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Performance of Coupled Anaerobic Baffled Reactor/ Gravel Bed Filter in Treatment of Domestic Wastewater: A Case Study of Ubiedya Wastewater Treatment Plant

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M.Sc. Thesis

Jerusalem-Palestine

2018/1440

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A Thesis Submitted in Partial Fulfillment of Requirements for the Degree of Master of Science in Environmental Studies, Department of Applied Earth & Environmental Studies, Faculty of Graduated Studies - Al-Quds University.

2018-1440

Al-Quds University
Deanship of Graduate Studies
Environmental Studies

Thesis Approval

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Master thesis submitted and accepted date: 11/ 12 /2018

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Jerusalem-Palestine

2018/1440

Dedication

To my dear parents who encourage and support me all the time

To my brothers, sisters, uncles, antis, friends and all those who stood beside me while preparing this thesis

To my lovely son “Jamal" who lightens my future and draws the smile on my face

To all of these, I wish to accept my dedication

Hadeel Fatafta

Declaration

I certify that this thesis submitted for the degree of Master in environmental science is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not be submitted for a higher degree to any other university or institution.

Hadeel Bader Mahmoud Fatafta

Signature: …………

Date: 11 / 12 /2018

Acknowledgment

Many thanks and gratitude to GOD who give me the power to finish this work. I would like to thank deeply my supervisor Dr. Jawad Shoqier for his continuous support, advice and suggestions that gave me a big help to fulfill this work. In addition, much graduate is dedicated to Dr. Samer Khalaf who had never hesitated to provide assistance to me during my study and preparation of this work.

Sincere gratitude goes to the staff of soil and hydrology Research Lab for further help and working together.

A special thank and respect for the academic staff at the Department of Earth and Environmental Science in Al-Quds University especially Dr. Adnan Al-Laham, Dr. Amer Marei, Dr. Amer Knaen and Dr. Mutaz Al-Qutb.

Sincere thanks and respect to Institute for Water Education (IHE Delft) represented by Prof. Peter van der Steen, Dr. Jack van deVossenberg and Dr. Hans van Bruggen for their suggestions and generous funding to the DUPAC 2 project.

I also would like to acknowledge Al-Ubeidya Municipality for their cooperation and providing all data that I needed in this research.

Sincere thanks for the examining members including Dr. Zaher Barghouthi as external examiner and Dr. Amer Marei as internal examiner.

Abstract:

Water and wastewater treatment are one of the most important issues concerning nations throughout the world especially in developing countries which basically characterized by deficiency of basic sanitation facilities in particular, and weakness of infrastructure in general. Accordingly, decentralized wastewater treatment systems rather than centralized systems might be economically and technically more efficient and able to conduct sustainable urban development, since it showed competitive costing, simpler technologies, high efficiency with good operation and maintenance costs.

The goal of this research was to examine the potential use of anaerobic baffled reactor (ABR) followed by a gravel bed filter (GBF) towards domestic wastewater treatment and to observe the effect of this coupling on the effluent quality. The efficiency of the system (ABR/GBF) was evaluated through testing the wastewater that is generated from the nearby primary schools (Yaffa and Al-Estiklal). The study showed that the wastewater treatment plant was receiving medium to high strong influent with high organic loading rate (COD 697.5 mg/L, BOD_5 323 mg/L).

During the period of the study, samples were collected biweekly and analyzed for different chemical, physical and biological parameters including: BOD, COD, TOC, TNb, TSS, EC, FC and TC.

This study revealed that the use of both the ABR and GBF could be promising in conducting a sustainable on site wastewater treatment with high average removal efficiencies of organic pollutants (33%-89% BOD, 55%-97% COD, 60% TOC, 46%TSS). The microbial analysis indicated a high reduction of total coliform and fecal coliform.

تقييم أداء النظام المتكامل المكون من المفاعل اللاهوائي/ فلتر الحصى في معالجة المياه العادمة: محطة العبيدية لمعالجة المياه العادمة كحالة الدراسة.

اعداد :هديل بدر محمود فطافطة
اشراف: د.جواد شقير

الملخص

تعتبر المياه ومعالجة مياه الصرف الصحي من أهم القضايا المتعلقة بالدول في جميع أنحاء العالم، لا سيما في البلدان النامية التي تتميز بشكل أساسي بنقص مرافق الصرف الصحي الأساسية على وجه الخصوص، وضعف البنية التحتية بشكل عام. وبناءً على ذلك ،فإن نظم معالجة مياه الصرف اللامركزية بدلاً من الأنظمة المركزية تعد الأكثر كفاءة من الناحيتين الاقتصادية والتقنية والأكثرقدرة على إجراء التنمية الحضرية المستدامة، حيث أنها تظهر تكاليف تنافسية وتكنولوجيات أبسط وكفاءة عالية مع تكاليف تشغيل وصيانة جيدة.

كان الهدف من هذا البحث هو دراسة الاستخدام المحتمل لنظام متكامل مكون من المفاعل اللاهوائي (ABR)المقترن بفلتر الحصى(GBF) لمعالجة المياه العادمة الناتجة عن المدارس الابتدائية القريبة من محطة المعالجة (مدرستي يافا والاستقلال) وملاحظة تأثير هذا الربط على جودة المياه. تم تقييم كفاءة النظام (ABR/GBF) من خلال اخذ عينات من المياه من المراحل المختلفة للمعالجة وإجراء الفحوصات اللازمة لها والتي تشمل الفحوصات الفيزيائية والكيميائية والبيولوجية.

أظهرت الدراسة أن محطة معالجة المياه العادمة كانت تستقبل تأثير قوي من متوسط إلى مرتفع مع ارتفاع معدل التحميل العضوي(COD 697.5 mg/L) ، (BOD5 323 mg/L) بالمقارنة مع مياه الصرف المنزلية.

خلال فترة الدراسة، تم جمع العينات كل أسبوعين وتحليلها لمختلف العوامل الفيزيائية والكيميائية والبيولوجية بما في ذلك BOD : COD، TOC، TNb، TSS، EC، FCو TC.

كشفت هذه الدراسة أن استخدام كل من ABR و GBF يمكن أن يكون واعدًا في إجراء معالجة مياه الصرف الصحي المستدام في الموقع مع ارتفاع متوسط كفاءة إزالة الملوثات العضوية (89٪ BOD، 97٪ COD ، 60٪TOC). أشارت التحاليل الميكروبية إلى انخفاض كبير في عدد بكتريا القولون والكولفورم الكلي.

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List of Abbreviations

PCBS	Palestinian Central Bureau of Statistics
PWA	Palestinian Water Authority
L/C/d	Liter per Capita per day
ABR	Anaerobic Baffled Reactor
GBF	Gravel Bed Filter
WWTP	Wastewater Treatment Plant
DEWATS	Decentralized Wastewater Treatment Systems
O & M	Operation & Maintenance
CWs	Constructed Wetlands
MST	Modified Septic Tank
BOD	Biological Oxygen Demand
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
OLR	Organic Loading Rate
COD	Chemical Oxygen Demand
Kg	Kilograms
C^o	**Celicuos**
UAF	Up – Flow Aerobic Filter
HSSCW	Horizontal Subsurface Constructed Wetland
HRT	Hydraulic Retention Time
SRT	Solid Retention Time
H	Hour
Ph	Degree of Acidity
M^3	Cubic meter
M	Meter
TOC	Total Organic Carbon
TNb	Total Bonded Nitrogen
EC	Electrical Conductivity
FC	Fecal Coliforms
TC	Total Coliforms
SOPs	Standard Operation Procedures
Nm	Nanometer
DO	Dissolved Oxygen

µS/cm	Micro Simon per Centimeter
Cm	Centimeters
NTU	Turbidity Unit
Mg/L	Milligrams per Liter

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Chapter One:

Introduction

This chapter contains a brief description for the current situation, the problem statement and justification of the study. In addition, the research questions, the objectives for the study were included.

1.1 Current Conditions and Justification of the Study:

Water scarcity and the huge pressure on the available freshwater resources are considered to be one of the most critical problems for communities especially in semi-arid areas like the Middle East (Gleick et al. 2014 and Leas et al. 2014). It was expected that by the year of 2025, most countries in Middle East and North Africa will face an “absolute” water scarcity (Abu Zeid, 2006). Under all these current criteria, wastewater recycling and reuse emerge as a critical solution for water crises in the region.

The current situation in Palestine is not much better than the surrounding countries. Due to the limited water resources, the Israeli control over the available Palestinians water resources and the high rate growth of population (estimated 2016 population of the West Bank is roughly 2.9 million Palestinians) (PCBS, 2016) which result at the end in increasing the water shortage problem. In addition to water scarcity, the region is suffering from the disposal of the raw wastewater into wadis without any pretreatment which increase the potential source of water pollution. According to the Palestinian Central Bureau of Statistics (PCBS) and the Palestinian Water Authority (PWA) the average domestic water consumption by the year 2015 was 82.2 (l/c/d) in Palestine, 84.3 (l/c/d) in the West Bank and 79.2 (l/c/d) in Gaza Strip. Depending on the same study of the PCBS & PWA, data indicated that during the year of 2015 about 53.9% of households in Palestine were connected to wastewater networks in order to dispose their wastewater.

Consequently, collection and treatment of wastewater have a huge impact on both environment and economy at local and global level (Risch et al. 2015). The two main goals of wastewater management systems are to protect and promote human health and to provide water quality and ecosystem protection (Capodaglio et al. 2017). Parkinson and

Tayler (2003) stated that wastewater treatment could form an alternative resource of water that could be used for agricultural and industrial purposes.

Since the wastewater treatment management in developing countries depends upon the economic status of these countries, which basically characterized by deficiency of basic sanitation facilities, non-availability of central sewer system in particular and weakness of infrastructure in general. Thus, selecting an efficient and low-cost alternative technology for wastewater treatment in these countries will be critical (Z.Haiming et al., 2014). Accordingly decentralized wastewater approach found to be economically and technically more efficient and able to conduct sustainable urban development, since it showed competitive costing, simpler technologies, high efficiency with good operation and maintenance costs (Wang, 2014).

Therefore it is imperative to conduct like this research in order to develop a feasible and sustainable treatment technique for decentralization. In this research, the performance of a pilot scale wastewater treatment plant which consists of coupled anaerobic baffled reactor / gravel bed filter was evaluated towards domestic wastewater treatment during the period (2017-2018) through collecting samples taken at determined intervals and analyzed for physical, chemical, and biological parameters assessment. This treatment plant was designed in order to treat the wastewater that is generated from Yaffa & Al-Estiklal schools at Ubiedya town.

1.2 Research Questions

This research will be able to introduce the ABR/GBF decentralized wastewater treatment system in towns and villages lack sewage infrastructure. In order to achieve the best output of this research two questions where developed:

1. Is the decentralized anaerobic baffled reactor an efficient solution to replace the porous cesspits in terms of water storage and water quality for reuse?

2. What is the added value of the gravel bed filter if combined to the anaerobic baffled reactor technology? And how this coupling will influence the effluent quality?

1.3 Research Aims

This study aims to setup a successful technology that meets the needs and expectations of the decision makers about the efficiency of the decentralized wastewater treatment systems. In order to achieve the main aim of this study a set of specific objectives has been assigned:

1. Evaluate the influent quality at different treatment stages and compare it to the Palestinian standards for water reuse.
2. Measure the total water consumption at each school and the effluent produced to quantify the amounts that can be reused.
3. Evaluate the possibility to use the treated effluent for flushing toilets or irrigation purposes.

Chapter Two:

Literature Review

This chapter consists of three parts: the first part contains a general background about the wastewater treatment systems which contains both centralized and decentralized systems. Then, the discussion was focused on the previous researches that were conducted on the performance and efficiency of anaerobic baffled reactors, constructed wetlands and coupled systems that employ both technologies in the treatment processes. The second part contains a specific discussion about the anaerobic baffled reactor mechanism. While, the third part focused on the ABR design and operating parameters.

2.1 Background

In general, the main component of domestic wastewater management consists of collection, treatment and disposal (Capodaglio et al., 2016). Depending on wastewater magnitude required to be treated, wastewater treatment systems could be divided into two main categories: centralized and decentralized systems (Maurer et al., 2005). Centralized wastewater treatment system or (off – site system) is used to treat household discharge streams through an extended sewer system. It was found that centralized wastewater treatment plant (WWTP) provide the best service and proper to areas with a high density, based on field conditions. Moreover, the pollution of ground water and natural water system can be avoided, and can accommodate all wastes. On the other hand, centralized treatment system requires high investment capabilities, high operational and maintenance costs, for example 80 % of operational costs are accounted only for wastewater collection (Diana et al., 2013). As well, centralized wastewater treatment systems could be established only by governmental parties which require long term planning and implementation.

On the other hand, decentralized wastewater management is used to treat and dispose relatively small volumes of wastewater originating from single households or groups of dwellings located relatively close to each other (indicatively, less than 3 km, maximum) and not served by a central sewer system, but they are connected with regional wastewater treatment plants (Capodaglio et al., 2017).

From the operational point of view, using decentralized wastewater treatment systems (DEWATS) decreases the operational cost since there is no necessity to use pumps, long and big pipes because wastewater collection, treatment and reuse will be performed at close vicinity to it's source (Libralato et al., 2011). Eventually, this treated water will contribute in decreasing freshwater consumption for agricultural activities.

During the last two decades, many researches have focused on DEWATS rather than centralized systems. According to (Singh et al., 2009) DEWATS might be more effective in wastewater treatment especially in developing countries since these systems do not require sophisticated technologies and high operation & maintenance cost (O& M).

Decentralized systems involve a wide variety of treatment/ disposal technologies such as: constructed wetland (CWs), membrane biological reactor, anaerobic digestion systems in general and anaerobic baffled reactor (ABR) in particular.

Previously, a number of studies carried out in various parts of the world have extensively demonstrated the potential use of these systems in different wastewater treatment. The design and the operation of treatment technologies are dependent upon the characteristic of pollutants and contaminants.

According to (Badalians et al., 2011 and Yu et al., 2014) anaerobic baffled reactor (ABR) might be a promising solution in domestic wastewater treatment since the system renowned through combining the advantages of up flow anaerobic sludge blanket (UASB) and phase separation.

Anaerobic digestion within the ABR results in the removal of organic compounds from the wastewater to different levels**.** Ferraz et al. (2009) evaluated the performance of an anaerobic baffled reactor (ABR) in the treatment of cassava wastewater, a pollutant residue. The results showed that the ABR was able to treat cassava wastewater with a removing efficiency of 92% of organic matter.

The removal efficiencies of an ABR treating domestic wastewater were investigated by Nasr et al. (2009) the results showed that the ABR was able to remove organic pollutants with removal efficiencies of 76% for total chemical oxygen demand (COD) and 55% for biochemical oxygen demand (BOD_5) at a hydraulic retention time (HRT) of 12 hours.

The degradation pattern of the substrate in the ABR varied as a function of the organic loading rate (OLR) over the operational period of the reactor. Yu et al. (2014) investigated the performance and stability of an anaerobic baffled filter reactor in the treatment of algae-laden water at several organic loading rates. The results showed that the COD removal efficiency reached 80% at OLR of approximately 1.5 kg COD/(m^3d) at an HRT of five days and an ambient temperature of 30 °C , which resulted in an 80% COD removal.

Many improvements can be introduced to the ABR reactor in order to satisfy better performance and removal efficiencies results. Bodkhe (2009) assessed the performance of a nine-chambered modified anaerobic baffled reactor (MABR) treating municipal wastewater at 11 different HRTs ranging from 6 days to 3 hours the results recorded removal efficiencies to be 86%, 87% and 84% respectively in suspended solids (SS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). In addition, Feng et al. (2008) used a bamboo carrier ABR to treat sewage achieving 69% COD reduction at a HRT of 18 hours.

Constructed wetlands are considered as one of the convenient ecological alternative that is suitable in treating municipal wastewater especially in small rural communities (Puigagut et al., 2007). Nowadays, the implementation of constructed wetlands for wastewater treatment has received greater attention since these systems are simple to construct, having Low construction and maintenance cost if compared to other wastewater treatment systems, and provide effective and reliable wastewater treatment under fluctuating hydraulic and contaminant loading rates (Vymazal, 2007). Moreover, it can be considered as an environmental friendly treatment since the treated wastewater can be used for irrigation or other purposes. Calheiros et al., (2007) assessed the application of different plant species in CWs receiving tannery wastewater. The treatment performance of the systems under two different OLR was evaluated. The results showed high removal efficiencies of organic matter (COD was reduced by 41- 73% and the BOD_5 was reduced by 41-58%) if compared with the nutrients removal efficiency which was low.

As it seems from above, most of the studies have focused on evaluating the efficiency of DEWATS that conduct the treatment process through applying only one technology (such as ABR, CWs, MST,….) but few studies have been conducted on evaluating the performance of the coupled treatment process. Usually, ABRs are applied in DEWATS in a combination with other treatment units such as a constructed wetland (Free-Water Surface, Horizontal Subsurface Flow or Vertical Flow).

Among these studies, Singh et al. (2009) evaluated the performance of a decentralized wastewater treatment system through applying a model consists of an anaerobic baffled reactor followed by a hybrid constructed wetland in treating high-strength wastewater. The results showed that the ABR is very effective in the removal of organic pollutants with removal efficiencies up to 78%, 77% for BOD and COD respectively.

Jamshidi et al. (2014) investigated the efficiency of using an integrated system consists of anaerobic baffled reactor followed by Bio-rack wetland planted with Phragmites sp. and Typha sp. for treating domestic wastewater. The study showed that the integrated system (especially the one vegetated with Phragmites sp) achieved high pollutant removal efficiencies (87% and 93% for COD & BOD_5 respectively) and could be an ideal technology for achieving a sustainable decentralization wastewater treatment.

