as sludge management and reuse legislations. Incineration option for example is not applicable according to sludge treatment processed at local WWTPs because this option is restricted by at least 35% of dry solids requirement, although incineration efficiency increases with higher concentrating. Also marine disposal option is prohibited in many countries (Marcos et al., 2005) however; this option has negative impact in Gaza Sea and the coastal area in Palestine. In fact, the main practiced option is landfilling as mentioned previously. Although the typical beneficial application of sewage sludge in developing countries is as soil conditioner which was been agreed as a worthy option especially at arid and semi-arid areas where land degradation problems and inadequate food production as well as the economic problems, it is not implemented in Palestine. However, monitoring sludge characteristics in different criteria and control pollutants parameters are good solutions for adapting agronomic option for sludge reuse.

1.5 AIM AND OBJECTIVES

The aim of this study is to assess produced sludge/biosolids from municipal WWTPs by analytical quantitative evaluation of the stability of the sludge treated. To realize this aim, the following research objectives are identified:

- Analyze the sludge pathogenic characteristics by FC microbiological analysis.
- Analyze the physical parameters; TSS, VSS, %VSS, EC and pH as main parameters for identifying sludge characteristics and sludge stability.
- Analyze chemical parameters; TN, TP, and N: P ratio and COD where these parameters describe sludge characteristics in order to be managed for cultivation.
- Comparing sludge characteristics with ideal compost characteristics.

1.6 RESEARCH QUESTIONS

Based on the existence of multiple problems related to the comprehensive management of sludge as indicated in this introduction, the basic questions of this research are:

- Are the produced sludge pathogenic characteristics complying with international guidelines and sludge legislations?
- Are the values of the distinguishing physical characteristics of the sludge consistent or near with the ideal values of stable sludge?
- Are the chemical characteristics of sludge in terms of key parameters acceptable for sludge description stable?

And so the findings can be beneficial as the following;

1. Data obtained shall minimize rejection of framers acceptance on sludge / biosolids utilization in agricultural purposes. Knowledge based on scientific research pertinent to pathogens, nutrients and stability shall promote sustainable practices in biosolids management in agricultural production with minimal possible effects on the public health and soil environment.
2. The appropriate sludge disposal paths considering adequate rules and upgrading regulations for its intended use can promote multi beneficial applications in view of soil types.

3. Safe use of biosolids in land applications as fertilizers or soil amendment under adequate governmental monitoring and follow ups can reduce chemical fertilizers and minimize the use of pesticides that can affect soil, produce and health.

1.7 THESIS OUTLINE

This thesis consists of six sections

First section: an introduction to the research includes; regulatory and public health aspects in Palestine, sludge production from WWTPs, sludge management in Palestine, research questions and objectives.

Second section: describes the literature review on three aspects; sludge international legislations and reuse, sludge characteristics and selected parameters and potential of sewage sludge as soil conditioner.

Third section: explains status of WWTPs and sludge management in Palestine; case studies.

Fourth section: clarifies materials and methodology carried out in the research.

Fifth section: provides data analysis and discussions.

Sixth section: displays conclusions and recommendations as outputs from the thesis.

2 LITERATURE REVIEW

2.1 REGIONAL LEGAL ASPECTS OF SLUDGE TREATMENT AND REUSE

The old practice by farmers thousands years ago was utilizing organic waste as enrichment matter for increasing land productivity, this experience activity was practiced in ancient times by Japanese, Chinese and Hindus people (Outwater, 1994). In Europe also, this practice became dominant till epidemic outbreaks, when large number of treatment systems during 19^{th} and 20^{th} centuries have entailed of direct land application of sewage. Through these facts, proper guidance for the use of sludge in agriculture is needed due to the huge increase in sludge quantities produced in proportion to population growth. Another factor that has played a role in the importance of legislation for sludge reuse is the economic situation of the country itself. Historically, in low income countries, wastewater treatment is with a limited coverage, indeed sludge is likely to be used informal with no any restriction, moreover, there would be lack on data on the use of sludge and lack on data of sludge production and characteristics. In contrast, in high income countries, sanitation and wastewater treatment cover almost the whole wastewater production as well as these countries were the pioneers in promulgation of sludge reuse regulations for insuring health and environmental protection in these countries (Scott et al, 2010).

Reaching any political decision for utilizing sludge treated in agricultural land depends on public acceptance (Scott, 2007). The social values play an important role in sludge management decisions. Usually public concerns are the quality of life and the equitable distribution of burdens and benefits of sludge treatment and disposal among population (Multimedium Management of Municipal Sludge, volume IX, 1977). Actually, from data results by sociological and psychological researchers there is no any significant measurements that prove or disprove the existence of popular distaste for sludge reuse. However, raw or processed sludge is dispatched ordinarily to landfills direct or indirect way. The absence of local legislation exacerbates the administrative and organizational intricacies. There are different alternatives for sludge recycling that already applied in developed countries instead of ocean disposal or incineration process every few days, one of the optimum is agricultural applications that require large cultivated lands with seasonal application of sludge treated.

When agricultural application is regulated the interest of crop safety and wastewater management is integrated. Sludge treated is being applied to crop, grazing and forest land, and that protect soil and water environment.

One of the first experiences of developed countries in regulating the use of sludge for agriculture was in America and some European countries. In America, the special legislation for the application of sludge to agricultural land was organized according to the application method, as well as according to the sludge quality in specific properties. Also, special specifications were required form sludge producers to determine the sludge characteristics and compliance assurance to these legislations. The certificates and permits were given to sludge producers periodically by regularly monitoring and this is to ensure that the sludge was monitored and tested to suit the conditions and characteristics. The U.S. Environmental Protection Agency (EPA) has promulgated rules (40 Code of Federal Regulations (CFR) Part 503), regulations that governs the agricultural use or sludge disposal. The goals of these regulations were to ensure that sewage sludge is used or disposed of in a way that protects both human health and the environment. The legislations were established according to pollutant limits, operational standards and management practices, plus standards for frequent monitoring and documentation and reporting. Sewage sludge was defined by nine of heavy metals concentrations and its ceiling concentrations for sludge land application license. On other hand, sludge classification was defined with respect to pathogen densities for meeting vector attraction reduction where sewage sludge classified into two groups class A and class B sludge. However, bulk sewage sludge applied to agricultural or non-agricultural land for example public contact sites must meet at least Class B requirements. Whereas, bulk sewage sludge applied to grasses and home gardens, and sewage sludge sold or given away in bags or other containers must meet the Class A criteria by applying one of pathogens reduction described processing options. In this legislation, the quality of sludge applicable to agriculture was determined according to the two classifications. These limitations have contributed significantly to the effective use of sludge and have contributed to reducing the uncontrolled disposal of sludge in the US regions.

The European Union legislation on sewage sludge management promulgated at June 1986 by Council Directive 86/278/EEC. The treated sludge defined as the sludge that undergo biological, chemical or heat treatment or long term storage for significantly reduce health hazards. Applying sludge on soil is described by spreading it on soil or any other application methods.

With no any restriction in commercial food crops including stock- rearing purposes. European states committed to prepare a consolidated report every four years for the quantities, the criteria followed and any difficulties encountered by the sludge usage in agriculture. The composition specifications identified for the nature of the sludge were limited to identifying concentrations of seven of heavy metals as well as the pH parameter. Actually a several directives on water protection, urban waste water treatment and on the use of sludge in agriculture have influenced sludge agricultural use after that. For last 25 years the management practices followed EU legislation but some states have modified some regulations. Furthermore, some states have established national legislation where the limit values for heavy metals in sludge changed according to national guidelines. A continuous improvement and more enforcement were continued and advised for effectual sludge management (Inglezakis, et al. 2011). In addition to these positive steps, EC proposed introduction of limit values for organic pollutants and limits for pathogen concentration.

When reading legislations to recycle sludge in the Mediterranean countries, the readings of some points were similar, but there were particular differences for each country. Improvements and developments could be made from those experiences.

In comparison to Tunisian Standards INNORPI, 1989b; NT 16.21; NT 16.22 and Sludge standard NT106.20 for agricultural use there are limits definitions for seven heavy metals, however, the limits are given by concentrations and not by accumulation rate or considering soil composition. Also the pathogens limits reported of fecal streptococci and fecal coliforms must not exceed $2x10^3$ and $2x10^6$ cfu.g $^{-1}$ of dry sludge respectively. Sludge recycle for agricultural purposes is limited for only that derived from urban WWTPs neither from pretreatment nor from cleaning wastewater infrastructure. The sludge agricultural use management is regulated by standards for sampling and type of cultivation.

The heavy metals thresholds according to standard NT106 Tunisia are higher than the European values. The main wastewater treatment technology used in Tunisia is the activated sludge technology, which is about 85% of total other technology (Tunisian standard NT106.20, 2002). Therefore, sludge produce is in continuous increase which makes recycling according to regulatory standards is an important benefit for the environment and for humans (according to the source).

Regarding Standards issued in Jordan for sludge cultivation reuse, (Water Authority, Jordanian Standard # 1145/1996). The identified guidelines are mainly adapted from US.EPA guidelines for ten heavy metals limits and pathogens limits plus, there is a requirement limit for analyzing salmonella parameter which is added as a must requirement and not accept the values for FC as replacement for pathogen limits only. Moreover, the types of sludge classified to sludge type I and sludge type II similarly to class A and class B in EPA rule part 503. Frequent analysis for monitoring sludge characteristics is regulated according to sludge quantities produced from WWTPs. The standards a according to a review search published by the ministry of water and irrigation (Nazzal et al., 2000) limits the places that such converted sludge can be used for soil enrichment and also limit the duration which the digested sludge can be applied for agriculture. From reviewing data for sludge reuse as land agricultural application the regulations severely restrict the uses of sludge so that the majority of sludge produced is disposed of by landfill (Al-Hmoud, 2008). As result there are no beneficial uses for sludge / biosolids in Jordan. Furthermore, no solid assessment for sludge agricultural application impact due to limit application. Another research presents the scarce available data for sludge characteristics and analysis data base that is needed for application assessment and updating for existing data (Halalsheh et al.,2005).

In Egypt, law 276/1994 for wastewater sludge reuse was amended by Decree No. 214/1997 and Decree No. 222/2002; deal for nine heavy metals limits requirements for use of sewage sludge in agriculture. In addition, severe requirements for pathogens limits defined by coliforms 10^3 count /g, salmonella by 3 count / 4 g, helminth 1 count /5 g of dry sludge. The Decree restricted the addition of nitrogen added by the sludge that should not exceed crop requirement and the C: N ratio should be within the range 18:1 - 22:1.

Also there are guidelines for management the agriculture application of sludge considering the annual addition rate of sludge according to soil texture.

The Decree prohibits sludge application on land for growing vegetables eaten uncooked or for grazing for 2 months after addition sludge and applying sludge under windy conditions and in public gardens or playgrounds. According to relevant studies these guidelines are described as very restrictive standards (Soulie, 2013). However, the sewage sludge reuse is under a Decree with very restrictive standards and this status boosted potential risk from toxic elements related to health risk linked with insufficient treatment of the WWTP and sludge management. Moreover, the National report from Egypt recommended a revise update and completes the institutional framework of the WWTP sludge management and reuse at all levels; national plan, regional plans and local plans. By reviewing the researches and studies for sludge legislation evaluation for agriculture reuse in Egypt, there are limited studies found in this area compared with similar studies in the region.

Regulations prepared by ministry of the environment and ministry of health and water council in Israel to control the improper sludge disposal. The regulations promulgated at 2004 and came into force in 2005. The requirements are well defined to produce stabilized sludge by WWTPs that to be transferred for agricultural use or soil conditioning. The stabilized sludge is classified to two types just like the EPA classification considering pathogens densities levels in terms of FC or salmonella as well as virus density. The regulations establish maximum limits for heavy metals concentrations of dry material basis and limits for heavy metals and nitrogen concentration that can be applied per dunam area per year. Furthermore, the requirements of frequent analysis of FC density to control class A at WWTPs that produce one ton or more of sludge per day, and virus analysis must done to monitor class B sludge every six months for WWTPs that produce one ton or less of sludge per day. In addition, regulations defined the uses for class A and class B by selected type of crops could be cultivated and soil texture and land location and distance to surface and ground water resources. Moreover, a detailed prescription for writing warning signs and how must be clarify to people that the land is loaded by defined sludge in date of application and WWTP name as reference source as well as the sludge quantity and percent of dry solids characteristics.

Transportation of stabilized sludge is also regulated. Despite the large amounts of untreated sludge that are disposed in the Mediterranean Sea, this practice is scheduled to be stopped in 2020. The expected future plan for sewage sludge fate is estimated to be set to 40%, 30% and 30% for incinerated sludge, reused as class A and reused as class B respectively.

As estimation was done using documented data and information taken from experts in the Israeli Water Authority and the Ministry of Environmental Protection that the cost of transporting sludge to disposal sites as fertilizer or landfilling by 2020 is about 7 million/year. However, the cost of sludge removal percent of the whole wastewater treatment operation varies according to the capacity of the plant design which is around 20% for each m^3 treated/day (Water Authority, Planning Department, 2010).

