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Performance Evaluation of Beit-Lahia Wastewater Treatment Plant in the Northern Gaza Strip

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بسم الله الرحمن الرحيم

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

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

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مستخلص

تعتبر محطة بيت لاهيا وبحيرة المياه العادمة (شبه المعالجة) الناتجة عنها مصدر أساسي لتلوث الخزان الجوفي والبيئة المحيطة. في الفترة الممتدة من فبراير إلى مايو 2005م، تم قياس العديد من الفحوصات الميدانية والمخبرية بالإضافة إلى مراجعة قياسات التشغيل خلال السنوات القليلة الماضية بهدف تقييم أداء المحطة من خلال قدرتها على إزالة الملوثات. حاولت الدراسة تحديد العوامل التي تؤدي إلى تقويض المعالجة وإزالة الملوثات في المحطة. تم تقييم كل مرحلة من مراحل المعالجة ومساهمتها في عملية الإزالة الكلية للملوثات.

أظهرت نتائج التحاليل في السنوات الماضية والفترة الحالية تراجعاً ثابتاً في كفاءة إزالة الأكسجين المستهلك حيوياً والأكسجين المستهلك كيماوياً والمواد الصلبة العالقة بالإضافة إلى البكتيريا القولونية. أزال نظام المعالجة في بيت لاهيا خلال برنامج المراقبة 87% من المواد الصلبة العالقة، 57% من الأكسجين المستهلك حيوياً، 60% من الأكسجين المستهلك كيميائياً، 20% من نيتروجين كلدال الكلي، 13% من الأمونيا، 15% من الأورثوفسفور، و94.7% من البكتيريا القولونية وقد كان تركيز هذه المواد في المياه الناتجة عن أخر مراحل المعالجة على الترتيب كالتالي 39 ملجم/لتر، 178 ملجم/لتر، 72 ملجم/لتر، 84 ملجم/لتر، 72 ملجم/لتر، 5.5 ملجم/لتر، 2x10^5وحدة/100 مل . انخفاض كفاءة إزالة الملوثات ربما يعود إلى زيادة الحمل العضوي والهيدوروليكي اللذان يتعديان قدرة المحطة، و إلى الأخطاء في تصميم المحطة وتشغيلها.

وقد خلصت الدراسة إلى أن زيادة الحمل العضوي والهيدروليكي، محدودية إمداد النظام بالأكسجين، والتصميم الغير ملائم لأبعاد الأحواض وعمقها هي العوامل الرئيسية التي أدت إلي انخفاض في أداء المحطة وقدرتها على إزالة الملوثات. وقد قدمت الدراسة بعض الإقتراحات مثل اعادة ترتيب مداخل و مخارج الأحواض و اضافة قواطع ، مصفاه دقيقة، أو وحدة كلورة كحلول قصيرة المدى لرفع كفاءة المحطة جزئياً وتحسين أداؤها.

ABSTRACT

Wastewater treatment plant at Beit Lahia and its partially treated effluent lake are considered the primary sources of pollution for the ground water and ambient environment. From February to May 2005, Field and laboratory tests were conducted and historical operating data were evaluated to assess the system performance in term of removal efficiency for the hybrid lagoon system. This study attempts to distinguish the factors leading to the inadequate performance of the BLWWTP in removing organic matter and nitrogen. The efficiencies of the different stages of the treatment and the global performance have been compared.

Collection and analysis of available historical data revealed a constantly decreasing removal of biochemical oxygen demand (BOD_5)*, chemical oxygen demand (COD), suspended solids (SS), and fecal coliform (FC). Analysis of data showed that the lagoon system removed 87%, 57%, 60 %, 20%, 13%, 16%, and 94.7% of the influent TSS,* BOD_5*, COD, TKN, NH3,* PO_4^{-2}*, and FC respectively with an effluent concentration of 39 mg/L, 178 mg/L, 72 mg/L, 84 mg/L, 72 mg/L, 5.5 mg/L, and 2.04E+05. The decreasing removal of pollutants appeared to be caused by increased hydraulic and organic load that exceeds treatment plant capacity, incorrect design that lead to inefficient hydrodynamics, and inadequate operation.*

Over hydraulic and organic loadings, limitation of Oxygen supply and unavailability of DO, inadequate design of plant geometry and high facultative and maturation ponds depth are the main factors leading to inadequate treatment system performance. The study present suggestions like repositioning of inlets and outlets and/or adding baffles, micro-screen, and chlorination unit which can be introduced as short and simple solutions to overcome and improve partially the inefficiencies and poor treatment plant performance.

DEDICATION

I wish to dedicate this **thesis** to my parents who have supported me all the way since the beginning of my studies.

Also, this **thesis** is dedicated to my wife, beloved sun Assim, beloved sun Mohammed, and beloved daughter Farah who have been a great source of motivation and inspiration.

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Raed M. Al-Khaldi

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LIST OF ABBREVIATIONS AND ACRONYMS

°C	Degrees (S) Celsius.
µS/cm	microSiemens/cm.
APHA	American Public Health Association.
BLWWTP	Beit Lahia Wastewater Treatment Plant.
BOD_5	5 Days Biochemical Oxygen Demand.
CAMP	Costal Aquifer Management Program.
cfu	Colony Forming Unit.
COD	Chemical Oxygen Demand.
Conc.	Concentrated.
EC	Electrical Conductivity.
EQA	Environmental Quality Authority
FC	Fecal Coliform.
h	Hour.
KW	Kilo Watts.
L	Liter.
MCM	Million Cubic Meters.
MGD	Million gallons per day
mg/L	Milligrams per Liter.
MOLG	Ministry of Local Governorate.
MOPIC	Ministry of Planning and International Cooperation.
NH_3	Ammonia.
O-P	Ortho-Phosphate.
pH	Hydrogen Potential.
ppm	Parts per Million.
PWA	Palestinian Water Authority.
SAR	Sodium Adsorption Ratio.

TDS	Total Dissolved Solids.
Temp.	Temperature
TFS	Total Fixed Solids.
TKN	Total Kjeldahl Nitrogen.
TP	Total Phosphorus.
TS	Total Solids.
TSS	Total Suspended Solids.
TVS	Total Volatile Solids.
UNEP	United Nation Environment Program
WHO	World Health Organization.
WSP	Waste Stabilization Pond.
WWTP	Waste Water Treatment Plant.

CHAPTER (1): INTRODUCTION

1.1 BACKGROUND

Gaza strip suffered years of occupation, negligence and infrastructures destruction. This caused rapid deterioration of all aspects of life including the fragile environment. Continuous closure of the Palestinian territories and the presence of permanent checkpoints disrupt civil society and aggravate the present pollution and resource depletion problems. In an already densely populated area, there is rapid population growth, scarcity of water, limited access to water resources, a long term refugee problem and desertification and land degradation.

Quality of the groundwater is a major problem in Gaza strip. The aquifer is highly vulnerable to pollution. The domestic water is becoming more saline every year and average chloride concentrations of 500 mg/L or more is no longer an exception. The permissible limits for nitrate are exceeded by a factor of eight for a number of public wells. Most of the public water supply wells don't comply with the drinking water quality standards and concentrations of chloride and nitrate of the water exceed the World Health Organization (WHO) standards in most drinking water wells of the area and represent the main problem of groundwater quality. Over pumping of groundwater and salt water intrusion are the main reasons behind high chloride concentration **(CAMP, 2000).** The uncontrolled discharge of untreated sewage to the ground surface and excessive use of fertilizers led to high nitrate levels in certain areas. With the limited rainfall and high evapotranspiration of the Gaza strip it may take long time to restore fresh water conditions in the aquifer **(EQA, 2004)**.

In Gaza strip, access to sewerage facilities at present varies from areas where more than 90 % of the households are served by well-functioning sewerage systems, to areas where there is no sewerage system at all. On average, it is estimated that about 60% of the population is connected to a sewerage network **(UNEP, 2004)**. Cesspits and boreholes are the other wastewater disposal systems in the area. The larger urban centers, with the exception of Khan Yunis, are equipped to some extent with a sewerage network. The densely populated refugee camps in the Middle Area is served partially with sewerage facilities, whereas Jabalya camp is well served. There are three treatment plants in Gaza strip, at Beit Lahia, Gaza City and Rafah, but none is functioning effectively **(MOPIC, 1998)**. The effluent from Gaza and Rafah treatment plants is mostly discharged into the Mediterranean Sea. In the case of the Beit Lahia wastewater treatment plant (BLWWTP), a substantial quantity of wastewater infiltrates into the ground, contaminating soil and groundwater in the area.

The total annual wastewater production in the area is estimated to be 30 Million Cubic Meter (MCM), of which 20 MCM passes into sewerage network and the rest to cesspits or pit latrines **(EQA, 2002)**. Waste vacuum tankers used to clear out cesspits should be transported to a treatment plant or to a disposal area designed specifically to deal with liquid waste. The present practice is to dump the waste into the nearest open wadi, into agriculture drainage channels, or onto open fields. Based on given data by Gaza Wastewater Master Plan, the projection of wastewater volumes will be increased four fold between 2005 and 2025, reflecting high population growth in the region and with corresponding pressures on the environment **(MOPIC, 1998)**.

1.2 SCOPE AND LIMITATION

The purpose of this study is to evaluate the performance of BLWWTP by reviewing the historical and existing monitoring data in the last five years as well as data generated by the researcher during the research period through a comprehensive field and laboratory analysis program of wastewater collected samples from different locations of the treatment plant. From these data, the options available to improve the performance of the plant and mitigate health and environmental problems will be examined, conclusions will be drawn and recommendations will be presented.

Performance was evaluated in term of removal system efficiency of a group of physical, chemical and biological parameters. The main limitation of the work was the lack of some chemical and reagents which used in analysis. This led to the fact that some other parameters couldn’t be accomplished. In addition, 24 h composite samples and flow measurements couldn’t be performed due to the sensitive and security conditions of the area.

1.3 RESEARCH JUSTIFICATIONS

The BLWWTP is located near one of the finest ground water aquifers in Gaza. High level of nitrate has recently been detected from the aquifer, and it is most likely that the excess effluent is responsible for the deterioration of the water quality of the aquifer **(Abu-Jalalah, 1999)**. Approximately 15,000 cubic meter of partially treated wastewater from the northern cities is discharged daily to surrounding sandy areas. The discharge of these high quantities of partially treated wastewater to the sandy areas causes serious problems which could be summarized in the following points:

- Aquifer pollution (high level of nitrate and detergents): In the wintertime, the pools become flooded by additional water from rainfall, which causes wastewater to flow, and in turn, to become a major source of groundwater pollution. As a result, water abstracted from the ground water wells is frequently polluted.
- Health hazards: These pools are a major source of pollution for the environment. Abundance of flies and insects which result from the pools have caused the spread of different diseases in the community - especially among children - including "*Gairdia lamblia*" and "*Entamoeba histolytica*",
- Odors problems: The pools cause odors nuisance for the citizens whom living beside the plant particularly in the summertime.
- Flooding the agricultural and residential surrounding area

On the base of the above reasons, The BLWWTP and its effluent lake is one of the major environmental hot spots where urgent remedial action is required. This study seeks to identify limiting performance factors of the treatment plant to produce effluent that may meet standards for reuse purposes and reduce or eliminate effect on the groundwater and environment.

1.4 AIM AND OBJECTIVES

The objectives of this study are to:

- § Evaluate and document the performance of treatment system with respect to the removal efficiency of BOD_5, COD, TSS, NH_3-N and other chemical and biological parameters.
- § Determine the measures that are needed for optimal operation and maximum waste removal.
- § Determine the performance limiting factors leading to inadequate treatment and inefficient pollutant removal.
- § Obtain data concerning the amount of organic and hydraulic loading that would be introduced into the treatment system.
- § Determine a short term solution that can be implemented to reduce or eliminate environmental impact of the effluent.
- § Recommend future upgrades on the short term.

1.5 METHODOLOGY

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

1- Historical operating data for the treatment plant were collected

2- Monitoring program was conducted to determine current performance data. Grape Samples were collected fortnightly for three and half months from the outlet of each treatment unit to assess physical, chemical and biological parameters.

3- Analysis of the results carried out to evaluate the efficiency of overall treatment plant and each treatment unit.

4- The results were compared against the design criteria and current standards.

5- By inspecting historical and generated data, the long-term treatment performance of the system was evaluated.

1.6 THESIS OUTLINE

Chapter one presents general introduction about environment and water situation in Gaza strip in the first section, while scope and limitation of this study, justification of selection of this topic, purpose, and objectives were displayed in the middle sections. Methodology and thesis outline are stated in the last two sections of chapter one.

Chapter two reviews the literature related to the kind of treatment process (waste stabilization pond) under evaluation in this study. At the opening section, all information about the study area that may be useful for the research were presented. Origin design, existing status, ongoing and planned activities of BLWWTP as well as its environmental impact on the surrounding area are given in section two. To provide a contextual framework for the treatment method under examination in this thesis, an introduction to the waste stabilization pond technology and its advantage, disadvantage, type of ponds and its function in addition to removal mechanism of different pollutant inside these ponds are given in the last section of this chapter.

Chapter three deals with material and methods that used and followed in conducting monitoring program. All media, reagents, and equipments that used in the laboratory experiments and field measurements are presented in section one. Section two contained sampling site selection, sample collection, physical, and chemical and biochemical analysis, in addition to microbiological analysis. The last section of this chapter displayed analysis of data.

Results were presented in chapter four that contained two sections. The first presented previous monitoring data of the treatment system, while the second displayed in details the results that generated from study monitoring program.

Discussion of findings is given in chapter five. Analysis of technical performance aspects, factors leading to inadequate treatment performance, and system modifications are given in sections one, two, and three respectively.

The conclusions and recommendations of the study are stated in the final chapter of the thesis. Thesis structure is shown in figure 1.1.

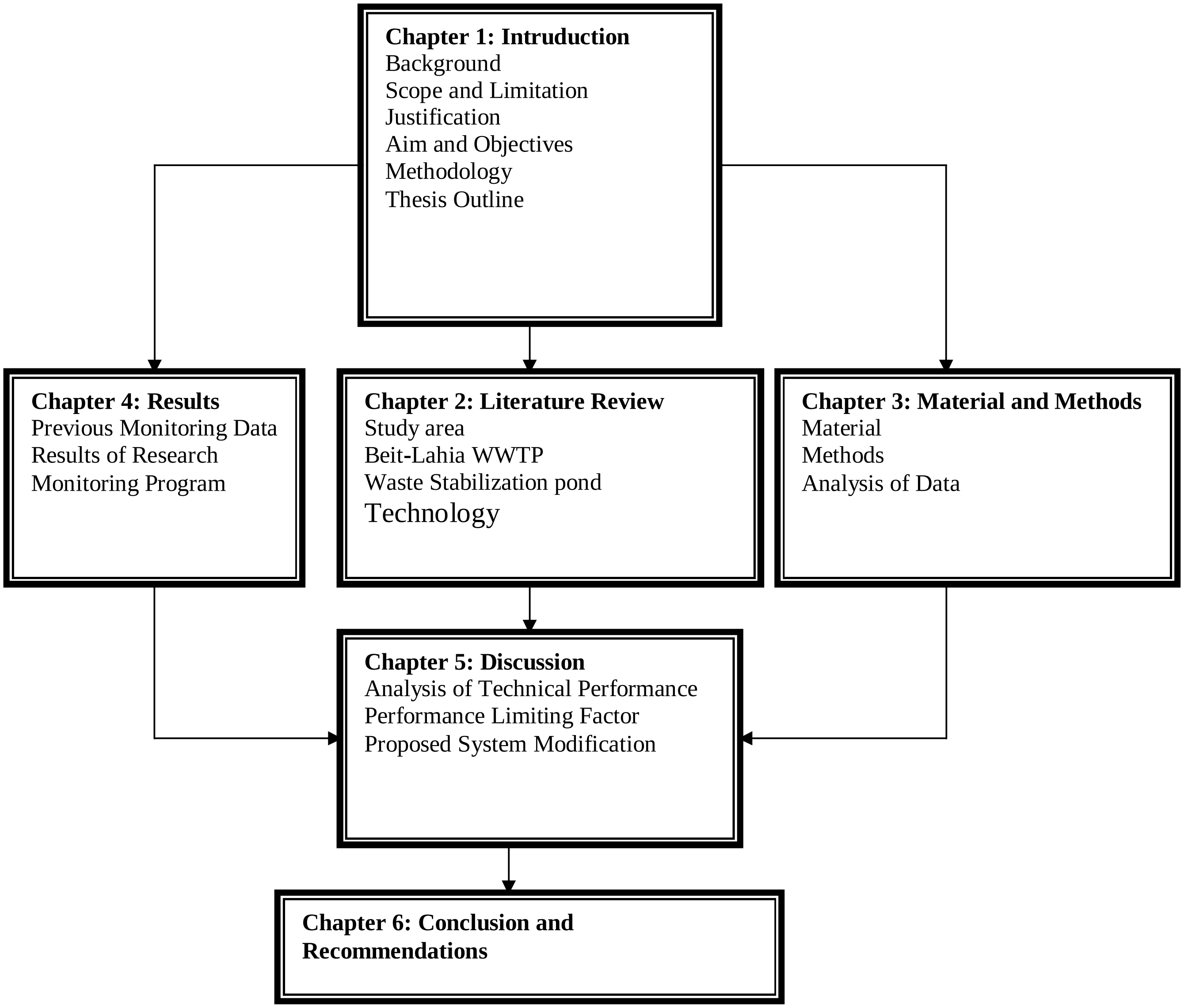


Figure 1.1: Thesis Structure.

CHAPTER (2): LITRETURE REVIEW

This chapter reviews the literature related to different environmental elements of the study area including wastewater situation and wastewater treatment process (waste stabilization pond and aerated lagoon) under evaluation in this study. Origin design, existing status, ongoing and planned activities of BLWWTP as well as its environmental impact on the surrounding area are given. An introduction to the waste stabilization pond/ aerated lagoon technology and its advantage, disadvantage, type of ponds and its function in addition to removal mechanism of different pollutant inside these ponds are given in the last section of this chapter. This will provide a contextual framework for the treatment method under examination in this thesis.

2.1 STUDY AREA

2.1.1 Location and Population

The Gaza strip is situated in the southeastern coast of Palestine with Longitudes of 34:21:38 E and Latitudes of 31:29:45 N. The area is bounded by the Mediterranean in the west, the 1948 cease-fire line in the north and east and by Egypt in the south (see figure 2.1). The total area of the Gaza strip is 365 km^2 with approximately 40 km long and the width varies from 8 km in the north to 14 km in the south **(UNEP, 2003)**. The total area of North Gaza Governorate is 62 square kilometers that is constituted 17% of total southern governorates **(PNIC, 1999)**. The population number in the north governorate reached about 265 thousand peoples divided as presented in table (2.1).

Table 2.1: Projected Mid-Year Population for North Gaza Governorate (2004-2006).

Locality Name	**Mid-Year Population**		
	2004	2005	2006
Aum El-Naser	2,501	2,618	2,739
Beit Lahia	54,385	56,919	59,540
Beit Hanun	29,400	30,770	32,187
'Izbat Beit Hanun	6,744	7,058	7,383
Jabalya Camp	85,363	89,340	93,455
Jabalya	75,700	79,228	82,877
Total	**254,093**	**265,932**	**278,180**

****Source: Palestinian Central Bureau of Statistics (PCBS), 2005.***

2.1.2 Administration

The Gaza strip consists of five Governorates; Northern, Gaza, Middle, Khan Yunis and Rafah. The municipalities or the village councils are responsible for public services, where Palestinian Water Authority (PWA) and Ministry of Local Governorate (MoLG) take the coordination role between the different municipalities and village councils concerning water and sanitation works. Nowadays, Palestinian water Authority as a regulator had put a plan towards the creation of Coastal Municipal Water Utility (CMWU) in Gaza strip which collects the municipal water departments that belongs to 16 municipalities and 9 village councils in a separate entity. This entity will be responsible for operation of water sector. Currently, the operation of water and wastewater sector in the northern governorate is lie under the charge of Common Service Council.

2.1.3 Climate

Gaza strip has an arid to semi arid Mediterranean climate. The southern part is almost arid while the northern is a semi arid to moderately humid climate. Rainfall occurs only in the winter season from October to the end of April. The last 14 year average rainfall larger form around 247 mm, in the south to more than 474 mm in the north **(MOPIC, 1997)**. The average annual temperature in the Gaza strip is form 19 °C to 21 °C and the maximum value is in August and ranges from 26-28 °C, while the minimum occurs in January from 12-14 °C **(MOPIC, 1997)**. The humidity rate in summers is about 65% during the daytime and 85% at night time in summers and reaches about 60% during the day and night times in winters. The average annual potential evaporation is about 1200 to 1400 mm **(PNIC, 1999)**.

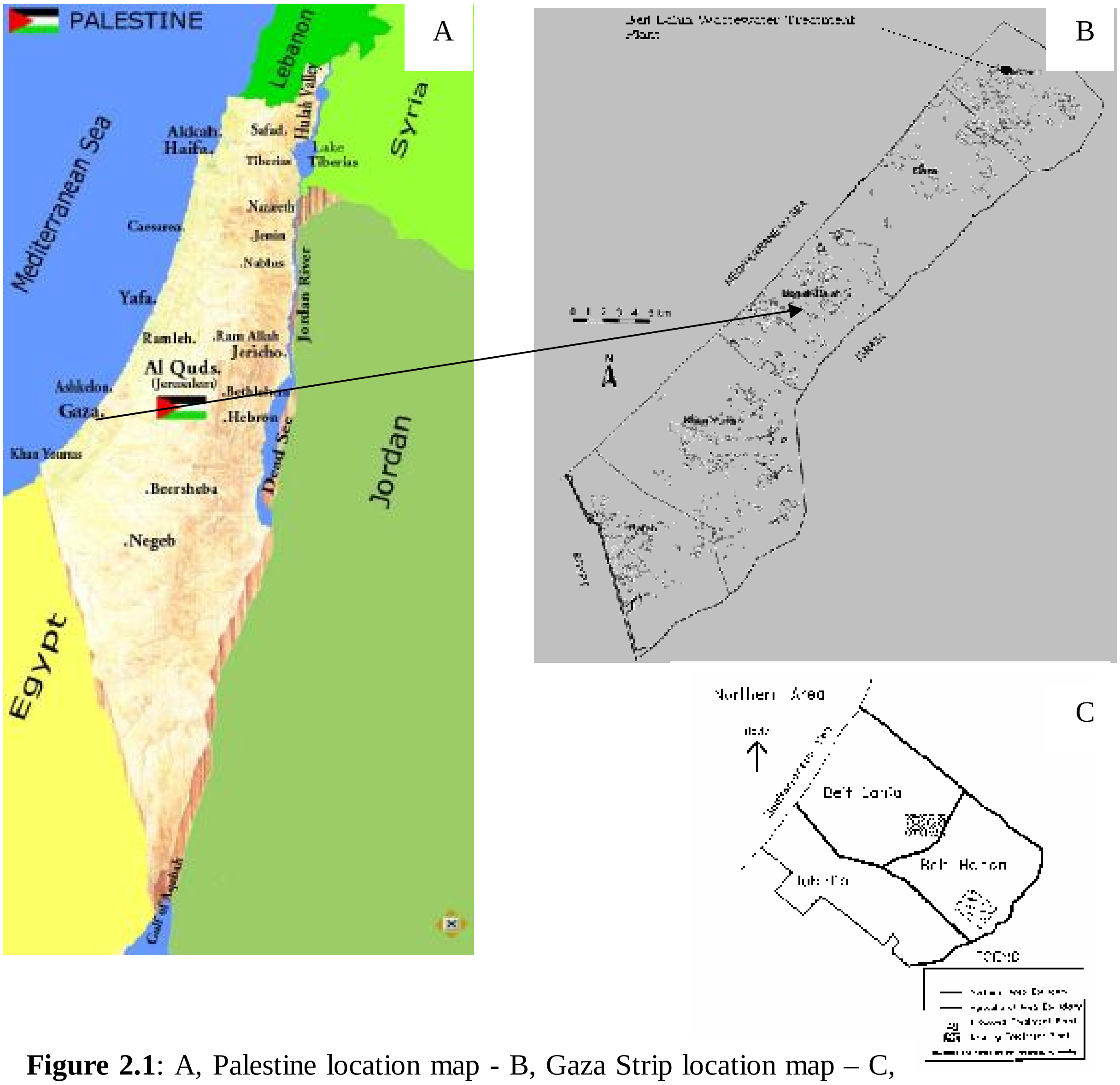


Figure 2.1: A, Palestine location map - B, Gaza Strip location map – C, Beit-Lahia location map.

2.1.4 Demography

The population in Gaza strip is about 1.36 million with an annual growth rate of 3.9% **(PCBS, 1997)**. The average population density is almost 2297 person/km^2. The population density in the refugee camps of the Gaza Governorates ranges form 29 to 100 thousands person/km^2 in the Beach camp **(PCBS, 1997).** Table 2.2 shows the revised estimates of the population projection in Gaza strip as given by PCBS in 2005.

Table 2.2: Revised estimates of the population projection in Gaza strip.