Merino-Solís et al. (2015) assessed the performance of a municipal pilot wastewater treatment system which consists of an up-flow anaerobic filter (UAF) followed by a horizontal subsurface constructed wetland (HSSCW). The experiment evaluated the removal efficiencies of organic matter and nitrogen under three hydraulic retention times (HRT) of 18, 28 and 38 h in the UAF, which corresponds to two, three and four days in HSSCW. The results showed that UAF was responsible for removing most of the organic matter while the HSSCW was corresponding of most nitrogen removal. Moreover, the study concluded that two days is adequate to remove organic matter, but when the objective is to remove organic matter and nutrients a three-day HRT is recommended (80% of the organic matter was removed in the UAF stage in 18 h, the HSSCW reached 30% of removal for N_{tot} was obtained in the HSSCW in a HRT of three days.

It is clear that coupling was positively influenced the treatment efficiency of the process. For instance, the required planted area and the retention time of the constructed wetland was reduced when an anaerobic baffled reactor was combined with a constructed wetland which consequently increases the CWs life cycle.

2.2 Anaerobic Baffled Reactor Mechanism

A typical anaerobic baffled reactor (ABR) is an improved septic tank that is suitable for influents with a high percentage of non-settleable suspended solids and a narrow COD/BOD ratio (Sasse 1998). It consists of a series of vertical, hanging and standing baffles that form several equal volume compartments. In order to direct the wastewater up and down the baffles through each compartment as it flows from the inlet to the outlet of the reactor (Foxon et al., 2004).

In addition, the up and down flow of the liquid tends to reduce bacteria washout, which enhance the ability of the ABR to retain active biological mass without the use of any fixed media (see Figure 2.1). The bacteria within the reactor tend to rise and settle with gas production in each compartment, but they move down the reactor horizontally at a relatively slow rate. As a result of the slow horizontal movement, the contact time between the wastewater and the sludge (active biomass) increased. Consequently, the treatment will improve (Wang et al., 2004 and Sarathai et al., 2010).

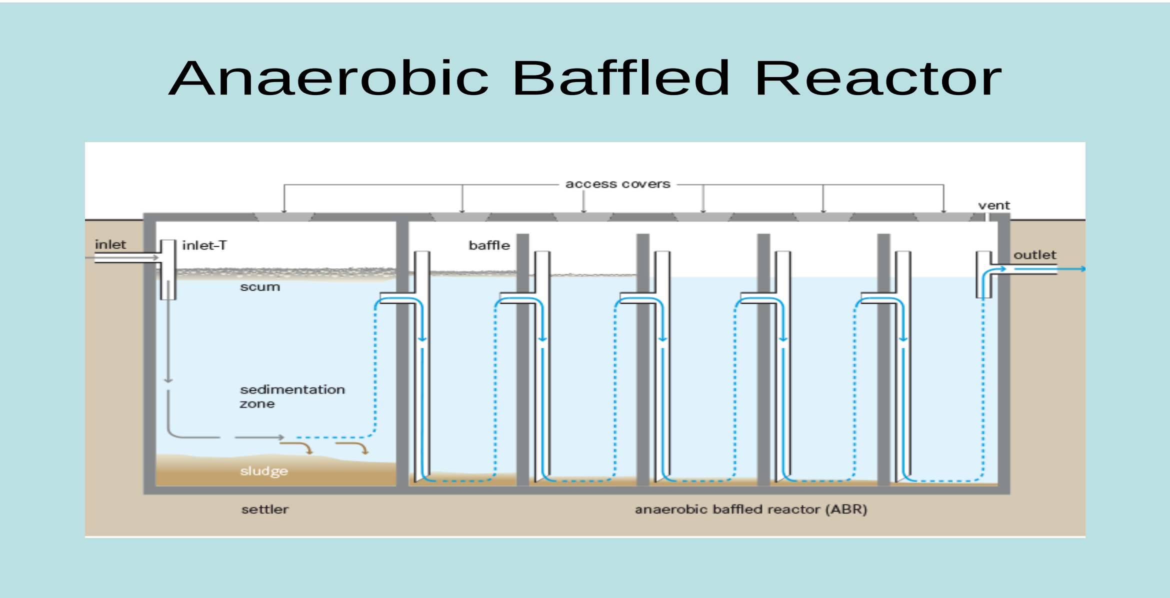

Figure 2.1: Schematic figure of the Anaerobic Baffled Reactor (ABR) system. Source: (Tilley et al., 2014).

The treatment system in the ABR is based on both physical treatment (settling) and biological treatment (anaerobic digestion). The majority of settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50% of the total volume. While, the up-flow chambers provide additional removal and digestion of organic matter and have consistently high BOD/COD removal which is far superior to that of a conventional septic tank. The compartmentalized structure in ABR is an important key of retaining biomass within the reactor. The more compartments in a reactor, the better biomass retention is. Also, this structure is helpful in separating acidogenic and methanogenic phases, which will enhance stability and higher organic loading rate (OLR) of the anaerobic process, as well as, increase the overall removal efficiency with shorter HRT.

Anaerobic digestion that takes place in an ABR consists of different groups of organisms. Usually, the organisms reaction in an anaerobic process is determined by four main steps which included : hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Liu et al., 2010 and Badalians et al., 2011).

Complex organics are converted to soluble organic compounds through hydrolysis , then the products from hydrolysis step are converted into acid, hydrogen, carbon dioxide and other low molecular weight organic acids by the mean of anaerobic microorganism. The following step is methanogenesis which is carried out through two types of methanogenes, the first converts hydrogen and carbon dioxide to methane, and the second converts acetate to methane and bicarbonate (acetoclastic bacteria). Two-phase operation permits acidogenesis to dominate in the first compartment and methanogenes is to dominate in the subsequent compartments.

The ABR has been found to treat high strength organic loads , as well as suspended solids, according to previous studies COD removal was up to 77%, BOD removal was up to 78 % and TSS removal was up to 91 % (Singh et al., 2009). While, the process has no effect on nitrogen and phosphorus removal. In addition, pathogenic organisms within the wastewater are only partially removed. As a result, post-treatment stage must be added in order to achieve higher removal rates for such parameters, as well as reducing concentrations of nutrients and pathogens. For this reason an aerobic post treatment is most likely needed to meet effluent standards (Nasr et al., 2008).

In general ABR technology does not require external power and meets the other requirements for sanitation alternative.

The use of the ABR for wastewater treatment is dependent on an existing water supply, and it is suitable for communities without a formal sanitation system. Also, it is a suitable alternative for on-site sanitation in areas with steep topography and limited available space (Foxon et al., 2004).

The operation of this technology has several advantages that are related to construction, biomass and operation. Related to construction, it requires simple design, no moving parts and no mechanical mixing are needed. In addition, it is inexpensive to construct and had low operating costs. Moreover, it has high void volume, and has the benefits of reduced clogging and sludge bed expansion (Donehue et al., 2009).

Regarding to biomass (sludge), it has low sludge generation, high solids retention times (SRT), and the retention of the biomass is done without fixed media or a solid-settling chamber. Also, no special gas or sludge separation is required, and it has no special requirement for the biomass with unusual settling properties (Ravindra et al., 2001).

Finally, it has low hydraulic retention times (HRT), and it is extremely stable to hydraulic shock loads. Moreover, it provides protection from toxic materials in influent and long operation times without sludge wasting (Ravindra et al., 2001).

Depending on the previous advantages of the ABR reactor, it seems that probably the most significant advantage is the ability of the reactor to behave as a two-phase (mention) system without the associated high cost and control problems (Barber and Stuckey, 1999).

Two-phase operation permits acidogenesis to dominate in the first compartment and methanogenesis to dominate in the subsequent section. As a result of this specific property, the acidogenic and methanogenic activity can increased because the separation of the two phases causes an increase in protection against toxic materials and higher resistance to changes in environmental parameters such as pH, temperature, and organic loading rates (Langenhoff et al., 1999; Nasr et al., 2008).

The main limitations for the ABR technology can be summarized in the following: it requires constant source of water, effluent requires secondary treatment and/or appropriate discharge, low reduction pathogens requires expert design and construction, and pre-treatment is required to prevent clogging (Tilley et al., 2014).

There are many materials that can be used in the construction of an ABR. Metal, concrete, and plastic are primarily used depending on the setting. Concrete is a cost effective and readily available construction material and is therefore a good option for remote and low income locations. Plastics and metals such as alloys, stainless steels, and coated metals are more expensive but save on space and land requirements.

In this research, the performance of Ubiedya wastewater treatment plant was monitored during the period (2017-2018) through collecting samples taken at determined intervals and analyzed for physical, chemical, and biological parameters assessment. This treatment plant was designed in order to treat the wastewater that is generated from Yaffa & Al-Estiklal schools.

2.3 ABR Design and Operating Parameters

As all biological wastewater treatment system, ABR has a set of design and operational parameters comprising organic loading rate (OLR), hydraulic retention time (HRT), temperature, pH, start up period and granulation.

Organic Loading Rate (OLR) doesn't directly influence the performance of an ABR, but has an impact on the removal efficiencies. Zhu et al (2015) concluded that the OLR is an indicator of nutritional condition of microorganisms. Thus lower HRT and higher OLR were preferred when treating low-concentration wastewater in order to ensure the availability of nutrients to the microorganisms. However, lower OLR is recommended when treating high-concentration wastewater in order to enable complete biodegradation of substrate and prevent sludge floating.

Hydraulic Retention Time (HRT) is among the important controlling factor in the operation of the ABR because it can control the organic and hydraulic load of the reactor. Zhao et al (2012) explained the reason of decreasing the removal efficiencies at very lower HRTs which can be attributed to the fact that at very low HRTs the bacteria will not get enough time to consume the substrate.

Temperature is considered to be another important factor that affects the treatment process in the ABR since the bacteria need an optimum temperature to grow. Generally, the optimum temperature for anaerobic reactors is in the range between 25ºC to 35ºC. Zhu et al

(2015) concluded that the removal efficiencies fall down if the temperatures are below the optimum range. In addition, Feng et al (2009) prevailed that at low temperature the reaction rates were influenced by the decrease in temperature.

The pH is an important controlling factor for operation of the ABR. Speece (1996) stated that the optimal pH for anaerobic digestion lies in the range of 6.5-8.2 and any pH outside this range will cause inhibition of microbial activity and limits the anaerobic digestion processes. According to Arnirfakhri et al (2006) different substances like NaOH and $NaHCO_3$ can be used in order to adjust the pH inside the different compartments of the reactor since each compartment has favorable pH.

Usually, the startup of the ABR reactor takes time due to slow growth rates of anaerobic microbes, especially the methanogens. Barber and Stuckey (1999) demonstrated that the aim of the startup period is to improve the proper microbial populations for the waste streams being treated. It is suggested that the initial loading rates should be low for a successful startup of the ABR due to the fact that at lower loading rates, there is lower gas production and hence a lower wastewater up flow velocity. So as to catalyze the startup of the reactor and to prevent overloading the reactor can be seeded with activated sludge containing appropriate microbial cultures. Liu et al (2010) suggested that greater reactor stability and performance can be achieved when the reactor is started with a constant HRT and gradual step wise increase in the substrate concentration or a constant substrate concentration and a gradual step wise decrease in the HRT.

Granular biomass enhances settleability consequently increasing biomass concentration in continuous reactors and leading to higher removal efficiencies. She et al (2006) studied the granule development in the lab scale ABRs seeded with sewage sludge from the primary anaerobic digester and it was found that granulation was achieved in 75 days. Moreover, it was observed that the addition of granular active carbon, bentonite and polyacrylamide enhance granule formation.

Chapter Three:

Methodology

This chapter includes a full description of the decentralized wastewater treatment plant (ABR/GBF coupled system) such as its location, monitoring, sampling, analysis and all the related field and laboratory work during the period of the study. Moreover, a demonstration of the used mathematical equations and formulas had been included.

3.1 Study Area

The wastewater treatment plant is located in Ubiedya town (31°43′24″N 35°17′26″E) which is located at Kidron Nar district at 8.4 Km east Bethlehem as indicated in (Figure 3.1, Table 3.1).

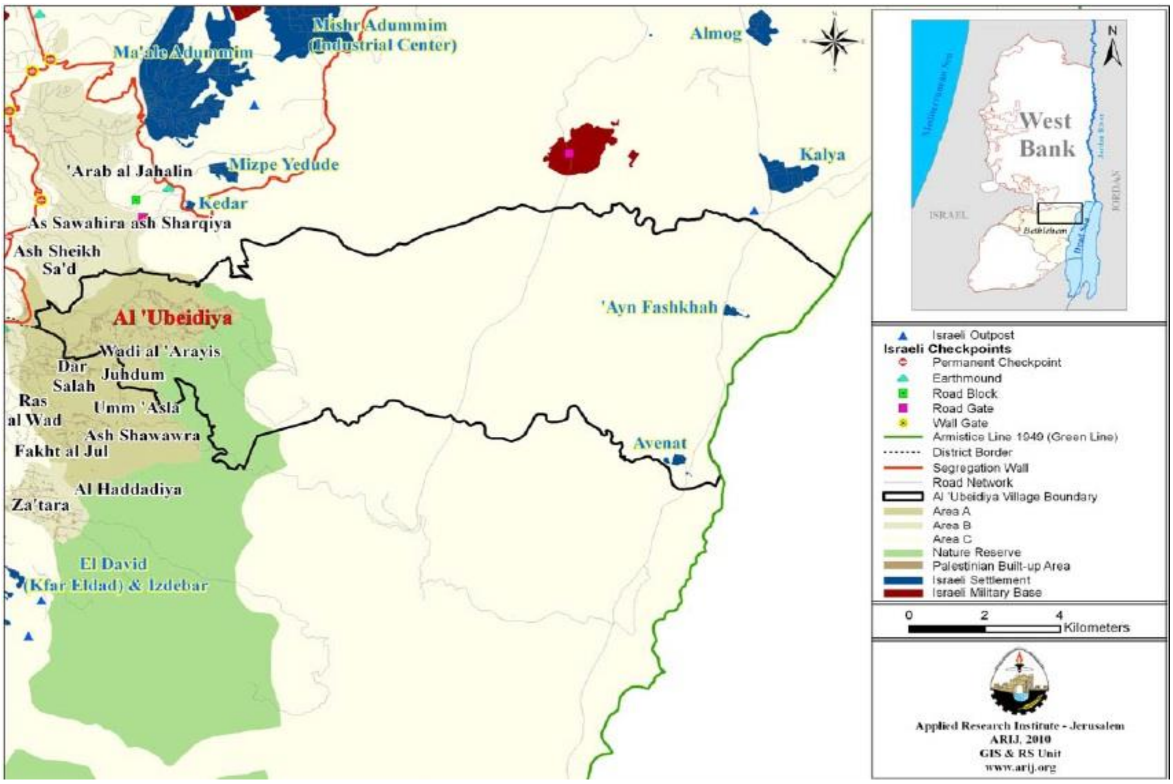

Figure 3.1: A map that demonstrates the location of Ubiedya. The town is bordered by the Dead Sea to the east, As Sawahira ash Sharqiya to the north, Dar Salah village to the west and Tuqu town to the south (ARIJ GIS, 2010).

Table 3.1: Information about the study area which includes location, altitude, mean annual rainfall, average annual temperature and humidity (ARIJ GIS, 2010).

Study area	Ubiedya
Location	8.4 km east Bethlehem
Altitude	532 m above sea level
Mean annual rainfall	246 mm
Average annual temperature	18.5^{o} C
Average annual humidity	58%

The region is suffering from serious environmental problems due to the improper discharge of wastewater into kidron Nar stream which forces many of the farmers in the nearby region of the open sewer to quit their lands as shown in (Figure 3.2). In addition, the town is suffering from bad odors, deficiency of basic sanitation facilities, weakness of infrastructure and water scarcity which can be considered as one of the major constraints to the social / economic human development in the region.

Figure 3.2: The wastewater open sewer in the Kidron Nar stream which flows from Jerusalem to the Dead Sea and causing many serious environmental and health hazard problems along the way which passes through it.

3.2 ABR/ GBF Treatment Plant Description

Ubiedya wastewater treatment plant consists of a coupled system of two main stages: the first stage was conducted using anaerobic baffled reactor (ABR) followed by the second stage which consists of a gravel bed filter (GBF) as mentioned in (Figure 3.3).