A study published at 2012 by Gilad Axelrad et al., highlighted the economic benefits of sewage sludge reclamation for use in Israeli agriculture moreover showed that the suitable allocating of treated sludge among potential users is an additional benefit that increase public acceptance and cooperation that also protect environmental pollution. The research findings illustrated that the good practice of sludge management will increase economic benefits by 19% while adhering to the requirements of applying legislations requirements for sludge reuse. Israel has new experience in the reuse of sludge in agricultural application in accordance with the regulations that were promulgated in 2004. However, there are studies directed at this subject, which examines the economic benefit of these legislations. The reason is that these legislations are implemented in a mandatory manner.

2.2 SLUDGE CHARACTERISTICS AND SELECTED PARAMETERS

The WWTP sludge is usually composed of combination of the primary settled sludge and the waste activated sludge portion that is not recycled to the aeration tank digester (Edith et al., 2015).The sludge characteristics vary widely according to waste source and sludge produced from the treatment of the wastewater technology such like; on-site treatment, for example septic tank and off- site treatment for example extended aeration tank.

Also, the variation of sludge characteristics can be affected by other factors such as; social factors, the legislation and the status of economic and political environments (Sagasta et al., 2013). Sludge contains large number of pathogens, heavy metal pollutants, and organic pollutants as well as a very high biochemical oxygen demand organic matter that cause odor and vector attraction resulting health and environmental risks. However, raw sludge contains nutrients such like; nitrogen, phosphorous and other unessential (not primary) nutrients (e.g. potassium and heavy metals within accepted levels).

These potential beneficial nutrients in addition to organic carbon constituents in sludge can be described as a soil conditioner material because it improves soil texture and increase plant productivity once it was applied to land agriculture.

The organic carbon in sewage sludge in fact is not stabilized, that means the sludge contains a very high biochemical oxygen demand (BOD). In order to recycle sewage sludge there must be a suitable sludge treatment scenario furthermore a good sludge management needed to handle it. According to different relevant scientific resources literature there are several sludge treatment options can be implanted which include stabilization, dewatering, thickening, drying and incineration. Generally, sludge treatment cost is equivalent to sludge removing from wastewater plant (Strauss et al., 2003).

To stabilize organic waste reduction of COD, BOD must be achieved and this process can be done by application one of two different technologies; aerobic or anaerobic treatment. Although aerobic stabilization achievement is expensive process, the composting application would be better option as an alternative with acceptable achievement cost (Javier et al., 2015).

Composting criteria according to many scientists and experts view is mainly attained by reducing carbon to nitrogen ratio from range of 500- 200 to below about 30. In addition to reduction of pathogen density by some selected methods and reduction of solids percent to at least 15%. The other treatment methods suggested are thickening, dewatering and drying processes where the differences are by the techniques and the solid and pathogen contents. The water removed from sludge by sedimentation tank for example to allow solids settling for a period of time is termed thickening. This process increase the solid percent in sludge but not achieving solidify phase that allow easily sludge handling. By dewatering mechanic techniques the sludge can be handled at which solids reach about 20% of sludge content. Mechanical techniques for instance are using press belts or filters or by centrifuging route. Another option can be used to treat sludge is by applying sludge on sand bed to allow natural water evaporation process to increase solid contents, this process is termed drying process where even bacteria content is decomposed and mostly removed (UNEP, 2000). Therefore, the solids level in sludge is a relevant control according to the treatment purposes and the sewage sludge characteristics produced for WWTPs.

The variation of sludge treated characteristics is related finally to mechanical process, chemical additives as coagulates or polymers, the volatile / total solids ratio that influence the vector attracting capability and finally the pathogens density (IWA, 2005). The fate of sludge depends on the overall sludge characteristics; many scientific studies illustrated values with cleared range for some main characteristic and these values were measured and conducted for by-products produced from WWTPs implementing different technologies of treatment.

Sewage sludge composed of 95 to 98 percent of water and dry solids remaining that contains of 50 to 85% of organic matter (UNEP, 2001). However, the sludge is classified as a function of solids content to three physical states; liquid sludge that water content of 93-98% where Up to 75% of the solid fraction is organic matter (Guidelines for Application of sewage Sludge to Industrial Crop in UK, 2001). The pasty sludge in two forms of flow degree or viscosity and this depends on the TS contents percent. The pasty sludge that is difficult to be stored in high piles consists about 14 to 17% of total solids, while the other form of pasty sludge can be stored easily in stable piles with slope up to 45° (CEMAGREF, 1990). In fact, the water high content in sludge can be beneficial utilized in land application, many states in US and Europe have changed their sludge management options towards land application from 20% of total solids in 1972 to 41% in 1998 (U.S. EPA, 1999; Spinosa and Vesilind, 2001) . In general, there are some basic properties that were studied and identified through different purposes and different researches nowadays. One of the most common of sludge characteristics is the total solids content (TSS) and the volatile solids (VSS).

Theses parameters reflect the biodegradability of organic matter which expressed in %VSS; the VSS to TSS ratio. Usually, according many literature scientific papers the %VSS range is 75-85%, the higher the VSS content indicates higher degradable organic matter that consist in sludge and that influence stabilization of sludge negatively. Reducing volatile organic matter for specify level force microorganisms to begin endogenous respiration where cellular material is oxidized for life support; synthesis and maintenance. Resulting reduction of total quantity of biomass plus the remaining is in low energy state which is considered biologically suitable for agricultural application.

A study was done for five different WWTPs in US at Ohio area for analyzing thermo-oxidation sludge process for class-A requirements; the study documented the preliminary TSS and VSS data as well as %VSS results for the five WWTPs.

The values were measured for three different sample locations; influent, mixed liquor and aerobic digester tank. TSS values of the mixed liquor samples were given at range of 1681-3713 mg/l while the VSS range of 1432- 3060mg/l. Whereas the aerobic digested samples TSS values varied between 11002- 19510 mg/l and the VSS values were between 9140-14220 mg/l. %VSS values in both mixed liquor samples and the aerobic digester tank are %85 and %82.4 respectively, in general, these values are similar to values of normal activated sludge values levels. Another TSS and VSS concentration profiles were analyzed during aerobic stabilization, the concentration were 3800 and 2400 mg/l for TSS and VSS respectively in day one of reactor filling and starting microbiological activity (Ozdemir et al.,2014). The TSS, VSS values were analyzed from day zero to 70 days to evaluate endogenous decay activity in aerobic stabilization of biological sludge in a fill reactor operated.

These values indicate the status of %VSS organic matter ratio that present at the mixed liquor sludge samples (fresh samples) which equals to %63. These values were significantly smaller than the values taken for %VSS for normal conventional activated sludge. According to the TSS and VSS limits in the septic sludge tanks, these values exceed the levels that are for the sludge produced from municipal WWTP which apply aerobic digestion technique (Henze et al., 2001) the values specified as 100,000 and 60,000 g/m^3 for TSS and VSS respectively.

The brewery sludge also was investigated and TSS was analyzed given an average result of 18,029 mg/l. The %VSS levels in many places of studies refer to the level of organic matter stabilization; however, there are other factors that influence stability.

Another essential properties of sludge that is evaluated frequently for land application determination are the nutrients content mainly nitrogen and phosphorous concentrations. Nitrogen and phosphorus have received considerable attention to be studied due to high abundancy in sludge, making the sludge an important source of fertilizers containing these nutrients. Nutrients concentrations vary considerably due to wastewater sources and composition furthermore, the technology that is adopted in treating affects the nitrogen and phosphorous removal efficiency. The fertilizer value of N in sewage sludge is according to nitrogen composition which could be as inorganic form or organic form, in addition to temperature factor that can influence decomposition of matter to release nitrogen.

It is reported that the utilization of nitrogen from sludge application needs long period of time when the nitrogen is as organic nitrogen form whereas the inorganic nitrogen form is recommended to be monitored as a criterion for sludge agriculture application to control the rate of the application. Also it is required to monitor the ratio of inorganic nitrogen concertation to metal concentration that is considered as another needed criterion (Alberta Guidelines for 2001). The nitrogen inorganic matter has a quick release of nitrogen as fertilizer due to the fast decomposition of the matter in soil (Coker et al., 1987; Wen et al., 1995). Despite of the beneficial utilization of nitrogen form sludge, the excessive nitrogen irrespective of its form will be transformed to nitrate that normally infiltrate and contaminate groundwater; however, land application of sewage sludge is regulated by monitoring nitrogen amount thresholds per hectare; which is equivalent to 5 up to 25 tons/ hectare/ year of sewage sludge that could be applied on cropland (Chang et al., 1988).

The other sludge content that is considered as essential nutrient that can be recycled is phosphorus, which draws scientific attention due to the increasing amounts that discharged through wastewater. It is reported that the annual P discharge into wastewater is about 1kg/ capita, (de Haan, 1981) in developed countries whereas, it is estimated that this amount is likely to be higher in developing countries. However, phosphorus in sludge is considered as a major advantage in sludge over commercial fertilizer, indeed, it is the key nutrient for cultivation and when deficient in agriculture it restricts productivity. Normally, the removal of P in conventional WWTPs is up to 90% so as to reach accepted concentration of P in water effluent. On other hand the P removed is therefore is condensed and remain in waste sludge. Cultivation requires generally about a ratio of 10 to 5 of N to P while the ratio of N to P in sludge usually is more. Many researches have studied the possible environmental risks that could be by P accumulation in soils and crops (Rydin and Otabbong, 1997). There are many factors such as; pH, temperature and soil texture affect the availability and the mobility of P in soils as well as plant uptake. However, there was no significant impact on plant from excess P but there was evidence that accumulation of P block plant uptake for some micronutrient elements like copper, iron and zinc (Kirkham, 1982). P content in sewage sludge was evaluated among about 40 years; the percent common ranges are 1.2 – 3.0% (Sommers, 1977). Also it was reported with a percent range of less than 0.1 to 14.3 % of dry basis (Dowdy et al., 1976). The values of N percent vary also but specified to be greater than that of the P; the range is from less than1 % up to 18 % (Sommers, 1977). It was found at 1987 that the total of N in sludge is 25% (Coker et al.,1987).

Another data values were taken from Pakistan and India where the values of N in sludge are equal to 16,000 mg/kg (16 %) in Pakistan and in India was from 15,400 up to 19,200 mg/kg of dry basis (i.e.: 15.4 – 19.2%) (Usman et al. 2012).

If N and P values are recycled from sludge and utilized as organic fertilizers source the worth could raise country economic status. About $ 16 million per year was estimated by *Gudmundur,1999* as economic benefit, in his research through addition the quantities of N and P of 13,400 and 8,600 tons annually, respectively, values were measured from sludge produced in Ontario, US. Furthermore, the treated sludge has a worthy potential demand in the Egyptian market as stated, (Ghazy et al., 2009).

By studying the prices of different fertilizers origins, not taken under consideration the quantities of nitrogen and phosphorus needed for fertilization, in general it was found that the treated sludge price has a good competition margin over other fertilizers and this indeed allow farmers to get monetary benefit by saving excess expenses and this was seen by the amount of dried sludge that was sold in year 2007 which represents more than 85% of sludge produced.

However, the article has pointed to the attention and caution of the agriculture application of sludge in an unattended manner.

Evaluating organic matter is an important criterion to determine the value of sludge as organic fertilizer, moreover, to evaluate sludge stability. COD refers to the amount of oxygen required to oxidize soluble and particulate organic matter in sludge. Recent application of wastewater treatment had introduced large amounts of waste sludge is generated from biological WWTPs, implementation of conventional activated sludge technology for example produce practically 0.3-0.5 kg dry biomass for 1 kg COD removed. COD parameter can be used to measure the degree of stability of sludge. The amount of COD produced in raw sludge normally is about 60% of the total COD inlet at aerobic activated sludge treatment. For research studies there was no clear evidence that refers to any risk from applying sewage sludge as organic fertilizers. According to (Diacono et. al, 2009), there is a strong deterioration of soil in European semi-arid Mediterranean regions.

This is due to many reasons such as erosion and luxury in irrigation practices moreover the extreme use of chemical fertilizers. All these factors cause degradation of soil organic content. Thus applying sewage sludge on land in order to increase fertility of the soil is a good option to recycle organic waste in which develops soil fertility.

Besides, improvement in soil biological functions as studied, the enzymatic activity increased by 30%. In addition, long term land application of organic amendments increased organic carbon for microbial biomass by up to 90% comparing unfertilized soil and up to 100% comparing to soil fertilized by chemical fertilizers. The COD removal efficiency estimation is a challenging task due to the sludge characteristic that make sampling and analysis not easy issues (Parravicini et al., 2008).

An Austrian study (Parravicini et al., 2008) examined post – aeration process for anaerobic digested sludge and the efficiency removal of the COD and nitrogen after applying this solution. The study was to test a COD removal efficiency solution in order to reach COD and TOC requirements for land application in Austria which is limited as 5% TOC of dry solids for 2004 which is described as strict criteria as labeled by the researcher. The research was conducted at WWTP that is loaded actually of 720,000 population equivalent. The sludge produced characteristics for TSS, %VSS and COD are; 36 g/l, %54.3 and 29,500 mg/l respectively, were the sludge (the thickened primary and the excess secondary) is digested anaerobically under mesophilic condition for 20 days of sludge age.

After implementation of post – aeration phases the estimated COD removal was conducted for four different time phases of the treatment according to oxygen concentration and oxygen mixing. COD was estimated by four methods; analytics, respirometry, energy consumption and heat balance. The average COD removal result was 16% COD; this value was the average of values taken from the four methods of COD estimation. According to literature there are no exact limits for COD level for land application, however, there is local regulation for this part in some developed countries. According to EPA legislation and European legislation for sewage sludge management, the amount of organic matter was not limited although sludge stability was described by increasing degradable organic removal percent.