Year	Mid Year Population	Growth Rate (%)	Year	Mid Year Population	Growth Rate (%)
1997	995,522	4.3	2007	1,499,369	3.8
1998	1,039,528	4.4	2008	1,556,201	3.7
1999	1,086,970	4.5	2009	1,614,018	3.6
2000	1,137,990	4.6	2010	1,672,785	3.5
2001	1,188,130	4.0	2011	1,732,438	3.5
2002	1,236,372	4.0	2012	1,792,895	3.4
2003	1,286,109	3.9	2013	1,854,353	3.3
2004	1,337,236	3.9	2014	1,917,019	3.3
2005	1,389,789	3.8	2015	1,980,825	3.2
2006	1,443,814	3.8			

Source: PCBS, 2005.

2.1.5 Historical View

Over the last eighty years, the Palestine was under Turkish, British, Egyptian and Israeli rule, The Israeli military occupation lasted for twenty-seven years. At the beginning of the twenty century, the entire region formed part of Turkish Ottoman Empire. After World War I, the Ottoman Empire was dismantled and the British ruled Palestine under the British mandate. In 1948, the Mandate was over and Israel declared independence as a Jewish state within 70% of the land of Palestine. Hundreds of thousand of Palestinians at that time fled their homes to neighboring countries and the West Bank and Gaza strip, where they live at refugee camps up to the present.

After signing of the Palestinian – Israeli Declaration of Principles (DOP) in Oslo in 1993 and the agreements for its implementation, the West-Bank and Gaza strip constitute a new Palestinian entity. After the Israeli disengagement from Gaza strip in September, 2005, it is expected to enable the Palestinian people to look for better human and environmental living conditions.

2.1.6 Land Ownership and Land Use

Land is one of the main scar natural resources in the Gaza strip. Land ownership is the major factors that play a role in any development plan. The major part of the Gaza strip land is owned by the private sector. Table 2.3 shows the distribution of land ownership in the Gaza strip. Table 2.4 presents the distribution status of land use in Gaza strip.

Table 2.3: Distribution of land ownership in the Gaza strip.

Land Ownership Type	Area (hectare)	Percentage
Governmental land	5300	14.5
Previous Occupied Settlement and Yellow a area [a]	5700	15.6
Private land	18540	50.8
Wagf land : Ownership by Ministry of Islamic Affair	760	2.1
Beir el-Saba'a land [b]	6200	17
Total	**36500**	**100**

Source (MOPIC, 1998)

[a]: Yellow area is the border area and security area

[b]: Beir El-Saba'a land is a governmental land taken that has been taken by private sector without any legal agreement.

Table 2.4: Land use distribution status in the Gaza strip

Land Ownership Type	**Area (hectare)**	**Area in %**
Build up area	5750	15.8
Previous Israeli settlement and Yellow area	5700	15.6
Agricultural area	16700	45.7
Unused land	8350	22.9
Total	**36500**	**100**

Source MOPIC, 1998

2.1.7 Water Resources

Due to the tremendous population increase, the water demand in Gaza strip increased sharply. The main source of water in the area is Groundwater. The existing situation, with annual recharge of 60 MCM and a deficit of approximately 55 MCM/year, has led to reduction in the available quantities of groundwater as well as degradation of water quality. The sustainable management of the available and renewable water resources together with developing new water resources are the main objectives of many projects in the area **(Afifi, 1998)**.

The surface water system in Gaza strip consists mainly of wadis. The major wadi is Wadi Gaza, which originates in the Negev Desert. Its catchment area is about 3500 km^2. The estimated average annual flow of Wadi Gaza is 20 to 30 Mm^3 **(PWA, 1997)**. In 1994 the runoff was estimated at about 40 Mm^3 , where the rainfall in the Gaza strip that year was about 1000mm. Dry periods lasting a couple of years without any significant runoff are experienced as well. When surface runoff occurs, it occurs during a limited number of days. In addition to Wadi Gaza, there are two small and insignificant wadis in Gaza strip, Wadi El-Salqa in the south flows to the sea and Wadi Beit Hanon in the north flows partially to the sea and partially into Israel. Presently, surface water resources are not more available in the Gaza Strip due to Israeli violations.

Groundwater in the Gaza strip is a confined Pleistocene age costal aquifer. It is divided into three sub-aquifers composed mainly of sand, sandstone and pebbles **(PWA, 1997)**. The sub-aquifers overlie each other and are separated by impervious and/or semi-pervious clay and clayey layers. The thickness of the aquifer in the eastern boundary is about 10 m and increasing gradually to about 150 m at the coast. The pumping test results indicate that the aquifer is highly permeable with a transmissivity of about 1000 m^2 /day and an average porosity of 25%. Depth to water level ranges from 8 to 90 meter in the West and the East of the Strip respectively **(PWA, 1997).**

Wastewater reuse, sea water desalinization, and rain-storm water harvesting are the main non-conventional water resource in Gaza strip. Reclaimed wastewater needs to be considered as one of the major source of water either for agriculture or for groundwater recharge but till now limited steps have been taken in this regards. Using treated effluent for irrigation will minimize the demand on groundwater for agricultural purposes and will reduce the degradation of the groundwater quality **(Afifi and Tubail, 1998)**. Sea water desalinization is another option that adopted to satisfy future demand.

Groundwater quality in the Gaza strip is changed in both Horizontal and vertical direction. The fresh groundwater is not distributed evenly through-out the Governorates. The Chloride ion (Cl^-) concentration of the pumped water is ranging form less than 250 PPM to more than 1500 PPM. Nitrate concentration is generally ranging form 50 PPM to more than 200 PPM all over the area even for aquifers that contain fresh waters. Highly saline water is found also in some places along the coast reflecting sea water intrusion. The thickness of the fresh water aquifer can be estimated at 10-50 meter. The Nitrate ion (NO_3^+) concentration is very high and range from about 30 PPM to more than 500 PPM. The highest level of nitrate is normally found beneath residential areas that are not provided with a sewer system. Most of the pumped water (about 42 Mm^3/yr.) used for domestic purposes contain high concentration of chloride and nitrate as shown in table (2.5)

Table 2.5: Chloride and Nitrate concentration in the pumped water used for domestic purposes

Area	**Cl^- < 250 PPM. (%)**	**NO_3^+ 50 PPM. (%)**
Northern Area	98	10
Gaza Area	23	6
Middle Area	4	81
Khan Yunis	18	47
Rafah	1	1

Source (PWA, 1997)

2.1.8 Agriculture and Industry

Based on Palestinian National Information Center in 1997, the agricultural used land area is about 38 thousand dunums distributed as given in table 2.6.

Table 2.6: Distribution of agricultural land area in Gaza strip.

Crop Type	**The way of irrigation**		**Total**
	Un-irrigated	**irrigated**	
Fruitful	646	18601	19247
Unfruitful	00	488	488
Vegetables	525	12380	12905
Different corps	2030	3525	5555
Total	**3201**	**34994**	**38195**

Source: (Palestinian National Information Center- PNIC, 1997).

According to PNIC in 1997, the number of laborers in the sectors of the governorate reached 29100 laborers; of whom 3420 laborers work in the field of agriculture and fishery **(PNIC, 1999)**. The number of the huge industrial institutions reached 152 whiles the number of workers 2117. In the other hand, the number of small industrial institutions reached 319 **(PNIC, 1999)**.

2.1.9 Sewerage System and Coverage in the Northern Area of Gaza

Most urban areas in the Gaza strip are only partially sewered. Access to sewerage facilities at present in the localities of the Northern Area varies from areas where completely households are served by well-functioning sewerage systems, to areas where less than 60% of the houses are connected to the sewerage network **(World Bank, 2004)**. The Palestinian Water Authority (PWA) plans for a large increase of the connection rate during the next 15 years period, with a development according to the figures in Table 2.7. Figure 2.2 shows the existing and planned sewerage system in the Northern Area.

Table 2.7: Expected connection rates to the public sewerage network

Year	1997	2000	2005	2010	2015	2020
% served	60	65	75	85	90	95

Source: (SCC, 1998)

Ongoing and planned coverage of the sewerage network are as follows:

In Jabalya: In east Jabalya, coverage is estimated to be about 100 percent, including the refugee camp. In the end of 2004, fifteen thousand people were connected to the network in the southwest portion of the municipality. And an additional 15,000 people were connected to the network in the northwest portion of Jabalya. These works were bringing the overall coverage in Jabalya to about 95 percent.

In Beit Lahia, after connecting of an additional 10,000 people to the network, the coverage of the sewerage system was raised from 55 percent of the population to 75 percent.

In Beit Hanoun, at the beginning of 2004 only 65 percent of the population had access to sewerage services. Two new residential areas had been built and about 15,000 people were connected to the sewerage network at the end of 2004.

In Um A1 Nasser, 5,000 people are expected to be connected by 2006. Based on this, the sewage inflow in North Gaza is expected to increase to 19,000 m^3 per day by 2006, and by 2012 the inflows are expected to reach 34,000 m^3 per day **(WB, 2004).** But according to

Environmental Impact Assessment study of proposed New Waste Water Treatment works that conducted by Engineering and Management Consulting Center, projection of wastewater flow in sewer as illustrated in table 2.8 show that domestic flow in year 2005 is 14,433 m^3/d. This figure is closed to WWTP manager and engineers believes and approximately mach the figure that produced by author (15,000 m^3/d) based on his own calculations.

Table 2.8: Wastewater Production Projection.

Year	**Domestic Flow (m^3/d)**	**Public Flow (m^3/d)**	**Industrial Flow (m^3/d)**	**Total average flow to WWTP (m^3/d)**
2000	8,717	768	687	10,164
2005	14,433	986	1,157	16,586
2010	21,407	1,157	2,094	24,993
2015	35,958	2,094	4,162	42,369
2020	44,511	3,550	6,025	54,086
2025	48,806	3,889	6,600	59,295

Source: Stormwater and sewerage project North Gaza, 1999.

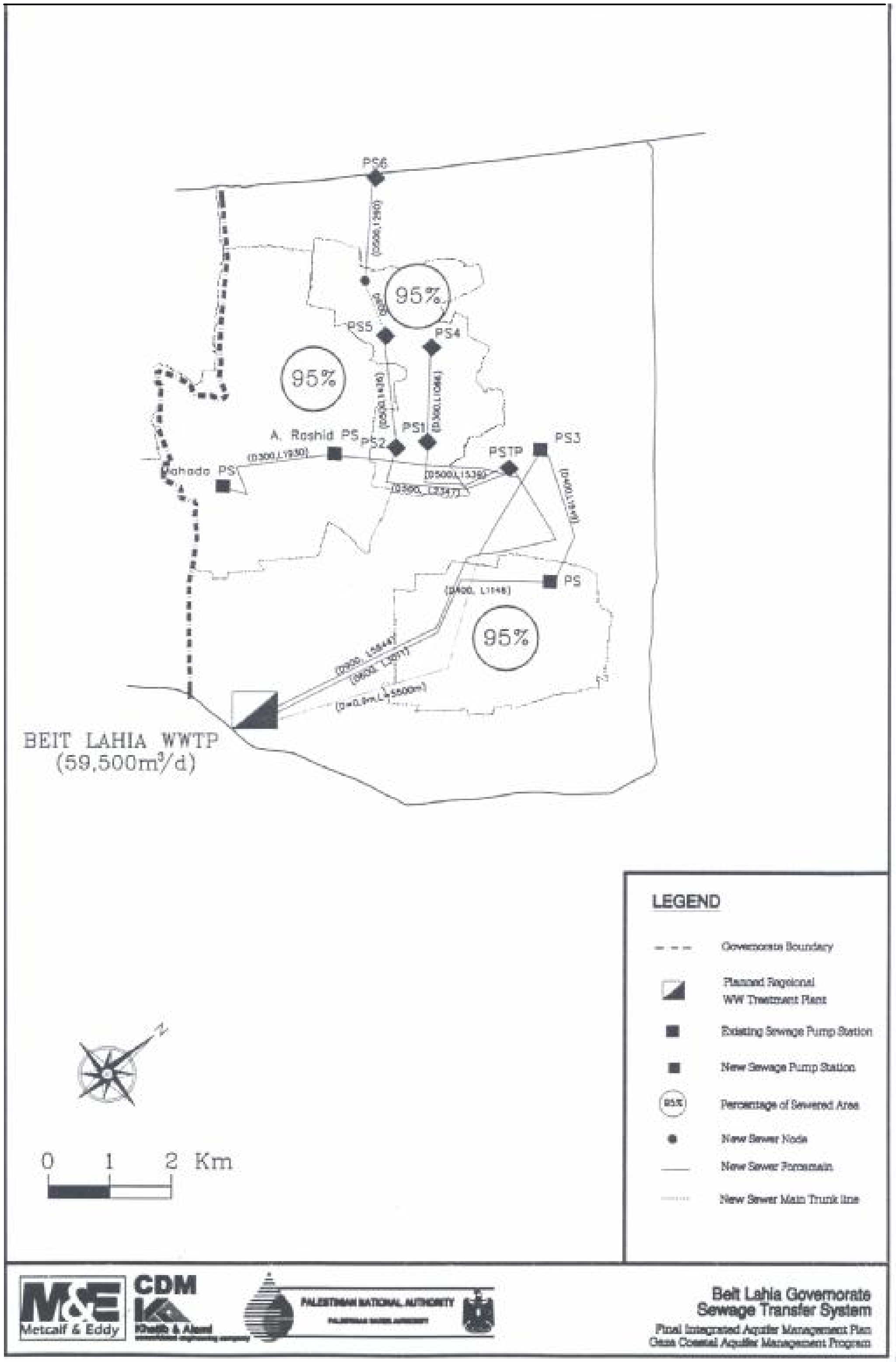


Figure 2.2: Northern Area Sewerage Transfer system.

2.2 THE BEIT LAHIA WWTP

BLWWTP was built in 1976 to treat the sewage from north Gaza strip region. The plant was first constructed to serve Jabalia, Nazla and Beit Lahia in form of 4 aerated ponds, each of 5,000 m^2 surface areas and capacity of 29,000 m^3. Three other ponds of different capacities were later added to the treatment plant. This section will give short description on the hydrogeology of the site, development of plant design and environmental impacts of the existing condition.

2.2.1 Hydrogeology:

The WWTP in Beit Lahia is constructed in a sand dunes overlies a clay layer of variable thickness. This clay layer exists between the groundwater table and the superficial sand dunes. Investigation and bore holes drilled nearby the plant shows that the thickness of this layer varies between 5-15 meters **(PWA, 1999)**. Figure 2.3 shows three dimensional fence diagram of the geology below the effluent lake to the north of the wastewater treatment plant and how the infiltrated wastewater accumulates above the low permeability layer. The very low permeability of the clay layer results in accumulation of the effluent water above this layer and then moves horizontally depending on the slope. The bore holes show that the clay layer slopes towards the sea. Although the extent of this layer is not known, the increase in the nitrate content and observing detergent in the surrounding wells proofs that the clay layer is not continuous. The existing monitoring piezometers in the area of the treatment plant reveals a water level of 1-2 m above mean sea level **(PWA, 1999)**. The regional groundwater flow direction is from eastern north to western south. Local flow in the other different directions may happen due to mounding produced by the wastewater infiltration. The local groundwater quality regarding the salinity is good (Cl^- concentration is 100-200 mg/L). Whereas the NO_3^+ concentration measured in some surrounding agricultural wells varies between 150-250 mg/L **(PWA, 1999)**.

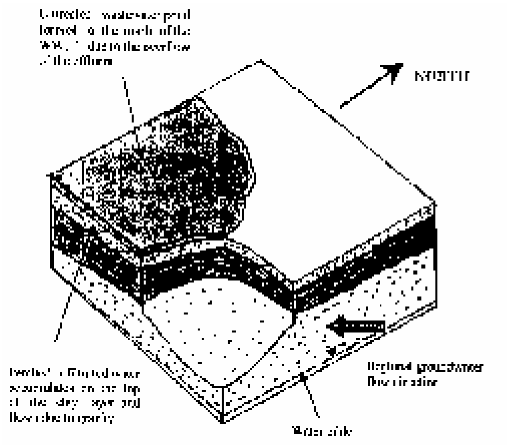


Figure 2.3: Three dimensional fence diagram showing the geology below the effluent lake (PWA, 1999).

2.2.2 Development of Original Design

The WWTP at Beit Lahia includes 7 ponds and was originally designed by the Israel Civil A demonstration in 1976 to serve a population of 50,000 inhabitants (fig.2.4). Today the population is about 265 thousand inhabitants from which about 70 to 75% are connected to the sewerage network.

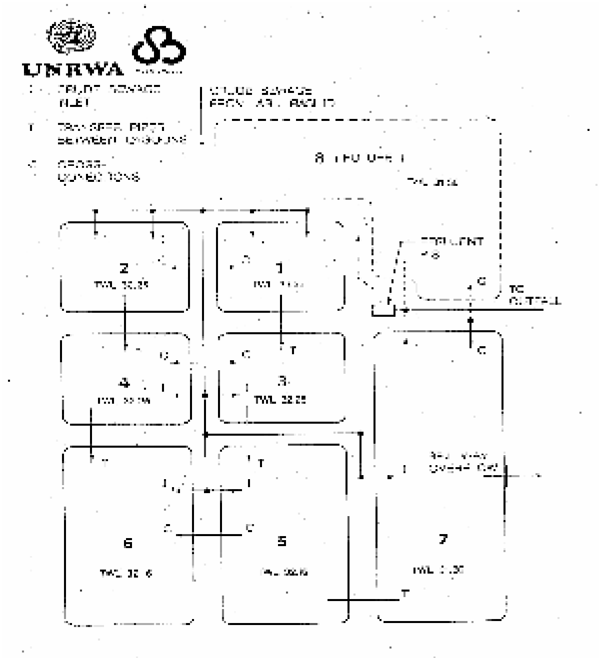


Figure 2.4: BLWWTP Layout Plan.

In the original design four primary aerated lagoons (from which the first two were fully mixed), followed by two secondary settlement/maturation lagoons and tertiary maturation /storage lagoon provide the biological treatment, together with pathogen reduction. The treatment plant layout had been planed with space provided for the construction of a further tertiary maturation/storage lagoon (8) in the future **(Nahman Nir Zone, Tel-Aviv)**. The original design of the plant envisaged producing an effluent of such quality to allow for agriculture irrigation reuse. At that time the goal of the Israel consultant was to meet a 20 mg/L BOD and 30 mg/L suspended solids standards after three month period. A pump station was designed which was supposed to pump the treated effluent towards the irrigation fields at Beit Lahia.

The plant was constructed in stages, commencing in 1983 with lagoons one to four. Lagoon five was then constructed followed by lagoon seven, both by an Israel contractor. In 1989 UNDP supplied the effluent pump station. In December 1993 surface aerators were installed and a maintenance contract for 12 months was awarded to the Israel Company who supplied the equipments. The bulk of the construction and mechanical/electrical equipment installation has been completed for some time, and flows have been passing through part of the plant since 1990/1991, however the plant has not been fully commissioned.

The lagoon bases were to be sealed with clay and 1/3 sloping sides were supposed to be lined with plastic sheeting and 100 mm layer of concrete **(Carl Bro Group for UNRWA, 1994)**. The basic mode of plant operation, intended by designers, was to have two parallel streams of 2 aerated lagoons, 1 secondary settlement/maturation lagoon and 1 tertiary/maturation lagoon. However, by virtue of paperwork to be provided it would have been possible to operate lagoons system in a number of ways, e.g. the primary aerated lagoons may be by-passed and adjacent lagoons are all cross-connected. This flexibility is a strong feature of the plant design **(Founas, 1999).** To deal with the future increases in flow expected at the plant the original designers proposed to install additional settlement tanks and an activated sludge mode, thus increasing its biological treatment capacity without additional aeration lagoon being required **(Founas, 1999)**.

At the end of 1999, rehabilitation activities of BLWWTP were include construction of screen and grit removal to avoid silting of the ponds and damage for equipments, as well as, a construction of two infiltration basin inside the treatment plant. At the beginning the first pond of each train (primary pond 1 and 2) were provided with four surface aerators, 18.5-kW each **(LEKA, September 1999)**. The first lagoon of each line was furthermore provided each with two floating mixers of horizontal flow type. It was then considered that the first primary ponds were totally mixed and consequently sludge was allowed to settle and accumulate on the bottom of the second (partially) and the third following pond of each train (ponds numbered 5 and 6), which were not mixed. The last pond (tertiary pond numbered 7) is a large and deep pond for polishing. The aerators of the two first ponds of each line (pond numbered 1 and 2) were removed some time after the first run of the treatment plant. In fact, due to the high loading of wastewater and particularly to the large sand content and the coarse material in the wastewater, failure of the aerators to work properly appeared. The two first lagoons worked therefore as anaerobic ponds and the aerators were removed from the two first ponds (pond 1 and 2). The problem was due to the absence of a sand/grit removal facility to the wastewater, prior to passing it to the treatment ponds.

For the purpose of reusing water for agriculture a pumping station was built as well as a first segment of a duct towards irrigation fields. But the line was never completed and up to now the effluent merely overflows the last pond of the plant, spreading in a neighboring area; there it both infiltrates in the ground and evaporates to the atmosphere.

2.2.3 Existing Condition

The actual treatment plant serves Jablia refugee camp, villages of Beit Lahia, Nazla, Aum El-Naser and Beit Hanoun and the system doesn’t operate in accordance with its original design. In fact, the actual plant differs from the original design on the number of ponds as well as on the function of the pond. The original plan was never completely implemented: the second maturation pond (pond 8) was never built and the two first ponds (number 1 and 2) turned out to be anaerobic lagoons. The plant is over loaded: it was designed to serve a population of 50 thousand inhabitants while it is currently serving around 265 thousand inhabitants.

Today, the ponds are operating in series with the following order: 2 anaerobic lagoons, 2 actively aerated lagoons, 2 facultative lagoons and 1 maturation lagoon. Thus the wastewater passes from one lagoon to the other as a series system: pond (2), (1), (3), (4), (6), (5), (7) to the discharging effluent lake. Moreover, the outlet of pond 7 has been modified as to have the greatest distance between the inlet and the outlet of this pond; that allows increasing the pathway of the water. Therefore the outlet of pond (7) is now at the opposite end to the inlet.

2.2.4 Ongoing and Planned Activities

In 2000, Palestinian Water Authority (PWA) obtained agreement for concessionary financing to fund a new wastewater treatment plant to serve the needs of the North Governorate in Gaza strip. The proposed plant was designed to adequately handle sewage volumes for the whole northern region, as projected by the Sewage Master Plan (1998) for Gaza. The treated effluent would then be recharged into the aquifer through better-designed infiltration basins and/or reused for appropriate irrigation. The design work for the new treatment facility and main carriers was substantially completed when the deteriorated security situation in Gaza made it difficult to pursue implementation, and activities under that project were suspended in November 2003 **(WB, 2004)**. Construction of the North Gaza Wastewater Treatment Plant (NGWTP) at the proposed site east of Jabalya has been designed for secondary biological treatment with nitrogen removal, as well as sludge treatment, digestion, electricity generation, dewatering, drying and storage. Treated effluent will be used to recharge the ground water through pumping it into the infiltration basins, while treated sludge will be used for agriculture as fertilizer or soil conditioner. The final engineering designs of the new treatment plant have been completed. The works for NGWTP are expected to take up to two years to be completed from starting date. The plant is designed with an ultimate capacity of 69,000 m^3 per day to cope with sewage inflows projected to materialize in 2025. The plant comprises five treatment modules to be constructed in two stages. The first stage will be consisting of the installation of three modules, which will result in a plant capacity of 35,000 m^3 per day. This will accommodate the projected sewage flows for the year 2012. The second stage will be initiated in the year 2011 and consists of implementing two other modules to reach an ultimate capacity of 69,000 m^3 per day. The required land for the ultimate plant design has been acquired and is available; however, additional land for further infiltration basins would be needed to cope with the long-term expansion.

BLWWTP effluent lake will transfer to the site of the planned NGWTP. Work in transmission line and infiltration basins is started. At the most favorable condition, the work in this task will be finished after one year from now. The activities implemented in this project will be an integral part of the new plant. However, until the plant is built, the effluent from the lake will be pumped to the infiltration basins in order to eliminate the immediate threat of flooding from the effluent lake into local communities **(WB, 2004)**. Specifically the project will include the construction of: (i) a terminal pumping station at the site of the existing BLWTP, with five pumps (four operational and one stand by), (ii) a ductile iron sewage pipe with about 8 kilometers in length to transfer the effluent from the lake to the infiltration basins; and (iii) nine infiltration basins with a base area of up to 8 hectares will be built at the proposed site of the NGWTP in Jabalya with an infiltration capacity of 35,600 m^3 per day. In addition, this component will cover costs related to operations and maintenance of the infiltration basins for 24 months, including the monitoring of effluent and ground water quality during the construction period of the new plant, and a coordinator for the maintenance of the basins, equipment and materials **(WB, 2004)**.