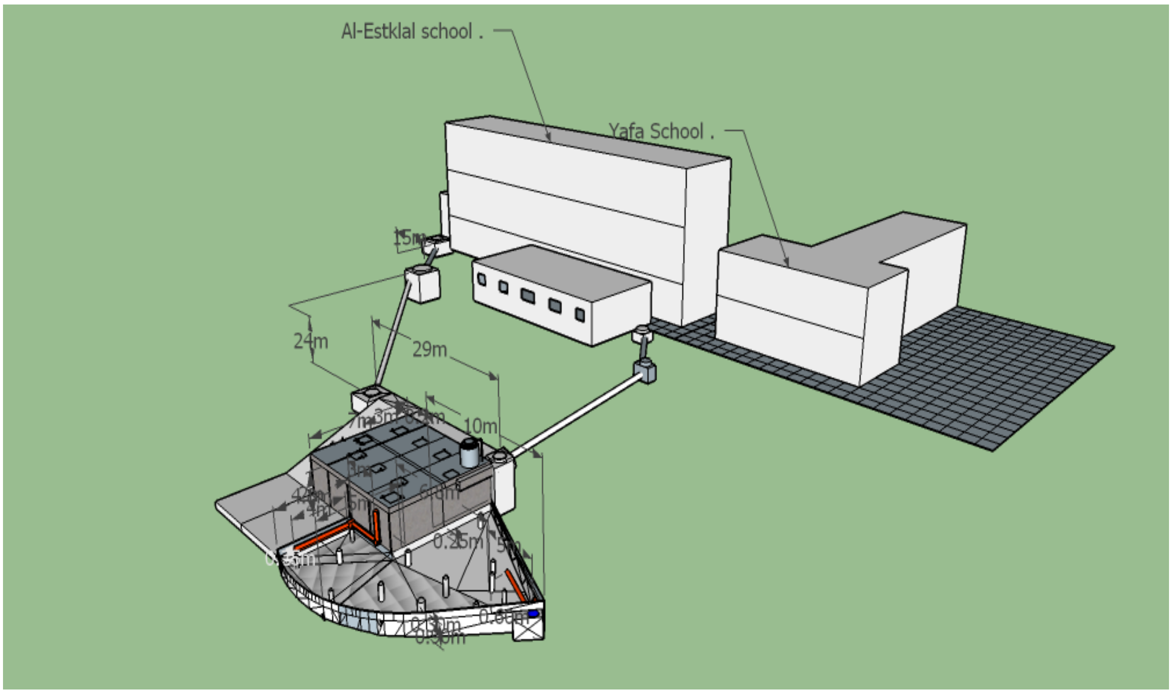

Figure 3.3: Illustrate the setup of the coupled ABR/ GBF treatment plant for Yaffa & Al- Estiklal schools in detailed .

This plant was built by the year 2017 in order to treat the wastewater that was generated from the two nearby primary schools (Yaffa & Al- Estiklal) as shown in (Figure 3.4) below. The construction of this treatment plant was funded through DUPAC2 project which aims to find solutions to the existing environmental problems in Wadi Nar (Kidron basin) that resulted from the improper wastewater discharge from the local communities into Wadi Nar stream, which flows from Jerusalem to the Dead Sea and along the way forms an environmental and health hazard.

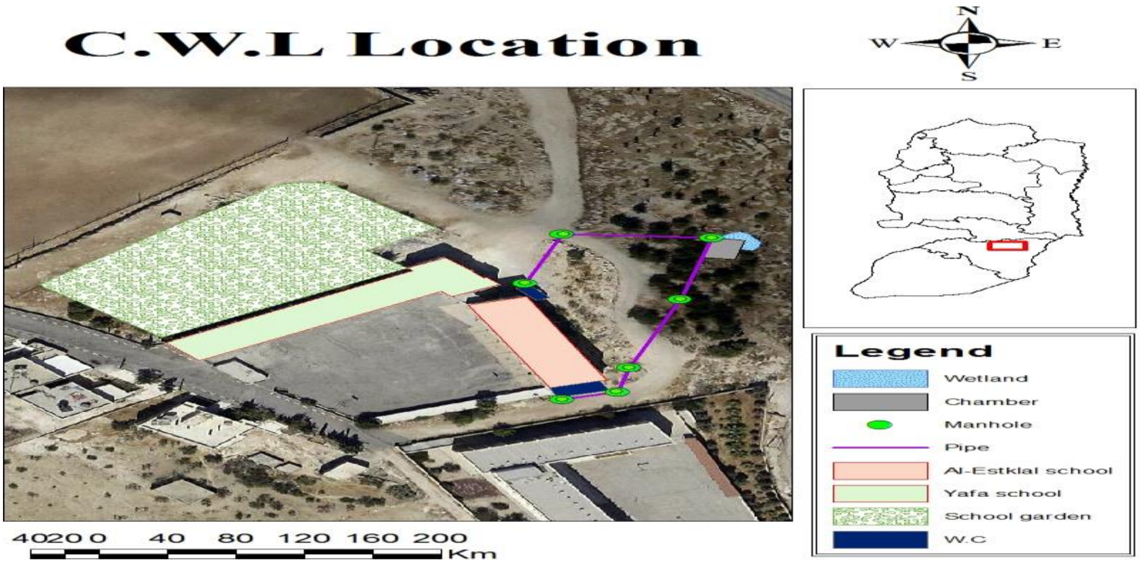

Figure 3.4: Schematic figure that explains the location of the ABR/GBF treatment plant nearby the schools and demonstrates the connection between the schools and treatment plant through pipes.

The ABR (Length: 3.0 m, Width: 2.0 m, Height: 2.5 m) with 15 m^3 net volume, consists of equally nine chambers that are separated using vertical standing baffles. It starts with a settling chamber followed by a series of up-flow chambers. The first chamber is responsible for settling of larger solids and impurities and most of the sludge is accumulated in this zone. In this process the wastewater enters the chambers through the inlet at the upper part of the chamber and passes through the sludge in order to move up to the next chamber. As the wastewater passes through the sludge, intensive contact between the active biomass in the resident sludge and newly incoming wastewater occurs. The vertical baffles in the tank force the pre-settled wastewater to flow under and over the baffles guaranteeing contact between wastewater and resident sludge which allowing an enhanced anaerobic digestion of suspended and dissolved solids. The biogas formed during the anaerobic digestion was released through valves located at the sides of the reactor.

The second stage consists of GBF with dimensions of 0.6 m deep, a surface area of 100 m^2 and a volume capacity of ±60 m^3. The main working principle of the GBF that the liquid from the ninth chamber of the ABB is transported through pipes which carry and distribute the effluent continuously and horizontally through the filter bed. Most of the organic matter and suspended solids are removed by filtration and microbiological degradation in anaerobic conditions in the ABR and most of the nitrogen is removed through the GBF. At the end of the process, the obtained effluent is collected through a tank for reuse.

3.3. Treatment Plant Monitoring

A start-up period of four months (September-2017 to December- 2017) was used before beginning the monitoring stage in order to ensure sludge formation, provides the opportunity of the microorganisms to grow up and biofilm development at the surface of the gravel which suggests a stable performance for pollutant removal. During this period, samples were collected monthly and analyzed for different parameters in the laboratory to ensure that the system is functioning well. After the treatment plant reached a stable performance towards wastewater treatment, a monitoring of the treatment plant was conducted during the period of January-2018 to April-2018. During this period, samples were collected biweekly at four monitoring points along the treatment plant in order to assess the efficiency of the coupled system in wastewater treatment.

3.4. Wastewater Sampling and Analysis

The efficiency of the coupled ABR/GBF system was evaluated through conducting biweekly sampling (as indicated in Table 3.2) from specific points in the treatment plant as it was shown in (Figure 3.5).

Table 3.2: Sampling schedule of the ABR/GBF coupled system (includes: date of sampling, number of samples).

Date	Samples
16/1/2018	S1, S5, S9, Out
30/1/2018	S1, S5, S9, Out
12/2/2018	S1, S5, S9, Out
26/2/2018	S1, S5, S9, Out
12/3/2018	S1, S5, S9, Out
26/3/2018	S1, S5, S9, Out
17/4/2018	S1, S5, S9, Out
30/4/2018	S1, S5, S9, Out

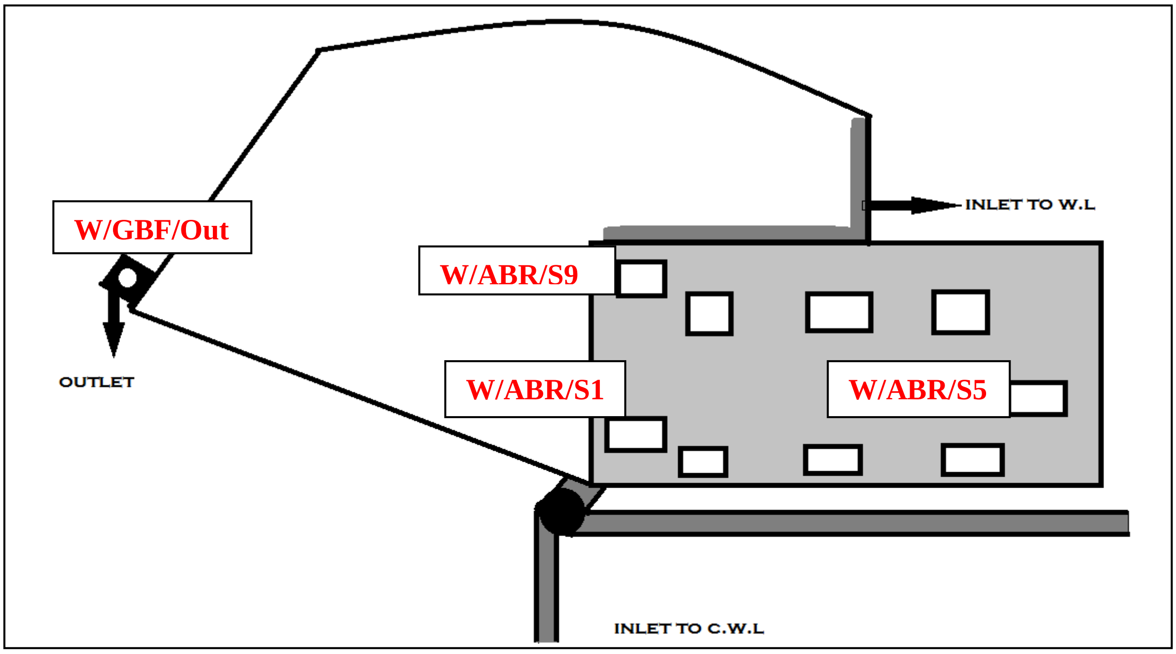

Figure 3.5: Illustration of the sampling points in ABR/ GBF system. Four sampling points in the (ABR/GBF) system including the following locations: chamber one (W/ABR/S1),

chamber five (W/ABR/S5), chamber nine (W/ABR/S9) and the outlet of the GBF (W/GBF/Out).

The samples were collected in sterile glass sample bottles (600 ml), stored at 4ºC and adjusted for different analysis in Soil & Hydrology Research Laboratory/Al-Quds University within 48 hours of collection. All samples were analyzed for physical, chemical, and biological parameters. The physical parameters include the total suspended solids (TSS), total dissolved solids (TDS), turbidity and electrical conductivity (EC), while the chemical parameters include chemical oxygen demands (COD), biological oxygen demands (BOD), pH, total nitrogen (TNb), total organic carbon (TOC), while the biological parameters includes fecal coliform (FC) and total coliform (TC). The samples were either analyzed on the day of collection or refrigerated at 4ºC and analyzed in the next day. Three replicates of each sample were analyzed according to the methods recommended in Standard Operating Procedures (SOPs) using various analytical methods as shown in (Table 3.3) below.

Table 3.3: Analytical methods used in the determination of various parameters including: analyzed parameters, method of analysis (Al-Quds University).

Parameters	**Method of analysis**
Turbidity, EC, DO and pH value	Multi – electrode meter
NH_3	Hach meter
TOC and TNb	TOC instrument
BOD	Standard Operation Methods.
COD	Standard Operation Methods.

3.5 Analytical Methods

This section includes all the parameters that were analyzed during the research and their importance to the operation of the treatment processes.

Biochemical Oxygen Demand (BOD_5): BOD_5 is a measure of the mass of oxygen required by aerobic organisms to decompose organic matter in the water. The standard BOD value is commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 °C. The test will be carried out due to CCBA- SOP- 016.

Chemical Oxygen Demand (COD): COD is a measure of the oxygen equivalent to the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The test will be carried out due to CCBA-SOP-017.

Total Suspended Solid (TSS): The "total solid" refers to the suspended or dissolved matter. TSS is solids that can be retained by a filter. The removal of TSS from water to the wetland sediment bed is essential for both the improvement of water quality and the function of the wetland ecosystem. TSS is predominantly removed via flocculation/sedimentation and filtration mechanisms. The test will be carried out due to CCBA-SOP-015.

Total Dissolved Solid (TDS): TDS are solids that can pass through filter. The test will be carried due to CCBA-SOP-014.

Nitrogen: Nitrogen is a serious concern in wastewater because of it's role in eutrophication and toxicity to aquatic. Numerous biological and physiochemical processes in wetlands are particularly important in the transformations of nitrogen into varying biologically useful forms. Additionally, plants that require nitrogen for their growth play an active role in removing it from the wastewater. The test will be carried out due to CCBA-SOP-010**.**

3.6 Chemicals and Instrumentation

The chemicals used in this study were as follows: Glucose-glutamic acid solution, Phosphate buffer (KH_2PO_4, K_2HPO_4, $Na_2HPO_4.7H_2O$ and NH_4Cl) , Calcium chloride solution ($CaCl_2$), Ferric Chloride solution ($FeCl_3.6H_2O$), Magnesium sulfate ($MgSO_4$), Potassium Hydrogen Phthalate KHP , digestion solution ($K_2Cr_2O_7$, H_2SO_4 and $HgSO_4$), Sulfuric acid reagent , 20% H_2SO_4, Potassium Nitrate (KNO_3), Hydrochloric acid solution HCl (1N) , Ethyl alcohol 70%.

The sample pH was measured using a pH meter model HQ 11 d. The EC and dissolved oxygen were measured using E.C meter model HQ 14 d, DO meter model multi 3430 SETF respectively. TOC & TNb were examined using TOC instrument. COD test was performed using COD reactor code F101A0125.

An incubator model LIB- 010 M was used to incubate the m-Endo and m-FC media at 35^{o}C and 44.5^{o}C respectively.

3.7 Piezometers Monitoring

In order to determine the flow behavior inside the GBF system, the water level and the dead zones, a set of piezometers (a total of fourteen piezometers) were distributed at different locations of the GBF system as shown in (Figure 3.6) below.

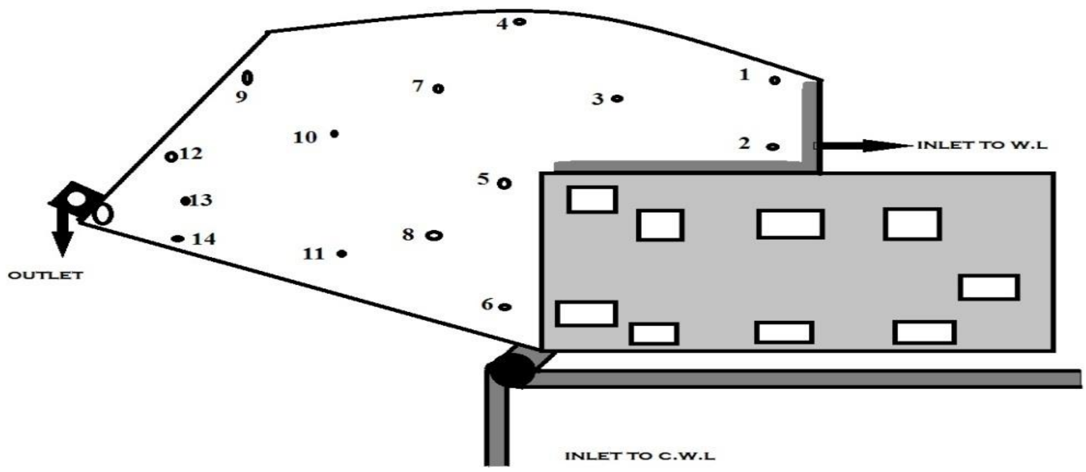

Figure 3.6: Piezometers configuration inside the GBF system.

3.8 Estimation of Evaporation

One of the most direct, common, accurate and reliable measurement/estimation methods of evaporation losses from a water surface is through using an evaporimeters and eddy correlation techniques (Linsley et al., 1982), In our case of study, an evaporimeter was applied to estimate the evaporation percentage in the GBF system. The idea of evaporimeter technique depends mainly on the distribution of seven labeled pans throughout the GBF system as it was shown in Figure 3.7 below.

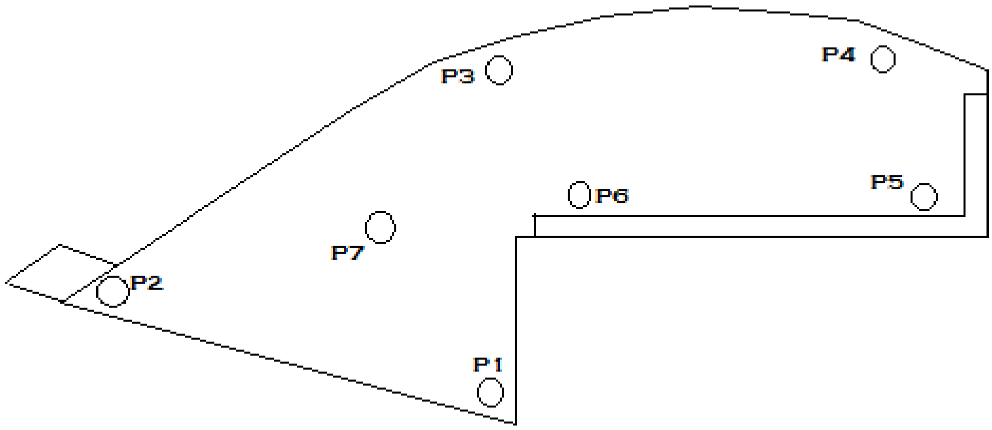

Figure 3.7: Pans distribution throughout the GBF as it was shown seven labeled pans with known level of water were distributed among the GBF surface.

Each pan was filled with known volume of water and then exposed to the atmosphere. The loss of water by evaporation from these pans were measured daily during one week for the seven pans as indicated in (Table 3.4). Meteorological data such as humidity, water temperatures, and precipitation are also measured and noted along with evaporation.