According to global legislations there are some heavy metals that were identified and were restricted by defining maximum concentrations that could be applied with a specify rate of accumulation. These regulations were promulgated due the existence of concerning heavy metals in some WWTPs that may have health risks.

In parallel to heavy metal contents in sludge the property of electrical conductivity (EC) and hydrogen potential (pH) are important characteristics that should be monitored and measured. Decreasing of pH value cause metal transformation to different ionic form of the metal, moreover, increasing of solubility of metal leads to chemical pollution.

When considering sludge land application EC control is a major concern that should be monitor, it is two -edged property. The higher the value of EC in sludge would enhance nutrient solubility thus, enhance mobility and plant uptake.

Whereas, exceeding limits of EC means rich availability of salts in sludge that have a diverse impact to soil as well as crop productivity. The importance of (EC) evaluation comes from the easy direct relationship between the measurement and soluble salt concentration which is a big concern for applying sludge for agricultural use. However, the level of salinity is given usually in electrical conductivity (EC) values, usually high value of EC may cause severe problem to soil and plants. That is because the accumulation of saline water in sludge with the saline soil may increase the salt concentration to high level that affect plant water absorption form the surroundings. In fact, plants concentrate solutes in their roots to maximize water absorption, but this cannot compete water with highly saline surroundings. In many agricultural lands in Palestine the geological material of which the soil formed is already saline such as the Dead Sea area, irrigated agriculture areas in the Jordan valley and also in Gaza Strip. And that leads to the necessity of monitoring and continuous evaluating for sewage sludge before agriculture application. Accumulation of salts in the embedded soil by sludge with high EC values affects adversely the physical conditions of the soil with respect to aggregate formation, water infiltration, and water-holding capacity (Lax et al., 1994). This affects growth of plants and even fruit deformities (Cicek and Çakirlar, 2002).

Consequently, sewage sludge treated cannot be permitted for cultivation according to isolated parameter, but this application requires frequent monitoring and evaluation.

2.3 Potential of Sewage Sludge as Soil Conditioner/ Case Studies

Nowadays, there is extensive bibliography available in assessing the sewage sludge land application in terms of the crop production and the soil characteristics improvement as well as economic benefits by reducing using of inorganic fertilizers.

A study conducted in Malaysia suggest proper sludge management and good economic solution for the increasing sludge quantities through increasing population and the by - production of sludge from WWTPs.

The study presented the different sludge management options applied in Malaysia like landfilling disposal, forest disposal, composting, or agricultural applications.

The application of sludge gained acceptance according to the author, however, researches and studies for evaluating these applications found that the ultimate solution for sludge management is soil amendment where the result of this criteria can be useful for reconditioning of soil texture and improving crop production (Salmiati et al., 2012). The analyses assess applying different sludge ratios in constant dried leaves volume and the impact in crop production. Results discussed the suitability of sewage sludge as soil amendment for agriculture and highlighted the beneficial addition of dried leaves that is easier in degradation and faster. In addition, the growth was best considering plant characteristics and heavy metals removal at a mix proportion of dried leaves: sludge with a ratio of 1:4 comparing other testing ratios. Actually, this analysis is not done for assessing sewage sludge only but the assessment is done for sludge with semi composting process which was done by addition of leaves.

An evaluation was conducted for comparing application of three types of soil conditioner and they are: sewage sludge, sewage sludge compost and inorganic fertilizers. The evaluation was for crop productivity and morphological properties, crop chemical content and also soil chemical composition (Casado-Vela et al., 2007). The results indicate that soil amendment by sewage sludge or by sewage sludge compost have enriched soil in organic matter, phosphorous and nitrogen content however, the soil amendment by inorganic fertilizer has least enrichment value of organic matter and both nutrients, nitrogen and phosphorous. In addition, these trials did not involve any environmental risks. Another clarified result was that organic wastes have no toxic affect to leaves or to fruits per plant (which was corn plants). However, the grain production increased and the corn quality was within the accepted levels in terms of chemical content. The author finally generalized that the land application of organic waste is a good solution as sewage sludge management.

Another comparative evaluation research; comparing sewage sludge (produced from activated sludge treatment) versus municipal solid waste compost that support the option of sewage sludge land application. The comparison study was by assessing soil enzymatic activities and soil nutrients contents, after treatment amendments through constant period of time. The assessment was done by two fixed doses of both sludge and sludge compost injected in soil, results were compared to control sample that was the existing salt soil in Tunisia (Lakhdar et al., 2010).

Results support the fact that by increasing carbon amount (organic matter) the levels of enzyme activities will be raised, thus the low productivity of saline soils due to their salt toxicity can be solved by organic waste addition and improve soil productivity.

However, soil nutrients content was enhanced through all levels; carbon/nitrogen ratio, nitrogen content and potassium concentration as well as three conducted heavy metals were increased within acceptations. These increased values enriched soil fertility in addition; the conducted values of pH and EC explain that the nutrient mobility was enhanced and so as a direct affect improve productivity. This research focused on soil physical and chemical characteristics that are affected by sewage solid compost of sludge application as respect to control soil with high salt concentration. The author concluded that increased enzyme activities that were measured indicated a better soil biological activity present. Although he noted that there must be a balance consideration between organic fertilization and any possible environmental risks could be exist by using land application as a sludge management option.

Increases organic matter concentrations in soil by biosolids applications have been noted by a number of workers. The cation exchange capacity (CEC) of the soil amended by biosolds mostly increased due to the present of organic matter degradation products. And this is another factor that inflence nutrient mobility and enhances soil physical properties. This was explained by the increasing in water aggregation due to binding properties between the microflora that is associated with organic matter. Because of increased aggregation the total porosity increased thus infiltration rate and hydrulic conductivity increased. As a consequence, the runoff water errosion decrease due to increase in water holding capacity.

In terms of economic interest there are a lot of researches that showed economic beneficence of sludge use as an organic fertilizer substitute for inorganic fertilizers. Most of these studies are based on the analysis of data documented by farmers or statistical results, as well as data taken from many experts in the field of sludge management. In general, the conclusion of these types of researches that the sewage sludge utility by land application in many countries was of the utmost importance in terms of sludge management cost reduction as well as cost reduction for inorganic fertilizers production.

In Brazil a study was conducted from 2007 to 2010, depending on data analysis of agronomic parameters and metals of number of batches produced from anaerobic and aerobic sludge treated (Simone et al., 2014).

At the study duration the analysis of nutrients percentage enrichment was measured covering area of 2,288 ha of agricultural land that a 33,404 dry tons of sludge has been spread for 239 agronomic projects investigation. Different crops were cultivated such as: soybean, bean, corn, oat, wheat and green manure. The study illustrated that the sludge provided about 74% of N, 35% of K_2O, 73% of P_2O_5 and 88% of lime.

According to farmers and relevant data the expenses on limestone and fertilizers for similar agronomic projects were reduced by saving an average of US$ 813/ha. Generally, the sewage sludge land application option is shown to be a promising option for sewage sludge stabilization. Another evaluation was studied in Egypt done by data analysis which was to compare different types of sludge (natural/mechanical dewatered sludge treated and sludge compost) with respect to energy balance, environmental impacts and economic aspects (Ghazy et al., 2009). The findings approved that sludge treated land application can save about 1299 kWh/ F.U of the increasing energy demand for the commercial fertilizer production. However, any of sewage sludge management options cannot be implemented and accredited locally without considering farmers and other stakeholders' perceptions. (Krogmann et al., 2001) results showed that a comprehensive understanding of farmers' perceptions and their choices regarding sewage sludge reuse in agriculture is the key for improving sludge management. The study was conducted through a survey of a number of farmers for fruits and vegetables in relation to the possibility of applying sludge treated on their agricultural lands. Farmers' interest focused mainly on protecting their land in terms of agricultural characteristics and the quality of their agricultural production, although few farmers had an interest in environmental issues or economic incentives to improve soil benefits. To summarize all factors that orient sludge management for reuse by choosing land application as a primary option for sewage sludge management, it is necessary to start locally by understanding social benefits for all different levels of stakeholders. However, different recent studies have showed multi- benefits in different criteria that sewage sludge agriculture application is an ultimate option of sludge management that can be achieved.

3 WASTEWATER TREATMENT AND SLUDGE MANAGEMENT IN PALESTINE; CASE STUDIES

There are few operational urban sewage works that could be viewed as representatives for medium-large scale WWTPs in Palestine. On the other hand, the sludge treatment that is applied mostly is aerobic digestion technology while sludge treatment by anaerobic digestion is implemented in a very limited scope, Nablus –west WWTP represents this treatment. The analytical study was conducted according to the analysis of samples from four selected stations that apply different treatment sludge technology with different scales, giving excellent perspective for comparative analysis and evaluation of sludge regarding to treatment technology.

3.1 AL-BIREH WASTEWATER TREATMENT PLANT

Al-Bireh WWTP was constructed in year 2000 and was funded by Germany. It is designed with capacity of 5750m^3/day and 11,500 m^3/ day at wet weather (Al-Bireh Municipality, 2010). Almost 95% of Al-Bireh residents are served plus two neighboring settlements. The capacity for the WWTP is for future serving about 50000 citizens. The process for treating domestic sewage is by using aeration tanks which is activated sludge technique. The wastewater firstly passes through physical separation by two screens then the biological process begins. In the aeration tank where the sludge is formed (the biological flocs), the flow continues to reach clarifier tank and by settling a separation of sludge blanket is oriented and recycled to the activated sludge tank. The final treatment of sludge is the dewatering process in order to minimize the sludge volume as well as to reduce pathogens. Figure 2 illustrates the dewatering (a) and the biological units (b) of the WWTP as described by Al-Sa`ed and Tomaleh (2012), who investigated the efficacy of Al-Bireh WWTP. In sludge treatment process, the polymers are mixed with the sludge and then it is dewatered by applying either centrifuge technique or belt press technique and both techniques works in parallel and this due to the increase sludge production capacity due to increase of loading. As practical application, there is no chlorination step in sludge treatment in this WWTP, as confirmed by the station operator. After that, the dewatered sludge is collected in small containers and gathered on site WWTP area to be transferred by huge trucks to the solid waste transfer station (Ramallah) in order to be dumped at Zahret Al- Finjan landfill (Jenin).

(a) (b)

Figure 2: Al-Bireh WWTP, (a) shows dewatered sludge output and (b) shows aeration tanks

3.2 JERICHO WASTEWATER TREATMENT PLANT

Jericho WWTP was started to operate in June 2014 receiving wastewater from Jericho municipality connections and from cesspits surrounding areas as first phase implementation. The purposes for the plant project according to stakeholders are as follows; provide the area with additional water source for water irrigation since the area is located in hot region and available water resources are limited also, the benefit of utilizing sludge as fertilizer was taken under consideration from the beginning of constructing the plant. And another basic reason was to protect groundwater and Jordan River from pollution. In addition, using treated wastewater in industry. Jericho WWTP is located at agricultural land, south-east of the municipality, which is near to palm farms. So, that can easily benefit the farms by utilizing the treated wastewater and the treated sludge efficiently. The design capacity is 9,800m^3/day. The project objective is to serve Jericho residents by increasing number of connections and the surroundings area; namely, Ain Sultan Camp, Duyuk District, Nwaeima District and Aqbet Jaber Camp.

The technology adopted in Jericho wastewater treatment is activated sludge technology. The process consists of the following; screening unit of two channels, two aeration tanks supported by blowers to increase nitrogen reduction, two clarifier tanks for sludge sedimentation including return-sludge pump for recycling sludge back to aeration tank to maintain the needed biosource for aerobic digestion and finally sludge drying bed unit of six beds.

Jericho WWTP plan for the second phase is to raise the used capacity of the plant from 10% to 43% and this achievement was supported by concerted efforts by Japan and the Palestinian

Water Authority, together with the support of the US Agency. Figure (3) shows units symbolized with two marked points for sample selection locations

(a) **(b)**

Figure 3 : Jericho WWTP, (a) shows aeration tanks and (b) shows sludge beds

The sludge volume was reported as 1000 m^3 in Jan. 2015 (data taken from monthly report example sheet for the WWTP, Jan 1st. 2015). This volume with density of 3.96 m^3/ kg was thickened only by static thickener and then was discharged to selected drying bed to complete treatment of sludge process without any additives. The sludge drying depth is about 30 cm and is dried for two weeks to reach about a density over 50% and after one month the dried sludge is collected and gathered nearby the drying beds. The dried sludge was stored for one year in an open area for stabilization in order to be used as fertilizer (The preparatory survey report on the Jericho wastewater collection, treatment system and reuse, 2011). In practice, the dried sludge is collected on site and no decision has been taken yet for the final route for dried sludge as reported from operator.