2.2.5 Environmental Effects of BLWWTP and Its Effluent Lake

The existing operation system of BLWWTP is now seriously threatening the neighboring environment. The daily effluent flow rate is about 15,000 m^3/d and the loading being greater obliged to operate the lagoons system as to the greater possible retention time. The area covered by the discharging pond can roughly be estimated to some 400 dunum **(UNEP, 2003)**. The area is growing very quickly to a point where the fence that has been erected round the discharging pond has been submerged (see figure 2.5). Now the boarders of the discharging pond are threatening the adjacent houses. The authorities have taken some protection measures. They consisted in the erection of a sand levee to retain the water mass as well as in the installation of a siphon system from the last pond of the WWTP, in order to redirect a part of the effluent to a second effluent lake. These measures were done to reduce the water mass in the last pond of discharge to avoid the danger of the sand levee to break down. However, the plant and surrounding effluent lake has serious health and environmental problem which can be summarized in the following points:

1- Ground Water Contamination

The BLWWTP is located near one of the finest ground water aquifers in Gaza. Nitrate is the most common groundwater contaminant in northern Gaza that causes serious health problems especially in children. The World Health Organization set the acceptable limit for nitrate at 50 mg/L, a number that is frequently exceeded in wells throughout the Gaza strip, where levels are as high as 272 mg/L in north Gaza. NO_3^+ concentration measured in some surrounding agricultural wells varies between 150-250 mg/L According to the study which evaluate the result of monitoring wells that located around BLWWTP (done by Water Resources and Planning Department in PWA), the most indicator parameter for wastewater pollution is the detergent which started to increase in a proportional way. Detergent concentration is above the WHO standards (0.2 mg/L). The study shows also another important notice is that the wells which have high concentration of detergent contain high concentration of Cl^- relative to the other wells **(PWA, 1999)**.

2- Health Hazards

Living at treatment plant and its overflow, the Um-An Nasir, Al-Nada, and Al-Awda towers population are the most affected group in the North Area. They suffer from the contamination of their groundwater sources, from the foul gases produced by the effluent lake and the sewage pools, and from millions of mosquitoes that find an ideal breeding environment in and around the lake.

According to Al-Mezan Center study in 2003, the authors describe the health situation in the village as “very bad” and estimate that more than 50% of the community’s children in the village have problems with their digestive system due to infection of parasites, helminths, and other diseases transmitted by the mosquitoes. The study also mentioned to other diseases such as skin infections, allergies, and respiratory system disorder that people suffer from **(Al-Mezan Center, 2003)**. Health professionals are seriously concerned about the long-term effects of this hazardous environment on the local population. In their view, these unhealthy conditions could lead to the increased incidence o f stunted growth, mental disorders and cancer **(WB, 2004)**.

3- Floods

Beside the permanent hazards to the environment and to people's health, the treatment pools also present a significant security threat to the surrounding areas. The consequences of spills and flooding affect the entire area. On two occasions, in 1989 and 1992, the sand barriers already collapsed under the pressure of the overflow. As a result, the sewage flooded houses and land in Beit Lahia, causing severe environmental, economic and health problems. Moreover, as the lagoons are close to the point where the pools' level and the water level in the effluent lake balance and as a consequence, water would not be able to spill into the overflow area anymore and would have to find its way into lower regions. These regions happen to be the Beit Lahia lands and housings. Thus, the people live in constant fear of being flooded by raw sewage **(Al-Mezan Center, 2003)**.

At rainy season, drainage of treatment plant effluent become very weak because of rising of water level inside random treatment pool. As a result they obligated to open each lagoon on the other and use these lagoons for storage till the water level in the pool is drooping. As consequence, wise operation is regarded and quality of effluent will be deteriorated.

4- Accidents

The lack of security has already resulted in two dreadful accidents. Since 1992, three children have died a terrible death in the sewage pools. There were no fences or any other safety measures. The Palestinian Authority has tried to set up fences, but they have been washed over by the rising water level. At that time, Israelis don't allow any activities to solve the problem; the only available protection method was increasing the sand fences **(Al-Mezan Center, 2003)**.

The yellow area indicates the sewerage treatment pools as they appear on a 1987 satellite image. The treatment pools are not able to handle the growing volumes of influent sewage, and a 40 hectare lake has formed as a result of the overflow.

Figure 2.5: BLWWTP and its random effluent lake (UNEP, 2003)

2.3 WASTE STABILIZATION POND AND AERATED LAGOON TECHNOLOGY

Waste Stabilization Pond (WSP) technology considers as a one of the most important natural methods for wastewater treatment in developing countries because it can be produce an effluent that meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirement. Referring to data provided on lagoonsonline site, the WSP have been used as a process for wastewater treatment for centuries. In the 1920's artificial ponds were designed and constructed to receive and stabilize wastewater. By 1950, the use of ponds had become recognized as an economical wastewater treatment method for small municipalities and industries. As of 1980, approximately 7,000 waste stabilization lagoons were in use in the U.S. Today, one third of all secondary wastewater treatment facilities include a pond system of one type or another. Of these, just over 90% are for flows 1 MGD or less. But ponds can be used for larger cities for wastewater treatment as well **(Rich, 2003)**.

WSP used for secondary wastewater treatment where decomposition of organic mater is processed naturally. The activity in the system is a complex symbiosis of bacteria and algae, which stabilizes the waste and reduces pathogens. The result of this biological process is to convert the organic content of the effluent to more stable and less offensive forms. Although the most important role of WSP is in the removal of pathogenic microorganisms, they are still capable of producing an effluent with a low BOD and nutrient concentration. The system used to treat a variety of wastewaters, from domestics wastewaters to complex industrial one. They can be used alone or in combination with treatment processes **(Ramadan & Ponce, 2004)**.

The aerated lagoon is a treatment pond which supported with artificial aeration system. The additional Oxygen supply will speeds up the natural process of biological decomposition of organic waste by stimulating the growth and activity of bacteria that degrade organic waste.

2.3.1 Definition of WSP

WSP is a relatively shallow body of wastewater contained in an earthen man-made basin into which wastewater flows and from which, after certain retention time a well-treated effluent is discharged **(Ramadan & Ponce, 2004)**. The often used term “oxidation pond” is synonymous and the terms “lagoon” and “pond” are often used interchangeably. The systems comprise a series of ponds – anaerobic, facultative and several maturation. The degree of treatment achieved is a function of the number of ponds in the series, and retention time of the wastewater in each pond. A pond requires only simple maintenance and relies on sunlight as its only source of energy. Because ponds rely on sunlight as source of energy and natural aeration, treatment process is slow. The retention time is relatively long and measured in weeks rather than hours. This necessitates a large land requirement, which is the major drawback to the widespread adoption of ponds as a treatment option **(Horan, 1990)**, especially in those parts of the world which suffer from scarcity of lands.

The primary treatment takes place in the anaerobic pond, which is mainly designed for removing suspended solids, and some of the soluble element of organic matter (BOD_5).

During the secondary stage in the facultative pond most of the remaining BOD_5 is removed through the coordinated activity of algae and heterotrophic bacteria. The main function of the tertiary treatment in the maturation pond is the removal of pathogens and nutrients **(Cinara & Colombia, 2004)**.

2.3.2 Advantages and Disadvantages of Lagoon Systems

Using the lagoon system has many advantages especially in some developing countries where high operational cost of advance technology is not affordable. On the other hand, the system could have some disadvantages where land resource is scar resource. In the following point, the advantages and disadvantages of the system will be short listed (**adapted from different resources**).

1- System Advantages

- Lagoon systems can be cost-effective to design and construct in areas where land is inexpensive.
- They use less energy than most wastewater treatment methods.
- They are simple to operate and maintain and generally require only part-time staff.
- They can handle intermittent use and shock loadings better than many systems, making them a good option for campgrounds, resorts, and other seasonal properties.
- They are very effective at removing disease-causing organisms (pathogens) from wastewater.
- The effluent from lagoon systems can be suitable for irrigation (where appropriate), because of its high-nutrient and low-pathogen content.

2- Disadvantages

- Lagoon systems require more land than other treatment methods. They are less efficient in cold climates and may require additional land or longer detention times in these areas.

- Odor can become a nuisance during algae blooms, spring thaw in cold climates, or with anaerobic lagoons and lagoons that are inadequately maintained.
- Unless they are properly maintained, lagoons can provide a breeding area for mosquitoes and other insects.
- They are not very effective at removing heavy metals from wastewater.
- High effluent suspended solids.
- Possibility of ground water contamination.
- Effluent from some types of lagoons contains algae and often requires additional treatment or "polishing" to meet local discharge standards.

2.3.3 Types and Function of WSP

WSP systems comprise a single series of anaerobic, facultative and maturation ponds, or several such series in parallel. In essence, anaerobic and facultative ponds are designed for BOD removal and maturation ponds for pathogen removal, although some BOD removal occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds.

2.3.3.1 Anaerobic Ponds

As its name implies, anaerobic pond lacks dissolved oxygen, and the active microbial population comprises facultative and strictly anaerobic microorganisms. They have a relatively small surface area to depth ratio to create the appropriate conditions for anaerobic bacterial activity. The origin material which present in the influent is therefore degraded by fermentative pathways. The degradation of organic substrates with production of volatile acid is known as putrefaction, and end-products such as butyric acid are extremely malodorous. If metabolism were to cease at this point, then the noxious smells produced by the pond would make them very unpopular.

Fortunately a group of strictly anaerobic bacteria, known as the methanogens, are able to obtain their energy for growth by coupling the oxidation of these volatile acids to the reduction of carbon dioxide, resulting in production of methane, which is the most reduced form of carbon **(Horan, 1990)**. On other hand, methanogens are very susceptible to environmental conditions, in particular changes in the pH, and they will only tolerate a pH in the range 6.2-8.0. If the rate at which volatile fatty acids are produced is in excess of the rate at which they are degraded by methanogens, and then the pH will fall, the methanogenes are inhibited and then ultimately killed. The growth rate methanogens is thus the rate limiting step and determines the maximum organic loading to anaerobic pond.

The resulting gaseous end-products are odorless and when they escape to the atmosphere they contribute to the process of BOD removal. In common with other anaerobic oxidation the energy available to methanogens is low, and consequently they have a low cell yield; as much as 70% of the BOD removed in anaerobic pond will be in the form of methane gas. Due to long retention times (up to 3 days), sedimentation provide an additional mechanism for removal of BOD which is in the form of suspended solids, and this mechanism is independent of temperature. The settled solids will undergo rapid anaerobic decomposition at the bottom of the pond. Anaerobic pond can therefore operate for many years without desludging **(Horan, 1990)**. As a result of vigorous release of gaseous end-products; sludge from the pond bottom is carried to the surface. This process serves to seed the upper layers of the pond with active methanogenes and also aids in pond mixing. A well-designed anaerobic pond can achieve up to 60% reduction in BOD depending upon the temperature and retention time. As a result of the degradation of sedimented organic material, a large amount of ammonia which was previously organically bound is released as ammonium. Nitrification cannot occur owing to the lack of oxygen and this ammonium leaves the pond in the effluent. The effluent from anaerobic pond often contains up to 20% more ammonium than was present in influent.

2.3.3.2 Aerated Lagoon

An aerated lagoon is a treatment pond that speeds up the natural process of biological decomposition of organic waste by stimulating the growth and activity of bacteria that degrade organic waste. In aerated lagoons, oxygen is supplied mainly through mechanical or diffused aeration rather than by algal photosynthesis. Aerated lagoons typically are classified by the amount of mixing provided. A partial mix system provides only enough aeration to satisfy the oxygen requirements of the system and does not provide energy to keep all total suspended solids (TSS) in suspension **(EPA, 2002)**. In some cases, the initial cell in a system might be a complete mix unit followed by partial mix and settling cells. Most energy in complete mix systems is used in the mixing function which requires about 10 times the amount of energy needed for an equally-sized partial mix system to treat municipal wastes. A complete mix wastewater treatment system is similar to the activated sludge treatment process except that it does not include recycling of cellular material, resulting in lower mixed liquor suspended solids concentrations, which requires a longer hydraulic detention time than activated sludge treatment **(EPA, 2002)**.

The lagoons are constructed to have a water depth of up to 6 m to ensure maximum oxygen transfer efficiency when using diffused aeration. In most cases, aeration is not applied uniformly over the entire system. Typically, the most intense aeration (up to 50 percent of the total required) is used in the first cell. The final cell may have little or no aeration to allow settling to occur. In some cases, a small separate settling pond is provided after the final cell. Diffused aeration equipment typically provides about 3.7 to 4 kg O_2 /kW-hour and mechanical surface aerators are rated at 1.5 to 2.1 kg O_2 /KW-hour. Consequently, diffused systems are somewhat more efficient, but also require a significantly greater installation and maintenance effort **(EPA, 2002)**.

Aerated lagoons can reliably produce an effluent with both biological oxygen demands (BOD) and TSS < 30 mg/L if provisions for settling are included at the end of the system. Significant nitrification will occur during the summer months if adequate dissolved oxygen is applied. Many systems designed only for BOD removal fail to meet discharge standards during the summer because of a shortage of dissolved oxygen. Nitrification of ammonia and BOD removal occur simultaneously and systems can become oxygen limited. To achieve nitrification in heavily loaded systems, pond volume and aeration capacity beyond that provided for BOD removal are necessary.

2.3.3.3 Facultative Pond

Facultative ponds are designed for BOD removal on the basis of a low organic surface load to permit the development of an active algal population. This way, algae generate the oxygen needed to remove soluble BOD. Healthy algae populations give water a dark green color but occasionally they can turn red or pink due to the presence of purple sulphide-oxidizing photosynthetic activity **(Mara et al., 1996)**. This ecological change occurs due to a slight overload. Thus, the change of coloring in facultative ponds is a qualitative indicator of an optimally performing removal process. The concentration of algae in an optimally performing facultative pond depends on organic load and temperature, but is usually in the range 500 to 2000 μg chlorophyll per liter. The photosynthetic activity of the algae results in a diurnal variation in the concentration of dissolved oxygen and pH values. Variables such as wind velocity have an important effect on the behavior of facultative ponds, as they generate the mixing of the pond liquid. As **Mara et al. (1992)** indicate, a good degree of mixing ensures a uniform distribution of BOD_5, dissolved oxygen, bacteria and algae, and hence better wastewater stabilization.

In order to encourage the growth of algae, the loading to a facultative pond must be controlled so that the oxygen demand of the influent wastewater does not exceed the rate at which oxygen can be supplied by photosynthesis. Because of the requirements of the algae for light, the rate of oxygen production and thus the concentration in the pond will vary both diurnally and with pond depth **(Horan, 1990)**. The photosynthetic activity of algae in facultative ponds varies with the intensity of the incident sunlight. In bright sunlight, the algae from dense bands in a layer up to 50 cm deep at the surface of the pond. Their rate of oxygen production is frequently so rapid that it is produced faster than it can diffuse to the atmosphere, and supersaturated oxygen concentrations are attained. In order to support this intensive rate of photosynthesis the algae utilize a large amount of a carbon dioxide, and as a result the pH at the algal band can reach as high 9.5. Below this surface layer the oxygen concentration declines rapidly as it is utilized by heterotrophic bacteria for aerobic respiration. During daylight the majority of the BOD is removed by facultatively aerobic bacteria at the oxic surface layer. As the intensity of the incident sunlight decreases, photosynthesis activity decline until at low light levels the algae switch from photosynthesis to respiration. During the hours of darkness, as the residual oxygen is utilized, the pond will slowly become anaerobic. Anaerobic metabolism in the pond sediment serves to degrade sedimented sludge, and thus increases the times between desludging. **(Horan, 1990)**

A large amount of nitrogen removal takes place in facultative ponds, but as yet the mechanism for this is unclear. Three mechanisms of nitrogen removal were suggested. Organic nitrogen associated with biomass is removed during desludging. The alternate aerobic/anaerobic conditions would suggest nitrification followed by denitrification. A third mechanism has been proposed in which the ammonia produced in the sludge layer by anaerobic degradation is converted to ammonia gas at the high pH´s of the active algal band.

Excessive concentrations of sulphide in ponds are detrimental to the growth of algae if present in an undissociated form (H_2S), and the proportion of undissociated sulphide increases at the pH decreases. At the pH range normally associated with facultative ponds, a total sulphide concentration of 8 mg/L will inhibit algal photosynthesis. Under these conditions the Chromatiaceae will completely replace the algal population and, as they perform anoxygenic photosynthesis, the pond becomes anaerobic. When such conditions prevail it is an indication of overloading, and the loading rate must be reduced in order to re-establish an oxygenic algal population **(Horan, 1990).**

2.3.3.4 Maturation Pond

The major role of maturation ponds is in the removal of pathogenic microorganisms such as viruses, bacteria and helminths. These ponds receive the effluent from a facultative pond and its size and number depend on the required bacteriological quality of the final effluent. Maturation ponds are shallow (1.0-1.5 m) and show less vertical stratification, and their entire volume is well oxygenated throughout the day. Their algal population is much more diverse than that of facultative ponds. Thus, the algal diversity increases from pond to pond along the series. The main removal mechanisms especially of pathogens and faecal coliforms are ruled by algal activity in synergy with photo-oxidation **(Cinara & Colombia, 2004)**.

There is a general agreement that the excreted eggs of helminths such as Ascaris, are removed by sedimentation due to their large size. Protozoal cysts of organisms such as Giardia behave in a similar way, but required longer retention time. As most viruses carry a strong negative charge, it is assumed that the major mechanism for their removal is adsorption to particular material, followed by sedimentation **(Horan, 1990)**. On the other hand, maturation ponds only achieve a small removal of BOD, but their contribution to nitrogen and phosphorus removal is more significant. **Mara et al. (1992)** reported a total nitrogen removal of 80% in all waste stabilization pond systems. This figure corresponds to 95% ammonia removal. It should be emphasized that most ammonia and nitrogen is removed in maturation ponds. However, the total phosphorus removal in WSP systems is low, usually less than 50%.

2.3.4 Removal Efficiency and Mechanisms in WSP

The removal efficiency and mechanisms of different wastewater condiment parameters depends mainly on design criteria, detention time and dominant environmental conditions.

2.3.4.1 BOD Removal

BOD removal in lagoons depends on detention time and lagoon water temperature. For all but anaerobic lagoons, the soluble BOD is reduced by bacterial oxidation **(Crites and Tchobanoglous, 1998)**. In anaerobic ponds BOD removal is achieved (as in septic tanks) by sedimentation of settleable solids and subsequent anaerobic digestion in the resulting sludge layer. This is particularly intense at temperatures above 15 ^{o}C when the pond surface literally bubbles with the release of biogas (around 70 percent methane and 30 percent carbon dioxide); methane production increases sevenfold for every 5 ^{o}C rise in temperature **(Marais, 1970)**.

In secondary facultative ponds and aerated lagoon that receive settled wastewater (usually anaerobic pond effluent), the remaining non-settleable BOD is oxidized by the normal heterotrophic bacteria of wastewater treatment. The bacteria obtain the oxygen they need from mechanical aeration in aerated lagoon and from the photosynthetic activities of the micro-algae which grow naturally and profusely in facultative ponds. In the last case, the algae, in turn, depend largely on the bacteria for the carbon dioxide which they photosynthetically convert into sugars. Of course some oxygen and carbon dioxide comes from the atmosphere by mass transfer **(Mara and Pearson, 1998)**. As a result of these algal-bacterial activities in facultative ponds, a high proportion of the BOD that does not leave the pond as methane ends up as algal cells. Thus in secondary facultative ponds “sewage BOD” is converted into “algal BOD” and this has important implications for effluent quality requirements.

In maturation ponds only a small amount of BOD removal occurs, principally as a result of lower algal concentrations (and hence lower “algal BOD”) which, in turn, result from a decreased supply of nutrients and predation by protozoa and micro-invertebrates such as Daphnia or by fish such as carp if these are present. Around 70-90 percent of the BOD of a maturation pond effluent is due to the algae it contains **(Mara and Pearson, 1998)**.

2.3.4.2 Total Suspended Solids Removal

The influent suspended solids are removed by sedimentation in lagoon systems. Algal solids that develop during treatment become the majority of the effluent suspended solids. Effluent suspended solids can range as high as 140 mg/L for aerobic lagoon to 60 mg/L for aerated lagoons. Because of the most algal solids are difficult to remove from water and effluent standards often cannot be met, additional process may be needed to remove the solids **(Crites and Tchobanoglous, 1998)**.

2.3.4.3 Pathogen Removal

Significant removal of bacteria, parasites, and viruses occurs in multiple cell lagoons with long detention times. Removal of pathogens in lagoons is due to natural die-off, predation, sedimentation, and adsorption **(Crites and Tchobanoglous, 1998)**.

Faecal bacteria are mainly removed in facultative and especially maturation ponds whose size and number determine the numbers of faecal bacteria (usually presented in terms of faecal coliforms- FC) in the final effluent, although there is some removal in anaerobic ponds

principally by sedimentation of solids-associated bacteria. The principal mechanisms for FC removal in facultative and maturation ponds are now known to be:
(a) Time and temperature,
(b) High pH (> 9), and
(c) High light intensity together with high dissolved oxygen concentration.
Time and temperature are the two principal parameters used in maturation pond design. FC die-off in ponds increases with both time and temperature **(Feachem et al., 1983)**. High pH values above 9 occur in ponds due to rapid photosynthesis by the pond algae. Faecal bacteria (with the notable exception of *Vibrio cholerae*) die very quickly (within minutes) at pH > 9 **(Pearson et al., 1987)**.

Light of wavelengths 425 – 700 nm can damage faecal bacteria by being absorbed by the humic substances ubiquitous in wastewater, these then enter an excited state for long enough to damage the cell. Light-mediated die-off is completely dependent on the presence of oxygen, and it is considerably enhanced at high pH. The sun thus plays a threefold role in promoting FC removal in WSP directly, by increasing the pond temperature ; and more indirectly, by providing the energy for rapid algal photosynthesis which not only raises the pond pH above 9 but also results in high dissolved oxygen concentrations **(Mara and Pearson, 1998).**

Little is definitely known about the mechanisms of viral removal in WSP, but it is generally recognized that it occurs by adsorption on to settleable solids (including the pond algae) and consequent sedimentation **(Mara and Pearson, 1998)**.

Protozoan cysts and helminth eggs are removed by sedimentation. Their settling velocities are quite high (for example, 3.4 X 10^{-4} m/s in the case of *Ascaris lumbricoides*), and consequently most removal takes place in the anaerobic and facultative ponds. It has recently become possible to design WSP for helminth egg removal **(Ayres, 1992)**. Removal will take place across the pond series and complete removal can be expected in ponds with overall retention times of 11 days or more **(Afifi and Tubail, 1998)**. Although they are removed from the pond effluent, they are not necessarily inactivated, and can remain viable in the sludge layer for several years. This is an important consideration during dislodging.

2.3.4.4 Nutrient Removal

In WSP systems the nitrogen cycle is at work, with the probable exception of nitrification and denitrification. Nitrogen removal appears to be the result of a combination of mechanisms including volatilization of ammonia (which is pH-dependant), algal uptake, sludge decomposition, and adsorption onto bottom soils **(Crites and Tchobanoglous, 1998)**. In anaerobic ponds organic nitrogen is hydrolyzed to ammonia, so ammonia concentrations in anaerobic pond effluents are generally higher than in the raw wastewater (unless the time of travel in the sewer is so long that all the urea has been converted before reaching the WSP). In facultative and maturation ponds, ammonia is incorporated into new algal biomass. Eventually the algae become moribund and settle to the bottom of the pond; around 20 percent of the algal cell mass is non-biodegradable and the nitrogen associated with this fraction remains immobilized in the pond sediment. That associated with the biodegradable fraction eventually diffuses back into the pond liquid and is recycled back into algal cells to start the process again. At high pH, some of the ammonia will leave the pond by volatilization.

There is little evidence for nitrification (and hence denitrification, unless the wastewater is high in nitrates). The populations of nitrifying bacteria are very low in WSP due primarily to the absence of physical attachment sites in the aerobic zone, although inhibition by the pond algae may also occur.

Without the addition of chemicals for precipitation, the removal of phosphorous in lagoons is minimal. Chemical addition using alum or ferric chloride has been used effectively to reduce phosphorous to below 1 mg/L **(Reed et al, 1995; Crites and Tchobanoglous, 1998)**. The efficiency of total phosphorus removal in WSP depends on how much leaves the pond water column and enters the pond sediments – this occurs due to sedimentation as organic P in the algal biomass and precipitation as inorganic P (principally as hydroxyapatite at pH levels above 9.5) – compared to the quantity that returns through mineralization and resolubilization.

As with nitrogen, the phosphorus associated with the non-biodegradable fraction of the algal cells remains in the sediments. Thus the best way of increasing phosphorus removal in WSP is to increase the number of maturation ponds, so that progressively more and more phosphorus becomes immobilized in the sediments. Table 2.9 summarized the removal mechanism and interferences associated with various contaminants in WSPs.