Table 3.4: Provides an example of pans monitoring (Includes: pan No, initial water volume, time (h), decrease in water level (due to evaporation) and the remaining volume of water).

Pan. No.	Int. Vol.	Time (h)	Evp. Vol.	Rem. Vol.
1.00	461.82	0.00		
		24.00	63.32568	398.49
		48.00	134.57	263.92
		72.00	126.65	137.27
		96.00	55.41	81.86
		120.00	47.49	34.37
		144.00	34.37	0.00
		168.00		
		Total	**76.97**	**152.65**

3.9 Electrodes

Two electrodes were installed at the first, fifth and ninth ABR chambers respectively at two different depths (d = 85 cm from the top of the chamber and d = 180 cm downward). The electrodes were used to record the following parameters (temperature, electrical conductivity and the water level) every 30 min during different periods of the study in order to observe the variation of these parameters with time and how this will reflected on the treatment processes.

3.10 Mathematical Equations

The performance of the coupled system was investigated during the monitoring period (four months). The treatment efficiency was assessed in terms of the percentage removal of organic pollutants through applying the following formula:

Removal efficiency % = (Ci – Ce) / Ce * 100

Where, Ci and Ce are the concentration of influent and effluent respectively expressed in mg/L unit.

In addition, the organic loading rate (OLR) during the anaerobic digestion processes was evaluated in terms of COD through multiplying the flow rate of wastewater (L. day^{-1}) into the reactor and the organic concentrations expressed in terms of COD (g.L^{-1}) divided by the volume of the reactor as it is demonstrated by the next relation:

OLR = [flow rate (L. day^{-1} * COD (Kg COD)] / volume of the reactor

The OLR unit is Kg COD. L^{-1} .day^{-1}.

Another important parameter which plays a significant role in wastewater treatment process is the hydraulic retention time (HRT). Depending on the HRT, the design, operational / investment cost and energy requirements can be selected. Simply, the HRT for the ABR was estimated using the next formula:

HRT = V / θ

Where V is the total volume of the reactor (ml) and θ is the amount of feed inside the reactor (ml . day^{-1}).

Chapter Four:

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4. Results and Discussion

The results and discussion in this chapter consists of four sections including in situ field measurements, performance and removal efficiencies, assessment of the treated wastewater quality and cost analysis.

All the related physical, chemical and biological parameters which were measured and collected during the study period are presented in the attached annexes as indicated in the following:

- Physical parameters (Annex A).
- Chemical parameters (Annex B).
- Biological parameters (Annex C).

4.1 In - Situ Field Measurements

This section includes all the field measurements that were carried out during the study period, which include the following: water level measurement, evaporation estimation, data loggers monitoring, organic loading rates, hydraulic retention time and water consumption.

4.1.1 Water Level Evaluation

The water behavior in addition to the water level at the GBF was measured frequently through installation of a set of piezometers at the surface of the GBF. The results of piezometers monitoring during the period of the study showed that the direction of flow at the surface of the gravel cover around 90% of the total area and the remaining 10% was considered as a dead zone with flow less than 5% based on the water level results as shown in (Figure 4.1).

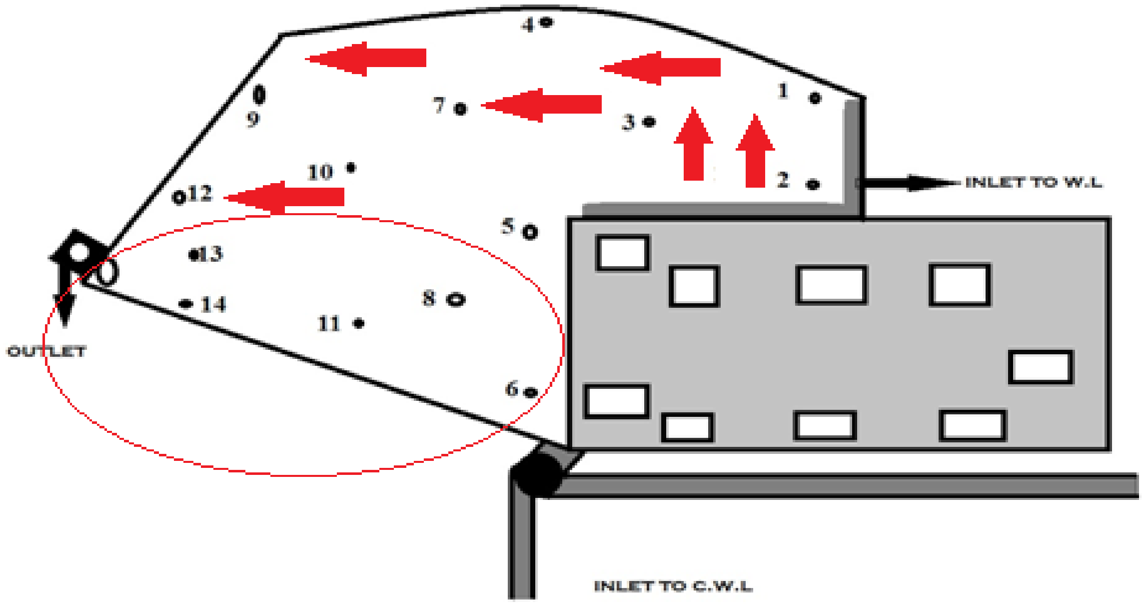

Figure 4.1: Direction of water flow at the surface of the GBF system as indicated the movement of water on the gravel surface follows the pattern shown by the arrows.

4.1.2Evaporation Estimation

The evaporation test was performed through distributing seven pans in each corner and at the center of the GBF as it was mentioned previously in Figure 3.7. The test was conducted within five days under the climatic conditions that has been identified in Table 4.1.

Table 4.1: Temperature in ºC and Humidity in % (according to the weather station).

Day	Temp (ºC)	Humidity
First day	32	26
Second day	35	25
Third day	34	25
Fourth day	32	25
Fifth day	31	25

For each pan the initial volume, the remaining volume and the evaporated volume were recorded daily as it was shown in (Table 4.2). The evaporation percentage for each pan was calculated through applying the next formula:

Evaporation % = Average evaporated volume / Average initial volume *100%

Table 4.2: % Evaporation of the seven pans that were distributed in each corner and at the center of the GBF. The table shows initial volume, remaining volume and evaporated volume all expressed in cm^3 unit.

Pan No.	Initial volume	Remaining volume	Evaporated volume	% Evaporation
1	461.82	152.65	76.97	16.67
2	461.82	180.02	91.82	19.88
3	461.82	136.60	115.45	25.00
4	461.82	141.48	92.36	20.00
5	486.19	197.72	95.62	19.67
6	461.82	163.65	92.36	20.00
7	461.82	140.94	115.45	25.00
Average	465.30	159.01	97.15	20.88

As it was mentioned the average daily evaporation was 97.15 cm^3 from a total volume of 465.3 cm^3 which indicates that the evaporation percentage from each pan was approximately 21% per day. Kohler et al. (1955) supposed a formula in order to estimate the evaporation from a dam or reservoir through multiplying the amount of evaporation from the pan by an appropriate coefficient (K_{pan})

Evaporation = E_{pan} *(K_{pan}).

Through substituting the values of 0.21 and 0.7 in the place of E_{pan} and K_{pan} respectively in the previous equation the evaporation rate from the surface of the gravel bed filter (GBF) will be approximately 0.15 m^3/day. This result represents the evaporation percentage in case where the water level is above the gravel level as indicated in (Figure 4.2). For that reason more gravel was added in order to minimize the evaporation rate.

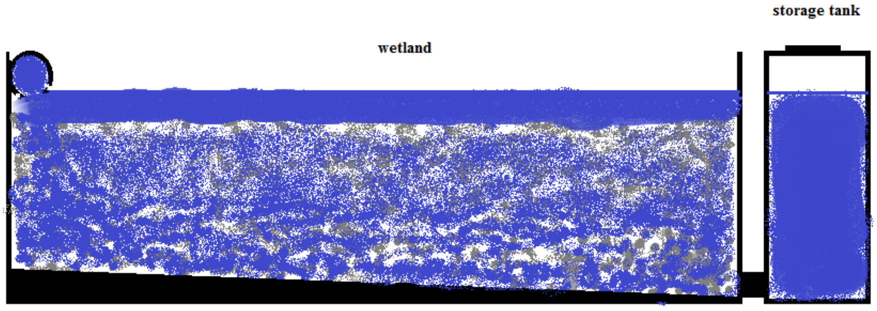

Figure 4.2: Schematic cross section of the gravel bed filter in a case where the water level is higher than the gravel level.

Based on the previous data the effluent level in the gravel bed filter should be maintained in a level less than surface of gravel level (less than 60 cm) in order to decrease the evaporation rate. This can be satisfied through using pumps in order to discharge the effluent to the storage tank and through adding more gravel to the gravel bed filter.

4.1.3 Data Loggers Monitoring

The water level, electrical conductivity and the temperature inside the chambers (mainly the first, fifth and ninth chambers) were monitored using SEBA HYDROMETRIE Electrode.

As Figure 4.3 demonstrates there was no variation in the water level inside the chamber. In general the water level was in the range of 120 cm-162 cm. The water level inside the chambers can be considered as an indicator on the flow rate of wastewater during the period of the study which in turn depends on the abundance of water in the two schools and the number of studying days during the week.

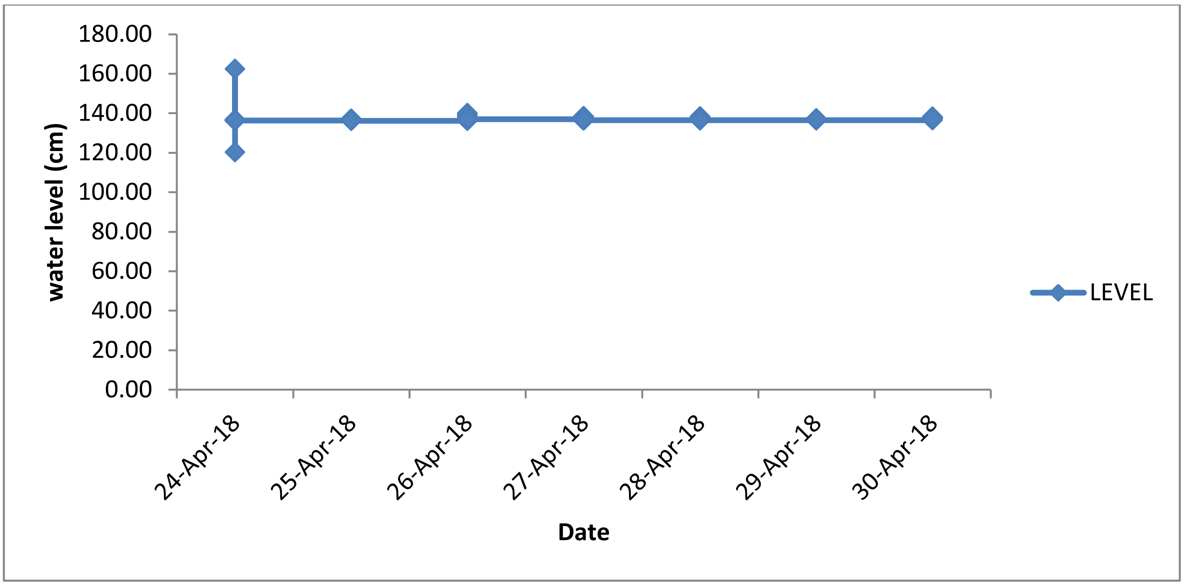

Figure 4.3: The water level (expressed in cm) inside the chambers at different periods of the study.

Regarding to the electrical conductivity the results showed that the values were in the range of 3043 µS/cm-4019 µS/cm as it was shown in (Figure 4.4) which revealed that the EC varied with time and showed maximum value during Mar to Apr which can be attributed to the flow of high organic load wastewater to the plant.

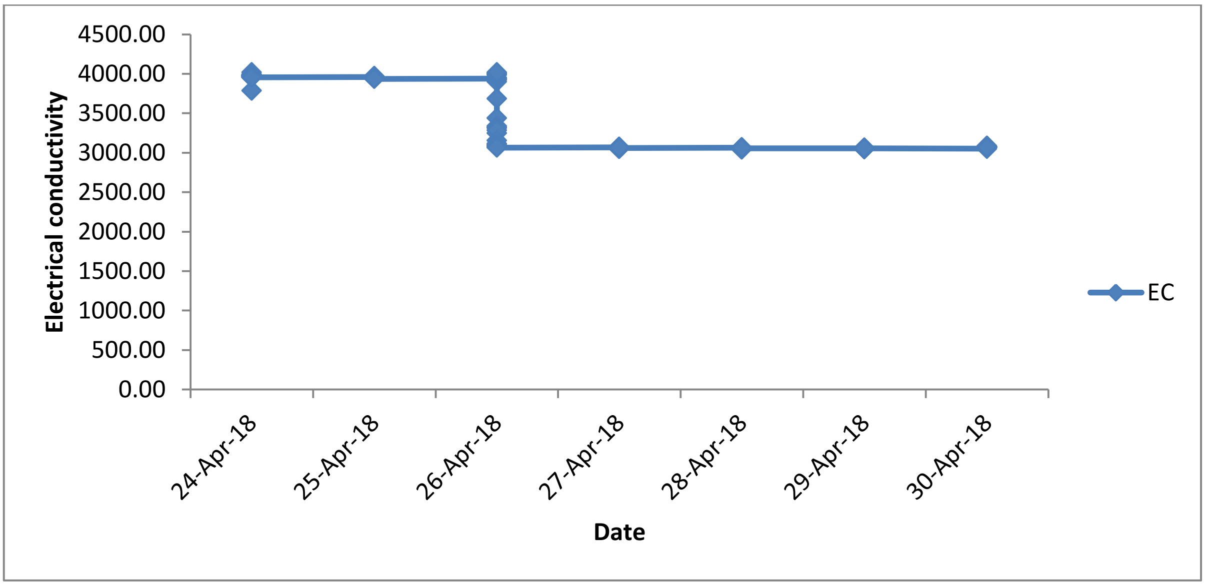

Figure 4.4: Electrical conductivity (µS/cm) behavior inside the chamber during the study peroid.

The results showed that the tempreature was not constant during the interval of the study and varied from one chamber to another as indicated in (Figure 4.5). The temperature was in the range between 18ºC-22ºC which might affect the removal efficiencies of the system.

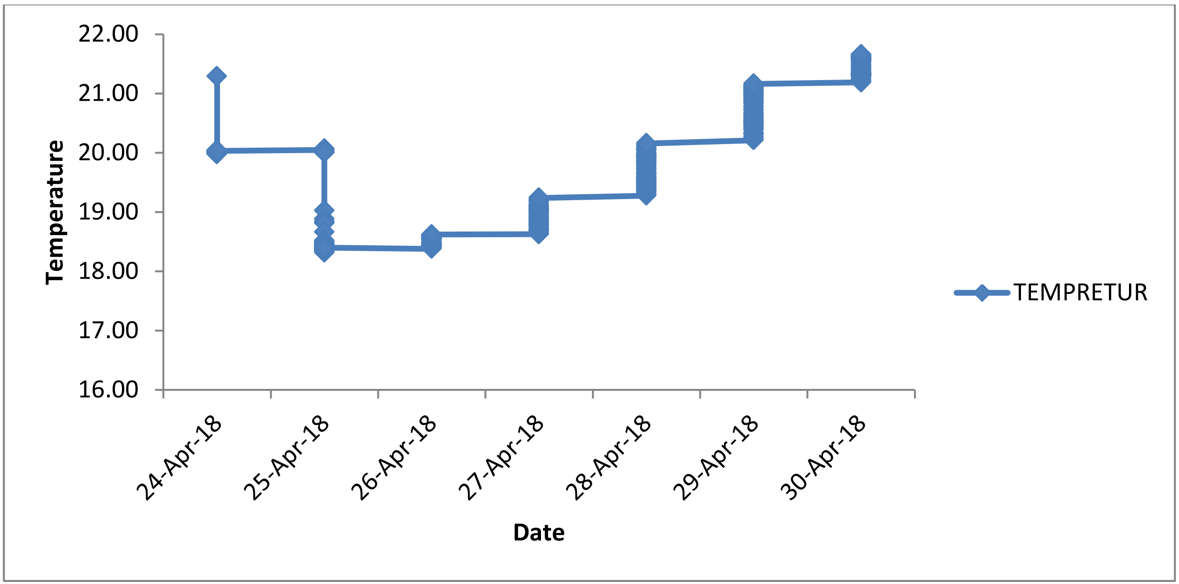

Figure 4.5: Variation of temperature (ºC) inside the chamber during different intervals of the study period.

4.1.4 Organic Loading Rates

The organic loading rate (OLR) can be defined as the influent organic concentration and the hydraulic retention time. Depending on the COD value at the different stages of treatment the OLR values were 16-83 mg COD L^{-1} day^{-1} in ABR influent, 2.5-33 mg COD L^{-1} day^{-1} in ABR effluent and 0.6-37 mg COD $^{L-1}$ day^{-1} for the GBF effluent.

In this study the raw wastewater considered as high strength wastewater (COD = 697.5 mg/L) while at the treatment stages it was considered as low strength (depending on the previous values of OLR) and decreasing from one stage to the next which is an indication of the positive performance of the treatment plant.