3.3 AL-TIREH WASTEWATER TREATMENT PLANT

In first of Aug. 2012 Al-Tireh WWTP project get started. The hydraulic design capacity of the WWTP is 2000 m^3 per day. The project population covered is 25,000 people from Al-Tireh resident and some connections domestic sewage. The applied technology is the membrane bioreactor (MBR), a modified activated sludge system with ultrafiltration membranes. The MBR facility is designed for domestic wastewater treatment with a reclaimed water quality of class-A requirements. According to operator, the quantity of the aerobically stabilized sludge (biosolids) ranged between 3 to 4 tons per day. The aerobically fixed sludge is further treated using polymers for dewatering by centrifuge machines. There are two centrifuge machines in the plant that work alternately but at emergency cases the two machines may work together. The produced dewatered sludge in fact is stored for a period of time until proper quantity is ready to be transported to Zahret Al- Finjan landfill. This is far from the site about 80km.

(a) **(b)**

Figure 4: Al-Tireh WWTP, (a) shows aeration tanks and (b) shows the outside WWTP building.

3.4 NABLUS- WEST WASTEWATER TREATMENT PLANT

The majority of households in Nablus are connected to public sewage system around 93% and the remaining is connected through cesspits. WWTP in Nablus West was established to overcome the increase in population and wastewater generated. The purposes are to protect water underground and to sustain local agriculture. Also, to prevent farmers from using untreated wastewater in agriculture (It is an old practice used by farmers) for the protection of public health. The plant started operating in July 2013 and with the technical assistance of the German. The amount of water currently treated is 10,000 cubic meters per day, with a capacity of 14,000 cubic meters per day in 2020, with high quality specifications compared to the requirements of the Palestinian Water Authority and the Palestinian Ministry of Agriculture (*Nablus Municipality, 2017*). The plant serves about 150000 people who live west of the city of Nablus.

The treating technology consists of several steps there, starting from coarse and soft screens to pick up solids and semi- solids following by first sedimentation tank that reduce total solids by 60%. The first biological treatment take place in aeration tanks where a portion of the recycled sludge is mixed with the fresh liquor and this phase of activated sludge is controlled by maintaining desired levels of some parameters. The next unit is the final sedimentation tank that the activated sediment was deposited into this unit as well as the production treated wastewater, large portion of the deposit is recycled to the feed aeration tank as previously mentioned and the remaining part of the deposit was intensified in the sludge treatment units.

Finally the operation of sludge line which consists of five steps in the following units: The mechanical thickening sludge (the primary thickening tank) that the sludge is mixed with polymer before entering the anaerobic digestion in the anaerobic tank digester and this is important to intensify the solids in order to increase the efficiency of the digestive digestion .The second unit is secondary thickening unit and this step is done and monitored automatically according to a program carried out by the station operators. Thirdly, the anaerobic digester, where the deposit sludge fermentation takes place boosting biogas energy (methane) and carbon dioxide at a ratio of 6:3. The treated sewage sludge is transported to sludge drying beds to reach a percent of 40% to 50% of solids. The last process is sludge storing step and this currency needs time and effort as a barren and it was done by the bulldozer plant and the tractor.

A solution for the stored treated sewage sludge is transferring it to Zahret- Al- Finjan landfill which is far about 40 km. It is documented that the quantity that was transferred in September 2017 is 320.230 tons (Nablus West WWTP).

Figure 5: Nablus West WWTP (overview of the aeration tanks)

The fresh sludge sample was taken from the outlet anaerobic digester directly. And the dewatered samples were taken from the drying sludge beds. The average treated dewatered sludge daily production according to operator information and experience is about 12 tons which is stored in order to be transported to Zahret- Al- Finjan landfill.

4 MATERIALS AND METHODS

4.1 INTRODUCTION

Evaluation the stability degree and pollutants limits in different types of wastewater sludge produced from Palestinian urban sewage works is a multi-criteria process that includes biological and physical-chemical analysis. The main three factors that are concerned for public health are: chemical pollutants, pathogens and vector attractiveness (EPA, 1993). For evaluation the stability of sewage sludge in terms of pathogens content a two tests are selected to compare with pathogen standards which are total- coliform test and fecal-coliform test. In fact, fecal coliform density is expected to show evidence probability of pathogens present. In addition, vector attraction property of the sample. Physical-chemical tests are done for analyzing total nitrogen quantity in dry solids (T-N), total phosphorous (T-P), carbon oxygen demand (COD) and volatile suspended solids percent. Chemical analysis for these parameters is essential to check sewage sludge stability. However, there are no exact limits for these parameters for applying sludge for agricultural land especially for nitrogen and phosphorous content but there is an agronomic rate advised for some crops fertilization (EPA, 1993).

Moreover, analyzing characteristics like: total suspended solids (TSS), volatile suspended solids (VSS), electrical conductivity (EC) and hydrogen potential (pH) is done to evaluate sludge stability and make comparison of the results of these characteristics with the values determined according to existing regulations. Sludge evaluation for some properties that are relevant to agriculture aspects is not a straightforward technique because there is no fixed standard method specified for sludge (Gudmundur, 1999). However, there are methods used for either evaluation manure or soil assessment can be simulated and applied on sludge evaluation. As the research progressed, it was found that some standard methods were identified with reference to the possibility of modification to suit the characteristics of the sewage sludge samples.

4.2 SAMPLING

Sampling of sewage sludge volumes of different types [fresh and treated] from four selective WWTPs of diverse treatment processes was done by selecting appropriate sampling points for each plant. The analytical method strategy depends on taking a representative samples from the WWTPs at a period of time. Thus, selected sampling points were determined for the test purposes. Samples were taken for study within three months from the first of March to the first of June, where the number of samples per month for each type of sludge from each WWTP is two samples. The total number of samples during the test period is 6 samples from each WWTP for each type of sludge.

At Al-Bireh WWTP the two sampling points were selected at; settling tank after the activation sludge tank directly and the other point was taken after the dewatering unit where the product is oriented to be thrown for land disposal. The second WWTP in Jericho, the first point was from the clarifier tank for getting the same situation of treatment comparing to Al-Bireh WWTP and the other point was from the drying beds where the disposal of a range of 2 to 5 days. Thirdly, Al-Tireh WWTP, taking into consideration the similarity in type of treatment thus, the points were the settling tank after membrane unit and the outlet of the dewatered unit. The last, Nablus - West WWTP has a different technology treatment; the first point was selected from the outlet of the anaerobic digester unit and the second at the dewatered outlet unit.

For biological assessment sterilized plastic containers were used for each two types. And plastic containers of 1 liter were used for getting samples to assess the rest of parameters. A cooler box was used for transportation samples from each WWTP location. To ensure handling samples within 24 hours the actual sampling days were one of three days a week from Monday to Wednesday (working days in Birzeit University labs) so the analysis for biological and physical-chemical quality parameters were carried out within the imposed time.

4.3 TOTAL COLIFORMS (TC) AND FECAL COLIFORMS (FC) ANALYSIS

The method adopted measures the number of viable bacteria in sludge samples, by counting the colony forming units in the media plates (U.S. EPA, method 1680, 2010). The viable colonies that appear on the media plates are expressed as CFU per one gram of the sample of dry solids. One gram of the sludge sample was mixed with 9 ml of deionized saline water of 0.9% of NaCl by homogenizer. Then a serial dilution was done for samples. Next, 200 µl of diluted samples were filtrated and then spread onto the surface of media plates then, incubated for 24 h at 37°C and 45°C for TC and FC incubation respectively. The number of bacteria is counted and then;

Colonies were calculated according to the following equation (*EPA*, *2010*):

$$\frac{CFU}{g}\, of\ sludge\ sample = \frac{[(number\ of\ colonies\ on\ a\ plate) * 5 * (dilution\ factor)]}{\%dry\ solids}$$

Where:

$$Dilution\ factor = \frac{1}{Dilution\ of\ sample}$$

- The plates which show too many colonies were excluded from counting; the range of 1 – 100 colonies on an media plate was selected and the dilution factor was adopted for the other samples from same type and location, the dilution ranges were performed according to first few trials of analysis for some samples was 10^{-3} and others was 10^{-4}. For the microbiological quality assurance, batches of prepared media were tested to assure media purity and suitability as positive control test.
- The dry solids percent was calculated from the physical analysis data for each type of sample and the average percent from each sludge type was adopted in CFU calculation.

  Where:

$$\%dry\ solids = [\frac{(dry\ sample\ wt.\ after\ heating\ up\ to\ 105°C)}{sample\ wt.}] * 100\%$$

4.4 TSS AND VSS ANALYSIS

Total Suspended Solids (TSS) is a sludge quality measurement that identifies the suspended solids within the liquor or within the dewatered sludge. TSS equals quantification of particulate solids, excluding soluble solids both organic and inorganic; the volatile suspended solids (VSS) refer to the organic volatile solids that vaporize at high temperature from 550°C - 600°C. VSS equals quantification of particulate organic solids, excluding soluble solids and inorganic solids.

The analysis was done for each type of sludge separately. The fresh sludge heating was done by pouring 25ml of the liquor into an already weighted fiber glass filter paper and was filtered gradually. Then it was grabbed gently to the dried weighted crucible and then it was directly put in the furnace. The heating was monitored to be done gradually up to 105°C taking under consideration choosing suitable crucibles with enough depth and narrow opening. The dried samples were allowed to cool for half hour and then were placed in desiccator for further cooling. The measurement of weights was done for the dried fresh sludge samples soon as crucibles cooled. VSS was analyzed for the same sample by heating it in furnace up to 550°C. Measurements values for TSS and VSS are obtained as follows:

Dry weight analyst after heating up to 105^{o}C (dry weight, DW) =

$$wt.of\ sample\ in\ the\ crucible\ after\ heating\ up\ to\ 105°C\ - (wt.of\ crucible + wt.of\ filter\ paper)$$

And

$$TSS\ = \frac{[DW] * 10^6}{25}$$

The results were kept in draft forms in $mg/\ l$

Ash wt. of analyst after heating up to 550°C (ash weight, AW) =

$$wt.of\ sample\ in\ the\ crucible\ after\ heating\ up\ to\ 550°C - (wt.of\ crucible + wt.of\ filter\ paper)$$

And

$$VSS = \frac{[DW - AW] * 10^6}{25}$$

The results were kept in draft forms in $mg/\ l$ and converted into ppm for the sake of results comparison of different sludge types(fresh/ dewatered).

Some of fresh sludge samples were thick with high density form, so the filtration was done by using two filter papers intervals to get rid from dissolved solids as possible.

Dewatered sewage sludge samples were tested by weighing a round ± 25 g (SW) in a dried weighed ceramic crucible. The selected quantities from the samples were taken from almost homogenous parts below the sample surface generally. The crucibles were heated up to 105°C.Then cooled for about half an hour and was put in dissector to prevent and vapor absorption. Weighing cooled crucibles was conducted within 24 hours and crucibles were placed back to furnace for further heating up to 550°C. Calculating the parameters of the dewatered sewage sludge was done according to the following equations:

$$Sample\ wt.(SW) = wt.sample\ in\ crucible - crucible\ weight;\ in\ (g)$$

Wt. dried analyst after heating up to 105°C (dried weight, DW) =

$$wt.sample\ in\ crucible\ - wt.of\ sample\ in\ the\ crucible\ after\ heating\ up\ to\ 105\ oC$$

And

$$TSS = \frac{[DW] * 10^6}{SW}$$

The results were kept in draft forms in $(g/kg\ )$.

Wt. ash of analyst after heating up to 550°C (ash weight, AW) =

$$wt.sample\ in\ crucible\ - wt.of\ sample\ in\ the\ crucible\ after\ heating\ up\ to\ 550°C$$

And

$$VSS = \frac{[DW\ - AW] * 10^6}{SW}$$

The results were kept in draft forms in (g/kg) unit. Results are converted to ppm for comparison purposes.

4.5 pH-PARAMETER TEST

Sludge pH is one of the most influential factors that can manipulate other parameters limits by small variations. Small pH changes can intensely disturb many physical, chemical, and biological properties and transformations in embedded soil by sludge. However, sludge pH can affect bacterial communities adversely by changing bacterial abundance that influence crop safety and crop production (Hartman et al., 2008).

The pH analysis was measured by pH-meter. For the fresh sludge pH measuring method, method 9040C, (EPA, 2004) was implemented for fresh sludge samples from Al-Tireh, Al-Bireh and Jericho WWTPs which they are in aqueous phase. On other hand, method 9045D was adopted for measuring pH in dewatered sludge samples and the fresh sludge samples taken from WWTP in Nablus west.

By portable pH electrometric meter supported by Palestinian Water Authority (PWA) the measurement was done in field, samples from Al-Tireh and Al-Bireh WWTPs were analyzed in lab because of their close location to Birzeit University lab.

Measuring pH for fresh sludge samples was done by calibrating the pH meter using two buffer solutions that were poured in a glass beaker (buffer of pH =4 and buffer of pH =7.2). The calibration was not done for each sample; it was done to monitor the two points almost once every week. Using detergent for cleaning the electrodes was frequent process to erase any greasy residues.

Values were taken after immersion of the electrode in the sample as well as conducting temperature value. The measurement was repeated for different aliquots from the sample for insuring accuracy.

For the heavy sludge, the dewatered sludge from the four plants, method 9045D was implemented as mentioned before. The sample was mixed with reagent water, and the pH of the resulting aqueous solution was measured. By using the same standard buffers calibration was done frequently for the electrode system. As dewatered sludge has hygroscopic feature the mixed solution was done by adding 10 grams of the sludge to 30 grams of water. This ratio was accredited for the whole samples after few trials at the beginning of testing. The pH reading based on the conventional pH scale from zero up to 14 at temperature of 25°C ± 1. Temperature was naturally controlled within range 20.1°C – 25.5°C due to the status weather during analysis period. The solution was mixed for about half an hour until a clear supernatant can be seen and then the electrode was adjusted and fixed by clamp to sink into the clear supernatant and results were documented with temperature concurrently.