Table 2.9: Removal mechanism and interferences associated with various contaminants in WSPs (**Curtis *et al*., 1992**).

contaminant	Removal mechanism	Critical factors	Interferences/ Contributions
Suspended solids	Sedimentation	Particle size, residence time	Re-suspension, Precipitation, algal growth
Dissolved salts/salinity	Precipitation	redox conditions, pH, temperature	Decomposition of organic compounds, changing redox conditions
Organic material (BOD, volatile solids)	Sedimentation	Particle size, residence time	Excessive algal growth and die-off. Decomposition of refractory organic compounds
	Microbial decomposition	Aeration status, temperature	
	Precipitation	Redox conditions, pH, temperature	
Organic nitrogen	Sedimentation	Particle size, residence time	Re-suspension, algal growth
	Mineralization (ammonification)	Aeration status, bacterial activity, temperature	
Ammonia	Nitrification	bacterial activity (nitrifires), oxygen availability (limited by exertion of BOD), temperature	Ammonification of suspended and deposited organic nitrogen
	Volatilization	Concentration, pH, temperature	
	Microbial assimilation	Aeration status, temperature	
	Algal assimilation	Oxygen availability, light penetration, temperature	
Nitrate	Denitrification (nitrate/nitrite)	Bacteria (denitrifires), anoxic conditions, available carbon, temperature	Nitrification
	Microbial assimilation	Aeration status, temperature	
	Algal assimilation	Oxygen availability, light penetration, temperature	
Total nitrogen	Sludge deposition (and desludging)	Sedimentation, bacterial activity	Release from accumulated sludge
	Mineralization, nitrification, denitrification	Sequential transformation under conditions described above	
	Ammonia volatilization	As above	
Organic phosphorous	Sedimentation	Particle size, residence time	Re-suspension, algal growth
	Mineralization	Aeration status, bacterial activity, temperature	
Dissolved inorganic phosphorous (phosphates)	Precipitation	Presence of Fe(III), Al, Ca, and Mg, redox conditions, pH, temperature	Mineralization of suspended and deposited organic P, microbial release, desorption, changing redox conditions or pH.
	Microbial assimilation	Oxygen status, temperature	
	Algal assimilation	Oxygen availability, light penetration, temperature	
Total phosphorous	Sludge deposition (and desludging)	Sedimentation, precipitation, bacterial activity	Release from accumulated sludge

CHAPTER (3): MATERIAL AND METHODS

The purpose of this study was to identify performance efficiency of BLWWTP in term of contaminant removal. Monitoring program was carried out to obtain field and laboratory data needed for determining performance evaluation. To attain historical perspective about WWTP performance, historical operating data and result from previous monitoring programs were collected in aim to deduce the trend of BLWWTP performance as well as to compare past and current removal efficiency. All the methods, techniques, and material are used to generate data from sample analysis will be presented in the following sections.

3.1 MATERIALS

3.1.1 Media and Reagents

Salmonella Shigella Agar (SSA), Hektoen Enteric (HE), mFC Agar, Alkaline Pepton Water, and Selenite F Broth (Oxoid) and API 20E for the identification of gram negative bacteria (biomrieux).

3.1.2 Equipments

- Incubator set at 37°C ± 0.5°C(Heraus).
- Incubator 44.5 °C (Heraus).
- Incubator 20 °C (Shellab).
- Stereoscopic microscope, with magnification of 10-15x, wide-field type.
- A microscope lamp producing diffuse light from cool, white fluorescent lamps adjusted to give maximum color.
- Hand tally.
- Pipet container of stainless steel, aluminum, or Pyrex glass.
- Membrane filtration units (filter base and funnel) (Gellman Sciences).
- Electric vacuum pump or aspirator is used as a vacuum source.

- Membrane Filters (MF), white, grid-marked, cellulose ester, 47-mm diameter, 0.45 µm ± 0.02-µm pore size.
- Water bath maintained at 50°C for tempering agar.
- Test tubes, sterile, screw-cap, 20 x 150-mm, borosilicate glass or plastic.
- Spectrophotometer (HACH) DR/2010.
- COD Reactor (Hach).
- COD Vial Adapter.
- Centrifuge (Hettich EBA8).
- Test Tube Rack
- pH Meter (Hanna 8424), portable.
- DO meter (Jenway 9070).
- EC meter (Hanna TH-2400).
- Kjeltic system, including distillation and digestion units (Labconco).
- OxiTop (WTW) for BOD measurements.
- Hot Plate (Freed electric).
- Balance, analytical (Sartorius).
- Desiccator.
- Turbidimeter (Hach 2100 AN).
- Flame photometer (Corning 410 c).
- Dish, aluminum.
- Imhoff Cone
- Oven (Harrow scientific).
- Furnace, muffle (Carbolite).
- Computer and Statistical Package for the Social Sciences (SPSS).
- A Water Quality Data Plotting Software Package (Plotchem).

3.2 METHODS

The data and information used in this thesis have been acquired from both a literature review and actual field investigation. The literature review consisted of a combination of the following: review of the topic on relevant books, reports, journals, and internet websites as well as consulting professionals. The sampling program was conducted at BLWWTP, in the Northern Area of Gaza strip. The treatment system was monitored for three and half months, started from 15/2/2005 to 26/5/2005. The study seeks to evaluate and identify the performance and removal efficiency of each treatment unit using historical records and data generated from monitoring program. Chemical and biochemical analysis were conducted in the laboratories of Environment an Earth sciences Department at the Islamic University while microbiological analysis were performed at the Ministry of Health laboratories (Public Health Laboratory).

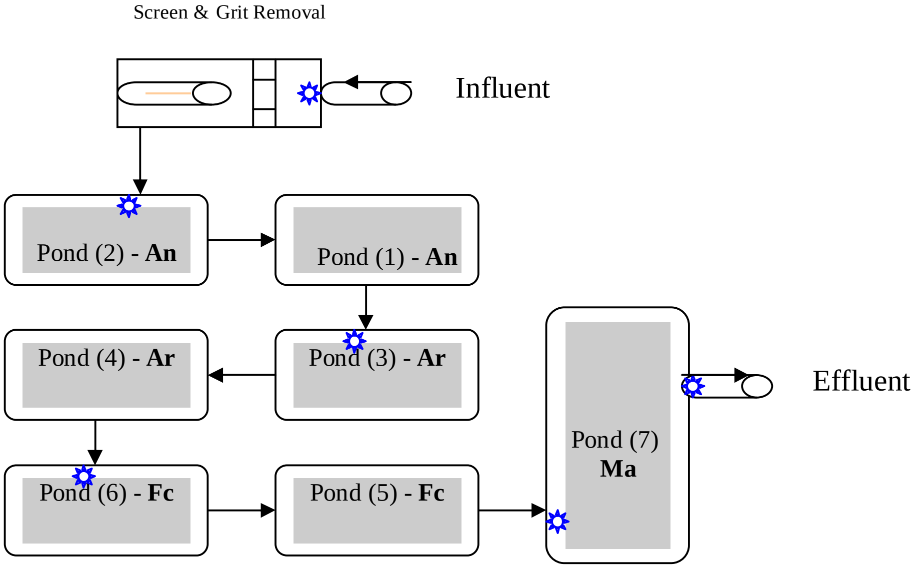
3.2.1 Samples Site Selection

Wastewater samples were collected from 6 locations. Each location selected to be inlet or outlet of treatment unit. The following table illustrates the purpose of selection of each location.

Table 3.1: Purposes of sampling sites selection.

Location	Purpose of selection
1	To determine the characteristics of raw wastewater.
2	To evaluate the performance of pre-treatment facilities (screen and grit removal unit).
3	To identify the removal efficiency of primary treatment unit (anaerobic lagoons-ponds 1+2)
4	To determine the removal efficiency of aerated lagoons (ponds 3+4)
5	To identify the removal efficiency of facultative ponds (ponds 5+6).
6	To determine the removal efficiency of maturation lagoon (pond 7).

Effluent from each treatment unit was analyzed for temperature, dissolved oxygen, pH, EC, BOD, COD, TKN, NH_4, TP, FC, solids, salmonella and nematodes. Location 1 was sampled for sulfate analysis while location 6 for SAR ratio determination. Chlorophyll-a was analyzed for location 4 and 5. Figure (3.1) depicts the sample locations.



☼ Sampling points.

Figure 3.1: Flow diagram of treatment system and sampling points. An = anaerobic pond, Ar = aerated pond, Fc = facultative pond, Ma = maturation pond

3.2.2 Sample Collection

The sampling of the wastewater was conducted 30 cm below the lagoons surface. Wastewater pumped to the sample bottles manually by using a pump with polyethylene pipe that immerged beneath the water surface. Precautions and proper procedures of sampling process were taken into account and done according to standard methods for the examination of water and wastewater **(APHA, 1995)**.

3.2.2.1 Sampling Frequency and Duration

Samples were collected fortnightly from 15/02/2005 to 26/05/2005. All collections were done on Thursdays between 08:30 and 11:00. The time of day in which sampling took place was consistent, as well as the days of the week in which sampling took place.

3.2.2.2 Sample Containers

One liter clean acid-washed polyethylene bottles were used to collect wastewater samples for chemical and biochemical analysis while 250 ml sterile bottles were used for microbiological analysis. The sample bottles were sterilized by adding 20 ml of 70%

ethanol and left overnight **(WHO, 1995)**. The ethanol was then discarded and bottles were rinsed thoroughly with wastewater before filling the bottle with the sample. For chlorophyll determination, 100 ml dark bottles were used.

3.2.2.3 Preservation and Storage of Samples

Field measurements (DO, pH, temperature) were measured on site during sampling process. The sample bottles were closed, stored into ice box and transported immediately back to the lab. Some parameters like BOD, NH_4, FC, solids, and salmonella were analyzed as quickly as possible on arrival at the laboratory where the rest was stabilized to a pH of 2 **(APHA, 1995)**. Then it was placed in refrigerator for no longer than a week before being analyzed. Part of the samples were filtered with no additives and stored at 4 °C for ortho-phosphorous analysis **(EPA, 2004)**.

3.2.3 Physical Analysis

3.2.3.1 Dissolved Oxygen

Dissolved oxygen was measured on site using DO meter (Jenway 9070). Concentrated Potassium Chloride solution was used to calibrate the DO meter and measurement was done by immersing the electrode to the appropriate level in the sample and stabilized readings were recorded.

3.2.3.2 Temperature

Temperature was taken synchronously with pH value using the same device (Hanna 8424) by selection of their modes.

3.2.3.3 Electrical Conductivity

Measuring conductivity is done by using EC meter (Hanna, TH-2400), that measuring the resistance occurring in an area of the test solution defined by the probe’s physical design. Voltage is applied between the two electrodes immersed in the solution, and the voltage drop caused by the resistance of the solution is used to calculate conductivity per centimeter. The display was showed the EC value automatically compensated for temperature.

The basic unit of measuring conductivity is the Siemen (or mho), the reciprocal of the ohm in the resistance measurement. Because ranges normally found in aqueous solutions are small, microSiemens/cm (µS/cm) are commonly used.

3.2.3.4 Total Solids

Quantification of solids in wastewater samples is usually done using gravimetric analysis following oven drying and ignition.

A well-mixed sample (50 mL) is evaporated in weighted dish and dried to constant in an oven at 103 to 105°C. The increase in dish weight over that of the empty dish represents the total solids **(APHA 1995)**.

Figure 3.2: Balance used to measure solids

3.2.3.5 Total Dissolved Solid

A well-mixed sample (50 mL) is filtered through a standard glass fiber filter, and the filtrate is evaporated to dryness in a weighed dish and dried to constant weight at 180 °C. The increase in dish weight represents the total dissolved solids **(APHA 1995)**.

3.2.3.6 Total Suspended Solids

Suspended solids calculated by subtracting dissolved solids from total solids **(APHA 1995)**.

3.2.3.7 Total Fixed Solids

The residue from TS is ignited to constant weight at 550°C. The remaining solids represent the fixed total solids while the weight lost on ignition is the volatile solids **(APHA 1995)**.

3.2.3.8 Total Volatile Solids

Volatile solids calculated mathematically by subtracting fixed solids from total solids **(APHA 1995)**.

3.2.3.9 Settleable Solids

Volumetric test was used to quantify settleable solids. 1 liter of the sample was filled into imhoff cone. After 45 minutes, the cone was gently agitated by spinning. It is left 15 min to allow adherent solids on the cone wall to settle **(APHA 1995)**. After 1 and 2 hours, the volume of settleable solids was recorded as milliliters per liter.

3.2.4 Chemical and Biochemical Analysis

3.2.4.1 pH

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

3.2.4.2 Biochemical Oxygen Demand (BOD)

BOD was measured with OxiTop measuring system. The quantity of samples was taken after well mixing according to corresponding measuring range recommended in the manufacturer manual. The samples discharged into OxiTop bottles followed by placing a magnetic stirring rod. Rubber quiver inserted in the neck of the bottle. Three sodium hydroxide tablets were placed into the rubber quiver with a tweezers. OxiTop bottle was directly tightly closed and pressed on S and M buttons simultaneously for two second until the display shows 00. The bottles were placed in the stirring tray and incubated for 5 days at 20 ºC. Readings of stored values was registered after 5 days by pressing on M until values displayed for 1 second **(Modified from OxiTop Manual)**.

Figure 3.3: OxiTop device used to measure BOD

3.2.4.3 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant.

The closed dichromate reflux method (colorimetric method) was used to determine COD. Two ml of the sample is refluxed in strongly acid solution vessel. After digestion in COD reactor at 160^{o}C for 2 hrs, oxygen consumed is measured against standard at 620 nm with a spectrophotometer.

Figure 3.4: Hach spectro-photometer used to measure COD.

3.2.4.4 Ammonia

Because of high concentration of ammonia in wastewater, Distillation method was used followed by titration step to determine the concentration of ammonia. NaOH solution was added to wastewater sample and ammonia distilled into a solution of boric acid. The ammonia in the distillate was determined titrimetrically with standard HCl. **(APHA 1995).**

3.2.4.5 Total Kjeldahl Nitrogen (TKN)

The total kjeldahl nitrogen method is based on the wet oxidation of nitrogen using sulfuric acid and digestion catalyst. In the presence of H_2SO_4, potassium sulfate (K_2SO_4), and cupper sulfate ($CuSO_4$), catalyst, organic nitrogen and ammonia were converted to ammonium. After addition of base, the ammonia is distilled from alkaline medium and absorbed in boric acid. The ammonia finally determined by titration against standard hydrochloric acid.

Figure 3.5: TKN distillation unit.

3.2.4.6 Ortho-Phosphorous

Although phosphorus can be classified as orthophosphates, condensed phosphates and organically bound phosphates, there are only two common laboratory tests for the determination of phosphorus. The first test is known as total phosphorus and the second is orthophosphate (also known as reactive phosphorus).

Ortho-phosphorous was determined using ascorbic acid colorimetric method. In this method, ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex. This complex is reduced to an intensely blue-colored complex by ascorbic acid. The color is proportional to the phosphorus concentration that determined by using spectrophotometer at 880 nm **(APHA, 1995)**.

Figure 3.6: Digestion unit used to measure TKN

3.2.4.7 Sulfate

Sulfate was determined using Turbidimetric Method. Sulfate ion (SO_4^{-2}) is precipitated in an acetic acid medium with barium chloride ($BaCl_2$) so as to form barium sulfate ($BaSO_4$) crystals of uniform size. Light absorbance of the $BaSO_4$ suspension is measured by a turbidimeter and the SO_4^{-2} concentration is determined by comparison of the reading with a standard curve **(APHA, 1995)**.

3.2.4.8 Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio was estimated by calculation after determination of Ca, Mg and Na concentrations in the wastewater. Sodium was determined by flame photometer, calcium was determined titrimetrically using EDTA method and Magnesium was estimated as the difference between hardness and calcium as $CaCO_3$. Values of Ca, Mg and Na concentrations were entered to plotchem software to determine the value of Sodium Adsorption Ratio.

3.2.5 Microbiological analysis

3.2.5.1 Fecal Coliform

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

3.2.5.2 Salmonella

General qualitative isolation and identification procedures described in the standard methods were followed to determine salmonella. Two hundred micrometer of the wastewater sample was transferred to 100mL peptone water (0.1% conc.) and incubated at 37 °C for 24 h. Part of turbid peptone water was transferred to enrichment medium (Selenite-F broth) overnight. Subcultures were made to Heckton Enteric and SS agars. Suspected colonies were tested for their biochemical characteristics (API 20E system) **(APHA, 1995)**.

3.2.5.3 Nematodes

In order to determine nematodes in wastewater samples, Formal Ether Concentration Technique was used which considered the best technique for the concentration of parasites. Two mL of settable solids were poured to a test tube.

Figure 3.7: Centrifuge used for concentrating parasites.

Four mL of formal water (10% v/v) and three mL of ether was transferred also to the test tube and mixed well for 1 minute. The sample was exposed to centrifuging immediately at approx 3,000 rpm for 15 minutes. The sediment was washed for about 3 times to remove the remaining preservative and examined microscopically by using the 10X objective and 40X objective to identify the parasite **(WHO, 1998)**.

3.2.5.4 Chlorophyll-a

The methanol extract technique described in Pearson, **Mara and Bartone (1987)** was used to determine chlorophyll-a. Fifty ml of the wastewater sample was filtered. Chlorophyll-a pigment was extracted and analyzed using spectrophotometer at 655 nm.

3.3 ANALYSIS OF DATA

All the data obtained from monitoring program were entered as Microsoft Excel sheet and results were arranged in tables.

CHAPTER (4): RESULTS

The results focus on analyzing the technical performance aspects of BLWWTP. The work presented the assessment results of some previous monitoring programs and the results of existing condition. The main parameters included in the analysis were the removal efficiencies of organic materials, nutrients, microbiological, and physiochemical parameters. Table 4.1 presented the different parameters which considered in the monitoring program conducted by the researcher in different location of the treatment plant.

Table 4.1: Considered parameters in monitoring program in different locations of the treatment plant.

Parameters	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Water Temp.	√	√	√	√	√	√
DO	√	√	√	√	√	√
EC	√	√	√	√	√	√
Imhoff Test	√	√	√	√	√	√
TS	√	√	√	√	√	√
DS	√	√	√	√	√	√
SS	√	√	√	√	√	√
FS	√	√	√	√	√	√
VS	√	√	√	√	√	√
pH	√	√	√	√	√	√
BOD	√	√	√	√	√	√
COD	√	√	√	√	√	√
SO_4^{-2}	√	-	-	-	-	-
Chlorophyll-a	-	-	-	√	√	-
SAR	-	-	-	-	-	√
F.Coliform	√	√	√	√	√	√
Salmonella	√	√	√	√	√	√
Nematodes	√	√	√	√	√	√

Location 1 (main inlet),
Location 2 (Inlet of anaerobic ponds)
Location 3 (Inlet of aerated lagoon)
Location 4 (Inlet of facultative lagoon)
Location 5 (Inlet of maturation lagoon)
Location 6 (Outlet of maturation lagoon)

4.1 Previous monitoring data of the treatment system

In the period between 1995 and 1999, short and few number of monitoring campaigns has been undertaken in view of determining the composition of the raw sewage entering BLWWTP. In all cases, the programs, compromising sample taking and analyses, have been performed by the Islamic University of Gaza, who dispose of required trained people and the facilities for that. After building of analyses laboratory in Gaza Wastewater Treatment Plant, regular performance monitoring programs were initiated and samples taken from BLWWTP to Gaza WWTP laboratory and analyzed on the monthly base during 2000 and 2001. These programs were stopped after the destruction of analyses laboratory by Israel tanks. It is worthy to mention that screens and grit removal unit were added in 1999 and the system operated (in series) before this date till now in the same manner. These similarities of conditions give more reliability and fairness for removal efficiency comparison among selected monitoring programmes. In the following paragraph, selected data are presented from the previous monitoring programs.

In May1999 a monitoring program was initiated to assess the performance of the system. Samples were taken from six points along treatment system in four different days during this month. Summery of overall removal of BOD, SS, and FC is presented in table 4.2.

Table 4.2: Summary of results of BLWWTP sampling program-May 1999.

Date	pH		5 Day-BOD (mg/L)			Suspended Solids (mg/L)			Total Coliform (cfu/100ml)		
	Inf.	Effl.	Inf.	Effl.	% Removal	Inf.	Effl.	% Removal	Inf.	Effl.	% Removal
03/05/1999	6.6	7.9	600.0	105	82.5	702	12	98.3	2.90E+06	3.60E+04	98.70
08/05/1999	7.5	8.1	530.0	80.0	84.9	300	5.0	98.3	1.00E+07	3.50E+03	99.96
18/05/1999	7.6	8.2	500.0	56.0	88.8	462	8.0	98.3	1.28E+06	3.10E+03	99.75
29/05/1999	7.7	8.1	320.0	56.0	82.5	704	15	97.9	2.00E+05	6.00E+02	99.70
Average	**7.3**	**8.1**	**487.5**	**74.3**	**84.7**	**542**	**10**	**98.2**	**3.60E+06**	**1.08E+04**	**99.53**

Source: PWA, technical paper no.52, June 1999.

According to table 4.2 results, average influent and effluent concentration of BOD, SS, and total coliform were 487.5 to 74.3 mg/L, 542 to 10 mg/L, and 3.6 E+06 cfu/100ml to 1.08E+04 cfu/100ml respectively, with removal percentage of 84.7%, 98.2%, and 99.53%.

Effluent BOD and FC concentration does not match treatment plant design criteria and WHO guidelines for non-restrictive irrigation (BOD: 25mg/L, FC: 10^3 cfu/100ml). While effluent SS is lower than WHO guidelines value (SS: 30mg/L).

A second group of performance results was obtained from PWA data bank for the year 2000 and 2001. Samples were not collected periodically. The number of samples per month varied from 1-4 times and only BOD, COD, and SS parameters were assessed. Average contaminant concentrations for 2000 and 2001 are presented in table 4.3. No documentation was available regarding the methodology used in the analysis of these parameters but it is assumed that samples were collected in a grab fashion, and analysis techniques followed standard procedures. The raw data from the two programs are given in **Appendix C**.

Table 4.3: Summary of results of BLWWTP sampling program in 2000 and 2001.

Year 2000

Month	BOD in	BOD out	Removal %	COD in	COD out	Removal %	SS in	SS out	Removal %
February	760.0	65.0	91.4	1474	158.0	89.3	330.0	21.0	94.0
July	420.0	50.0	88.1	857.0	149.5	82.5	309.7	33.8	89.3
August	466.7	45.0	90.3	900.0	156.7	82.6	332.3	30.3	90.9
September	540.0	57.5	89.3	1200	134.0	88.8	512.5	29.5	94.2
October	620.0	25.0	96.0	1207	125.0	90.0	495.0	24.0	95.0
November	680.0	50.0	93.0	1101	118.0	89.0	535.0	14.0	97.0
December	720.0	35.0	95.1	1591	141.0	91.1	628.5	17.0	97.3
Average	**600.9**	**46.7**	**91.9**	**1190**	**140.3**	**87.6**	**449.0**	**24.2**	**93.9**

Year 2001

Month	BOD in	BOD out	Removal %	COD in	COD out	Removal %	SS in	SS out	Removal %
January	521	45.0	91.3	1180	128.0	89.1	460.0	26.6	94.2
February	500	70.0	86.0	913.5	154.5	83.1	381.5	28.5	92.5
March	508	74.0	85.4	991.6	191.0	80.7	486.8	29.8	93.8
April	680	61.0	90.9	1202	167.5	86.0	562.5	31.5	94.4
May	460	90.0	80.4	744.5	201.0	73.0	324.0	51.5	84.1
June	320	50.0	84.3	657.0	133.0	80.0	153.0	25.0	83.7
August	ND	ND	ND	ND	ND	ND	ND	ND	ND
September	433	35.0	91.9	904.0	107.6	88.1	332.0	37.7	88.6
October	527	36.0	93.2	1070	109.5	89.8	465.8	49.0	89.5
November	460	39.0	91.6	711.0	101.0	85.8	245.0	45.0	81.6
December	760	40.0	95.0	1348	80.0	94.0	710.0	62.0	91.0
Average	**517**	**54.0**	**89.0**	**972.2**	**137.3**	**84.9**	**412.1**	**38.7**	**89.3**

Source: PWA, data bank section.

One can note that these monitoring programs are not included microbiological analysis and it is just limited to carbonaceous organic matter and suspended material. Samples are not collected in the first half of year 2000 (except in February) as happened in year 2001. At year 2000 Influent average concentration of BOD, COD and suspended solids were 600.9, 1190, and 449 mg/L respectively. The average removal efficiency of the treatment system for BOD, COD and suspended solids concentrations through the entire system were 91.9%, 87.6% and 93.9%, respectively. In the year 2001, average influent concentration of BOD, COD and suspended solids were 517, 972.2, and 412.1 mg/L with removal of 89%, 84.9%, and 89.3% respectively. Comparison between the two years reveals two main observations. The first, strength of raw wastewater in 2001 is lower than that in 2000 which may reflect increasing of per capita water consumption or may due to new wastewater networks connections in the areas where cesspools are used and its settleable solids evacuated to BLWWTP. The second is that removal efficiency of BLWWTP decreased over the years as organic and the hydraulic load increase and retention time decrease due to connections of new residential areas. Another comparison between average influent BOD concentration and its removal at May, 1999 and 2001 shows that strength of wastewater and removal efficiency are continually reduced over the years.

4.2 RESULTS OF RESEARCH MONITORING PROGRAM

This section presents the results of conducted monitoring program, which performed as a part of this study. The results include the main physical, chemical and biological parameters which considered in the monitoring program of different location of the treatment plant. The raw data of the monitoring program is provided in Appendix D. Table (4.4) summarized the average values of different parameters at different sampling locations of the wastewater treatment plant.

Table 4.4: Average monitoring values of different parameters of the sampling locations of the wastewater treatment plant.