4.1.5Hydraulic Retention Time

The hydraulic retention time (HRT) is considered to be one of the most important operating parameters that affect the operation of wastewater treatment systems. Simply the HRT can be defined as the time required for the influent feed to spend inside the reactor in order to be treated to the needed grade. It was calculated using the following formula (HRT = V/ϴ) which was indicated previously at statistical analysis section. Through substituting the values of V (volume of the reactor = 2*3*2.5 = 15 m^3) and ϴ (feed = 1.84 m^3/day) in the formula then the HRT estimated to be 8.2 days. The obtained value of the HRT resulted in increasing the contact time with the anaerobic sludge beds of the ABR. If the HRT value reduced to the half time then the treatment plant will be able to absorb extra quantities (about 2 m^3) of water which consequently resulted in increased effluent without changing the water quality.

4.1.6 Schools Water Consumption and Load Calculations

The levels of wastewater flow were measured by reviewing the water consumption statistics of the schools which aid in estimating the wastewater production. The visual observations of the wastewater flow that comes from the two schools inside the manhole revealed that the flow reached it's maximum value during the break time in the schools and at the end of the school day. Moreover, the visual observation clarified that effluent flow was stronger from Al-Estiklal school than Yaffa school which seems to be appropriate to water consumption values which confirms the higher water consumption of Al-Estiklal school as it was indicated in (Figure 4.6).

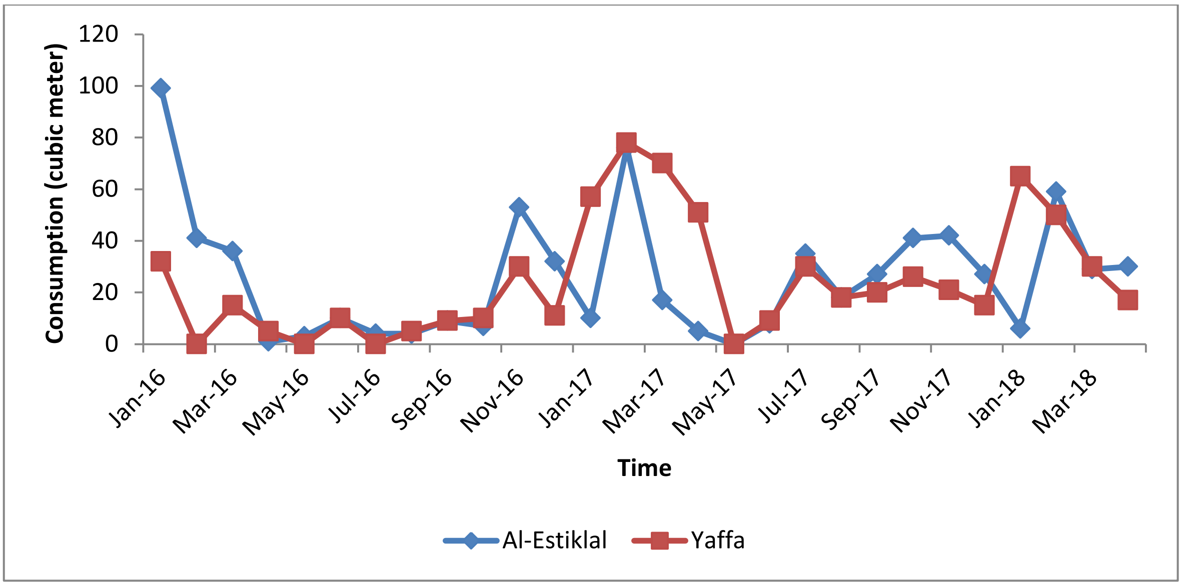

Figure 4.6: Water consumption in (m^3 unit) for Yaffa and Al-Estiklal schools during the period of Jan-2016 to Apr-2018. As it seems the higher water consumption was generated from Al-Estiklal school.

The statistics of water consumption revealed that the daily consumption for both schools was 2.3 m^3. Knowing that the schools contain approximately 920 persons including students and the staff along with the administration, the average wastewater production for each person was estimated to be 2.0 L/person/day and the estimated amount of wastewater generation was 80%, accordingly the daily production of wastewater was estimated to be 1.84 m^3/day.

4.2 Performance and Removal Efficiencies

The performance of the coupled system (ABR/GBF) was determined in terms of organic matter (OM) decomposition which occurred through the predominant anaerobic, aerobic and physical processes during the treatment process. Usually the OM is expressed in terms of BOD and COD.

4.2.1 The Characteristic of Raw Wastewater

The overall characteristic of raw wastewater during the study period was indicated in Table 4.3 below.

Table 4.3: The concentration of different parameters ± SD value for the raw wastewater during the study period.

Parameter	Concentration
COD	697.5 ± 43 mg/L
BOD_5	323 ± 26 mg/L
DO	0.19 ± 0.07 mg/L
EC	3770 ± 41 µS/cm
TNb	5.14 mg/L
PO_4-P	36 ± 1 mg/L
Total coliforms	$5.8*10^7$ CFU/100 ml
Fecal coliforms	1360 CFU/100 ml

Depending on the concentration of the previous parameters, the wastewater could be categorized as a high strength wastewater as presented in (Table 4.4).

Table 4.4: Typical municipal wastewater characterization (Metcalf and Eddy, 2003).

Constituents	Unit	Concentration		
		High	Medium	Low
COD	mg/L	800	430	250
BOD	mg/L	350	190	110
Nitrogen (Total)	mg/L	70	40	20
TOC	mg/L	260	140	80
Phosphorous (Total)	mg/L	12	7	4
TSS	mg/L	400	210	120
Cl^-	mg/L	90	50	30
$SO4^{-2}$	mg/L	50	30	20
Oil and Grease	mg/L	100	90	50

4.2.2 Biological Oxygen Demand Removal

The mean values of BOD during the period of the study were shown in (Figure 4.7) below. It was observed that the BOD concentration (except the last three rounds of sampling) in the ABR influent (S1) was 60-137 mg/L, 15-105 mg/L for the ABR effluent (S9) and 10-77 mg/L for the GBF effluent (Out).

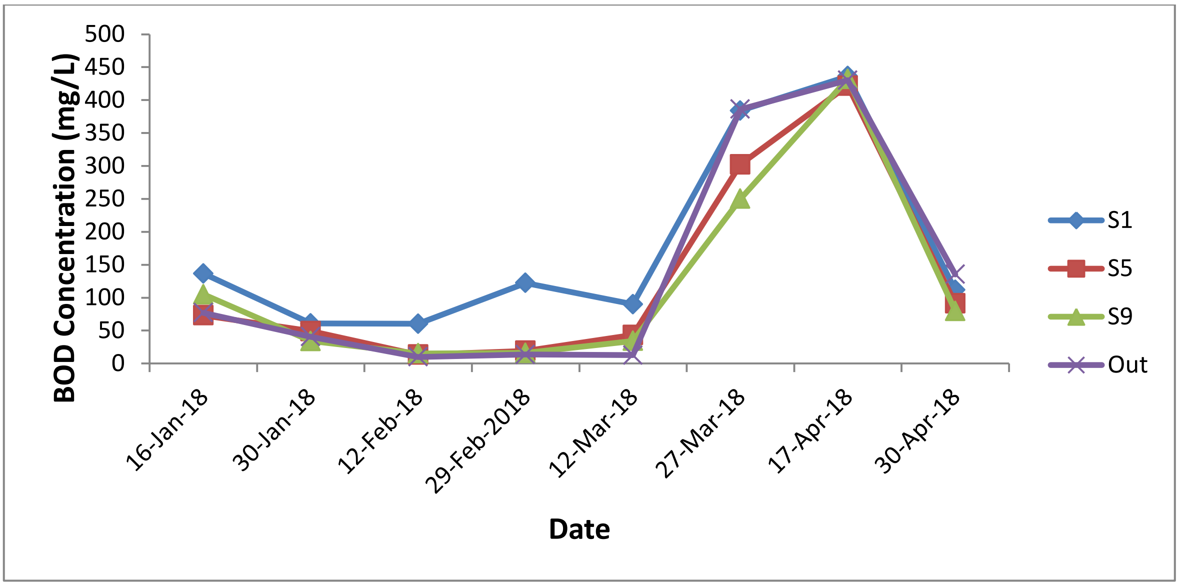

Figure 4.7: Concentration of BOD_5 (mg/L) for the different sampling points which including the ABR chambers S1, S5, S9 and the GBF outlet at different rounds of sampling during the study period.

The results showed a reduction of BOD values across the ABR chambers except for the last three rounds of sampling (the period from 27/Mar to 30/Apr) which indicates that treatment plant was not function well during this period and this can be attributed to the repeated usage of detergents that used for cleaning purposes in the schools. These detergents containing high concentrations of acids which reflected negatively on the treatment process through causing the death of bacteria that was responsible on the degradation of the organic matter. The average %BOD removal for the ABR system was calculated throughout the study period as demonstrated in Figure 4.8, the results showed accepted removal efficiency in the range between 23%-87% except for the following round of sampling (17/Apr) with a removal efficiency around 1% which indicates that treatment plant was not function well during this period.

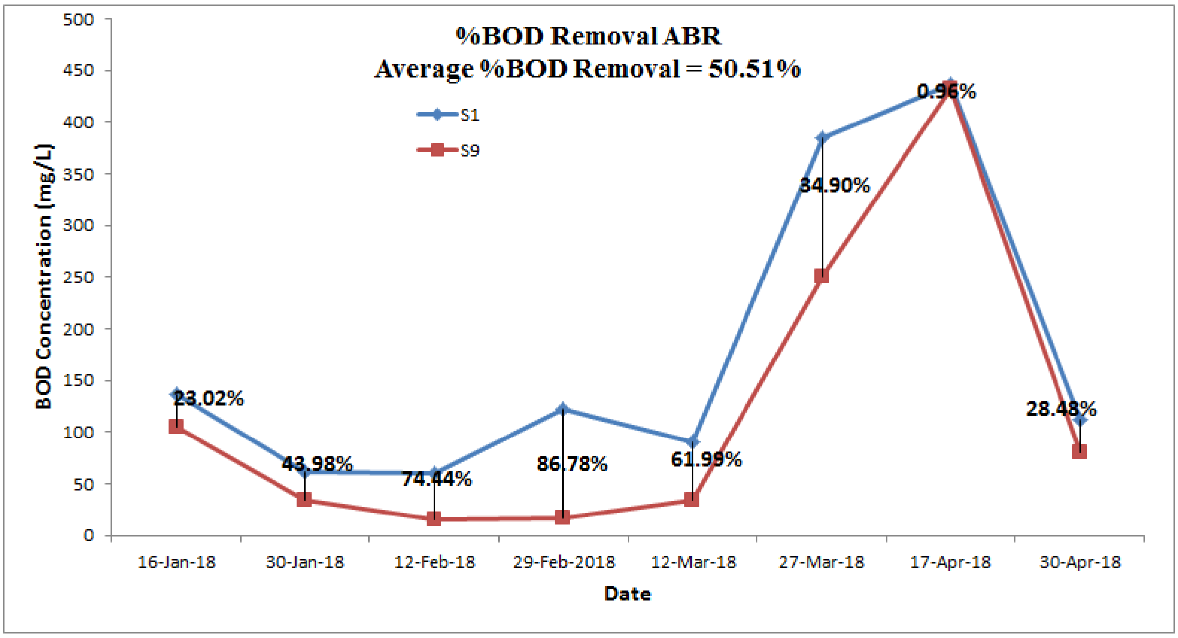

Figure 4.8: Concentration of BOD_5 (mg/L) for the influent (S1) and effluent (S9) of the ABR system related to the different periods of the study. The vertical lines were used to represent the average BOD removal percentage throughout the series rounds of sampling.

As Figure 4.9 shows the average %BOD removal for the coupled system (ABR/GBF) was in the range between 33%-89% which can be considered as an acceptable value if compared to the result achieved by Singh et al. (2009), whereas the BOD removal of the coupled system was around 78%. It is clear that the coupled system showed a normal removal efficiency of organic pollutants except the last three rounds of sampling and this confirm that the treatment plant was not functioning well through this period due to the death of bacteria that responsible on the degradation of organic matter.

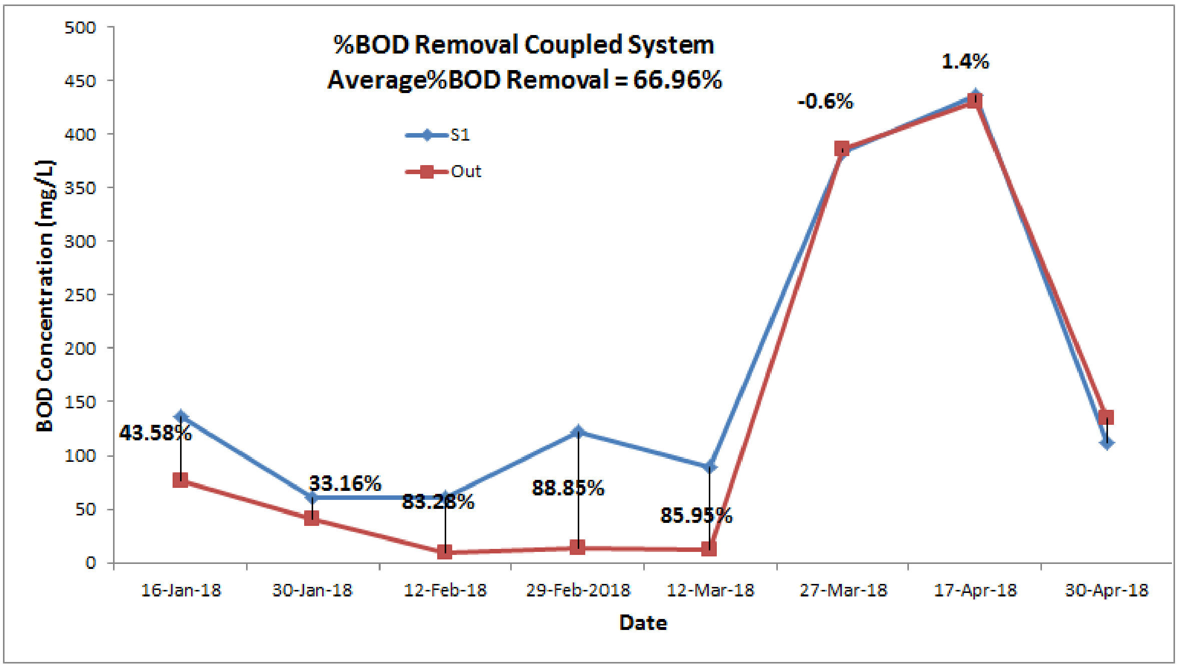

Figure 4.9: Concentration of BOD_5 (mg/L) for the influent (S1) and effluent (Out) of the coupled (ABR/GBF) system during the different periods of the study. The vertical lines were used to represent the average BOD removal percentage throughout the series rounds of sampling.

Depending on the Palestinian Standards, the effluent is with a medium quality and can be used for irrigation purposes. The BOD concentration in effluent was 10-77 mg/L which fit to a medium quality effluent that is suitable for irrigation purposes.

4.2.3 Chemical Oxygen Demand Removal

The mean values of COD during the period of the study were shown in (Figure 4.10) below. It is obvious that there was a net reduction of COD concentration across the treatment processes. The COD concentration (except for the following round of sampling that was in 27/Mar) in the influent of the ABR (S1) was 130-376 mg/L, 20-133 mg/L for the ABR effluent (S9) and 5-93 mg/L for the GBF effluent (Out). The COD concentration in the effluent fit to a medium quality effluent that is suitable for irrigation purposes. As it was noted all the samples showed a maximum values of COD concentration during 27/Mar (673 mg/L, 270 mg/L and 300 mg/L for S1, S9 and out respectively) which indicates that the treatment plant was receiving high organic load during this period which might be attributed to discharge of a huge amount of wastewater with high organic load from the schools to the plant. Then, during the last two rounds of sampling (17/Apr and 30/Apr) the COD values dropped again to it is normal range.

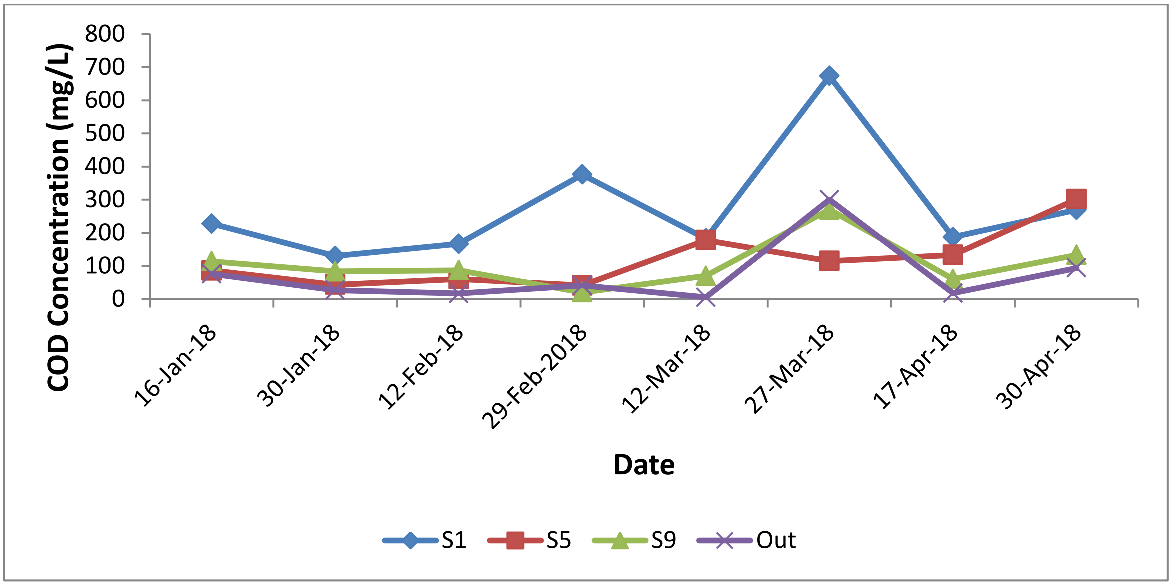

Figure 4.10: Concentration of COD (mg/L) for the different sampling points including the ABR chambers S1, S5, S9 and the GBF outlet at different rounds of sampling during the period of the study.