4.6 ELECTRICAL CONDUCTIVITY (EC) METHOD

Electrical conductivity (EC) is widely used to indicate the total ionized constituents of sewage sludge. It is a numerical expression of the ability of an aqueous solution to carry electrical current. EC at equilibrium in a liquor suspension of sludge is expressed $ms.cm^{-1}$ but the official international unit for EC is Siemens/meter ($s.\ m^{-1}$), some values that were measured in the study were read in $\mu s.\ cm^{-1}$ and converted to be expressed as mentioned previously in ($ms.cm^{-1}$).

(EC) gives quick indication for total salt concentration that is expressed at temperature of 25°C.The measurements were carried in lab within the current temperature. Calibration was done frequently every set of measurement by using a potassium chloride solution (0.01M) with a conductivity of 1412 $\mu mho.cm^{1}$ (ms/cm) at 25°C.

Samples measurement was done within 24 hours where samples cooled to below 8°C for conserving. Fresh sludge samples were tested directly without pretreatment done for the samples. For determination the EC values for fresh sludge samples the evaluation was done directly for the samples on site. On other hand, EC values for the dewatered sludge samples were measured by applying the same procedure used for pH measuring. Measuring EC with a conductivity meter in a sludge-water extract based on a fixed sludge: water ratio (1: 3). This method was easily done, and reproducible for the dewatered sludge samples. The mixed suspension was left to equilibrate for at least 30 minutes or long enough for the allowing solids to settle then the clear liquid was measured and the results then were documented.

4.7 COD ANALYSIS

Sewage sludge is described by the nutrient-rich organic materials resulting from wastewater treatment; the organic matter naturally would be with high level.

Referring to organic compounds the assessed parameter was carbon oxygen demand that indicates the overall presence of organic matter by standard methodology. The amount of oxidizable organic compounds react with reducing the dichromate ion ($Cr_2O_7^{2-}$) to green chromic ion (Cr^{3+}) is termed as carbon oxygen demand (COD). This test was done according to HACH method, 2014.

The principle of the COD test is to detect most types of organic matter that oxidized using potassium dichromate and sulfuric acid in heating condition for 2 hours by color detection using spectrophotometer at 600nm, and then the absorbency was recorded. The sludge samples were diluted to serial dilution and were filtered on a filter of pore size 4.4 µm.

A series of standard solutions were analyzed and absorbance was taken for each standard then linear equation was obtained from plotting data; absorbance and concentration, by excel sheet. A series of standard solutions where analyzed and measure absorbance was taken for each standard then linear equation was obtained from plotting the data; absorbance and concentration, by excel sheet.

The concentration of the sample is calculated by the following equation:

$$Concentration\ of\ sample\ COD\ in\ mg/l = \left[\frac{Absorbance\ + 0.0046}{0.0003}\right] * \ dilution\ factor$$

Where dilution factor varies through sludge sample concentration; the fresh type got the lower dilution criteria which was 10. And the thickned sludge samples were diluted by the factor of 100.

4.8 T-N AND T-P ANALYSIS

Total nitrogen analysis and total phosphorous analysis were conducted by adopting standard methods at Birzeit University (Sanitary and environmental engineering lab).

5 RESULTS AND DISCUSSIONS

Results obtained from the research are categorized into four sections. The first section is the evaluation of pathogens level according the sludge types and locations. The second section of the results is for the chemical evaluation, the level of total nitrogen, total phosphorus and COD level. Third section is for showing the results of TSS and VSS levels. The last section gives results for measuring pH and EC results. Discussion was displayed immediately after each section of the results in order.

5.1 PATHOGEN RESULTS

Analysis for TC was done for evaluating and comparing the results of FC measurements. In fact, the results where naturally similar to the scientific prediction when comparing TC to FC results for each sample, TC results are shown in appendix 1. According to EPA, 1999 part 503 the sludge classification depends on limited levels of FC presence; class A and class B sludge. However, the lowest value of FC presence was obtained at Nablus WWTP, where the measurement taken was for the dewatered type and that was 3 x10^5 cfu/g (of DS), which is within the range for class B for agricultural application. All results obtained from sludge treated analysis was accepted for class B, the evaluation taken for fresh sludge samples from WWTPs at few measurements exceeds the limit which is $\leq 2 \times 10^6$ cfu/g for class B. All data resulted from analyzing the dewatered samples indicate that treated sludge produced is within class B characteristics; where FC density is $\leq 2\text{x } 10^6$ cfu/g.

Results from Al-Bireh WWTP for FC showed that the sludge treatment approached the second place in terms of efficiency of sludge treatment compared to other WWTPs after Jericho WWTP. The lowest reading was 3x 10^5cfu/g where the highest was 2x 10^6cfu/g of DS for treated type. The FC results in fresh type typically were denser comparing to treated sludge type. Table (3) illustrates the values of FC in cfu/g of DS at Al- Bireh WWTP.

Table 3: FC results in Al- Bireh WWTP for fresh and dewatered four samples, during the analysis period (March – June, 2017).

Sample #	FC in fresh sludge (cfu/g of DS)	FC in dewatered sludge (cfu/g of DS)
1	9.E+05	3.E+05
2	2.E+06	3.E+05
3	3.E+06	2.E+06
4	5.E+06	8.E+05
Average	3.E+06	9.E+05
Min Max	9.E+05 5.E+06	3.E+05 2.E+06

According to FC values in sludge samples from Jericho WWTP the fecal removing is higher in the dried sludge and this is due to the sludge drying treatment which is naturally more affective, the sludge treatment was the most effective comparing to the other WWTPs. Table (4) shows results for FC in cfu/g of DS analysis in Jericho WWTP. Data obtained from fresh samples analysis showed higher values than data taken from sludge treated samples which is described as usual approach.

Table 4: FC results in Jericho WWTP for fresh and dewatered four samples

Sample #	FC in fresh sludge (cfu/g of DS)	FC in dried sludge (cfu/g of DS)
1	4.E+05	3.E+05
3	3.E+06	4.E+05
3	1.E+07	1.E+06
4	2.E+06	3.E+04
Average	4.E+06	4.E+05
Min Max	4.E+05 1.E+07	3.E+04 1.E+06

Sludge treatment at Al-Tireh WWTP was found to be less effective than other WWTPs. Where the percentage of pathogens removed was about 50%. Table (5) shows the results for FC analysis in Al-Tireh WWTP.

Table 5: FC results in Al-Tireh WWTP for fresh and dewatered four samples

Sample #	FC in fresh sludge (cfu/g of DS)	FC in dewatered sludge (cfu/g of DS)
1	1.E+06	5.E+05
2	3.E+06	3.E+04
3	4.E+06	-
4	8.E+06	2.E+06
Average	4.E+06	2.E+06
Min Max	1.E+06 5.E+06	2.E+04 2.E+06

Table (6) shows FC measurements where the conducting was successfully measured in Nablus west WWTP. Unusual FC results were obtained from fresh samples; the data were lower than the FC data in treated samples.

Table 6: FC results in Nablus WWTP for fresh and dewatered four samples

Sample #	FC in fresh sludge (cfu/g of DS)	FC in dried sludge (cfu/g of DS)
1	2.E+05	1.E+05
2	2.E+05	1.E+06
3	2.E+04	2.E+05
4	1.E+05	1.E+05
Average	1.E+05	3.E+05
Min Max	2.E+04 2.E+05	1.E+05 1.E+06

FC parameter average results for the four WWTPs and types are labelled in Table (7) and illustrated in Figure (6)

Table 7: FC average results in WWTPs.

Source #	Sludge source	Average of four samples(cfu/g of DS)
1	Al-Bireh fresh	3.E+06
2	Al-Bireh dewatered	9.E+05
3	Jericho fresh	4.E+06
4	Jericho dried	4.E+05
5	Al-Tireh fresh	4.E+06
6	Al-Tireh dewatered	2.E+06
7	Nablus fresh	1.E+05
8	Nablus dewatered	3.E+05

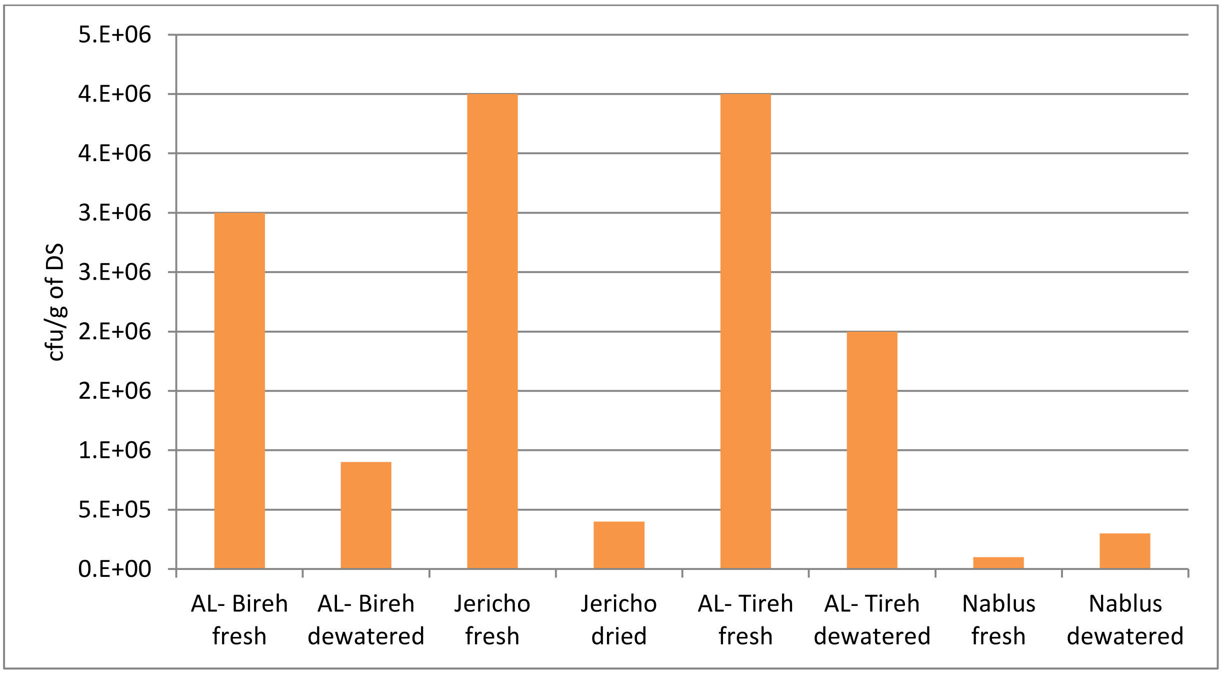

Figure 6: FC average results from four readings in cfu/g of DS in the eight sludge samples.

Values for FC obtained by the analytical measurements form the four WWTPs have proved that the generated treated sewage sludge from these plants is categorized as class B sludge, where the FC values did not exceed the density limit which is ≤ 2.0E+06 cfu/g. The highest peaks of FC results were obtained at Al-Tireh WWTP for the both sludge types comparing to the similar types from the three other sludge resources.

It is noted that there are differences in sludge treatment efficiency between the four WWTPs, this is due to different technology applied in treatment, different sewer quantity and different sewer sources. For the Al-Bireh WWTP sludge treatment performance, the pathogens removal reached up to 70%. The treatment status in the design and according to operators is that the dewatering system adopted is centrifuging technique in parallel with belt pressing technique. Moreover, polymerization process is done at earlier step using polycrystalline polymer, whereas chlorination is not practiced at this WWTP. This situation of good performance could be explained due adopting extended aeration tanks technology for wastewater treatment, plus the treatment and capacity management in Al-Bireh WWTP.

The highest sludge treatment performance was found at Jericho WWTP, where the pathogens removal reached 90%. The wastewater treatment technology is similar to Al-Bireh but the sludge treatment goes through static thickening and dried by sludge bed application without chlorination or polymerization processes. Sludge drying treatment technology appears the optimum solution choice for sludge treatment at sunny regions, where 80% of WWTPs in some Eastern European countries and Russia adopt drying beds technique (Climate policy watcher, 2018). On the other hand, sludge drying beds have recognized to be a feasible sludge treatment technology (Cofie et al. 2009).

At Al-Tireh WWTP the pathogen removal efficiency was on the third place in treatment which is 50% of pathogen removal. The FC density was found the highest value at fresh sludge type and also the highest value at the treated sludge type comparing to other WWTPs. The explanation could be due to the ultrafiltration membranes system that is used for wastewater treatment which is either is prone to blockage or need to be replaced. The sludge treatment technique is done by two processes, adding polycrystalline polymer which is the same type that is used in Al-Bireh WWTP and adding chlorine for disinfection. Then the sludge is dewatered by two centrifuge machines. Actually the FC measurements at the sludge treated appear that the sludge treatment performance is not very efficient at this plant and need to be managed and monitored.

The FC values in sludge samples for Nablus WWTP showed opposite trend, however, FC data in dewatered sludge were found to be slightly higher in values than FC values in fresh sludge, this can be explained by the sludge sampling location, as mentioned at sampling section, the sludge sample is collected after the first step of treatment i.e.; dewatering step, before the second step of sludge treatment in Nablus WWTP which is drying technique for the dewatered sludge on drying beds.