Parameters	**Unit**	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**	**Remo %**
Water Temp.	C	21.50	21.80	21.00	20.00	21.00	21.30	-
DO	mg/L	2.300	2.100	2.100	4.400	2.800	2.800	-
EC	µS/cm	1.900	1.900	1.900	1.800	1.900	1.900	-
Settleable S	1hr - ml/L	9.400	2.100	0.700	1.600	0.300	0.100	98.93
Settleable S	2hr - ml/L	9.600	2.400	0.800	1.700	0.310	0.120	98.75
TS	mg/L	1382.5	1235	1165	1082.5	1090	1065	22.96
DS	mg/L	954.6	914.7	920.7	891.0	903.9	912.3	4.43
SS	mg/L	308.8	206.3	129.6	80.60	73.80	39.40	87.24
FS	mg/L	792.5	880.0	885.0	868.1	845.0	845.0	-
VS	mg/L	590.0	355.0	280.0	214.4	245.0	220.0	62.71
pH	mmol/L	7.400	6.900	7.400	7.800	7.500	7.600	-
BOD	mg/L	425.0	290.6	210.0	124.4	178.1	178.8	57.93
COD	mg/L	885.0	590.1	470.4	393.3	377.6	349.8	60.47
SO_4^{-2}	mg/L	37.62	-	-	-	-	-	-
Chlorophyll a	mg/L	-	-	-	55.40	145.3	-	-
SAR	meq/L	-	-	-	-	-	4.650	-
TKN		106.1	81.70	86.00	82.80	84.70	84.30	20.54
NH4	mg/L	84.10	72.20	71.60	72.60	73.9.0	72.9.0	13.31
Ortho-phosph	mg/L	6.600	6.100	6.300	6.500	5.400	5.500	16.60
F.Coliform	u/100ml	3.86E+06	2.59E+06	9.40E+05	1.00E+06	3.50E+05	2.04E+05	94.70
Salmonella		-ve	-ve	-ve	-ve	-ve	-ve	-
Nematodes		+ve	+ve	-ve	-ve	-ve	-ve	-

Location 1 (main inlet)
Location 2 (Inlet of anaerobic ponds)
Location 3 (Inlet of aerated lagoon)
Location 4 (Inlet of facultative lagoon)
Location 5 (Inlet of maturation lagoon)
Location 6 (Outlet of maturation lagoon)

4.2.1 Temperature

Figures 4.1 and 4.2 showed the temperature variation over the sampling period between the various stages of treatment. Air temperature data was obtained from Beit Lahia meteorology weather station and is given in Appendix E. The maximum and minimum water temperature measured during the whole monitoring program was 14.4 and 26.3 respectively. Variations of average water temperature among the different location were minimal. As the air temperature getting increase through sampling period from February to

June, water temperature also is proportionally increased. It is noticed that average water temperature raised slightly in location 2 and dropped in location 4.

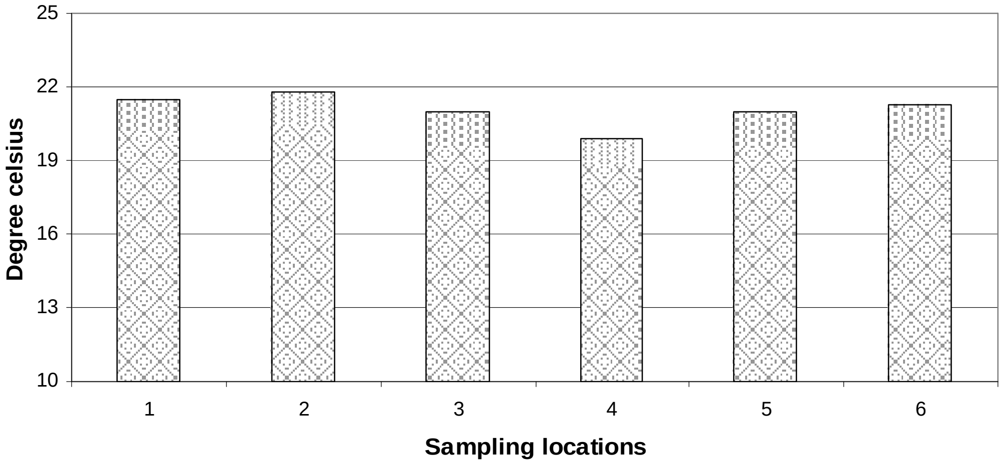


Figure 4.1: Average water temperature at sampling points.

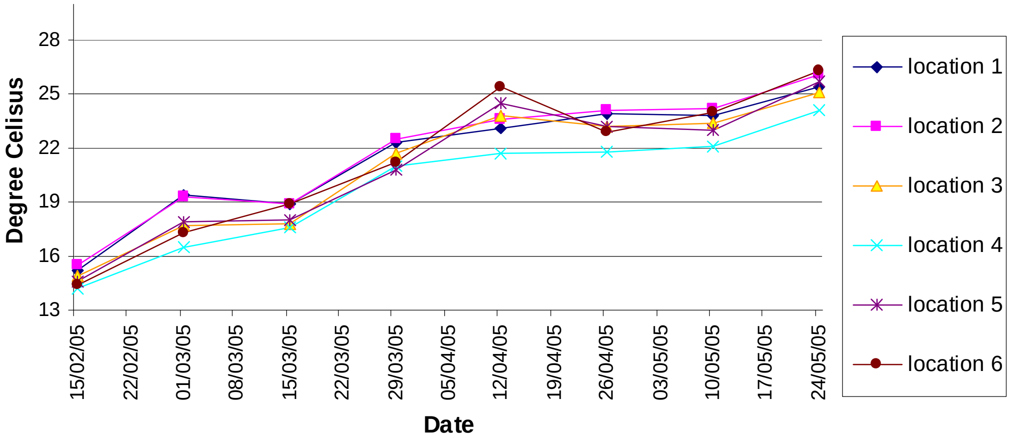


Figure 4.2: Temperature variation over the sampling period of different locations.

4.2.2 Dissolved Oxygen (DO)

Average DO and Temperature valued along sampling location are shown in figure 4.3. Measurements taken from aerated, facultative and maturation ponds show that Average DO concentrations are 3.07mg/L, 2.52mg/l, and 2.57 mg/L respectively. Concentrations of dissolved oxygen are maintained in aerated lagoon by aerators and by algae in facultative and maturation ponds. Solubility of gases generally declines with temperature increase. As the temperature increase from February to May, the average dissolved oxygen concentration decrease as shown in figure 4.4.

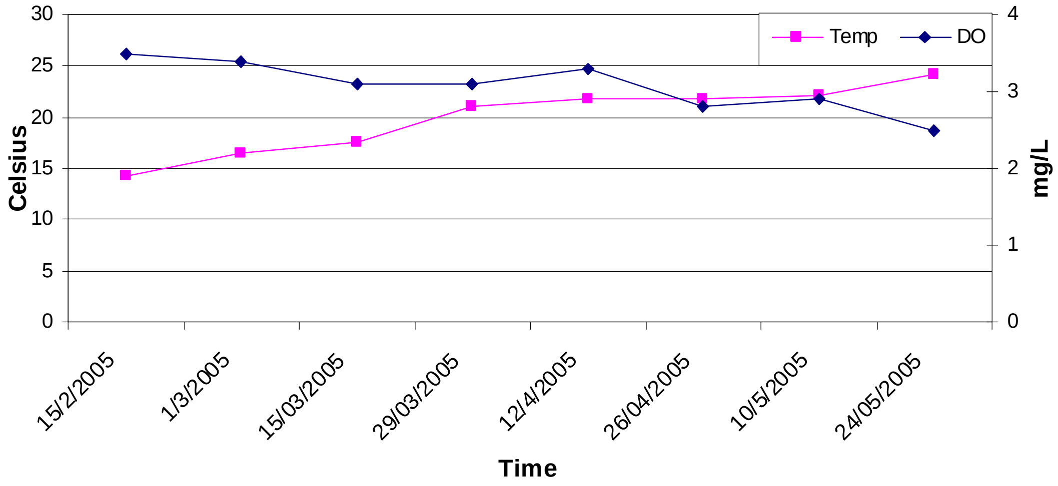


Figure 4.3: Average dissolved oxygen and temperature values along the sampling location

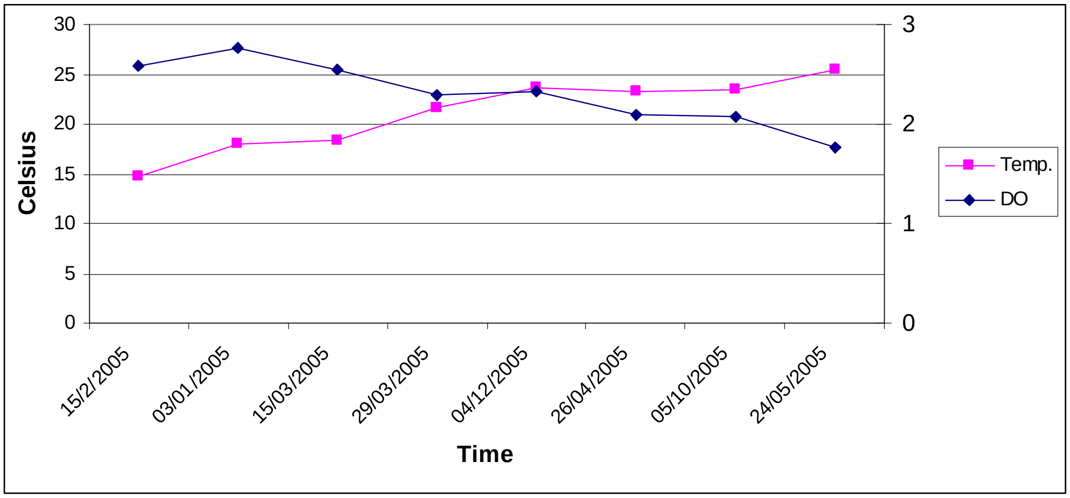


Figure 4.4: Average dissolved oxygen and temperature values over the time.

4.2.3 pH

Variation of pH values within different location in sampling periods is minimal. Average pH values of different ponds of the system, influent, anaerobic pond, aerated ponds, facultative pond, maturation pond, and final effluent were 7.35, 6.92, 7.40, 7.79, 7.46, and 7.57 respectively. The data in figure 4.2 are shown consistent inlet pH levels with that measured in previous monitoring program in 1999 (see table 4.5), but the effluent pH levels in 1999 (8.1) higher than those generated in this study (7.57).

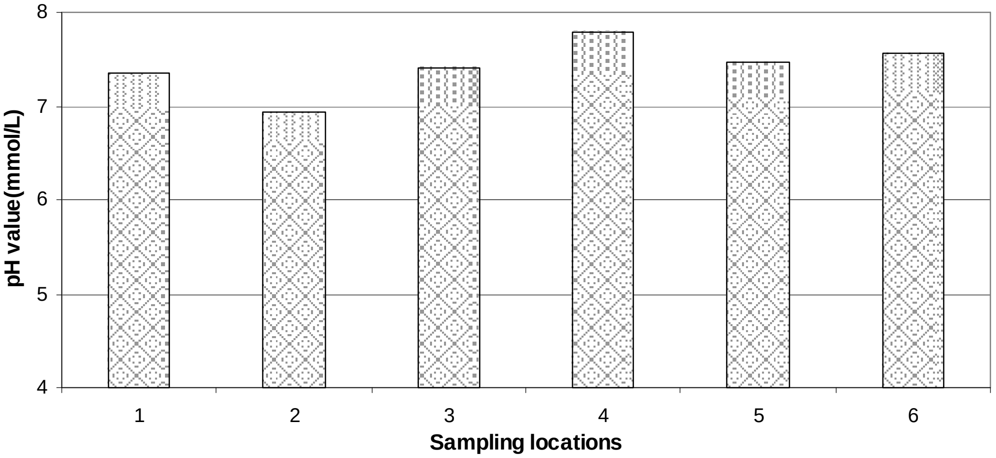


Figure 4.5: Average pH values at sampling points.

4.2.4 Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR)

The treatment process is not expected to influence the both EC and SAR in a significant way. However, the parameters can influence the possibility of reusing the effluent in agriculture. The average measured electrical conductivity parameter for both influent and effluent of the plant are almost closed, 1909 and 1867 µs/cm, respectively. Figure 4.6 present the average values of different sampling location in the monitoring period.

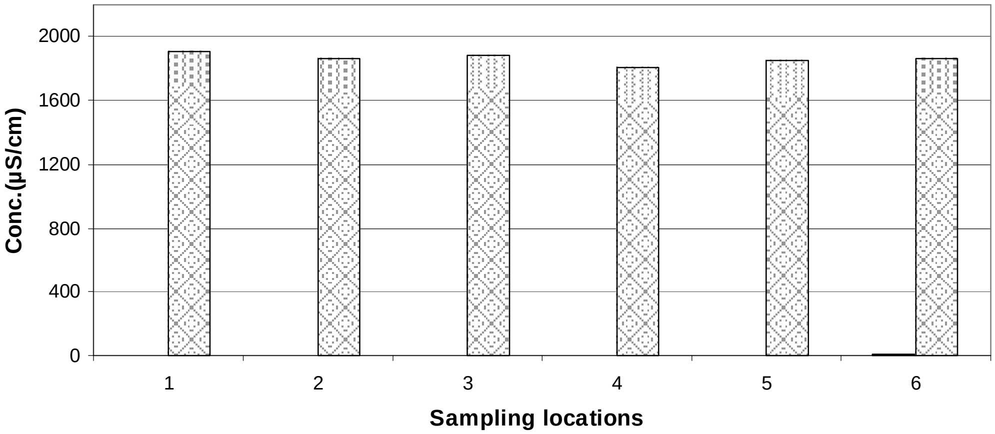


Figure 4.6: Average electrical conductivity at the various sampling points.

The SAR parameter is only measured for the effluent wastewater (location 6) during the monitoring period. All SAR readings were in the range from around 4 meq/L in wet time to 5 meq/L during dry period as presented in figure 4.7.

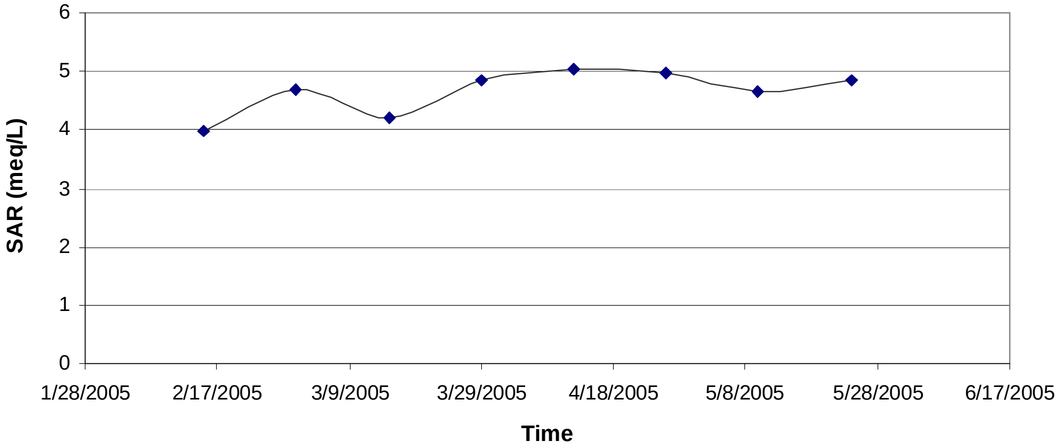


Figure 4.7: Fluctuation of effluent SAR values in location 6 of BLWWTP.

4.2.5 Sulfate

Unlike other parameters, sulfate is analyzed only for location one which explore its concentration in raw sewage and its contribution to odor problems. Figure 4.8 shows SO_4^{-2} concentration results along the monitoring program period.

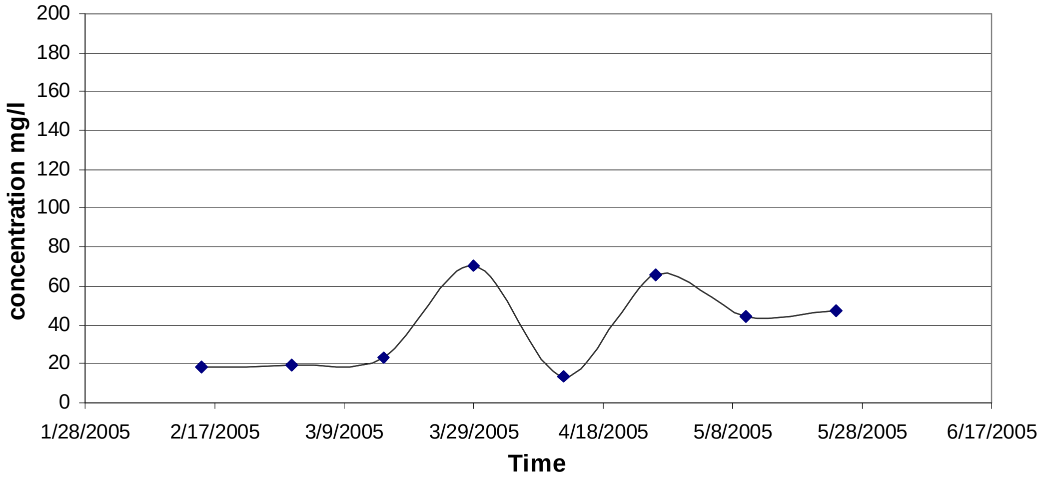


Figure 4.8: Sulfate concentration in Beit Lahia raw sewage.

Influent SO_4^{-2} concentrations ranged from 13 to 70 mg/L with average value of 37.5 mg/L. The average COD/SO_4^{-2} ratio in the influent was 23.6 while the average COD divided by maximum SO_4^{-2} was 12.6.

4.2.6 Solids

The different solids type's contents of the six sampling locations are presented in figure 4.9. The plots show that the system is achieving remarkable reductions of total solids, total volatile solids, and total suspended solids concentrations while total fixed and total dissolved solids reveal fluctuation in concentration without significant reduction. Influent to the system contained on average 1382, 308 and 590 mg/L total solids, suspended solids and volatile solids respectively.

The average percentage reductions for TS, TSS and TVS concentrations through different treatment stages of the system were 23%, 87% and 63%, respectively. With comparison to previous monitoring programs, the average pond effluent TSS removal for 1999, 2000, 2001, and 2005 are 98.2%, 94%, 90.5%, and 87.2% respectively indicating deterioration of treatment plant performance with respect to this parameter.

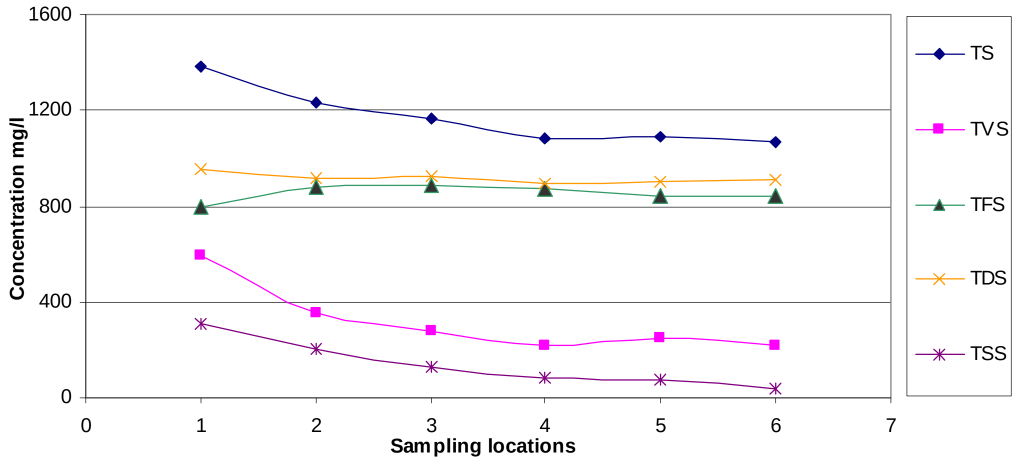


Figure 4.9: Concentration of TS, TVS, TFS, TDS, and TSS at different sampling points.

Accumulative removal of TSS along sampling points is presented in figure (4.10). Samples collected as part of this study showed that the average TSS concentration was reduced from 308.75 mg/L to 129.625 mg/L by the anaerobic ponds with an average removal of 58%. The average TSS through the aerated lagoons (pond 3, 4) was reduced from 129.625 mg/L to 80.625 mg/L for a removal of 37.8%. Reductions of TSS solids that take place in facultative lagoons (pond 6, 5) were 8.5% while it reaches 46.6% in maturation lagoon (pond 7). Over all removal of TSS in the whole treatment plant is 87.24% with an average of 39.375 mg/L effluent concentrations. Anaerobic lagoons and to lesser extent maturation pond registered highest TSS removal while facultative pond had a limited contribution of TSS removal due to algal growth.

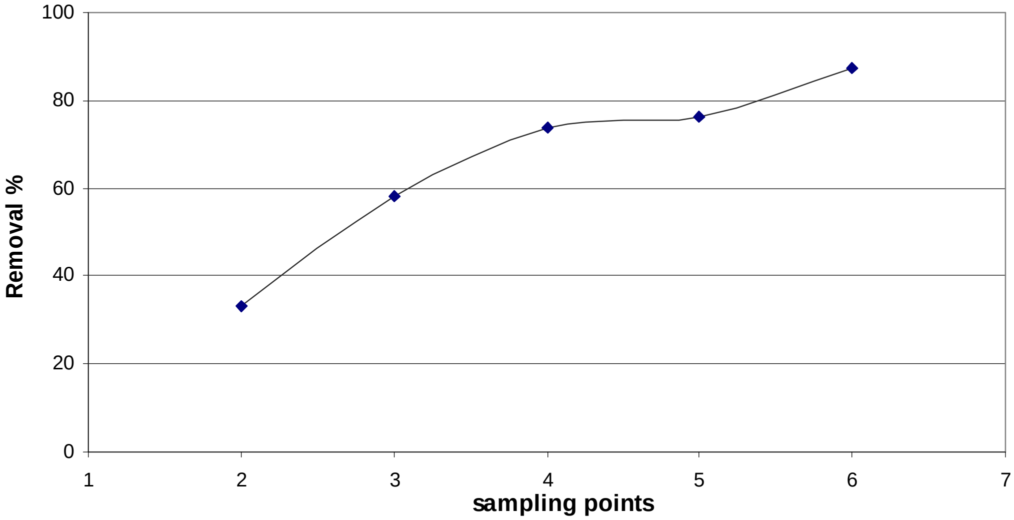


Figure 4.10: Cumulative removal of TSS along sampling points.

TS and VS are reduced mainly in anaerobic ponds with a lower reduction in aerated and maturation pond. As in the case of SS, slight increase of TS and VS in facultative ponds is refer also to algal growth.

Settleable solids were measured in the laboratory using imhoff cone for one and two hour settling periods (see appendix A). The average settleable solids concentration after one hour settling time was reduced from 9.4 ml /L to 0.103 ml /L with an average removal of 98.80% (Figure 4.11) in the all stages of treatment system. The main reduction of settleable solids concentration taken place in grit removal and anaerobic pond with an average removal of 92.8%. Settleable solids increased from 0.675 ml /L to 1.55 ml/L in aerated lagoon. This increase is due to mechanical agitation of aerators and mixers which make excitation for settled particles.

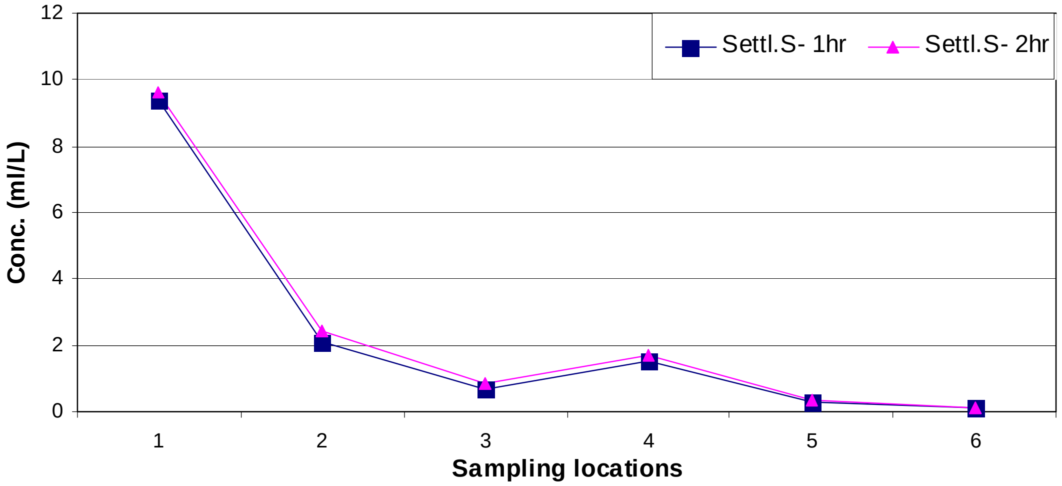


Figure 4.11: Average settleable solids after one and two hour concentration at different sampling points.

4.2.7 Carbonaceous Organic Matter

The carbonaceous organic mater removal was measured through biochemical and chemical oxygen demand (BOD_5 and COD).

4.2.7.1 Carbonaceous Biochemical Oxygen Demand

Figure 4.12 present the average BOD_5 concentration at different sampling points of the treatment system.