Both of the ABR and the coupled (ABR/GBF) system accomplished an acceptable organic pollutants removal with percentage COD removal to be between in the range of 36%-95% and 55%-97% respectively as indicated in (Figure 4.11) and (Figure 4.12) below. The obtained results fit to the result that was mentioned by Maria et al. (2015), the achieved removal rate of COD during their study was 80%-86%.

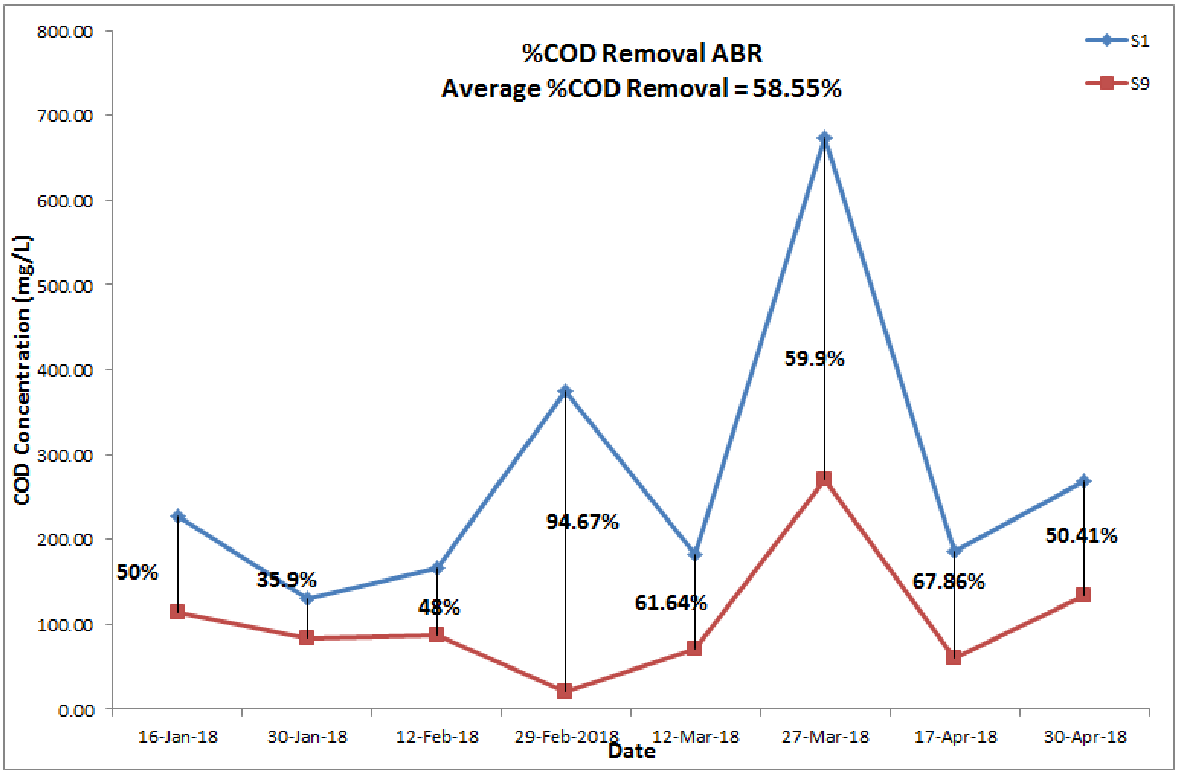

Figure 4.11: Concentration of COD (mg/L) for the influent (S1) and effluent (S9) of the ABR system related to the different periods of the study. The vertical lines were used to represent the average COD removal percentage throughout the series rounds of sampling.

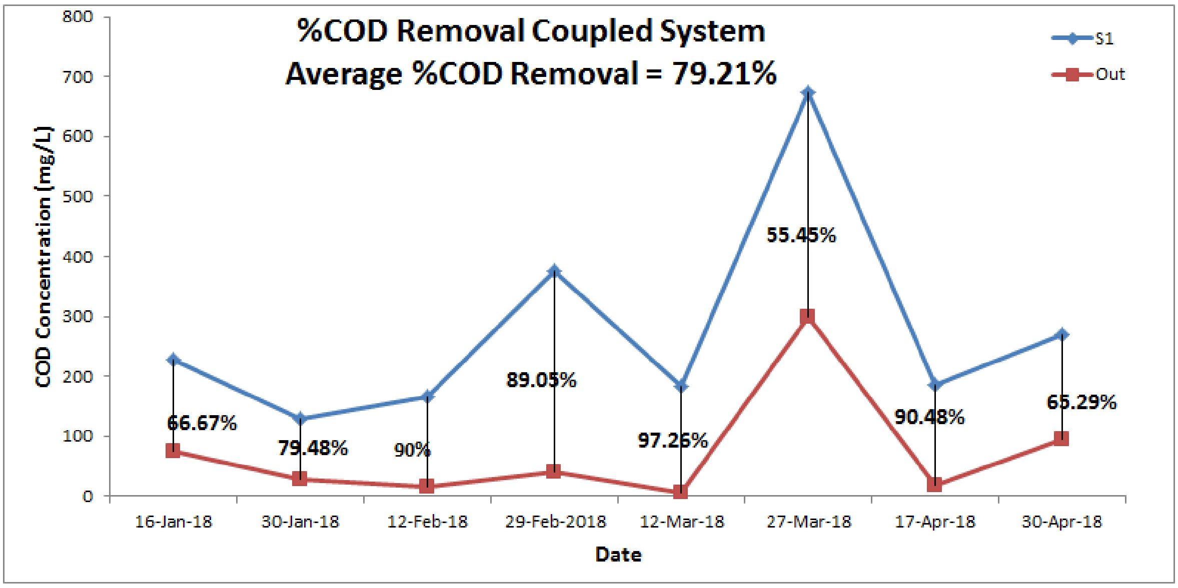

Figure 4.12: Concentration of COD (mg/L) for the influent (S1) and effluent (Out) of the coupled ABR/GBF system related to the different periods of the study. The vertical lines

were used to represent the average COD removal percentage throughout the series rounds of sampling.

4.2.4 Total Organic Carbon and Total Nitrogen

The mean values of total organic carbon (TOC) and total nitrogen (TNb) were shown in (Figure 4.13) and (Figure 4.14) respectively. As it was observed the TOC concentration in the ABR influent was 25-193 mg/L, 23-80 mg/L for the ABR effluent and the GBF effluent concentration was 15-41 mg/L. The results showed a reduction in the TOC concentration during the treatment process with an average removal efficiency of 43% and 60% for the ABR and the coupled system respectively except for the last rounds of sampling (30/Apr) which showed poor treatment efficiency and low percentage of TOC removal. Also, both influent and GBF effluent showed a maximum TOC value during 27/Mar which confirms that during this period wastewater with high organic load was flowed to the treatment plant.

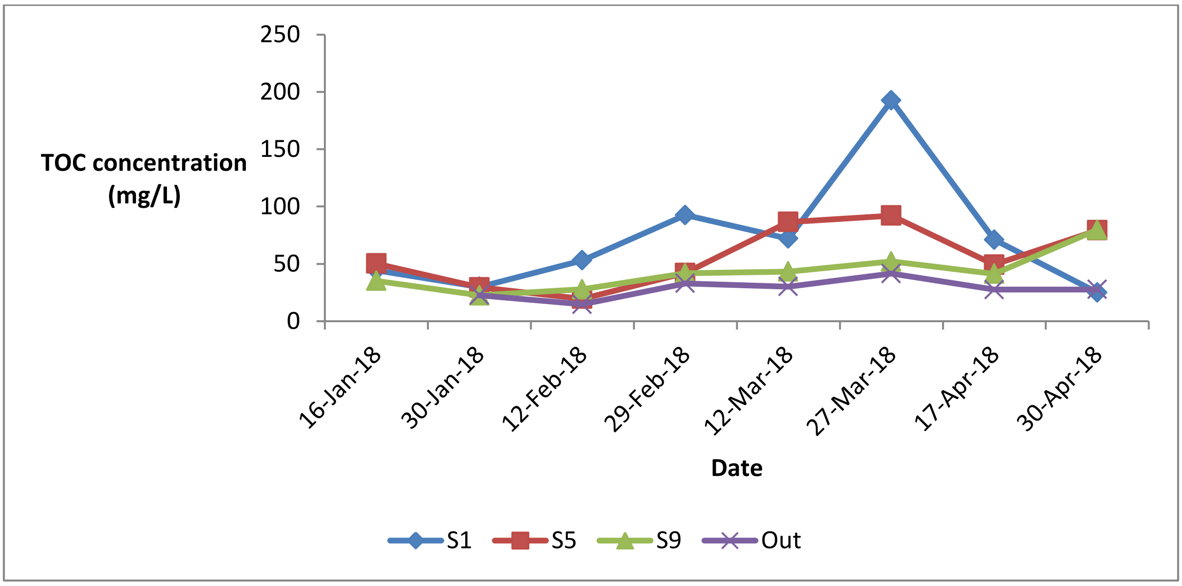

Figure 4.13: Concentration of TOC (mg/L) for the different sampling points including: S1, S5, S9 and out.

Regarding to total nitrogen (TNb) during the period of the study, the results showed a reduction of effluent TNb concentration except for the following periods (30/Jan, 17/Apr and 30/Apr) as it was demonstrated in (Figure 4.14). In addition, the TNb concentration in the influent was 43-379 mg/L and 14-176 mg/L in the GBF effluent with a maximum influent concentration during 27/Mar which can be attributed to the flow of high organic wastewater to the treatment plant.

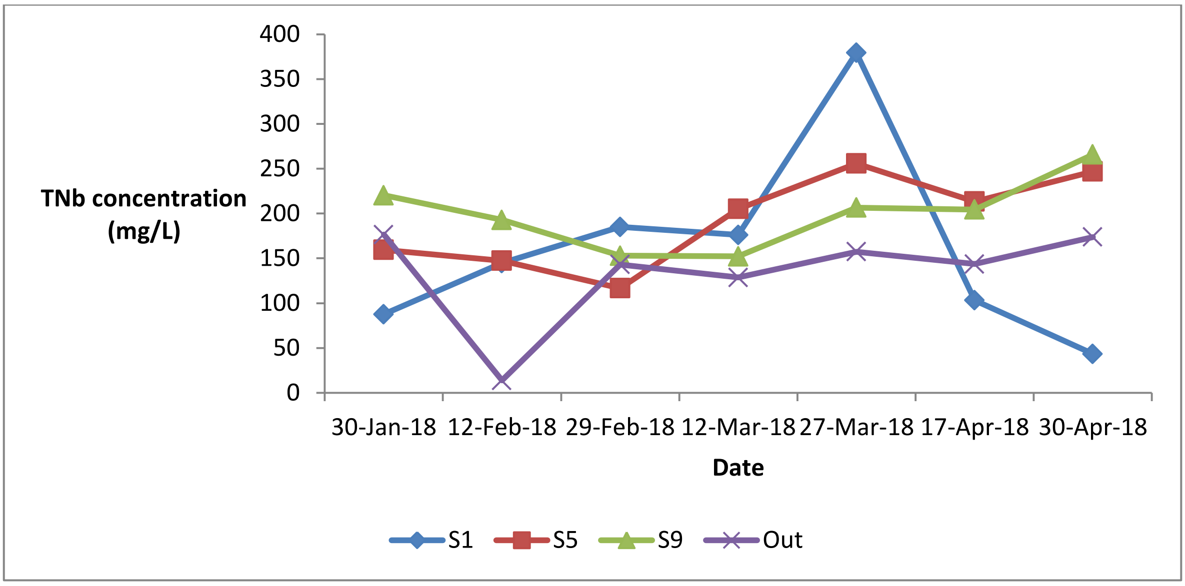

Figure 4.14: Concentration of TNb (mg/L) during the study period for the different sampling points

4.2.5 Ammonium Removal

The mean values of ammonium (NH^{4+}) were shown in (Figure 4.15) below. As it was observed the influent showed a maximum concentration during 27/Mar which can be attributed to the flow of high organic load wastewater to the system. Depending on the concentration of (NH^{4+}) in the effluent it assumed to fit medium quality and suitable for reuse.

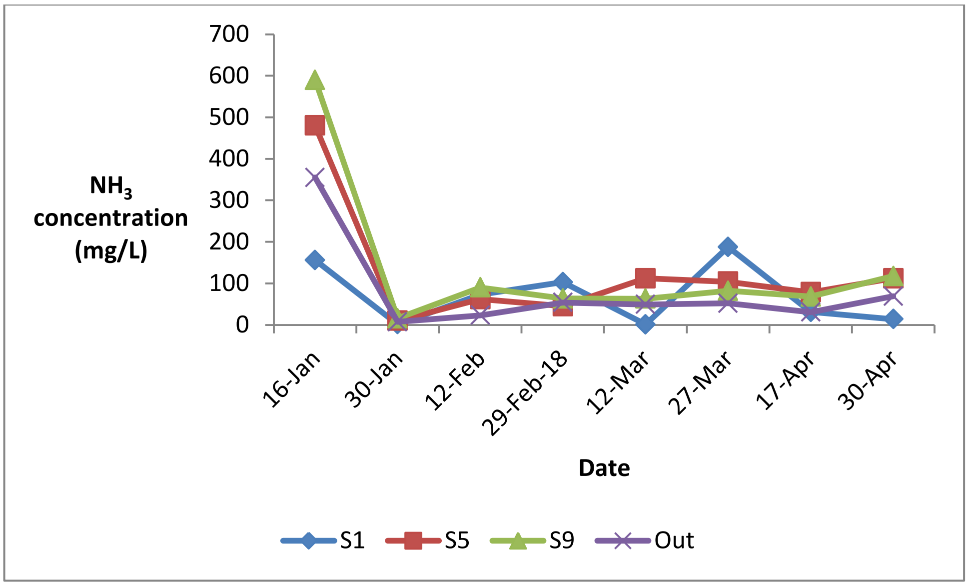

Figure 4.15: Concentration of ammonia (mg/L) during the study period for the different sampling points.

4.2.6 Electrical Conductivity and Turbidity

The results of EC and turbidity for the four sampling points were shown in Figure 4.16 and Figure 4.17 respectively. It was observed that the influent EC values were in the range 917-4360 µS/cm and showed a maximum value in 27/Mar (4360 µS/cm). The effluent EC values were in the range 529-2503 µS/cm which indicate slight to moderate salt content that is acceptable for reuse purposes (EC < 3000 µS/cm) (Jordanian Standards No. JS893/2006).

It is obvious that the turbidity varied significantly along the ABR compartments, however generally decreased at the end of the treatment, which means that the ABR retains particulate material.

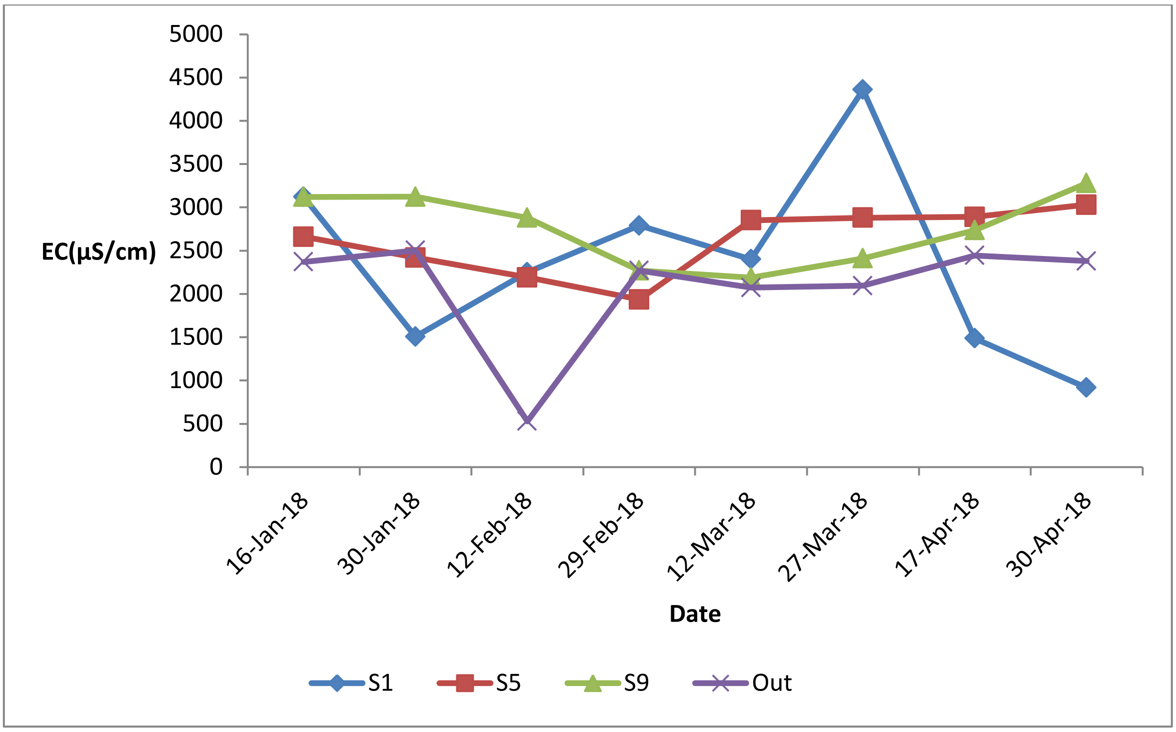

Figure 4.16: Electrical conductivity (µS/cm) behavior as a function of time in different treatment stages.