However, the least FC density was obtained in this plant for both types. The FC average results in fresh sludge samples were found to be within the class B range unlike the fresh sludge samples from other WWTPs which exceed the class B characteristics, the clear explanation for this result is that the fresh sludge samples from Nablus WWTP is treated by anaerobic conditions that increase the FC removal (Wright, P. E., et al. 2001), (Topper P. et al., 2006).

5.2 TOTAL NITROGEN (T-N), TOTAL PHOSPHOROUS (T-P) AND COD

For measuring values of T-N and T-P in sludge samples, analyses were done at Birzeit University lab. Data at Table (8) is for T-N values in ppm obtained from four samples analysis and Table (9) show T-P values measured in ppm unit for four samples. Average values from the four analytical measurements out of five samples during the research period and the calculated N: P ratios are shown in Table (10).

Table 8 : Values for T-N in ppm acquired during the analysis period (March – June, 2017).

#	Sludge source	April 9th in ppm	May 7th in ppm	(27-30) of May in ppm	(6 -10) of June in ppm
1	Al-Bireh fresh	69700	73293.5	73820	413.8
2	Al-Bireh dewatered	70500	74159.2	76850	12310
3	Jericho fresh	53500	72149.3	483230	213.9
4	Jericho dried	6100	62000	63250	5460
5	Al-Tireh fresh	49900	51572.1	69210	572.9
6	Al-Tireh dewatered	61500	62468	77330	11960
7	Nablus fresh	72100	51741.2	62530	1166.7
8	Nablus dewatered	73100	54656.7	47910	12870

Table 9 : Values for T-P in ppm acquired during the analysis period.

#	Sludge source	April 9th in ppm	May 7th in ppm	(27-30) of May in ppm	(6 -10) of June in ppm
1	Al-Bireh fresh	11551	12304	11454	85.6
2	Al-Bireh dewatered	15341	10890	10191	1752
3	Jericho fresh	15527	13714	14916	36.8
4	Jericho dried	14407	12369	13410	1466
5	Al-Tireh fresh	17786	12940	19530	71.6
6	Al-Tireh dewatered	15535	9222	17507	1640
7	Nablus fresh	11483	19242	13410	196.1
8	Nablus dewatered	12345	18647	18654	2670

Table 10 : Average values of T-N and T-P in ppm (from four samples) and N:P ratio.

Source #	Sludge source	T-N ppm	T-P ppm	(N:P) Ratio
1	Al-Bireh fresh	72271	11770	6
2	Al-Bireh dewatered	73836	12141	6
3	Jericho fresh	62825	14621	4
4	Jericho dried	43783	13395	3
5	Al-Tireh fresh	56894	16752	3
6	Al-Tireh dewatered	67099	14088	5
7	Nablus fresh	62124	14712	4
8	Nablus dewatered	58556	16549	4

Figure (7) illustrates averages of T- N values and T-P values from four samples / source.

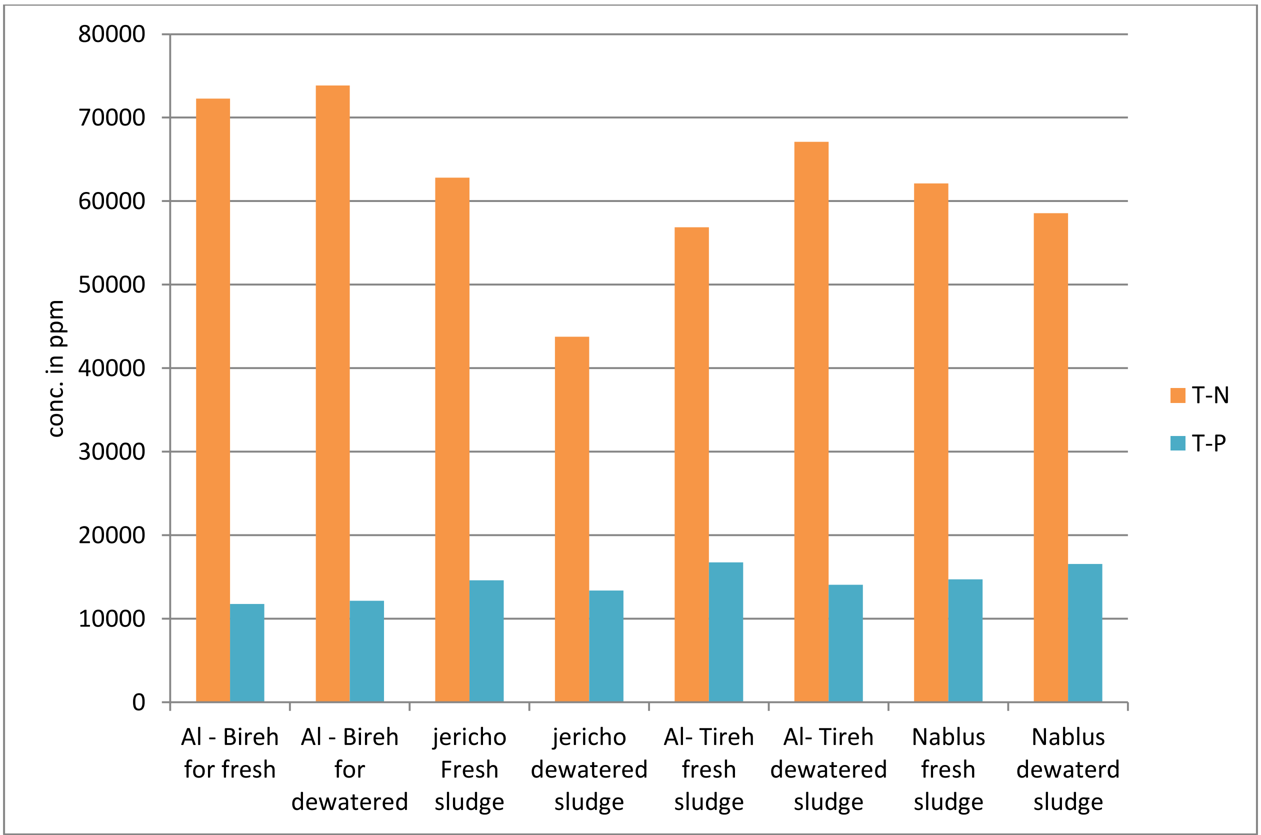

Figure 7: Averages of T-N and T- P values in the eight sludge sources.

The results in Table (11) are values of COD expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution.

Table 11: COD results in mg/l

Source #	Sludge source	COD mg/l Trial1	COD mg/l Trial 2	Average results from Two successful trials
1	Al-Bireh fresh	26867	26867	26867
2	Al-Bireh dewatered	32533	59200	45867
3	Jericho fresh	4467	1353	2910
4	Jericho dried	39867	39867	39867
5	Al-Tireh fresh	4200	5386	4793
6	Al-Tireh dewatered	101200	101533	101367
7	Nablus fresh	25867	25867	25867
8	Nablus dewatered	74533	74867	74700

Figure (8) illustrates comparison between values and pointed to the higher concentration of COD in sludge generated from Al- Tireh plant of dewatered type.

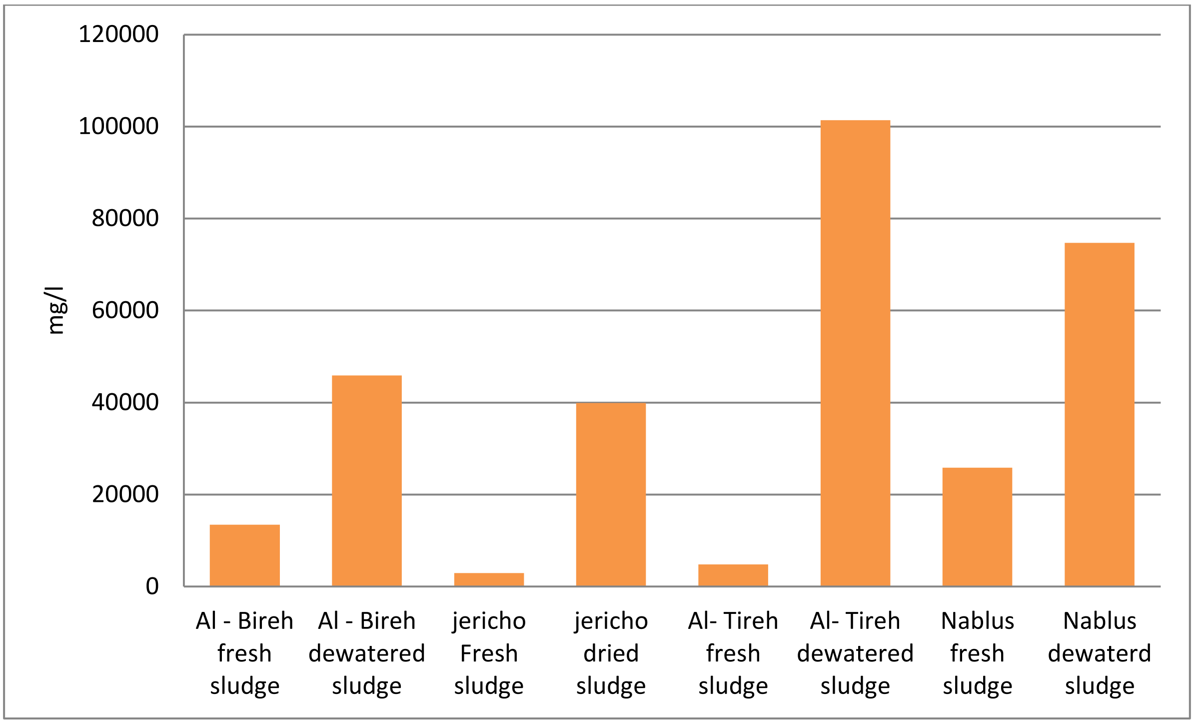

Figure 8: Average results for two COD analysis in (mg/l) from each sludge source

The nitrogen ppm results converted to percent unit as used in scientific searches, the TN% comply with much sewage sludge T-N characteristics in European countries, taking into account that the N % is much higher if the treating technology is under anaerobic conditions, (Mtshali1 et al., 2014). The percent content of nitrogen in all sludge samples ranged between 4.3 to 7.3 %, the lowest value was measured for Jericho sludge the dried type where, the highest value was resulted at Al-Bireh WWTP although the treatment technology implemented is aerobic digestion. Despite that the highest T-N results were recorded at Al-Bireh WWTP at both types fresh and dewatered with percent of 7.2 and 7.3 respectively, the T-P results were not high in these sludge samples comparing to sludge samples from the other different resources. This yielded that the ratio of N: P in sludge from this source was the highest N: P ratio of the whole samples which equals 6. And these findings indicate the uniqueness of this WWTP with the high proportion of organic nitrogen and inorganic nitrogen substances entering the plant.

Waste with high nitrogen content could be excess waste of fertilizers and could be originating from the nearby settlement, whose sewage pumps into this WWTP.

Percent of T-P content in all sludge samples results varies between 1.2 to 1.7%. The ratio N: P that equals to 3 was recorded at Jericho WWTP for the dried type and also at Al-Tireh for the fresh type, which sounds within the range of the typical ratios that were measured for sludge content that produced from municipal WWTP, applying conventional activated sludge technology. In fact, the nitrogen content at Jericho sludge dried type close to the amount of T-N that was measured in many research studies.

According to scientific researches there were no fixed amounts of nutrients content in sewage sludge. Contents vary due to sludge sources and treatment. Available data for sludge Properties used for land application in Ontario as documented by (Johannesson, 1999), TN values fluctuate between 3.1% to 7.4% through 12 sludge types and sources. And also TP data varies from 1.4% to 3.0% through the twelve sources. Usual range that was noted at European region, a study in Swaziland recorded T-N and T-P in sludge that used in agricultures of (1.5- 5%) and (1.1-2.3%) respectively (Mtshali, 2014).

The recorded ranges for T-N (1.6- 1.7%) in Pakistan and (1.5- 1.9%) in India, whereas the phosphorous content was very low and far below the ranges, it was recorded as 70mg/kg (equals 0.007%) in Pakistan and as (44-60) mg/kg (0.004 - 0.006 %) in India (*Usman et al., 2012*). N:P ratio calculated from previous searches excluding data from (Usman et al., 2012) and found with range of 1.5 – 2.5, where the evaluated sludge types showed N:P ratio from 3 to 6, this status can be improved by increasing nitrogen removal. The least ratio was measured in Jericho and Nablus sludge for both types. With reference to nitrogen removal at sludge treatment, it was noted that the reduction of nitrogen content was achieved at both Jericho and Nablus WWTPs.

COD results for the sludge treated comparing to fresh sludge are typically higher values; this is due to the fact of increasing solids percent through polymerization (except at Jericho), thickening and next dewatering or drying processes that would increase density of organic matter.