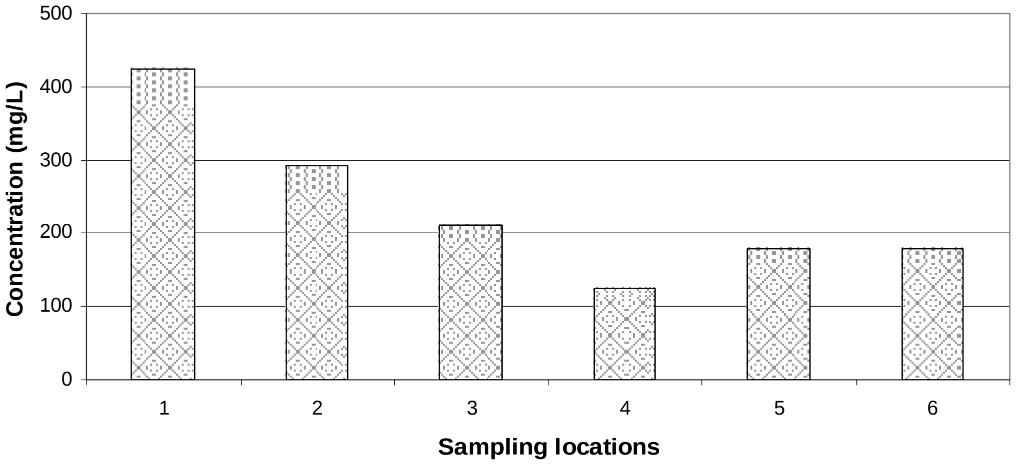


Figure 4.12: Average BOD_5 concentration at different sampling points.

The average BOD_5 concentration was reduced from 425 mg/L to 210 mg/L in the anaerobic ponds with a removal of 50.6% and reduced from 210 mg/L to 124.375 mg/L in the aerated lagoons with an average removal of 40.8%. Through passage of wastewater in the facultative lagoons (pond 6, 5), the average BOD_5 was increased from 124.375 mg/L to 178.1429 mg/L with an average of 30.18%. No considerable change in BOD_5 has been measured in maturation lagoon. Over all BOD_5 removal in the whole treatment plant system is 57.94% with 178.75 mg/L effluent concentrations.

To set aside the effects of algae growth on effluent BOD_5, analysis were also performed on selected samples for BOD_5 before and after filtration (as seen in table 4.5). The average BOD_5 value for filtered samples was 115 mg/L. The contribution of algae to effluent BOD_5 concentration is around 36%. That means the total removal efficiency of the system is around 72% taking in account only the average soluble BOD value of the effluent.

Table 4.5: Unfiltered and filtered BOD concentration.

Date	15/3	29/3	26/4	24/5	average
Unfiltered BOD	220	200	140	190	187.5
Filtered BOD	150	130	80	100	115

4.2.7.2 Chemical Oxygen Demand

The average influent COD concentration was 885 mg/L over the monitoring period. Figure 4.13 presents the average percentage removal efficiency and accumulative removal effects of different ponds types. The total removal efficiency of the system was by an average of 60.6%. The greater portion of reduction was achieved in the anaerobic ponds (46.9%), while the aerated, facultative, and maturation lagoons effected a reduction of 16.4%, 4.1%, and 7.4% respectively.

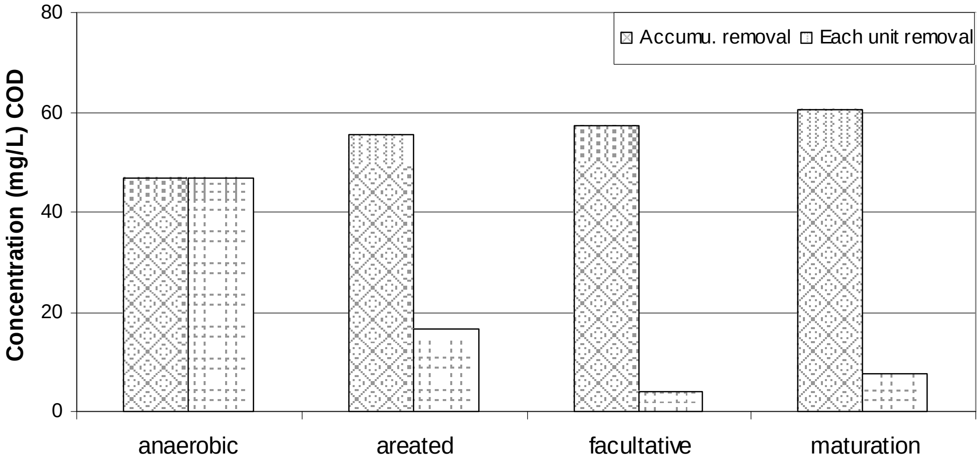


Figure 4.13: COD average percentage removal efficiency and accumulative removal effects of different ponds types.

The study results show that effluent COD concentrations for the existing condition were notably higher than COD concentration in years 2000 and 2001 by two and half folds (349 mg/L); in spite of that average influent COD concentration at the present time is lower than it in these years. Average COD reduction efficiency in 2000, 2001 were 87.6% and 84.9%.

Average COD: BOD_5 ratio was increased steadily from 2.15 at the treatment plant inlet to 3.68 at the outlet of aerated lagoons (as seen in figure 4.14) while it decreased after that to reach 2.03 at the treatment plant outlet.

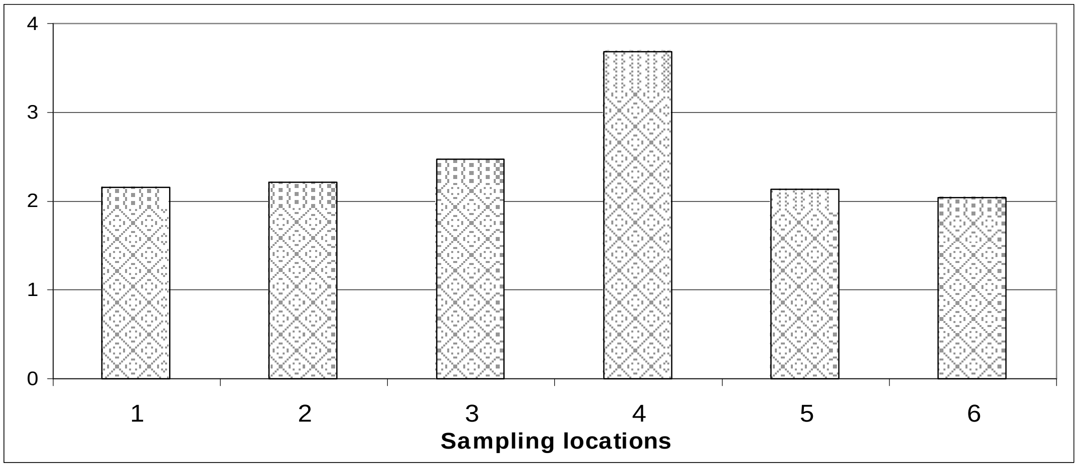


Figure 4.14: Average COD: BOD_5 ratio at different sampling points.

The digestion behavior of the system is also characterized by the COD: TS ratio, which decreased from 0.65 in the treatment plant influent to 0.33 in the ponds effluent as shown in figure 4.15.

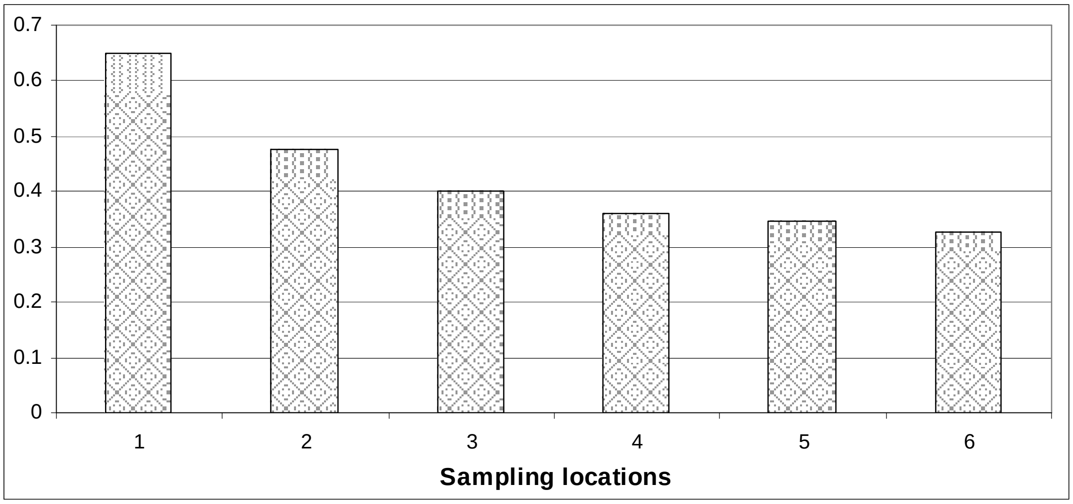


Figure 4.15: COD: TS ratio in all studied sampling points

4.2.8 Chlorophyll-a

Unlike other parameters, chlorophyll-a was measured only in influent and effluent of the facultative ponds (locations 4 and 5) to determine the concentration of algae biomass. Table (4.6) shows Chlorophyll-a concentrations at the effluent of locations 4 and 5 of the facultative lagoons in the period from February to May 2005.

Table 4.6: Chlorophyll-a concentration at the effluent of facultative lagoons.

Sampling Date	Location 4 µg/ L	Location 5 µg/ L
15/02/2005	34.1	34.1
15/03/2005	38.4	68.1
29/03/2005	45.4	79.5
12/04/2005	56.8	272.5
24/05/2005	102.2	272.5
Average	**55.4**	**145.3**

The results indicate a good increase of chlorophyll-a in facultative pond effluents from winter season to spring and the values varied between about 34 and 102 µg/ L with an average of about 55 μg/L in location 4, compared with effluent values in location 5 from a range of about 34 to 272 μg/L and an average of 145 μg/L.

4.2.9 Nutrients

The Key nutrients associated with wastewater treatment are nitrogen and phosphorous. Together these two elements are known as nutrients and their removal is known as nutrient striping. The major problems likely to arise from sewage effluent discharges are nutrient enrichment (Eutrophication), with its associated algal blooms and deaeration of the watercourse resulting from oxidation of ammonia to nitrate by the nitrifying bacteria. In addition, nitrate and ammonia pose a risk to soil and groundwater as well.

4.2.9.1 Nitrogen

Sewage of domestic origin contains nitrogen either organically bound as protein and nucleic acids, as urea or as the ammonium ion (NH_4^+). Nitrates and nitrites are rarely present. The total nitrogen content of a wastewater is often referred to as the total Kjeldah1 nitrogen (TKN). The nitrogen present in TKN parameter represents the organic nitrogen and the free ammonium. Figure 4.16 present average values of TKN and NH_4 of different sampling location during the monitoring period. The results show relatively high TKN content of the influent. Limited reductions of both parameters were achieved. The average percentage of ammonia fraction from TKN was more than 75%.

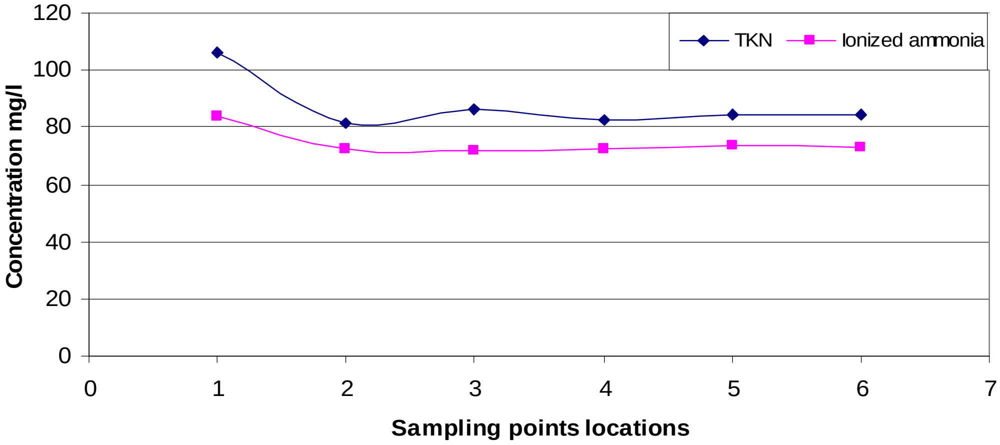


Figure 4.16: Average TKN and NH_4 concentrations along sampling points.

By examining total nitrogen concentrations at sampling locations 1 and 6, it was found that only a 20.55% removal of total nitrogen was accomplished in the treatment system with an effluent concentration of 84.3 mg/L. Ionized ammonia was reduced from 84 mg/L at the inlet to 72.8 mg/L at the outlet with an average removal of 13.2%. The difference between amount of ammonium present in the sample and the TKN, given the fraction of organically bound nitrogen. The main reduction step was in anaerobic pond location 2.

4.2.9.2 Phosphorus

The major sources of phosphorus in domestic wastewater are from human excreta and synthetic detergents. Phosphorus can be found in form of organic-, poly- and orth-phosphorus in sewage. Figure (4.17) shows the notable consistency of Ortho-Phosphate concentrations in the effluent from the different ponds of the treatment system. Phosphorus reductions through the treatment plant were relatively low. Ortho-phosphorus concentrations entering the system averaged 6.58 mg/L and were reduced by an overall average 15%.

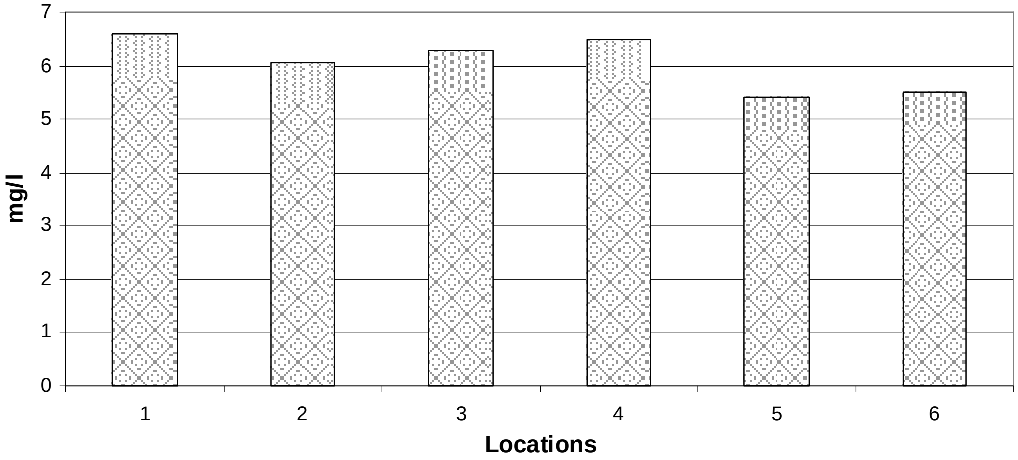


Figure 4.17: Ortho-phosphorus concentration a long sampling points.

4.2.10 Biological Parameters

Fecal coliform (FC), Salmonella and Nematodes were used as indicators parameters for biological contamination level of collected samples. Figure 4.18 presented the average FC content of the different sampling locations of the treatment plant. The average removal of FC through the whole treatment train was 94.7% with an average effluent concentration of 5.00 log units/100 ml. The FC content in the final effluent of the treatment system never lowered from 4.00 log units/100 ml along the period of study. With comparison to monitoring programs that carried out in 1999 (table 4.2), the average removal of FC is 99.52% with an average effluent concentration of 4.00 log units/100 ml.

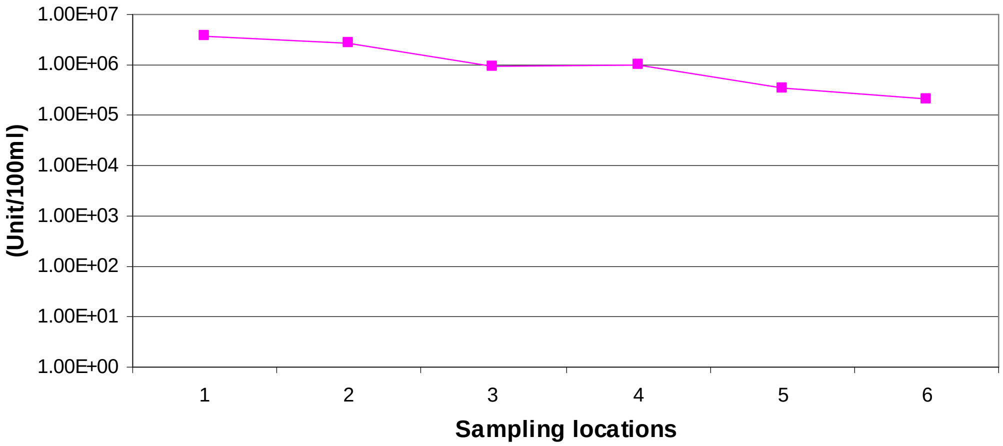


Figure 4.18: Average FC content of the different sampling locations of the treatment plant.

Time and temperature are the two principal parameters used in maturation pond design. FC die-off in ponds increases with both time and temperature. Increase of water temperature along the time from winter to summer reflected the increase of sun radiation ability to disinfect FC. The relation between temperature and FC over time is presented in figure 4.19.

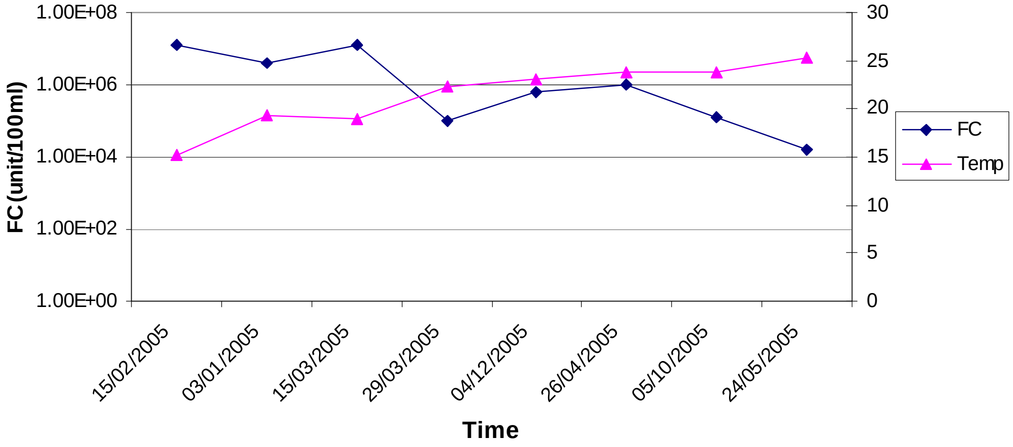


Figure 4.19: Relation between FC and temperature over time.

Salmonella and nematodes are waterborne organism. As with most waterborne pathogens, Salmonella is difficult to detect and enumerate with accuracy in wastewaters due to methodological limitations. Qualitative analysis for nematodes and salmonella has been conducted 7 times from the different sampling collection sites of the treatment system. Table 4.7 presented the number of isolation incidences of studied samplings. Salmonella was not isolated from any of the collected samples during the whole monitoring program. Nevertheless, the presence of pathogenic enteric microorganisms in water constitutes a potential threat to human health.

The nematode was isolated 3 times from location 1 (raw sewage) and 5 times from location 2 (effluent of anaerobic ponds). No nematode was isolated from other locations.

Table 4.7: Nematodes and Salmonella detected from the various sampling locations.

Location	**Number of isolation incidence or presence out of 7 sampling occasions**	
	Nematodes	**Salmonella**
1	3	0
2	5	0
3	0	0
4	0	0
5	0	0
6	0	0

CHAPTER (5): DISCUSSION

This chapter discusses the finding results of different performance parameters of BLWWTP. From the comparison of the different historical available monitoring programs data and the new generated one, a decline of treatment capacity and decrease of removal efficiency of the system was generally observed over the last years. Analysis of the technical performance aspects of BLWWTP and the factors leading to inadequate performance of the system will be discussed. In addition, modification on the treatment system that can be improved the system performance will be suggested.

5.1 ANALYSIS OF TECHNICAL PERFORMANCE ASPECTS

The results of different field and laboratory physical, chemical and biological parameters of treatment system performance will be analyzed.

5.1.1 Physical Field Parameters:

Temperature, pH and DO were the main field measurement which considered in this study. The results showed increase of temperature in location 2, which may be due to anaerobic digestion and decrease of temperature in location 4, which could be refer to the action of aerators and mixers in aerated lagoons. As expected, results reveal that water temperature in the wintertime is higher than air temperature. Steady increase of water temperature observed from the first collection time (15/2/2005) to the last one (24/5/2005).

Regarding pH parameter, the results showed a minimal variation of pH values throughout the sampling points. Dropping of pH value in location two in the anaerobic pond is attributed to the volatile acids and carbon dioxide that produced from anaerobic digestion of organic matter. Action of aerators in aerated lagoon increase reagent foams in the upper layer of the wastewater where the sample collected from. This could be responsible for slight increase of pH in location four. Its notice that system has adequate buffering capacity to neutralize the production of volatile acids and carbon dioxide that produced in anaerobic pond.

With suitable organic loading, high pH values above 9 expected to occur in facultative and maturation ponds during the sunlight due to rapid photosynthesis by the pond algae which consume CO_2 faster than it can be replaced by bacterial respiration; as a result carbonate and bicarbonate ions dissociate:

$$\mathbf{2\ HCO_3^{-} \rightarrow CO_3^{-2} + H_2O + CO_2}$$

$$\mathbf{CO_3^{-2} + H_2O \rightarrow 2\ OH\ - + CO_2}$$

The resulting CO_2 is fixed by the algae and the hydroxyl ions accumulate so raising the pH, often to above 10 **(Mara and Pearson, 1998)**. The reduction in photosynthetic activity was reflected in pH, which ranged from 7.3 to 7.65 in the effluent of facultative pond. The chlorophyll-a concentration in facultative pond effluents was less than 150 μg/L, which is usually in the range of 500−1000 μg/L. So, it is clear that algae can not play effective role in maintaining and raising pH in the facultative pond to expected value. This could be as a direct result to organic overloading that lead to insufficient concentration of algae. The current average system effluent pH is lower than pH reported in 1999 indicating that this dropping of pH value in the effluent along the year may reflect the increase application of organic load to the treatment plant and decline of its removal efficiency. The dropping of pH also may lead to decrease of maturation pond disinfection ability.

Aerobic ponds rely on an oxygenated water column and a symbiotic relationship between algae and bacteria to function effectively. Dissolved oxygen levels are maintained by surface aeration, which is assisted by wind and rain and algal photosynthetic activity. Oxygenation from photosynthesis is directly proportional to algal activity levels, which are controlled by the presence of light, temperature, availability of nutrients and other growth factors **(Reed et al., 1995)**. The availability of dissolved oxygen (DO), which regulates processes such as microbial oxidation of carbonaceous and nitrogenous compounds, is strongly temperature dependent. The solubility of oxygen is greatest in cold, wet seasons and lowest in dry, warm periods, which would suggest that BOD reduction would be enhanced in winter **(Reed et al., 1995; Kadlec and Knight, 1996)**.Concentration of dissolved oxygen in BLWWTP is eligible to be dropped in the summer time as long as water temperature increases (see figure 4.4) and as a result BOD removal expected to decline.

The concentration of algae in an optimally performing facultative pond depends on organic load and temperature, but is usually in the range from 500 to 2000 µg chlorophyll-a per liter **(Cinara, Colombia, 2004)**. **(Curtis et al., 1992)** stated that the concentration of algae in a well-functioning facultative pond depends on loading and temperature. It is usually in the range 500−1000 µg chlorophyll-a per liter (algal concentrations are best expressed in terms of the concentration of their principal photosynthetic pigment).

5.1.2 Chemical and Biochemical Oxygen Demand:

Inspection of the historical operating data of the system for BOD_5 revealed that maximum reported concentration of effluent BOD from 1999 to 2001 was 105 mg/L. As can be seen from the results, removal efficiency of BLWWTP during the same period with respect to BOD_5 was in the range from 80% to 95%, while the average removal percent in this study monitoring program was 57.94%. Effluent BOD_5 has been serious increasing since 1999 and comparison of average BOD_5 removal percent data that obtained in the same month (May) of 1999, 2001, and 2005 reveals that BLWWTP removal efficiency is continually decreased over time (See figure 5.1). This phenomenon may enhance claim that BLWWTP is seriously hydraulically and organically overloaded.

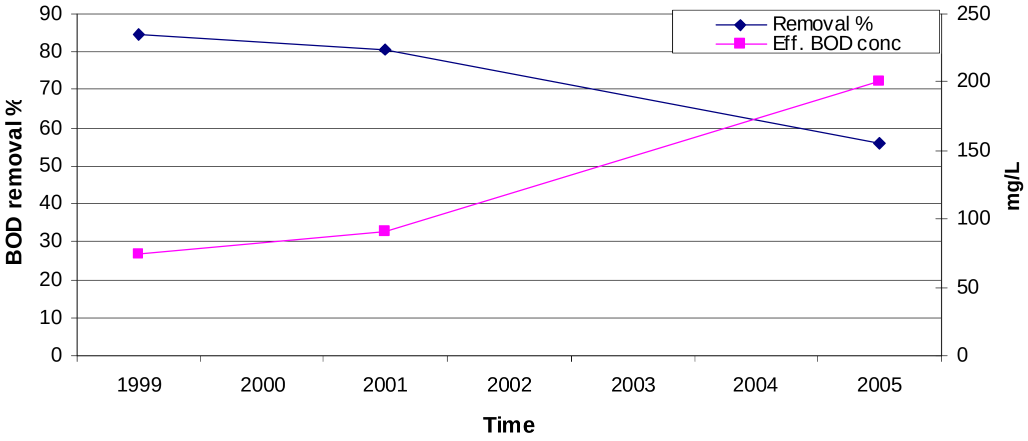


Figure 5.1: Percentage removal efficiency and effluent concentration of BOD_5 over the time of BLWWTP.