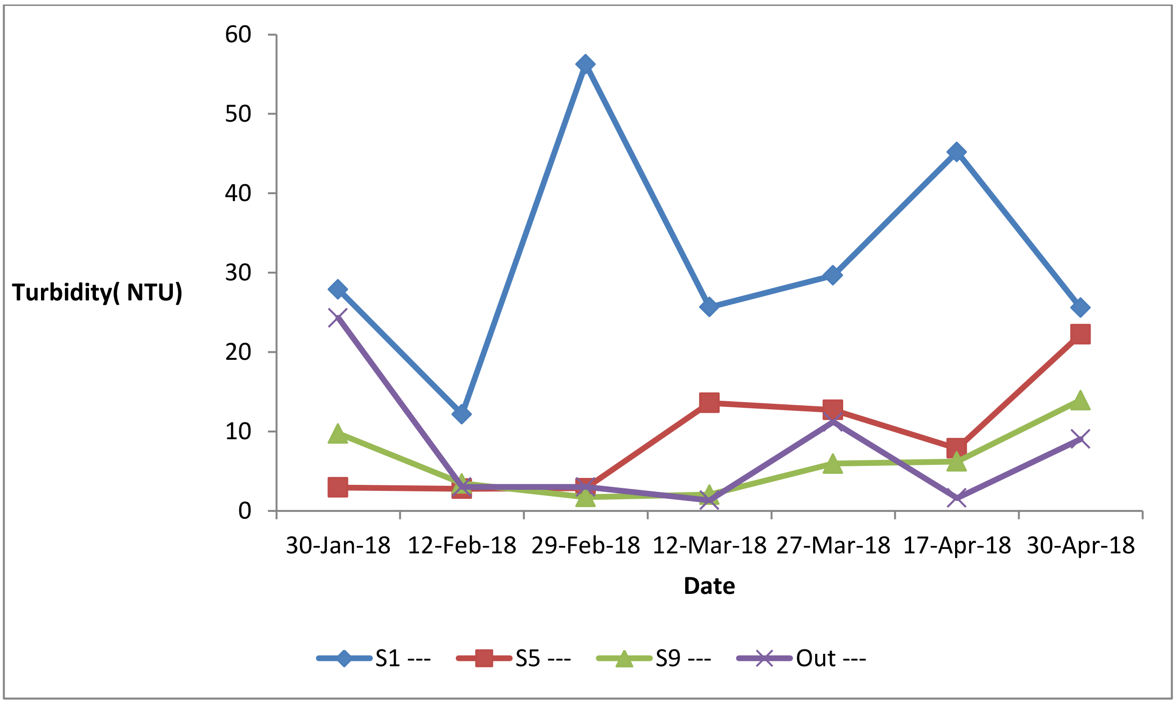

Figure 4.17: Turbidity behavior (NTU unit) as a function of time during the different treatment stages.

4.2.7 Total Suspended Solids & Total Dissolved Solids

The total suspended solids (TSS) & total dissolved solids were shown in Figure 4.18 & Figure 4.19 respectively. The TSS concentration in the influent was in the range between 12-37 mg/L and the effluent concentration was in the range between 12-39 mg/L. The TDS concentration in the influent was 559-2659.6 mg/L and the effluent concentration was 322-1527 mg/L with an average %removal efficiency of TSS to be 46%.

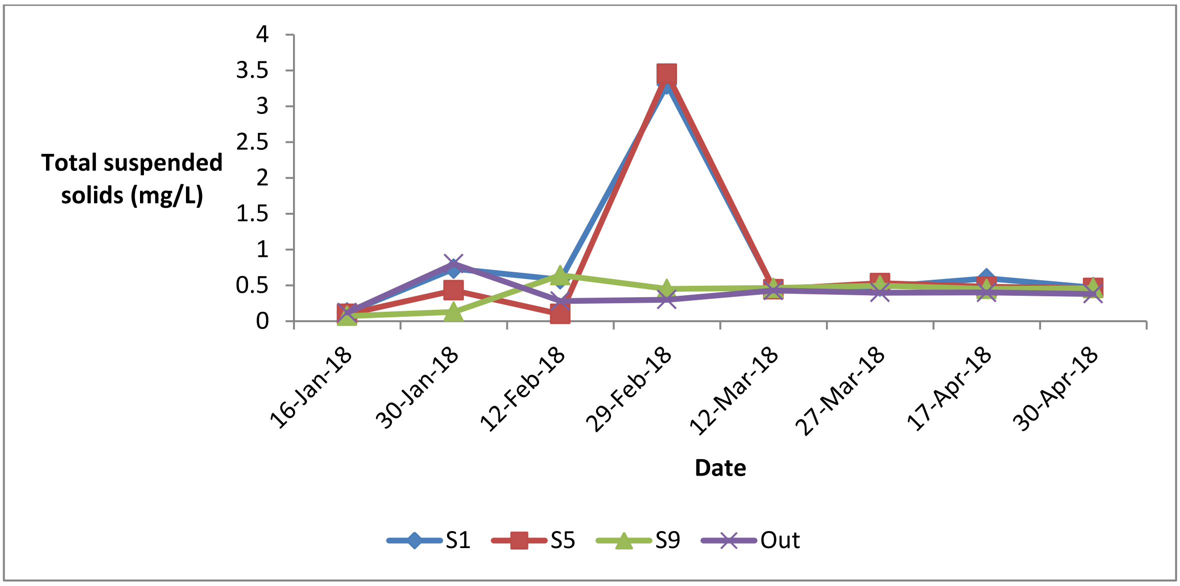

Figure 4.18: TSS concentration (mg/L) during the study peroid.

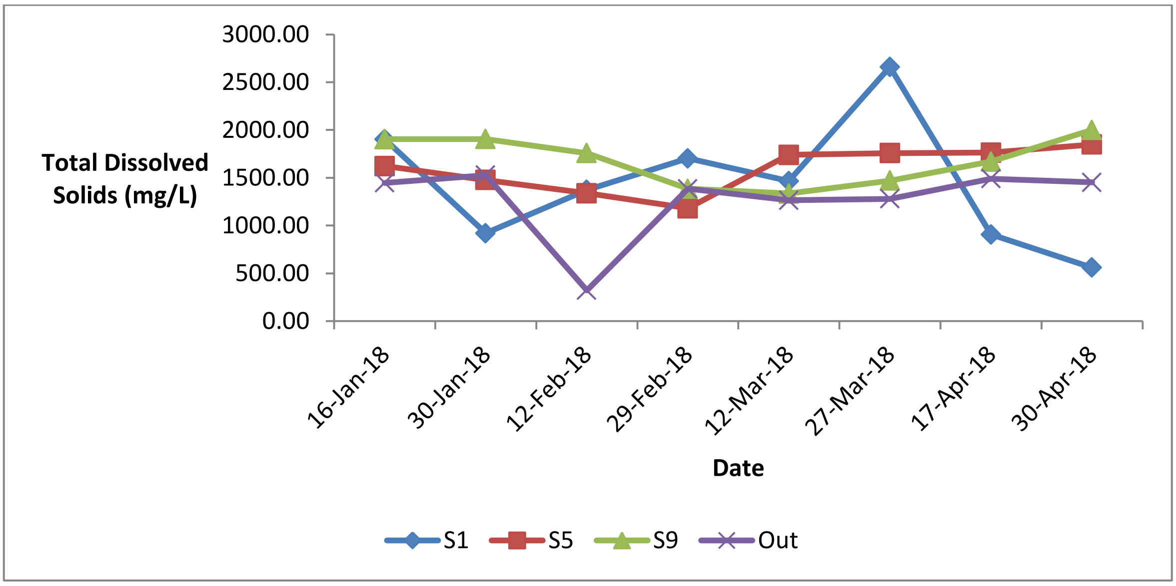

Figure 4.19: TDS concentration (mg/L) during the study period.

4.2.8 Acidity

The results of pH for the four sampling points were shown in (Figure 4.20) below. It was observed that there was a slight pH reduction among the compartments (if we compared S1 & S5). This can be attributed to the predominant anaerobic conditions in the ABR which results in the degradation of organic matter, formation of amino acids and finally cause a slight pH reduction. Moreover, the pH behavior among the compartments can be helpful in providing an indication about the dominant groups of organisms. Depending on the results, we can expect that the acidogenic groups are much more active in the first chamber while the last compartments (mainly chamber five (S5)) showed higher methanogenic activity. The effluent pH was 8- 9 which considered as acceptable pH range if compared to wastewater effluent (pH values 6 – 9) (Palestinian Standards No TS 34-2012). It was observed that the effluent showed a minimum pH value in 27/Mar.

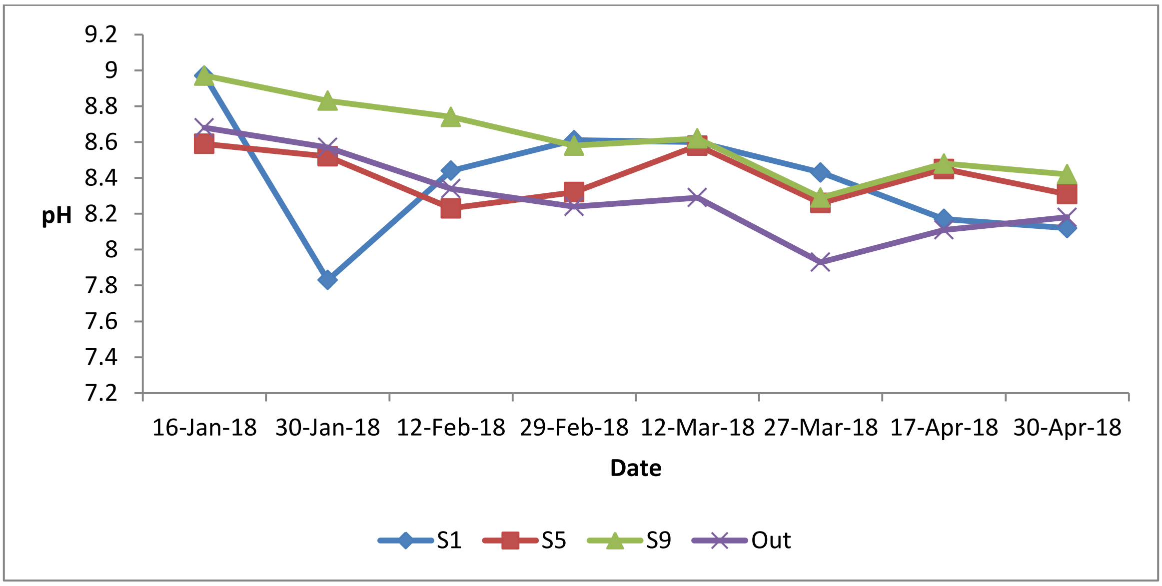

Figure 4.20: pH behavior as a function of time for the sampling points (S1, S5, S9, Out).

4.2.9 Fecal Coliforms and Total Coliforms

The microbial analysis during the period of the study showed a reduction in terms of fecal coliforms (FC) and total coliforms (TC) as indicated in Table 4.5 below. The results showed clearly that the coupled (ABR/GBF) was able to significantly reduce the F.C concentration from $4.0*10^6$ CFU/100ml to <1 CFU/100 ml.

In addition, the results revealed that the continuous usage of concentrated acidic detergents in the schools which later on mixed with wastewater and flow to the treatment plant was highly affected the microbial communities inside the ABR chambers and lead to bacterial death, and thus affect the biological treatment efficiency which was clearly appeared in some analytical results of the wastewater samples.

Table 4.5: Fecal coliforms and total coliforms in (CFU/100 mL).

	FC				TC			
Date	S1	S5	S9	Out	S1	S5	S9	Out
16/Jan/2018	0	2000	0	6000	$4.8*10^6$	$4.0*10^7$	$6.0*10^5$	1.0*106
30/Jan/2018	4*10^6	0	0	0	$7.4*10^6$	0	2000	2000
12/Feb/2018	0	0	0	0	0	6000	0	0
29/Feb/2018	4000	0	0	0	0	0	0	0
12/Mar/2018	1040	0	0	0	$2.6*10^7$	$1.6*10^6$	$2.0*10^6$	0
27/Mar/2018	0	0	0	0	0	0	0	0
17/Apr/2018	0	0	0	0	$1.84*10^7$	0	0	$1.6*10^6$
30/Apr/2018	0	0	0	0	0	0	0	0

4.3Assessment of Treated Wastewater Quality Based on Palestinian Standards

The effluent quality was investigated and compared with the Palestinians Standards for reclaimed water (see table 4.6). Depending on these standards, the obtained effluent meets the criteria of medium quality effluent (C) which can be used for irrigation purposes (see Table 4.7).

Table 4.6: Concentration of analyzed parameters for the effluent (all expressed in mg/L except for FC & TC that were expressed in CFU/100 ml unit and PH which is unitless).

Parameter	**Effluent**
	Concentration
COD	93
BOD_5	31
FC	0
PH	8-9
TSS	39

Table 4.7: Classification of the treated water according to its quality (Palestinian Standard PS 742-2003).

Parameter	**The Quality of the treated water**			
	High quality (A)	Good quality (B)	Medium quality (C)	Lowquality (D)
BOD_5	20	20	40	60
TSS	30	30	50	90
FC**	200	1000	1000	1000
COD	50	50	100	150
DO	>1	>1	>1	>1
TDS	1200	1500	1500	1500
PH*	6-9	6-9	6-9	6-9
Nitrate nitrogen, NO_3-N	20	20	30	40
Ammonium nitrogen,NH_4-N	5	5	10	15
TN	30	30	45	60

Note that: All chemical and biological parameters were expressed in (mg/L) unless otherwise stated.

*Unit less, **(CFU/100 ml).

4.4 Cost Analysis

The total capital costs and operational costs of the coupled system through 25 years were calculated as indicated in Table 4.8, Table 4.9 and Table 4.10 below.

Table 4.8: Capital costs in ($) of construction of the wastewater treatment plant.

Capital costs - WWTP		
Initial Capital Costs – WWTP	42,857	$
Total Life Span	25	years
Salvage value	40% of the initial value = (40*42857) = 17142.80	$
Depreciable cost	= (initial cost –salvage value) = 25,714	$
Depreciation	= (Depreciable cost/ life span) =1,029	$/year

Table 4.9: Capital costs in ($) for pump replacement.

Capital Costs - Pump replacement		
Reinvestment - new pump	159	$
Life Spam	5	years
Salvage value	0	$
Depreciable cost	159	$
Depreciation	32	$/year

Table 4.10: Operational costs in ($).

Operational Costs		
Energy consumption	-	$/year
Staff/Transport	1,782	$/year
Sampling and analysis	571	$/year
Total	2,353	$/year
Inflation	2%	/year
WWTP Capacity	5	m^3/day
	1,345	m^3/year

The total capital cost and the total operation & maintenance cost of the coupled system after 25 years was estimated to be 43,853$, 75,383$ respectively (The total capital cost will be 1754 $/year and the total O&M cost will be 3015 $/year). In addition, the average treatment cost was estimated to be 2.3 $/m³ (for more information see Annex D). If we compared the obtained values with the values that were obtained by Guo et al., 2014 and COWI Consulting, 2005 we can observe that the ABR/GBF coupled system have a moderate capital and O&M costs if compared to the other treatment technologies as indicated in Figure 4.21 and Figure 4.22 below.

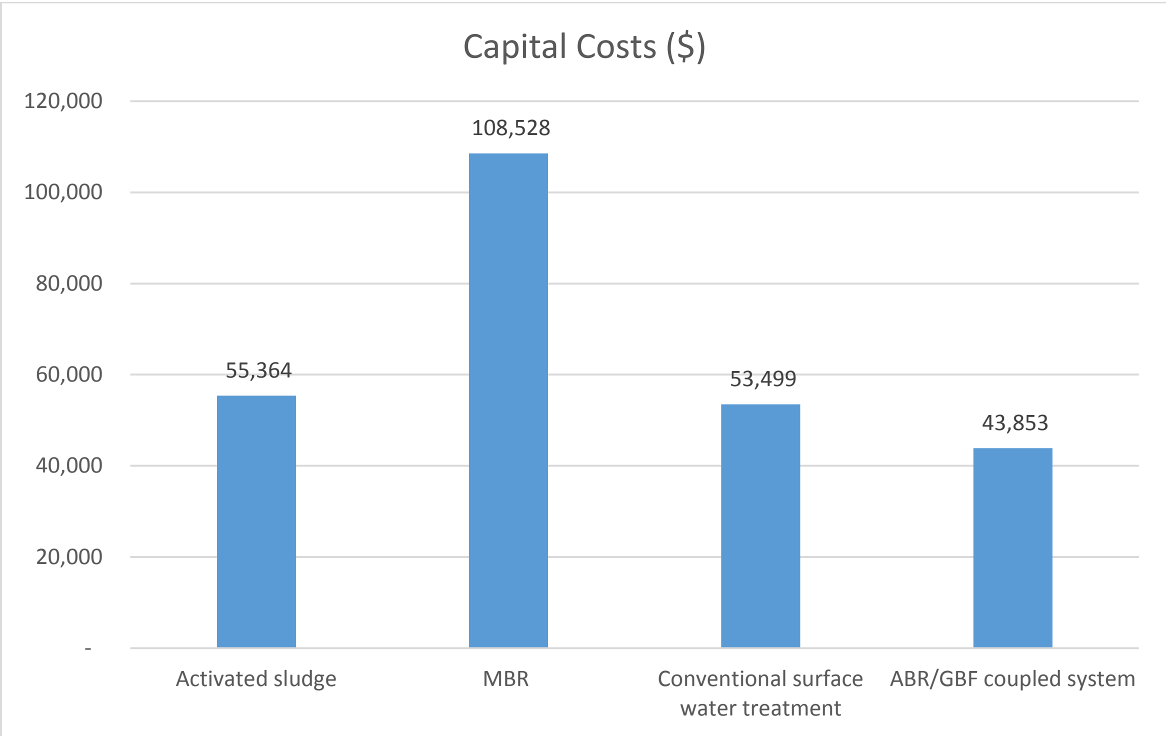

Figure 4.21: Capital costs in ($) for different treatment technologies including activated sludge, membrane bioreactor, conventional treatment of surface water and ABR/GBF coupled system (case of study).