Discussing COD typical values, the analytical results for the sludge samples ranged between 0.5% to 4% (excluding treated sludge in Al- Tireh and Nablus,10% and 7.5% respectively, and excluding fresh type in Jericho, 0.3%) this range comply with data taken for sludge land application aiming agricultural reuse (Andreoli, 2007). Values of the dewatered sludge samples from Al-Tireh WWTP were the highest values and it is noted that the COD value was multiplied 19 times after dewatering treatment; actually values of COD in the dewatered sludge from Al- Tireh WWTP exceeded the registered values for septic sludge characteristics (*Henze and Comeau, 2008*). Jericho sludge values of COD match with the fact of the treating technology that was adopted in the design, the activated sludge technology was modified to extended aeration method for increasing digestion rate, and this technique was advised by Japan International Cooperation Agency (JICA). In addition to the low COD values in dried sludge samples at Jericho WWTP, the quantity of sludge generated is relatively small that allow sludge treating process to be done directly without chemical polymerization for thickening or applying electrical power (PWA, 2011).

Sludge treatment efficiency can be evaluated by measuring COD removal percent (Kazimierczak, 2012) moreover; COD can use as a measurement of sludge stability degree (Graczyk, 1984). Actually, the sludge is treated in one single unit in the WWTPs except at Nablus WWTP. The process in this unit is either by the dewatering or by drying, this is the case in both (Al-Tirah and Al-Bireh WWTPs) or (Jericho) WWTPs respectively.

The high value of COD at Nablus sludge, dewatered type, is not correlated with %VSS data that appeared to be the least value comparing to other sludge sources and this could be explained by the organic polymers presence that are hardly degradable.

5.3 TSS AND VSS

TSS and VSS values measured for fresh sludge and dewatered sludge samples were showed at Appendex 1 for 6 samples for each sludge source and type during the analysis period. The results of VSS% were near the range appeared from different studies.

Fresh sludge TSS and VSS parameters were measured in mg/L and converted to ppm to compare it with the dewatered sludge parameters that were measured in g/kg and similarly converted to ppm. According to VSS% measurements for dewatered sludge samples the findings in Jericho and Nablus WWTPs showed generally slightly stabilized dewatered sludge characteristics. Whereas the ratio of (VSS: TSS) in Al-Tireh and Al- Bireh WWTPs were typically between the ranges of 70% - 85% as for normal sludge with similar treatment (Haandel and Lubbe, 2012).

Table (12) shows the average data resulted from analysis for TSS and VSS for both sludge types in the four WWTPs.

Table 12 TSS and VSS results in ppm and VSS%

Source #	Sludge source	TSS in ppm	VSS in ppm	VSS% (VSS:TSS)
1	Al-Bireh fresh	17097	12816	75
2	Al-Bireh dewatered	166400	137400	83
3	Jericho fresh	9341	6325	68
4	Jericho dried	75833	56667	75
5	Al-Tireh fresh	5532	4845	88
6	Al-Tireh dewatered	167200	139200	83
7	Nablus fresh	22904	15856	69
8	Nablus dried	191000	130200	68

Data for analytical measurements are presented in tables at appendix 1, values for six measurements analyses through study duration.

Figures (8) and (9) illustrate the ratio of VSS: TSS and VSS% for the eight samples respectively

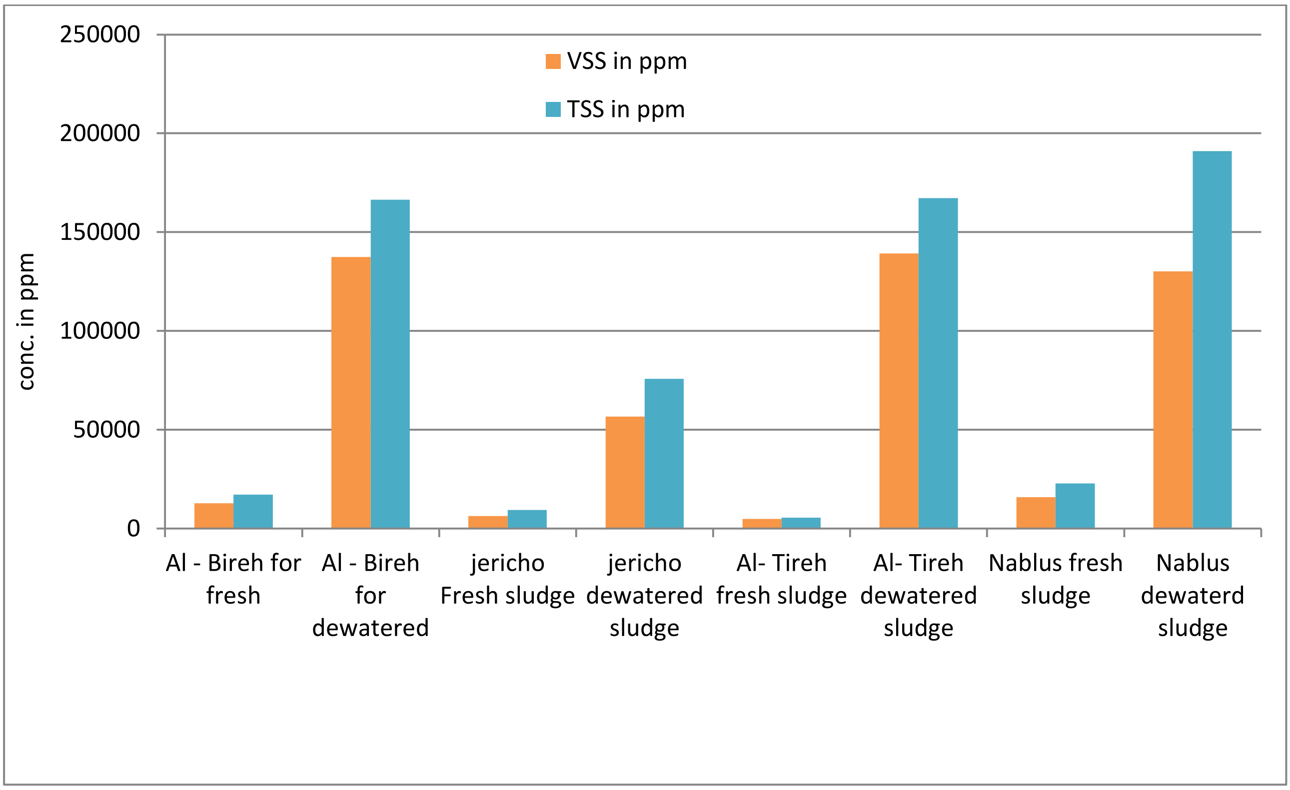

Figure 9 (VSS: TSS) ratio of sludge types and sources

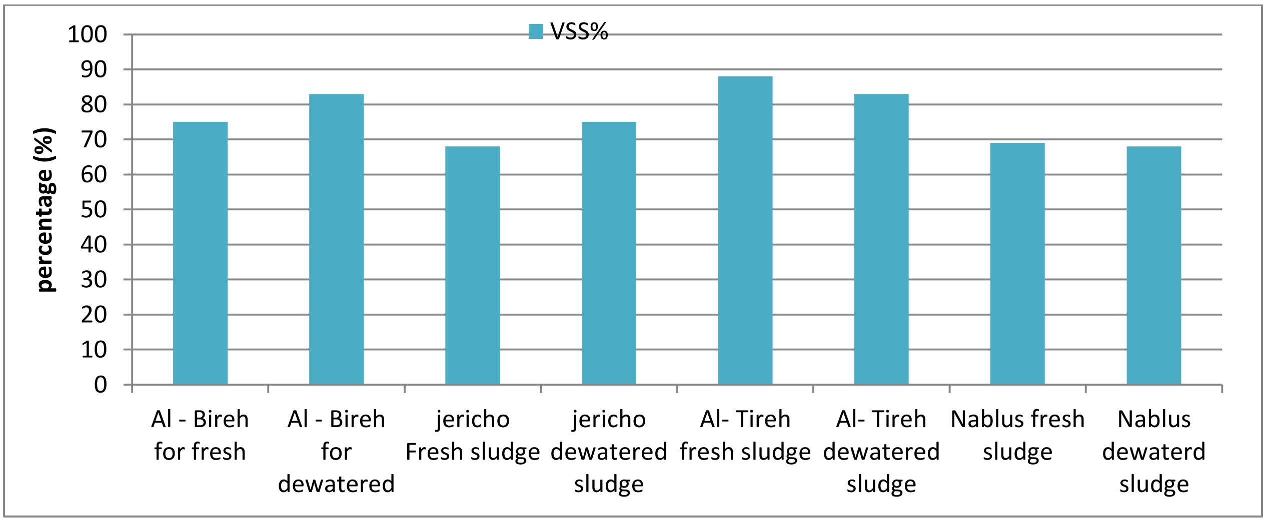

Figure 10: Average VSS% values for sludge types and sources (average of six values)

Evaluating TSS results for the whole treated sludge samples indicate that the sludge produced from WWTPs is described as a heavy sludge except the dried sludge generated from Jericho WWTP.

TSS values that were measured in dried sludge from Jericho source were around 75833 ppm (7.5%) and this value is below 100000 ppm and this value is considered as low to medium TSS value, whereas the other treated sludge samples recorded values above 150000 ppm of TSS (Holder et al., 2015).

Comparing TSS values between fresh type and the treated type for the samples, within each source, it is clearly noted that there is a huge jump in TSS value after dewatering of sludge is in Al-Tireh WWTP. Addition chemical polymers in sludge thickening process explain this status.

VSS % values in sludge generated form domestic WWTPs that apply conventional activated sludge technology vary widely due to differences in sludge treatment design. Similar researches in Europe have showed that VSS% values for sludge treated in range of 40% - 70%. However, some studies have recorded VSS% as 20% by applying thermo-oxidation of sludge technique for production of Class A biosolids. This value indeed refers to high performance in sludge treatment. In fact, VSS% values between 50% -60% characterize sludge treated as stabilized sludge that contains low amount of volatile organic matter (ie: low amount of degradable organic matter) (Holder et al, 2015; Henze et al., 2002) .

The analysis has clearly presented sludge treated in Nablus –west WWTP in the first rank of sludge treatment efficiency, where the VSS% equals to 68%. The next reading was conducted in Jericho WWTP with far value of 75%. Generally, anaerobic digestion treatment is more progressive in removal efficiency for biodegradable matter, hence Nablus-west WWTP treated sludge is characterized as the most stabilized sludge comparing to other treated sludge samples due to the anaerobic digestion technique that is adopted there.

The VSS% values at treated sludge generally are higher than at fresh sludge from each source except in Al- Tireh WWTP, where VSS% in fresh sludge is 88% and in the dewatered is 83%. However, TSS and VSS values in the dewatered type in Al- Tireh measured higher by 29 times more than the values of the fresh type in the same WWTP. The results display match with COD results for the same comparison, but the noted data for COD in fresh and dewatered sludge in Al-Tireh WWTP is 5387 mg/l and 101367 mg/l respectively.

The explanation of VSS% data in the sludge emphasizes the influence of addition polymers that increase COD hugely but this organic increase mostly is not degradable.

5.4 pH AND EC RESULTS

According to McCauley, et al.,2017, pH has a deep effect on nutrient uptake, ion toxicity, plant growth, and plant function. The common pH values that describe stabilized sludge are normal pH degree to slightly acidic or slightly basic degree.

The highest value of pH was conducted at Nablus dewatered samples with range of 8.29 to 8.59 although it is measured as typical pH at fresh samples where the values range is 6.83-7.02 for anaerobic technology treatment. Other pH measurements were around reading of 7.00 but the lowest readings were conducted at Al- Bireh fresh sludge with 6.26 and this reading was repeated through analyzing tests. And also this was figured while analyzing Al-Tireh dewatered samples although the average was 6.39. However, all pH readings were considered as normal values for stabilized sludge according to literature. Table (11) shows average values resulted from measuring pH parameter for sludge samples. Table (12) shows average results of EC values conductivity expressed in ms/cm, automatically total dissolved solids in ppm values were read from the portable meter and recorded.

Table 13: pH average values from four samples taken from each sludge type and source.

Source #	Sludge source	pH	Pretreatment; Sample: water Ratio (10g:30g)
1	Al-Bireh fresh	6.49	-
2	Al-Bireh dewatered	7.02	1:3
3	Jericho fresh	7.02	-
4	Jericho dried	7.20	1:3
5	Al-Tireh fresh	7.17	-
6	Al-Tireh dewatered	6.56	1:3
7	Nablus fresh	6.08	1:3
8	Nablus dewatered	8.00	1:3

Table 14: Average results of EC in ms/cm and TDS ppm from four samples taken from each sludge type and source.

Source #	Sludge source	EC ms/cm	TDS in ppm	Pretreatment; Sample: water Ratio (10g:30g)
1	Al-Bireh fresh	2.17	1081	-
2	Al-Bireh dewatered	0.68	339	1:3 ratio
3	Jericho fresh	1.32	657	-
4	Jericho dried	0.59	295	1:3
5	Al-Tireh fresh	1.20	602	-
6	Al-Tireh dewatered	1.45	639	1:3
7	Nablus fresh	5.71	2865	1:3
8	Nablus dewatered	1.47	733	1:3

All pH results indicate that sludge treated or fresh type is considered as normal sludge and accepted for land application (McCauley, et al., 2017). The range of pH results for the WWTPs except Nablus source is between (6.49- 7.20) which is typically with pH of stabilized sludge.

The sludge from Nablus-west source, the dewatered type has recorded an average result of 8.00 and this relatively is a high value, the reason of this is caused by the lime addition that is added into the anaerobic digestion tank to control the pH as recorded from the Nablus -west WWTP reports. However, the average measured pH for the fresh type is the lowest value, 6.08, below of the range resulted from the whole analyses. As a matter of fact, the low pH is caused by the anaerobic digestion at the first stage of sludge treatment (fresh type) and on the second stage for sludge treatment the effect of lime has caused the raise of pH.