Lowering of BOD_5 is both a physical process by way of settling of organic particles and a biochemical process through decomposition and mineralization of organic and inorganic compounds **(Reed, 1995)**. A well-designed anaerobic pond has been reported to achieve up to 60% reduction in BOD depending upon the temperature and retention time **(Horan, 1990)**. The anaerobic pond removed BOD_5 by two processes, settling and decomposition of organic matter. Settling consider the dominant BOD_5 reduction mechanism and need few hours to be accomplished, while the reduction by decomposition is increased as the residence time of the wastewater increased. Although anaerobic pond achieved more than 50% of the influent BOD_5 removal of BLWWTP through a good settleableaty of SS, the residence time is suspected to be sufficient to remove that accumulated organic mater by anaerobic decomposition. Consequently, anaerobic ponds could not be operating for long time without desludging.

In a good designed system, aerated lagoons can reliably produce an effluent with both biological oxygen demands (BOD_5) and TSS < 30 mg/L if provisions for settling are included at the end of the system **(EPA, 2002)**. Effluent of this quality from aerated lagoon is not produced along the monitoring program in BLWWTP due to incorrect operation and high surface organic loading. High organic load that applied to facultative pond creates conditions that prevented normal concentration of algae which reflected on BOD_5 removal efficiency in these lagoons. **(Mara and Pearson, 1998)** stated that around 70-90 percent of the BOD_5 of a maturation pond effluent is due to the algae contains. During study monitoring program, final effluent were measured for filtered BOD in four occasions and the result showed that maximum contribution of algae to effluent BOD_5 was 38.7%. This is incorporated with low concentration of chlorophyll-a due to overloading of facultative. Failure of BOD_5 removal in aerated lagoon affected negatively maturation pond ability to make effective disinfection of fecal coliform. From the previous discussion, it is clear that underperformance of any treatment unit will be complicated the treatment process in the consequent treatment unit leading to failure in the overall treatment system. This failure is clearing by producing effluent with poor quality which may affect ambient environment seriously.

The results showed that reduction percent of COD are higher slightly than BOD_5. Figure (4.12) that displayed average COD: BOD_5 ratio at different sampling points is indicating slight increase of this ratio in anaerobic lagoons. The quite increase could be related to the fair decomposition of readily biodegradable material (BOD_5). The sharp increase of COD: BOD_5 ratio in aerated lagoon is not indicates a reasonable level of digestion activity of readily biodegradable material (BOD_5) but may refer to the action of aerators that re-suspended a well stabilized settled organic matter and as a result elevated COD concentration in the sample collected from these lagoons. Easily evacuation of re-suspended well stabilized organic matter by resettling and decrease of algae concentration in facultative and maturation ponds that absorb BOD_5 may be responsible for reduction of this ratio. The reduction of COD:TS ratio (figure 4.13) in the treatment plant can be attributed to the rapid decomposition of BOD_5 if the effluent contain small concentration of dissolved BOD_5, but in the contrast, most BOD_5 removed as settleable and partially as suspended solids with the slower decomposition of refractory organic material. So it can be concluded that the decomposition activity of the treatment system is modest. Increase of effluent COD and Decline of its removal efficiency (figure 5.2) is consistence with BOD_5.

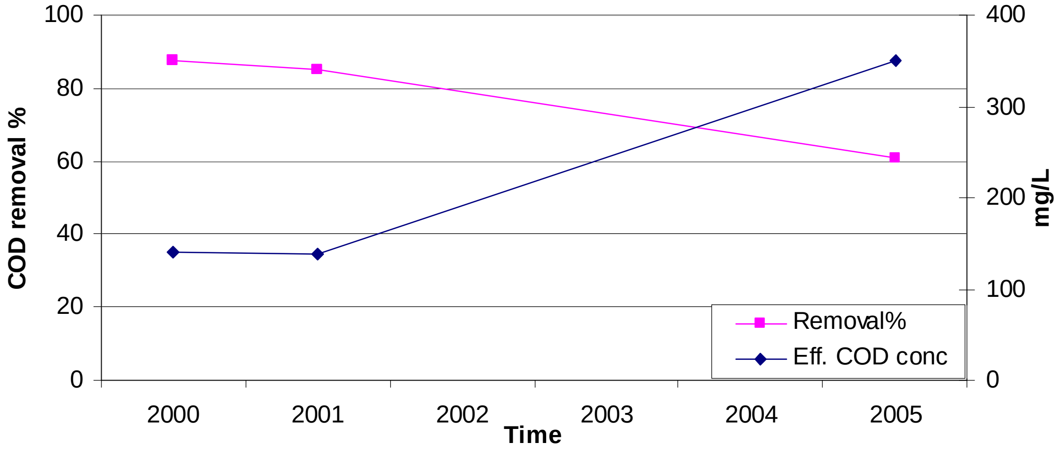


Figure 5.2: Percentage removal efficiency and effluent concentration of COD over the time of BLWWTP.

The excessive organic surface loading on the BLWWTP facultative ponds reduced Chlorophyll-a level to the dangerously low levels that hard to sustain aerobic conditions on the surface layers of the facultative ponds. Based on that, the contribution of facultative pond in BOD_5 removal was dramatically negative effected with about 30% as showed in figure 4.12.

5.1.3 Solids Removal:

The organic and inorganic components of wastewater are present in both a soluble and insoluble form. Three distinct types of solids are recognized in wastewater: suspended solids, dissolved solids and volatile suspended solids. Using such a system of classification it has been shown that the soluble solids in a wastewater comprise largely inorganic material, whereas suspended solids can contribute up to 60% of the BOD_5 of the wastewater and consequently they will undergo biodegradation and exert an oxygen demand, in a similar way to the solved solids. In addition, however, owing to their larger size and more rapid settling, they may frequently settle quickly and form a sludge blanket near the point of the effluent discharge. The results showed that the system is achieving remarkable reductions of total solids (TS) concentrations. Most reductions of TS were apparent as suspended and volatile solids, however reductions of the more conservative dissolved and fixed fraction solids reveal fluctuation in concentration without significant reduction.

The production of suspended solids in aerated lagoon may be due to disturbance and re-suspension of settled organic matter caused by aerators. TSS reductions in facultative and maturation ponds were hindered by contributions of suspended material from algal growth. Average reduction of suspended solids in the treatment plant (87%) was less effective than observed in previous years. **Reed (1995)** reports that short-circuiting resulted in decreased suspended solids removal. Over the years, BLWWTP received increased amount and higher flux of flow which exceeded the design capacity of the WWTP resulting on short detention time

Removal of suspended solids is facilitated by much of the same processes as that of BOD_5 removal, i.e., physical settling of particles and subsequent biological decomposition and mineralization of compounds. **Crites and Tchobanoglous, (1998)** stated that the influent suspended solids in BLWWTP are mainly removed by sedimentation in lagoon systems. Some reduction in suspended solids is due to the breakdown and oxidation of suspended particulates. Algal solids that develop during treatment become the majority of the effluent suspended solids. Effluent suspended solids can range as high as 140 mg/L for aerobic lagoon to 60 mg/L for aerated lagoons. Because of the most algal solids are difficult to remove from water and effluent standards often cannot be met, additional process may be needed to remove the solids. **(Reed et al., 1995)** reported that the effluents from WSP systems are characterized by a high concentration of suspended solids, which in some occasions can exceed 100 mg/L due to algae in the effluent. The BLWWTP treatment system is performing relatively well with regard to TSS removal. It is believed that about 37% of effluent suspended solids refer to contribution of algae. Because of the most algal solids are difficult to remove from water and effluent standards often cannot be met, additional process may be needed to remove the solids.

Settleable solids were measured in the laboratory using imhoff cone for one and two hour settling periods. Minimal variation had been reported between the two readings which reflect high settleability of organic material removed by gravity especially in primary treatment unit.

5.1.4 Nutrient Removal:

The major problems likely to arise from sewage effluent discharges are nutrient enrichment (Eutrophication) with its associated algal blooms and deaeration of the watercourse resulting from oxidation of ammonia to nitrate by the nitrifying bacteria (nitrification). Where nitrification does occur, and the water is abstracted as a potable source, there is the associated problem of nitrate toxicity. Although sewage effluents are not the only source of nitrogen pollution they are major one, and also the one which is most amenable to control.

TKN represents two forms of nitrogen, organic nitrogen and ionized ammonia. The results showed that ammonia was the mean percentage fraction of the influent TKN with more than 75%, which mean rapid mineralization of organic nitrogen that converted to ionized ammonia inside sewerage networks which characterized as a highly anaerobic environment. The three mechanisms for ammonia removal in ponds are volatilization, assimilation into algal biomass and biological nitrification coupled to denitrification **(Middlebrooks et al., 1982)**. **Mara et al. (1992)** report a total nitrogen removal of 80% in all waste stabilization pond systems, which in this figure corresponds to 95% ammonia removal. It should be emphasized that most ammonia and nitrogen could be removed in maturation ponds, but the monitoring results, as seen in figure (4.14), showed that limited removal of TKN and NH4 parameters along sampling points. Removal of around 20% of TKN and ammonia was taken place in the inlet and anaerobic ponds while other lagoons did not reveal significant contribution in the removal. Strong flux of wastewater flow from closed sewerage system to open screening and grit removal unit makes agitation which allows ammonium volatilization especially if we take into account relatively high water temperature. So, 50% of total removed TKN can be attributed to ammonia volatilization while the rest is settled as organic nitrogen in anaerobic ponds. Treatment after anaerobic ponds was maintained steady concentration of TKN and ionized ammonia. Nitrification-denitrification process which eligible to accomplished in aerated and facultative ponds is not expected to be realized due to high organic load and limited oxygen supply. Low concentration of algae can be interpreted the limited assimilation of ionized ammonia into algal biomass.

Phosphorus load control has been demonstrated as one of the most effective ways of dealing with man-made eutrophication; for this reason several countries apply a phosphorus standard for sewage effluent discharges. The uptake and removal of phosphorus through the treatment units of BLWWTP were relatively low. The average overall reduction in term of ortho-phosphorous is 15%. This reduction had taken place mainly in facultative ponds. **Reddy et al. (1998)** pointed that consistency of effluent ortho-P concentration in treatment units inside WWTP is indicative of a high irreducible background concentration, which is related to saturation of sorption sites in the soil and sediment (sludge) of the system and almost Ortho-phosphorus removal taken place in facultative pond where the algae expected to uptake it to build own biomass. **Mara et al. (1992)** mentioned that maturation ponds only achieve a small removal of BOD_5, but their contribution to nitrogen and phosphorus removal is more significant. But results exhibited no contribution of maturation pond in BLWWTP to Ortho-phosphorus removal. Pond reduction of Ortho-P (15%) is lower than partitioning that is generally anticipated to occur in typical lagoon systems. The efficiency of ortho-phosphorus removal in WSP depends on how much leaves the pond water column and enters the pond sediments – this occurs due to absorption of ortho-phosphorous by algae and sedimentation as organic P in the algal biomass as well as precipitation as inorganic P (principally as hydroxyapatite at pH levels above 9.5). Low ortho-phosphorus removal in the facultative and maturation pond would also primarily be related to the increasing saturation of sediment sorption sites, low pH, and low algae concentration. The increase of settled sludge layer with progress of operation may be in charge for dissolution of P into the water column from accumulating P-rich sludge/sediment in the ponds and P-saturated bottom soil which led to more increase of effluent phosphorus concentration. Recent experimental studies indicate that the best way of increasing phosphorus removal in WSP is to increase the number of maturation ponds.

5.1.5 Biological Parameters

Fecal coliform (FC), Salmonella and Nematodes were used as indicators parameters for potential removal of biological contamination. The average contents of FC in the final effluent of BLWWTP were about 2 X 10^5 with removal efficiency of 94.7%. **Arthur, (1983)** anticipated FC cumulative percentage reductions to be 99.975% as given in table 5.1 for the same lagoon system arrangement in Beit Lahia at approximately the same temperature and retention time.

Table 5.1: Anticipated BOD_5 and FC cumulative percentage reductions for various pond systems at 12°C, 20°C and 25°C.

	Cum. % BOD_5 Reduction			Cum. % FC Reduction		
	12°C	20°C	25°C	12°C	20°C	25°C
Anaerobic Pond	45	62	70	60.0	86	93
an. + fac.	86	92	94	99.0	99.975	99.995
an. + fac. + mat.	86	92	94	99.0	99.975	99.995
an. + fac. +3 x mat.	94	95	95	99.95	99.9996	99.99999

Key: an. anaerobic pond; fac. facultative pond; mat. maturation pond.
Assumptions:
1. Systems treating normal domestic sewage.
2. Anaerobic pond detention time of 2 days.
3. Facultative pond detention time 7 to 15 days depending on ambient temperature.
4. Maturation ponds detention time of 5 days, accept first maturation pond following aerated lagoons - 10 days.

The final effluent of BLWWTP is not complied with the WHO guidelines for unrestricted irrigation regarding the FC content (≤1,000 CFU/100 ml). Consequently the effluent can not be used for unrestricted irrigation of several crops without any additional disinfection treatment.

As stated earlier in literature review, faecal bacteria are mainly removed in facultative and especially maturation ponds. But the results showed that the highest removal efficiency was achieved at anaerobic and facultative ponds. The increased organic loading that lowering pH value and the concomitant shortening of the HRT as well as the inadequate design of the maturation pond (regarding its depth) can be the main reason of underperformance of maturation pond. In the last 5 years and taking into account increased volume of wastewater inflow, high organic loading, and improper design criteria particularly in maturation pond, it can be claimed that the capability of the treatment system to remove FC is reduced continually. Comparison between average FC removal in May-1999 and May-2005 reveals significant reduction of removal efficiency with time as shown in figure 5.3.

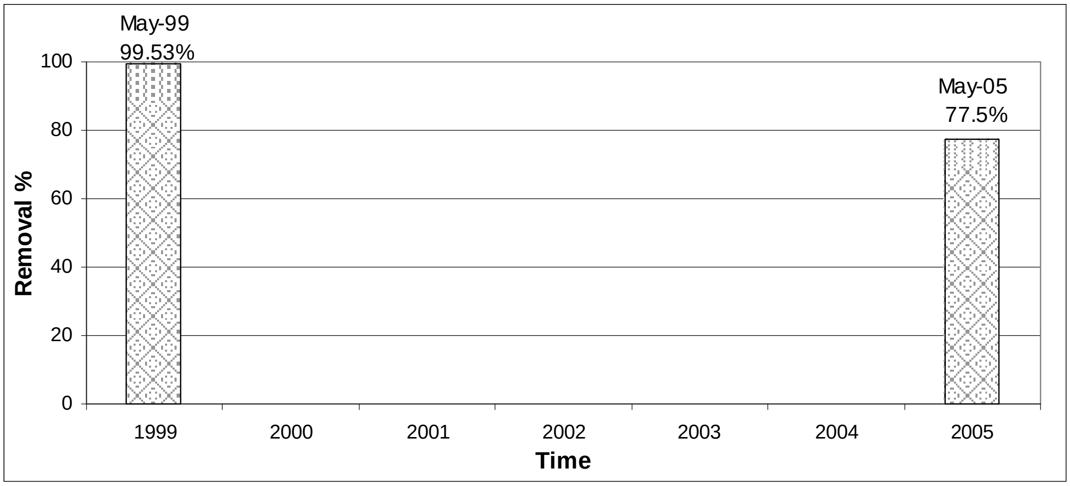


Figure 5.3: The average FC removal in BLWWT with time.

Mara and Pearson (1998) mentioned that baffling in maturation ponds is advantageous as it helps to maintain the surface zone of high pH, which facilitates the removal of fecal bacteria. **(Pearson et al., 1987)** assured that fecal bacteria (with the notable exception of *Vibrio cholerae*) die very quickly at pH > 9. **(Pearson et al., 1995)** in their study around the influence of pond geometry and configuration on facultative and maturation WSP performance indicated that baffled maturation ponds are more efficient at Faecal coliform removal than un-baffled ponds.

Nematodes were analyzed qualitatively in the base of presence or absence. Helminth eggs were not counted during the monitoring program. The study results showed that nematodes are found in raw sewage (location 1) and in location 2 after the wastewater passing screen and grit removal. No nematodes were detected in the effluents of any of the anaerobic, aerated, facultative, and maturation ponds. **Pearson et al., (1996)** found that a combination of anaerobic pond plus a secondary facultative pond with an overall retention time of 2 days eliminated helminthes eggs**. (Mara and Silva, 1989)** concluded that effluents with < 1 egg per liter can be produced by a 1 day anaerobic pond followed by a 5 days secondary facultative and 5 day maturation pond. In comparison with BLWWTP, the wastewater has retention time that matches or exceeds retention time suggested by Mara and Silva. So, Egg-free effluent was expected to be produced by BLWWTP.

5.1.6 Other Chemical Parameters

Some other chemical parameter like sulfate, electrical conductivity (EC) and sodium adsorption ratio (SAR) were include in monitoring program in selected locations. To evaluate physicochemical quality of treated wastewaters for the purpose of reuse in crop irrigation, EC and SAR were measured. The Sodium Adsorption Ratio is an important parameter because, in combination with EC, it can indicate whether a water source will reduce the infiltration rate of water into the soil. High Sodium Adsorption Ratios reduce the infiltration rate of water into the soil. The values of SAR with 13 or more may result in reduction of soil permeability and aeration and a general degradation of soil structure **(NRCS, 1993)**. The EC effluent measurement showed that eighty five percent of the samples did not exceed 2000 µS/cm and none of them reached 2500 µS/cm. To determine the combined effects of SAR and EC on soil, the salinity hazard chart after Wilcox, 1955 were used (Figure 5.4). The projection of average values showed that effluent quality matched category A which express low salinity hazard. It can be confirmed that BLWWTP effluent would not create an infiltration or soil permeability problems in case of use it for agriculture.

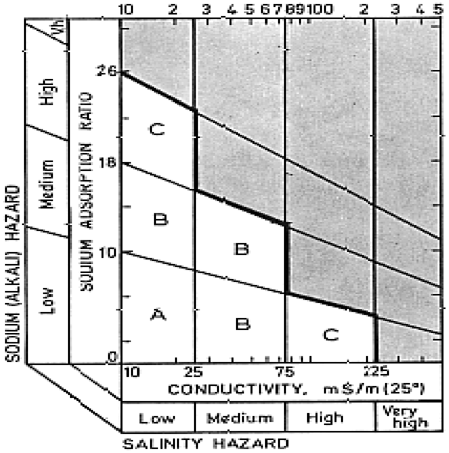


Figure 5.4: Salinity hazard chart of combined EC and SAR **(Wilcox, 1955)**.

The peak influent SO_4^{-2} concentrations may cause transient problems of odor and also upset the methanogenic activity due to competition between Sulphate reducing bacteria (SRB) and Acetoclastic methanogenic bacteria (AMB) **(Visser, 1995)**. However, for SO_4^{-2} concentrations less than 500 mg/L in the raw wastewater, there should be no problem with odor release in well-designed and operated anaerobic pond **(Mara et al., 1992)**. **Rinzema (1988) and Visser (1995)** pointed out that at low sulphate concentrations (i.e. domestic wastewater), the growth of acetotrophic SRB is limited, and AMB will outcompete them. Consequently, at COD/SO_4^{-2} ratio normally encountered in domestic wastewater, acetotrophic methanogenesis will not be inhibited provided that the anaerobic pond is properly loaded. Nonetheless, the oxidation of hydrogen and propionate may be still carried out by SRB. **Lin and Yang (1991)** recommend a minimum COD/SO_4^{-2} ratio of 7 to 10 in the influent regardless of the pH value. This is a safe limit to avoid problems of odor, corrosion and toxicity. It is concluded that SO_4^{-2} in BLWWTP is not a source of odor even with maximum reported concentration and its fell within safe limits.

5.2 FACTORS LEADING TO INADEQUATE TREATMENT PERFORMANCE

The following sections discuss variations in the BLWWTP design and other factors that may be causing the problems in treatment performance.

5.2.1 Hydraulic and Organic Loadings

The different loading parameters of BLWWTP were increased overtime since the treatment plant construction. The Israeli occupation authority and UNDP try to solve the problem in the eighties through adding new ponds. Since more than 15 years, the system had the same treatment capacity and in contrast, the hydraulic and organic loadings were increased dramatically in this period.

Equations that stated by **Mara and Pearson (1986)** is used to determine design value of permissible volumetric and surface BOD_5 loadings that could be experienced to anaerobic, facultative, and maturation ponds (see appendixes D). Data obtained from study monitoring program reveals that average influent BOD and temperature were 425, 21.5 respectively. The anaerobic ponds each had the approximately volume of 13000 m^3. The volumetric BOD loading experienced to BLWWTP anaerobic ponds is calculated to be 244 g/m^3d which is lower than the maximum recommended value (300 g/m^3d) for properly functioning anaerobic pond **(Horan, 1990)**. Aerated lagoons have the same volume of anaerobic ponds, but their volumetric organic loadings are 117 g/m^3d. Taking into account influent BOD and temperature, theoretical effluent BOD is calculated to be assumed 50 mg/L which is lower than actual BOD effluent of 124 mg/L. The actual surface loading applied to BLWWTP facultative ponds is 61 g/m^2 d which is higher than the maximum surface organic load (39.6 g/m^2 d) **(Mara and Pearson, 1998)** that can be applied to a facultative pond before it fails (becomes anaerobic). To maintain surface organic load in facultative pond at current flow rate (15,000 m^3/day) lower than the maximum one, effluent BOD should not be exceeded 81 mg/L. The dimensions, flow rates, and hydraulic loading of the various ponds are presented in table (5.2).

Table 5.2: Characteristics of BLWWT lagoon system.

Lagoon Type	No.	Surface area m^2	Volume m^3	Mean Daily Influent (m^3/d)	Volumetric & surface BOD loading
Anaerobic	2	6,600	12,740	15,000	244 g/m^3d
	1	6,600	13,310	15,000	
Aerated	3	6,600	13,480	15,000	117 g/m^3d
	4	6,600	12,910	15,000	
Facultative	6	15,230	34,000	15,000	61 g/m^2 d
	5	15,230	38,570	15,000	
Maturation	7	26,930	135,940	15,000	99.14g/m^2 d

Source: adapted from different resources.

The surface BOD_5 loading on the maturation ponds is 99.14 g/m^2 d which is approximately sixty folds recommended value (1.7 g/m^2 d) by Metcalf & Eddy (See table 5.3).

Table 5.3: Typical design BOD_5 loading for stabilization ponds.

Pond type	BOD_5 loading g/m^2 day
Anaerobic ponds	22.5-56
Aerated lagoon	---
Facultative ponds	5.6-20
Maturation ponds	≤ 1.7

Source: Metcalf & Eddy, 1991.

A further increase in influent flow will increase the hydraulic loading which will decrease the retention time of the BLWWTP leading to a further reduction in BOD removal.

5.2.2 Availability of Oxygen

The critical factor of the BOD removal in aerated and facultative ponds is the presence of oxygen. Sampling performed at aerated lagoons indicated dissolved oxygen concentration in ranged from 2.5 to 3.5 mg/L with an average of 3.1 mg/L while dissolved oxygen concentration in facultative lagoons varied from 1.9 to 3.2 mg/L with an average of 2.51

mg/L (see appendixes A). The two aerated lagoons in BLWWTP have eight floating aerators each rated at 18.5 KW in addition to 4 jet-mixing aerators **(LEKA, September 1999)**. The eight aerators are producing 88 KW which provides about 5.865 KW/$10^3$$m^3$. According to European standards, power requirements are more than 5 KW/$10^3$$m^3$ to maintained ponds working as a completely mixed **(EMCC, 2004)**. Based on the previous figures, theoretically energy supply for aerated lagoon in BLWWTP enable it to work as completely mixed aerated lagoons if it operated correctly, but continuous breakdown, un-periodical maintenance, and turn on and off of the aerator are lowering oxygen concentration and giving suspended material chance for settling. As a result, aerated lagoons transform to act as partially mixed and accumulated sludge in these ponds supported this assumption. Under these circumstances, effluent BOD from aerated lagoon is lower than expected and nitrification also far expected to be accomplished due to quick depletion of DO that consumed in carbonaceous matter oxidation. **(Founas, 1999)** recommended in its investigation study of BLWWTP that limited BOD removal problem can be partially solved by keeping aerators and mixers working continuously instead of operating on and off as existed currently.

5.2.3 Hydraulic Retention Time

Theoretical retention time is calculated by dividing lagoon volume on daily flow rate. In reality ponds don't operate at their theoretical HRT. Hydraulic efficiency is still likely to be sub-optimal due to partly filling of sludge, hydraulic dead space, and hydraulic short-circuiting. The theoretical retention time in anaerobic, aerated, facultative and maturation are 1.73, 1.79, 4.8, and 9 days respectively. Taking into account incorrect positioning of inlet-outlet of each pond in BLWWTP and resulted short-circuiting, actual or effective retention time expected to be lower than calculated theoretical retention time.