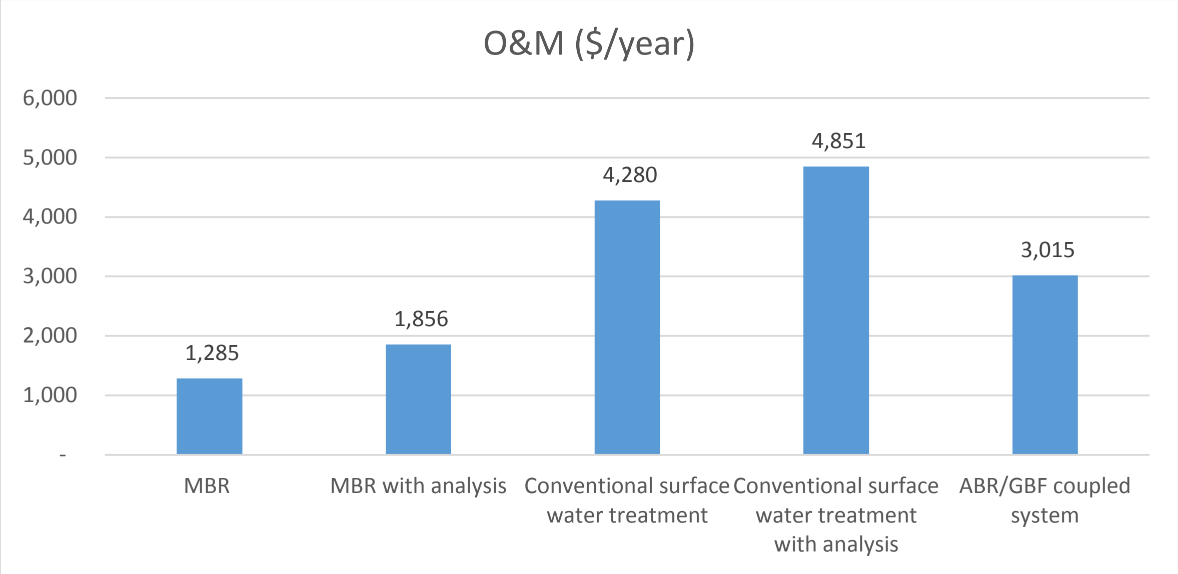

Figure 4.22: Operation and maintenance cost ($/year) for different treatment technologies including MBR, MBR with consideration of the analysis costs, conventional surface water treatment, and conventional surface treatment with consideration of the analysis costs and the coupled ABR/GBF system.

The last part in this section includes the depreciation rate of the plant for the 25 years which was discussed in more detail in the annex E.

4.4.1 Rehabilitation of the Wastewater Treatment Plant

During the operation period many incidents have occurred that negatively affect the operation of the ABR. Among these incidents the leakage problem from the ABR chambers to the gravel bed filter and from the gravel bed filter to the outside. In order to solve these problems a rehabilitation of the treatment plant was managed as the followings:

Phase 1: Determination of all the cracks from the ABR/GBF system and removing all the gravels from the bed filter. This phase includes the followings:

1. Cleaning the ground of the bed filter and remove any remained gravels, sands or dusts.
2. Stop the leakage / discharging the water outside the ABR chambers.
3. Close the pores by special material.
4. Painting the ground and the walls by a layer of black liquid asphalt as a primary layer to close all the cracks.

5. The ground and all internal walls of the gravel bed filter have been furnished by another layer of yareut of 4.0 mm thickness.

6. Return the gravel.

7. Protect the wetland by fence.

Phase 2: Protect and develop the wastewater treatment plant

This phase of rehabilitation includes the followings steps:

1. Strengthening the outer wall of the treatment plant through the addition of columns and concrete belt around the wall to avoid collapsing under water pressure inside the constructed wetland because the outer wall was belt only from blocks without any supporting irons.

2. The second step in this phase is to add a reservoir tank with capacity of 2000 L to accommodate the treated water resulted from the treatment plant before distribution either to schools as a flushing water or to the garden near the treatment plant or for both directions.

Chapter Five:

Conclusions and recommendations

5.1 Conclusions

The coupled ABR/GBF system was evaluated during the fourth months of operating period. The overall results of physical, chemical and biological analysis showed that the coupled ABR/GBF system could be promising in conducting onsite wastewater treatment and would provide an applicable alternative especially in countries with poor sanitation facilities. The ABR system has lower instillation, operation and maintenance costs if compared with conventional treatment systems.

The results of chemical analysis showed that the coupled system was able to reduce organic pollutants to acceptable levels. The average removal efficiencies of COD, BOD, TOC and TSS during the entire period of study were 55%-97%, 33%-89%, 60% and 46% respectively.

The microbial analysis indicated a high reduction of total coliforms and fecal coliforms which confirms that the effluent can be reused without further treatment for flashing toilets or irrigation purposes.

5.2 Recommendations:

Results revealed that the coupled treatment (ABR/GBF) system showed promising positive results that meet the Palestinian standers. Therefore the obtained results concluded that the effluent can be safely reused in gardening and other relevant uses. Several recommendations suggested through this research that would improve the performance of the treatment system and reduced the non-expected incidents during the operation period.

- The flow rate of the ABR influent should be regulated using an electronic flow meter positioned at the inlet and engaged with software in order to control the amount of feed to the ABR system and prevent over feed. This action will lead to stable operation conditions with continuous flow rate of wastewater.
- Further studies should be conducted to determine the effects of aeration on the performance and how this will affect the water quality.
- The recent study was concerned in evaluating the performance of the coupled system through school community which means that at summer period the wastewater feed stopped due to summer holiday. In this case the effluent should be recycled to the ABR chambers which according to Barber and Stuckey (1999) leads to reduce the removal efficiencies because the reactor becomes highly mixed so further studies should be applied in another community situation with continuous flow rate in order to observe the removal efficiencies in case without recirculation of effluent .
- More studies are required to determine the effect of covering and / or planting the gravel bed filter (GBF) and how this will be reflected at the removal mechanisms of nitrogen.
- Periodic and regular monitoring is recommended to the wastewater treatment plant through conducting regular sampling every two weeks and adjusting the samples to the necessary tests in order to ensure that the plant is functioning well and to prevent non-expected incidents.

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Appendices:

Annex A: Results of physical parameters

Average Results of the Electrical Conductivity (µS/cm) and turbidity (expressed in NTU unit) ± SD

	EC ± SD				Turbidity ±SD			
Date	S1	S5	S9	Out	S1	S5	S9	Out
16/Jan/2018	3120	2660	3120	2370	-----	------	-----	-----
30/Jan/2018	1506.33 ± 4.04	2420.00 ± 0.00	3123.33 ± 5.77	2503.33 ± 11.55	27.9 ± 0.10	2.94 ± 0.01	9.74 ± 0.02	24.31 ± 0.10
12/Feb/2018	2250.00 ± 0.00	2191.50 ± 2.65	2880.00 ± 0.00	528.67 ± 0.58	12.17 ± 0.21	2.78 ± 0.30	3.45 ± 0.01	3.01 ± 0.02
29/Feb/2018	2790.00 ± 0.00	1935.00 ± 0.00	2270.00 ± 0.00	2270.00 ± 0.00	56.25 ± 0.35	2.85 ± 0.11	1.73 ± 0.02	3.01 ± 0.06
12/Mar/2018	2400.00 ± 0.00	2850.00 ± 0.00	2186.67 ± 1.15	2071.67 ± 2.08	25.65 ± 0.21	13.60 ±0.42	2.03 ± 0.06	1.32 ± 0.01
27/Mar/2018	4360.00 ± 0.00	2880.00 ± 0.00	2410.00 ± 0.00	2095.50 ± 0.71	29.65 ± 0.21	12.70 ± 0.14	5.95 ± 0.06	11.20 ± 0.00
17/Apr/2018	1485.67 ± 2.89	2890.00 ± 10.00	2736.67 ± 5.77	2443.33 ±5.77	45.20 ± 0.28	7.87 ± 0.01	6.21 ± 0.18	1.61 ± 0.04
30/Apr/2018	916.67 ± 1.15	3030.00 ± 0.00	3280.00 ± 0.00	2380.00 ± 0.00	25.57 ± 0.15	22.23 ± 0.06	13.93 ± 0.06	9.03 ± 0.08

Annex B: Results of chemical parameters

Average Results of Biological Oxygen Demand and Chemical Oxygen Demand (expressed in mg/L unit) ± SD.

Date	BOD ± SD				COD ±SD			
	S1	S5	S9	Out	S1	S5	S9	Out
16/Jan/2018	136.54	73.07	105.11	77.03	227.27	86.36	113.64	75.76
30/Jan/2018	60.68 ± 23.34	49.09 ± 5.38	33.99 ± 6.81	40.56 ± 1.51	130.00 ±0.01	43.33 ±0.01	83.33 ±0.01	26.67 ±0.01
12/Feb/2018	60.24 ± 19.35	13.41 ± 10.31	15.40 ± 7.79	10.07 ± 9.84	166.67 ±0.01	60.00 ±0.01	86.67 ±0.01	16.67 ±0.01
29/Feb/2018	122.31 ± 14.58	19.15 ± 0.03	16.17 ± 0.86	13.64 ± 0.11	375.56 ± 0.01	41.11 ± 0.01	20.00 ±0.01	41.11 ± 0.01
12/Mar/2018	89.98 ± 23.16	43.21 ± 5.03	34.20 ± 9.82	12.64 ± 8.39	182.50 ±0.01	177.50 ±0.01	70.00 ± 0.01	5.000 ±0.01
27/Mar/2018	249.95 ± 13.90	302.31 ± 33.57	383.92 ± 26.64	386.24 ± 16.18	673.33 ±0.01	115.00 ± 0.01	270.00 ± 0.01	300.00 ± 0.01
17/Apr/2018	421.86 ± 12.70	436.18 ± 3.03	432.00 ± 1.55	430.08 ± 1.01	186.67 ±0.01	133.33 ± 0.01	60.00 ± 0.01	17.78 ± 0.01
30/Apr/2018	111.61 ± 44.18	91.48 ± 8.65	79.82 ± 0.21	135.40 ± 42.58	133.33 ± 0.01	301.11 ± 0.01	268.89 ± 0.01	93.33 ±0.01

Average Results of Ammonia (expressed in mg/L unit) ± SD

Date	**NH_3 ± SD**			
	S1	**S5**	**S9**	**Out**
16/Jan/2018	156	480	590	355
30/Jan/2018	1.5 ± 0.01	10.08 ± 0.01	15.75 ± 0.01	7.33 ± 0.01
12/Feb/2018	72.70 ± 0.01	62.00 ± 0.01	90.33 ± 0.01	23.00 ± 0.01
29/Feb/2018	103.00 ± 0.02	45.00 ± 0.01	63.67 ± 0.01	54.00 ± 0.02
12/Mar/2018	1.00 ± 0.01	112.00 ± 0.02	63.00 ± 0.01	49.33 ± 0.01
27/Mar/2018	187.67 ± 0.02	104.00 ± 0.01	82.00 ± 0.01	52.00 ± 0.01
17/Apr/2018	31.00 ± 0.01	78.67 ± 0.01	68.00 ± 0.01	30.67 ± 0.01
30/Apr/2018	13.67 ±0.01	112.00 ±0.01	117.67 ±0.01	69.00 ± 0.01

Average results of pH ± SD

	pH ± SD			
Date	S1	S5	S9	Out
16/Jan/2018				
30/Jan/2018	7.83 ± 0.01	8.52 ± 0.01	8.83 ± 0.01	8.57 ± 0.24
12/Feb/2018	8.44 ± 0.02	8.23 ± 0.04	8.74 ± 0.01	8.34 ± 0.06
29/Feb/2018	8.61 ± 0.01	8.32 ± 0.01	8.58 ± 0.01	8.24 ± 0.01
12/Mar/2018	8.60 ± 0.01	8.58 ± 0.01	8.62 ± 0.01	8.29 ± 0.01
27/Mar/2018	8.43 ± 0.00	8.26 ± 0.01	8.29 ± 0.01	7.93 ± 0.01
17/Apr/2018	8.17 ± 0.00	8.45 ± 0.01	8.48 ± 0.01	8.11 ± 0.01
30/Apr/2018	8.12 ± 0.02	8.31 ± 0.01	8.42 ± 0.00	8.18 ± 0.01

Annex C: Results of biological parameters

Fecal coliforms and total coliforms in (CFU/100 mL)

	FC				TC			
Date	S1	S5	S9	Out	S1	S5	S9	Out
16/Jan/2018	0	2000	0	6000	$4.8*10^6$	$4.0*10^7$	$6.0*10^5$	1.0*106
30/Jan/2018	4*10^6	0	0	0	$7.4*10^6$	0	2000	2000
12/Feb/2018	0	0	0	0	0	6000	0	0
29/Feb/2018	4000	0	0	0	0	0	0	0
12/Mar/2018	1040	0	0	0	$2.6*10^7$	$1.6*10^6$	$2.0*10^6$	0
27/Mar/2018	0	0	0	0	0	0	0	0
17/Apr/2018	0	0	0	0	$1.84*10^7$	0	0	$1.6*10^6$
30/Apr/2018					0	0	0	0

Annex D: Capital costs and O&M costs in ($/year)

Years	Capital Costs ($/year)	Operational Costs ($/year)	Capital and Operational Costs ($/year)	Total Flow (m^3/year)	Treatment Cost ($/$m^3$)
0	43,016	-	43,016	1,345	32.0
1	0	2,353	2,353	1,345	1.7
2	0	2,401	2,401	1,345	1.8
3	0	2,449	2,449	1,345	1.8
4	0	2,498	2,498	1,345	1.9
5	0	2,547	2,547	1,345	1.9
6	179.23	2,598	2,778	1,345	2.1
7	0	2,650	2,650	1,345	2.0
8	0	2,703	2,703	1,345	2.0
9	0	2,757	2,757	1,345	2.1
10	0	2,813	2,813	1,345	2.1
11	197.88	2,869	3,067	1,345	2.3
12	0	2,926	2,926	1,345	2.2
13	0	2,985	2,985	1,345	2.2
14	0	3,044	3,044	1,345	2.3
15	0	3,105	3,105	1,345	2.3
16	218.48	3,167	3,386	1,345	2.5
17	0	3,231	3,231	1,345	2.4
18	0	3,295	3,295	1,345	2.5
19	0	3,361	3,361	1,345	2.5
20	0	3,429	3,429	1,345	2.5
21	241.22	3,497	3,738	1,345	2.8
22	0	3,567	3,567	1,345	2.7
23	0	3,638	3,638	1,345	2.7
24	0	3,711	3,711	1,345	2.8
25	0	3,785	3,785	1,345	2.8
Total	43,853	75,383	119,236		

Note that:

- **The Capital Costs ($/year) were calculated using the next formula:**

Capital Costs ($/year) = cost of reinvestment of new pump * (1 + inflation (2%))$^{\wedge Year}$…. **Equation 1.**

Regarding to the capital costs for the year zero it is the sum of the initial costs of construction and reinvestment of a new pump. Then, during the followings five years the capital costs was estimated to be zero. At the sixth year the capital costs was estimated using equation 1.

- **The Operational Costs ($/year) were calculated using the next formula:**

Operational Costs ($/year) = initial operational cost * (1+ inflation (2%))……. **Equation 2**

Regarding to the operational costs it is zero for the year zero and equal to the calculated value of the operational costs during the first year. Then, during the following years from the second year to the 25 year were estimated using equation 2.

- The total flow in (m^3/year) was considered to be constant with time.
- The treatment cost ($/$m^3$) was calculated through dividing the total operational and capital costs over the total flow.

Annex E: Depreciation rate through time

Years	Capital Costs ($/year)	Depreciation - WWTP ($/year)	Depreciation - Pumps ($/year)	Assets Value ($)
0	43,016	-	-	43,016
1	0	1,029	32	41,956
2	0	1,029	32	40,895
3	0	1,029	32	39,835
4	0	1,029	32	38,775
5	0	1,029	32	37,714
6	179.23	1,029	32	36,833
7	0	1,029	32	35,773
8	0	1,029	32	34,712
9	0	1,029	32	33,652
10	0	1,029	32	32,591
11	197.88	1,029	32	31,729
12	0	1,029	32	30,668
13	0	1,029	32	29,608
14	0	1,029	32	28,548
15	0	1,029	32	27,487
16	218.48	1,029	32	26,645
17	0	1,029	32	25,585
18	0	1,029	32	24,525
19	0	1,029	32	23,464
20	0	1,029	32	22,404
21	241.22	1,029	32	21,585
22	0	1,029	32	20,524
23	0	1,029	32	19,464
24	0	1,029	32	18,403
25	0	1,029	32	17,343