EC values varies within narrow range between 0.6 ms/cm up to2.17 ms/cm excluding an average result taken for untreated (fresh) sludge form Nablus source, where the recorded data equals to 5.71. The ideal range had been reported for stabilized sludge and also for commercial compost range is from 0.78 to 3.35 ms/cm (Chen and Tarchitzky, 2009).

Although the documented EC value for high quality finished compost is approximately 1.5 to 2.0 ms/cm.

The EC value that is reported for fresh sludge from Nablus-west WWTP is actuality due to the anaerobic conditions and that explained by the high soluble salt content. This anaerobic condition that cause increase in EC and TDS was reported at (Johannesson, 1999).

The EC values were not above ranges for cultivation, 1.5-2.0 ms/cm, although plant growth is described to be affected negatively if EC exceeds 2.0ms/cm (Hanlon *et al. 1993*), and this degree is within or higher than the EC values obtained from the analysis.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

- The chemical characteristics (TN and TP) of dewatered sludge revealed that the sludge generated from selected WWTPs is a valuable resource for soil amendment, for soil conditioning.
- The criterion for selecting sludge agronomic application option depends on identification of main parameters. Indeed, this option is the optimum alternative according to literature over other sludge management options according to developed countries. In this research the analytical measurements were conducted for main characteristics to evaluate stability of generated treated sludge from selective local municipal WWTPs, findings comply with sludge characteristics that can be enabled in cultivation.
- Concerning sludge pathogens content, the FC results insure the potential of sludge land application. Furthermore, data collected for nutrients sludge content and ratios clearly shows the conformity of sludge treated characteristics that is generated in local area with values for treated and stabilized sludge. On the other hand, percent of VSS values for sludge treated were beyond or slightly higher than the accepted levels for certain crop cultivation. However, there is a need for increasing VSS removal in sludge treatment process in order to improve sludge quality and stability. In addition, VSS destruction decrease sludge mass that facilitates transportation as well, lowering the VSS% reduces vector attraction.
- Results on pH parameter; the sludge treated is described to have optimal degree of acidity which complies with stabilized sludge characteristics that could be applied on agricultural land. In parallel, EC results emphasized the possibility of considering sludge land application as a good option for the sludge management.
- Concisely, sewage sludge management by recycling sludge through land application is an alternative option has the potential to make serious contribution towards sustainable solutions for sludge accumulation status that is generated from local WWTPs. Furthermore, protect environment from pollution impact that influence water, earth and mankind.

6.2 RECOMMENDATIONS

Throughout this study there are some solid recommendations that contribute to the success of sludge land application, especially in arid and semi-arid regions, those are:

- It is possible to recover and utilize sewage sludge (biosolids) in Palestine. This can be enhanced by modifying environmental licensing and legislations. And more, promulgation of mandatory rules on sludge treatment and final destination route.
- To protect crop production from chemical fertilizers that influence productivity negatively, government should encourage application of sludge on land and this could be done by two strategies:
    i. Encouraging research to study the amounts of nitrogen and phosphorus needed to add to land areas through sludge application and to study the estimated annual sludge addition.
    ii. Establishing competent authority to promote and manage sludge application in cultivation.
- The Information of presence of heavy metals in sludge produced is limited; reported from operator, (IWS, 2006), and (Samara, 2009), that concentrations for heavy metals in selected areas complied with the strictest Israeli standards and the United State Environmental Protection Agency regulations. However to mitigate any impact that could appear from presence of heavy metal it is essential to analyse metal concentration in sludge and to set plan for monitoring according to case by case.
- According to scientific studies (Berchenko et al., 2017), it has been shown that the possibility of outbreaks for some diseases can be predicted by monitoring the characteristics of the produced sludge from municipal WWTPs. Therefore, it is necessary to establish a special body for research and following in this subject, through establishing a comprehensive data base supported from integrated management criteria.
- There is an urgent need in Palestine to protect environment and resources, hence, the current situation requires official contribute to raise public awareness among society. This is essential for reaching sustainable solutions in the sludge management.
- There is a necessity need for data documentation, which is an essential for monitoring evaluating sludge characteristics, to ensure stake holders satisfaction for taking sludge agriculture application as an option for fertilization.

- Scientifically, there are no fixed criteria for selecting sludge processing for land application. However, the rule that regulates land disposal is the degree of sludge stability. Considering sludge produce from municipal WWTPs in Palestine it is important to study the possibility of sludge reuse according to each sludge production issues such as degree of removal efficiency for the main parameters plus studying the economic aspect.
- For any future plan for the WWTPs establishment, there are two main factors to achieve project efficiency and sustainability, namely the choice of the location of the WWTP, to be close to compatible area to benefit from the treated water and treated sludge, and the second is the choice of water and sludge treatment technology. This requires decision-makers to develop criteria for the WWTPs establishment projects and to oblige donors on the basis of the studied criterion.
- For comprehensive results for this study purpose, it is recommended that these analyses be carried out in winter season. And further parameter to be added not only the heavy metals parameters, but also oxygen uptake rate (OUR) parameter which contributes in support the study results.

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8 APPENDIX 1

A. Regional standards for sewage sludge agricultural application:

Table shows; Regional standards for sewage sludge agricultural application.

	Tunisia	Jordan		Egypt	Israel		Palestine	
Sludge type		I	II		A	B	I	II
Heavy metal (mg/kg) DS		The concentrations are restricted by maximum accumulation and maximum addition rate in kg/ha/year					The concentrations are restricted by maximum accumulation and maximum addition rate in kg/ha/year Based on 10 years as an average	
Cd	1-39	85		39	20		0.15	
Cu	44-431	4300		1500	600		12	
Hg		57		17	5		1	
Ni	2-293	420		420	90		3	
Pb	57-1580	840		300	200		15	
Zn	170-1500	7500		2800	2500		30	
Cr	33-490	3000		1200	400		6	
Se		100		36				
As		75		41				
Mo		75						
Co	11-34	150						
B	12-14							
Pathogen limits								
(MPN)or FC (cfu/g)		1000/g	2 log 6	1000/g	1000/g	2 log 6		
Salmonella		<3/4g	-	<3/4g	<3/4g	-		
Viable eggs		<1/4g	-	<1/4g	<1/4g	-		
Intestinal viruses		<1/4g	-	<1/4g	<1/4g	-		

B. Total coliform (TC) and fecal coliform (FC) data analysis

Tables below show the results for TC and FC of fresh and dewatered sludge samples taken during this study. All results data are given in (cfu/g) of DS

1. Al-Bireh WWTP

Fresh type			Dewatered type	
#	TC	FC	TC	FC
1	4.E+07	9.E+05	4.E+07	3.E+05
2	2.E+06	2.E+06	2.E+06	3.E+05
3	2.E+07	3.E+06	1.E+07	2.E+06
4	5.E+07	5.E+06	4.E+07	8.E+05
Average	3.E+07	3.E+06	2.E+07	9.E+05

2. Jericho WWTP

Fresh type			Dried type	
#	TC	FC	TC	FC
1	4.E+08	4.E+05	2.E+07	3.E+05
2	2.E+07	3.E+06	1.E+06	4.E+05
3	2.E+07	1.E+07	1.E+07	1.E+06
4	2.E+08	2.E+06	2.E+07	3.E+04
Average	1.E+08	4.E+06	1.E+07	4.E+05

3. Al-Tireh WWTP

Fresh type			Dewatered type	
#	TC	FC	TC	FC
1	2.E+08	1.E+06	4.E+07	5.E+05
2	3.E+07	3.E+06	2.E+07	3.E+04
3	3.E+08	4.E+06	2.E+07	-
4	2.E+08	8.E+06	2.E+07	2.E+06
Average	2.E+08	4.E+06	3.E+07	2.E+06

4. Nablus- west WWTP

Fresh type			Dewatered type	
#	TC	FC	TC	FC
1	9.E+07	2.E+05	4.E+06	1.E+05
2	3.E+05	2.E+05	8.E+05	1.E+06
3	8.E+05	2.E+04	8.E+05	2.E+05
4	6.E+06	1.E+05	4.E+06	1.E+05
Average	2.E+07	1.E+05	2.00E+06	3.E+05

C. COD analysis results:

The following table shows Absorbance values versus COD measurements in (mg/l).

Two readings of two successful analytical trials were approved after calibration curve was obtained.

Source #		Absor.	COD mg/l	Absor.	COD mg/l
1	Al-Bireh for fresh	0.07600	26867	0.076	26867
2	Al-Bireh for dewatered	0.09300	32533	0.173	59200
3	Jericho Fresh sludge	0.01000	4467	0.036	1353
4	Jericho dewatered sludge	0.11500	39867	0.11500	39867
5	Al-Tireh fresh sludge	0.008	4200	0.157	5386
6	Al-Tireh dewatered sludge	0.299	101200	0.3	101533
7	Nablus fresh sludge	0.073	25867	0.073	25867
8	Nablus dewatered sludge	0.219	74533	0.22	74867

D. TSS and VSS analysis results:

The following tables shows values of TSS, VSS and VSS% at the four WWTPs analysis were taken from March to June, 2017 by taking two samples each month.

1. Al-Bireh WWTP

Sludge type	Al- Bireh fresh sludge type			Al-Bireh dewatered sludge type		
Sample date	TSS mg/L	VSS mg/L	VSS: TSS (VSS%)	TSS mg/kg	VSS mg/L	VSS: TSS (VSS%)
March., 18-19	5164	4604	89%	147	119	81%
April, 4-9	21200	-	-	148	128	87%
April, 24	19556	17184	88%	143	91	63%
May, 7	24716	21948	89%	131	113	86%
May, 27 - 30	18952	14776	78%	151	129	85%
June, 9-10	237724	233256	98%	255	198	78%

2. Jericho WWTP

Sludge type	Jericho fresh sludge type			Jericho dried sludge type		
Sample date	TSS mg/L	VSS mg/L	VSS: TSS (VSS %)	TSS mg/ kg	VSS mg/kg	VSS: TSS (VSS %)
March., 18-19	2384	2128	89%	118	88	74 %
April, 4-9	19872	14196	71%	26	21	82 %
April, 24	23404	13916	59%	23	18	77 %
May, 7	2648	2352	89%	170	125	74 %
May, 27 - 30	3008	1888	63%	54	40	74 %
June, 9-10	4727	3472	73%	64	48	75 %

3. Al-Tireh WWTP

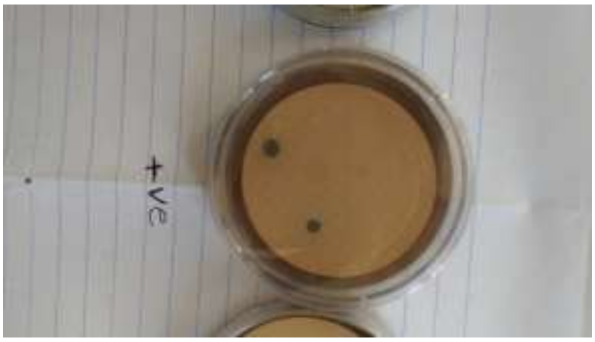
Sludge type	Tireh fresh sludge type			Tireh dewatered sludge type		
Sample date	TSS mg/L	VSS mg/L	VSS: TSS (VSS %)	TSS mg/kg	VSS mg/ kg	VSS: TSS (VSS %)
March., 18-19	5944	5320	90 %	144	120	83 %
April, 4-9	4788	4188	87 %	163	137	84 %
April, 24	4760	4292	90 %	169	137	81 %
May, 7	6636	5580	84 %	125	102	82 %
May, 27 - 30	-	-	-	235	200	85 %

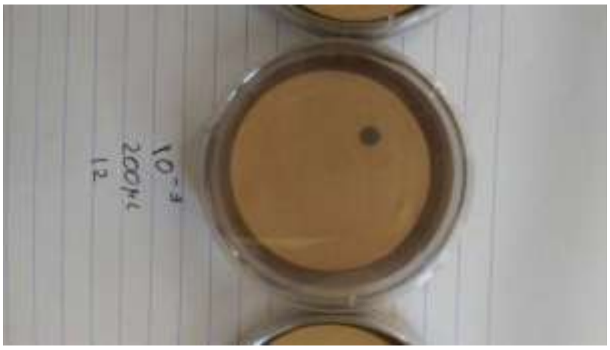
4. Nablus- west WWTP

Sludge type	Nablus-west fresh sludge type			Nablus-west dewatered sludge type		
Sample date	TSS mg/L	VSS mg/L	VSS: TSS	TSS mg/kg	VSS mg/ kg	VSS: TSS
March., 18-19	7608	5460	72 %	198	130	65 %
April, 4-9	17832	9180	51 %	200	139	70 %
April, 24	19000	13484	71 %	192	130	68 %
May, 7	33616	24652	73 %	182	126	68 %
May, 27 - 30	31020	21488	69 %	183	126	68 %
June, 9-10	28348	20872	74 %	1199	627	52 %

9 APPENDIX 2

A: Figures for incubated plates for 24hrs (FC at 42◦c and TC at 37◦c).





B: Figures for analytical equipment.

The homogenizer used for sample preparation and dilution

Membrane filter instrument.