Theoretical retention time of anaerobic ponds in BLWWTP is lowers than typical retention time of 3-5 day **(Mara and Person, 1998)**. Insufficient retention time will increase the organic load to the subsequent lagoons (aerated and facultative) and directed the extra leading to system failure. Table (5.4) presented typical retention time for different type of lagoons and the theoretical calculated retention time in the BLWWTP. A 4-day retention time will achieve 70 to 90% BOD_5 removal in a partially mixed aerated lagoon **(Rich,**

2003). The calculated theoretical retention time in BLWWTP aerated lagoons equal to 1.79 day nearly same as the anaerobic lagoons. This retention time is not enough to produce BOD_5 effluent that match maximum surface organic loading that applied for subsequent facultative lagoons as mentioned before. The calculated theoretical retention time of facultative lagoons is 4.8 day. No references indicated typical retention time for facultative ponds in such hybrid lagoons system found in BLWWTP, but under-performance of overloaded facultative lagoons can be indicated insufficient retention time at these deteriorated conditions.

Table 5.4: Typical retention time and theoretical calculated retention time in the BLWWTP of different lagoons types.

Pond type	Typical retention time (days)	System Theoretical Retention Time (days)
Anaerobic ponds	3-5	1.73
Aerated lagoon	10-30	1.79
Facultative ponds	20-40	4.80
Maturation ponds	4-6	9.00

Regarding maturation pond, retention time of less than 9 days will be sufficient to produce an effluent of microbiological quality that mach WHO standards for reuse. However, the lagoon system: depth, surface organic loading and pond hydrodynamics in BLWWTP doesn't meet the standards design criteria.

5.2.4 Plant Geometry

In general, anaerobic and primary facultative ponds should be rectangular, with length-to-breadth ratios of 2 – 3 to 1 so as to avoid sludge banks forming near the inlet. However, the geometry of secondary facultative and maturation ponds is less important than previously they can have higher length-to-breadth ratios (up to 10 to 1) so that they better approximate plug flow conditions **(Mara & Person, 1998)**. The **USEPA (1973)** recommends a rectangular arrangement of aerated lagoons with a length-width ratio of 3:1 to 4:1 **(Wolfe & Tremblay, 2001)**.

Length and breadth ratio of BLWWTP anaerobic and aerated lagoons is not consistent with the ration stated by Mara and person. Length and breadth were 102.5m and 85m respectively with ratio of 1.2 to 1. So, during sampling and field trip, it was easily notice a thick blanket of floating material which may affect hydrodynamics of anaerobic ponds.

5.2.5 Inlet and Outlet Arrangements

Many studies showed that the position and design of the inlet/ outlet does have a significant impact on the performance efficiency of lagoons (**Wood, 1997; Persson, 2000 and Shilton, 2001)**. The inlet to anaerobic and primary facultative ponds should discharge well below the liquid level so as to minimize short-circuiting, especially in deep anaerobic ponds and thus reduce the quantity of scum which is important in facultative ponds. Inlets to secondary facultative and maturation ponds should also discharge below the liquid level, preferably at mid-depth in order to reduce the possibility of short-circuiting **(Shilton & Harrison, 2003a)**. **Pearson et al., (1995)** concluded that the positioning and depths of the inlet and outlets may have a greater beneficial impact on treatment efficiency than pond shape. Many studies assured that the best inlet-outlet arrangement is located in diagonally opposite corners of the pond. Design of BLWWTP shows that inlets and outlets are incorrectly located in adjacent corners leading to expected hydraulic short-circuiting and died zones.

Regarding type of inlet and outlet, BLWWTP have a vertical inlet type in all treatment lagoons which has in general an advantage on horizontal one. **(Shilton & Harrison, 2003b)** mention that, when a vertical inlet was computer modeled and tested on a full-scale pond, it had been assumed that the tracer would be discharged and then slowly spread out evenly across the pond. However, in this case the tracer appeared to move out in two plumes along either adjacent wall alone. So, using a vertical inlet with short baffles placed on either adjacent wall to block the circulation around the edges has made the performance of the vertical inlet more effective and reliable than using vertical inlets alone **(Shilton & Harrison, 2003b)**.

5.2.6 Ponds Depth

The depth of each pond was measured through EIA study that conducted by Engineering and Management Consulting Center (EMCC) (February, 2005) in order to assess the operation of BLWWTP under the existing conditions. Table (5.6) shows the typical depth design of different lagoons system compared by original design and existing depth of BLWWTP.

Table (5.6): Typical depth design of different lagoons system compared by original design and existing depth of BLWWTP.

Pond no.	Pond type	Typical pond liquid depths	BLWWTP design depth	Existing depth from the water surface
1	Anaerobic pond	2-5 m	2.4	2.55
2	Anaerobic pond		2.4	2.55
3	Aerated lagoon	1.8 -6	2.4	1.5
4	Aerated lagoon		2.4	1.75
5	Facultative pond	1-2 m	2.96	2.65
6	Facultative pond		2.96	2.63
7	Maturation ponds	1-1.5 m	6.75	6.9

Source: Engineering and Management Consulting Center (February, 2005).

Anaerobic and aerated lagoons depths were lie within typical pond liquid depth but exceeded design values. The anaerobic ponds were desludged two month before the depths measurement was taken. Regarding aerated and facultative ponds, the actual liquid depths decrease with comparison to design depth indicate existence of sludge layer. The depth of sludge layers are expected to be ranged from 65 to 90 cm in aerated lagoons and from 33 to 31 cm in facultative ponds. Sludge layer in aerated lagoon formed as a result of intermitted operation of aerators and high flow velocity which can wash out stabilized organic matter that previously settled in anaerobic ponds. When aerator are turn on, suspended material cannot settle in aerated lagoon and sludge layer form in facultative ponds, but if aerators are turn off suspended material can be settled in aerated lagoons.

In **(Pearson and etal, 1995)** study of the influence of pond geometry and configuration on facultative and maturation waste stabilization pond performance, they suggested that increasing facultative pond depth and thus the hydraulic retention time whilst maintaining the same organic surface loading did not significantly improve physiochemical or microbiological effluent quality . Since increasing the depth decreased the volumetric loading rates (whilst keeping the surface loading rates the same), and yet did nothing to improve effluent quality. In case of BLWWTP facultative ponds, increase of depth more than typical recommended value could has advantage, since increase of depth allow facultative pond to operate beside its primary function as settling zone for flocs that format in aerated lagoon.

It is obvious that the level of water in maturation pond has increased by at least 15 cm over the maximum designed levels and the actual liquid depth is more than maximum typical depth at least fourfold. One of the important findings of the former mentioned study was that reducing the depth of maturation ponds also reduced the retention time but this did not adversely affect effluent quality in addition to that shallower maturation pond were more efficient at natural disinfection than the deeper maturation ponds.

Raising the water level is necessary most of the year to create a little hydraulic head between the BLWWTP ponds and the effluent lake which is now almost the same water level as the treatment plant. If the water level in the lake is allowed to rise slightly, the flow direction will be from the lake to the treatment plant and the whole treatment system will be disabled.

5.3 SYSTEM MODIFICATIONS

Based on historical data and monitoring program results, the BLWWTP is not performing in satisfactorily condition. The system needs to be improved or totally replaced. The PWA is planning to transfer the existing treatment plant to east area on the northern governorate. So, any modification of the system depend on the construction of new extra lagoons will be unreasonable. However, the following suggestions can be introduced as short and simple solutions that may lead to overcome and improve partially the inefficiencies and poor treatment plant performance:

Option 1: Rearrangement of inlet-outlet position of each pond to be diagonally opposite will decrease short-circuiting that leading to improve hydrodynamic efficiencies as shown in figure 5.5.

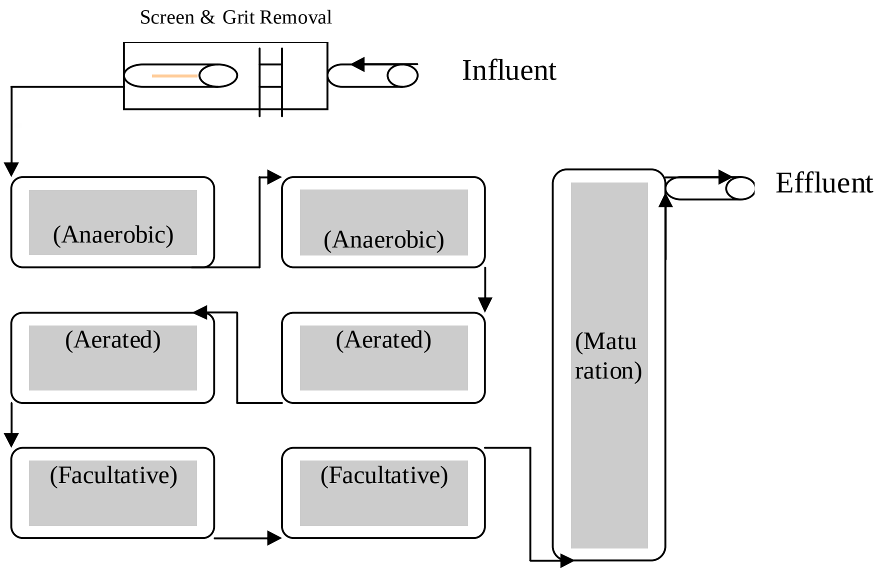


Figure 5.5: Rearrangement of inlet-outlet position of different lagoon.

***Option 2**:* Baffling is considered another solution when the site geometry is such that it is not possible to locate the inlet and outlet in diagonally opposite corners. Baffling can be also combined with the previous option to overcome short-circuiting in lagoon system generally, but particularly in maturation ponds it helps to maintain the surface zone of high pH, which facilitates the removal of faecal bacteria (figure 5.6). No need for baffles in aerated lagoons as long as aerators are operated and distributed in manner that not allows any chance to form dead areas in these lagoons. Based on the above discussion, it is strongly recommended to partitioning anaerobic ponds, facultative ponds, and a single big maturation pond with widely long spaced baffles.

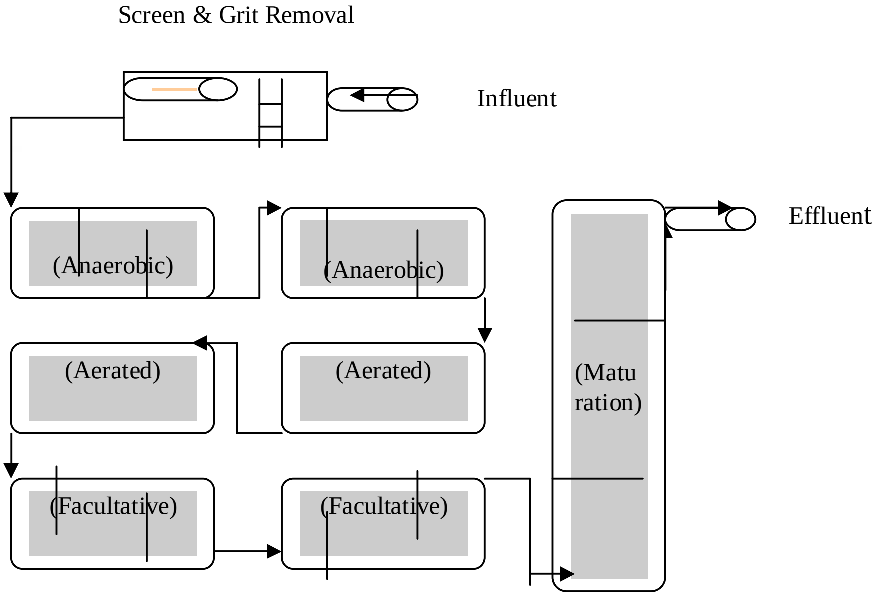


Figure 5.6: Proposed baffling system to improve wastewater hydrodynamics.

Option 3: The addition of the stub baffles appears to have made the performance of the vertical inlet of Beit Lahia lagoon system more effective and reliable than using vertical inlets alone (figure 5.7).

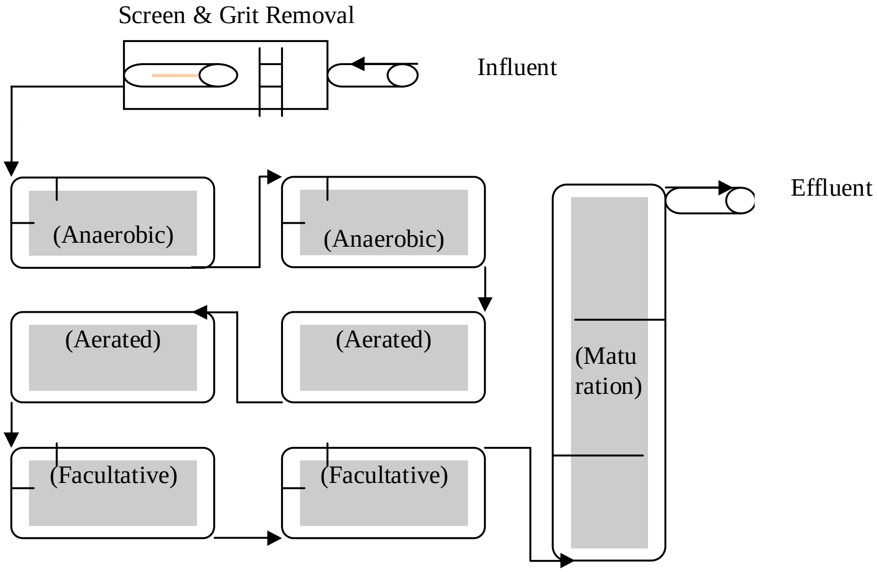


Figure (5.7): Addition stub baffles of the vertical inlet of lagoon system.

Option 4: The previous suggestions are expected to improve treatment plant performance, but are not to the limit that can be produced effluent meets WHO standards for reuse. Collaboration among one or more of the previous suggestions with adding micro-screen and disinfection unit at the outlet of maturation pond will be give better effluent quality that may mach reuse standards. Micro-screen removes suspended solids that give a good chance for effective disinfection and reduce the FC bacteria. In addition, it can lead to lowering BOD concentration in the effluent. This solution will be more rational if there are a need for use these extra units in the new WWTP.

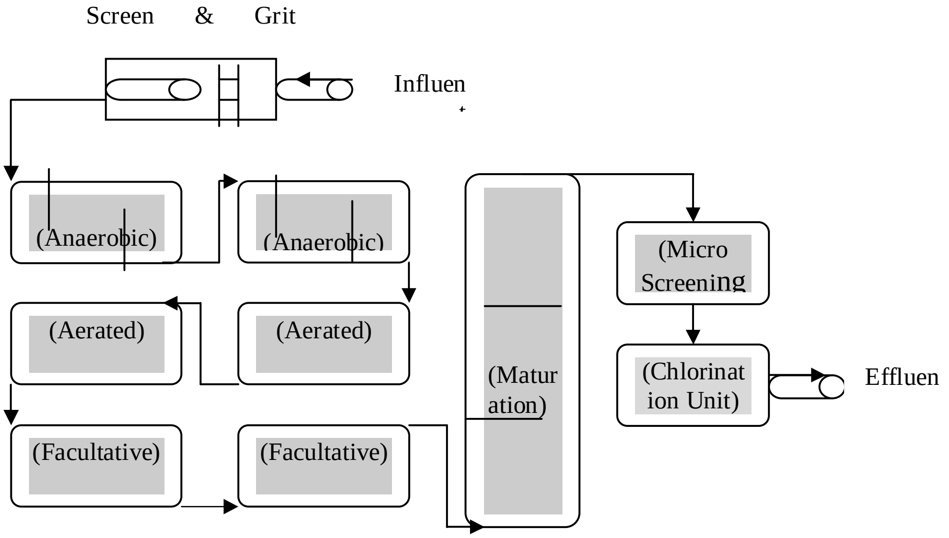


Figure 5.8: Adding micro-screen and disinfection unit at the outlet of maturation pond.

Option 5: A complete mix wastewater treatment system is similar to the activated sludge treatment process except that it does not include recycling of cellular material. So, installation of pipe line to return settled sludge from first facultative pond (that can be working as settling tank in addition to its origin function) to inlet of first aerated lagoon resulting in high mixed liquor suspended solids concentrations, which requires a smaller hydraulic detention time .

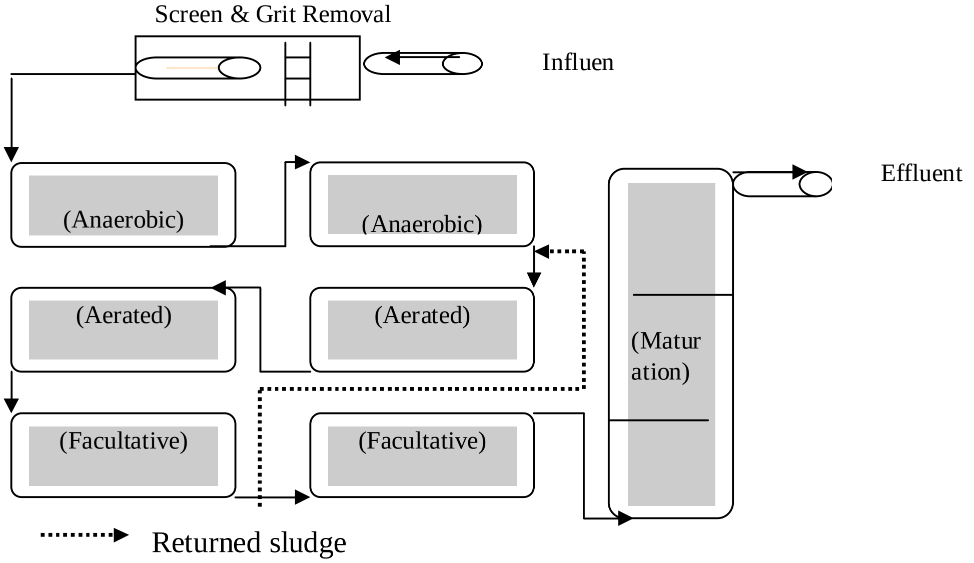


Figure 5.9: Change aerated lagoon to activated sludge.

CHAPTER (6): CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The causes of the BLWWTP underperformance were studied by evaluating the treatment efficiency of each step in the treatment process. The following conclusions were drawn from this research and from the literature review:

1. Over the years, communities in the northern area were provided with sewerage networks, which were subsequently connected to the BLWWTP. Consequently, the volume of sewage inflows at the BLWTP was exceeding the plant's capacity. The combination of the increasing volume of sewage inflows and insufficient capacity to properly handle it has led to poorly treated effluent overflowing from the treatment plant into the surrounding sand dunes, creating a growing lake of nearly 1.5 MCM of foul water, which now covers over 30 hectares. The water level in this poorly treated effluent lake continues to rise and is threatening to hydraulically overflow the whole sewerage collection system and flood the neighboring communities. The transfer of effluent lake as an urgent short-term solution to infiltration basins which are currently under construction at the site of the planned North Gaza Wastewater Treatment Plan will ensure that the immediate threat of flooding posed to the communities adjacent to the BLWWTP and the backflows of raw sewage in the sewerage system are eliminated.

2. The BLWWTP were experiencing significant underperformance due to the overloading and hydrodynamic inefficiencies that refer to some design mistakes. The removal efficiency of organic matter, nutrient, and fecal bacteria has continually declined due to a reduction in the mean detention time of the treatment plant. The result showed that BLWWTP are produced an effluent with BOD, ammonia-nitrogen, total nitrogen, orthophosphate-phosphorous and TSS content of 178.8 mg/L, 72.85 mg/L, 84.3 mg/L, 5.5 mg/L and 39.4 mg/L respectively. Influent SO_4^{2-} concentration ranged from 13 to 70 mg/L with mean value of 37.5 mg/L. The average removal of FC is 99.52% with an average effluent concentration of 4.00 log units/100 ml. In the other hand, no nematodes were detected in the effluents of BLWWTP a long the study period.

3. With comparison to previous monitoring programs, the mean pond effluent TSS removal for 1999, 2000, 2001, and 2005 are 98.2%, 94%, 90.5, and 87.2% respectively indicating dramatic deterioration of treatment plant performance over the years. The theoretical retention time in anaerobic, aerated, facultative, and maturation ponds are 1.73, 1.79, 4.8, and 9 days respectively which are in general lower than typical retention time. In addition, the actual organic loading in facultative ponds and maturation lagoon exceeded the design recommended figures. This limited the biodegradation of organic matter that occurred in the system. Excessive organic loading, inadequate removal of carbonaceous organic matter and the limited supply of oxygen to the treatment plant resulted in little or no removal of nitrogen in the system and low concentration of algal biomass in facultative and maturation pond.

4. The following points summarized the factors leading to inadequate treatment system performance:

- Over hydraulic and organic loadings
- Limitation of Oxygen supply and unavailability DO
- Inadequate design of Plant Geometry and incorrect arrangements of lagoons and ponds inlet and outlet
- High facultative and maturation ponds depth

5. The whole set of results showed that it is possible to improve the system performance to a certain level by enhancing its hydrodynamics. The following suggestions can be introduced as short and simple solutions that may lead to overcome and improve partially the inefficiencies and poor treatment plant performance:

- Rearrangement of inlet-outlet position of each pond to be diagonally opposite will decrease short-circuiting that leading to improve hydrodynamic efficiencies
- Baffling is considered another solution when the site geometry is such that it is not possible to locate the inlet and outlet in diagonally opposite corners.
- Adding micro-screen and disinfection unit at the outlet of maturation pond will be give better effluent quality that may mach reuse standards.

6.2 RECOMMENDATIONS

- Inlet-outlet rearrangement to be located in diagonally opposite corners of the pond is a simple intervention to improve the performance of BLWWTP.
- The provision of two baffles in the anaerobic pond placed at 1/3L and 2/3L increases the pond retention time and BOD_5 removal efficiency.
- Baffling of maturation pond can be increasing its disinfection power.
- Disinfection facilities should be installed at the final effluent overflow point to secure harmful microbiological effects on the ambient area of the effluent lake.
- Periodical cleaning and desludging of partially-mixed aerated lagoons is needed.
- Installation of an instrument to measure the hydraulic load for both influent and effluent.
- A monitoring and control system should be incorporated to give warning of any breakdown in treatment and effluent quality.
- The effluent lake should be transferred as an urgent short-term solution to prevent immediate threat of flooding posed to the communities adjacent to the BLWWTP.
- The implementation and construction of the North Gaza Wastewater Treatment Plant (NGWTP) should be accelerated to prevent environmental impact of semi-treated effluent that produced from existing overloaded treatment plant.

- Further studies using tracers are required to describe the hydraulic regime and predict treatment efficiency. Such studies are needed also to evaluate fully effect of inlet-outlet arrangement and baffling on pond hydrodynamics efficiency.

GLOSSARY

Aerated Lagoon: A holding and/or treatment pond that speeds up the natural process of biological decomposition of organic waste by stimulating the growth and activity of bacteria that degrade organic waste.

Aerator (mechanical): a means of aerating wastewater to increase dissolved oxygen, to enhance aerobic treatment and reduce offensive odors.

Aerobic Treatment: Process by which microbes decompose complex organic compounds in the presence of oxygen and use the liberated energy for reproduction and growth. (Such processes include extended aeration, trickling filtration, and rotating biological contactors).

Aerobic: water environment containing enough dissolved oxygen for micro-organisms to break down waste by respiration.

Algae: Simple rootless plants that grow in sunlit waters in proportion to the amount of available nutrients. They can affect water quality adversely by lowering the dissolved oxygen in the water. They are food for fish and small aquatic animals.

Algal Blooms: Sudden spurts of algal growth, which can affect water quality adversely and indicate potentially hazardous changes in local water chemistry.

Anaerobic Bacteria: Bacteria that grow only in the absence of free elemental oxygen.

Anaerobic: A biological environment that is deficient in all forms of oxygen, especially molecular oxygen, nitrates, and nitrites.

Anoxic: A biological environment that is deficient in molecular oxygen, but may contain chemically bound oxygen, such as nitrates and nitrites.

Biochemical Oxygen Demand (BOD): A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD, the greater the degree of pollution.

Chemical oxygen demand (COD) A quick chemical test to measure the oxygen equivalent of the organic matter content of wastewater that is susceptible to oxidation by a strong chemical.

Chlorophyll-a: The most important of the pigments in chlorophyll, found in all photosynthetic plants except bacteria.

Conductivity A measure of the ability of a solution to conduct an electrical current and is proportional to the concentration of ions in the solution.

Detention Time: The theoretical length of time for water to pass through a basin or tank, if all the water moves with the same velocity.

Disinfectant: A substance used to purify water by removing or killing contaminants.

Dissolved Oxygen (DO): The oxygen dissolved in water, wastewater, or other liquid; usually expressed in milligrams per liter, parts per million, or percent of saturation.

Dissolved solids: The total colloidal and suspended solids in a liquid. Any particle passing a 1.2 µm filter is defined as dissolved.

Domestic Wastewater: Wastewater that comes primarily from dwellings, business buildings, institutions, and does not generally include industrial or agricultural wastewater.

Effluent: treated wastewater discharged from a water or wastewater treatment plant.

Facultative Anaerobic Bacteria: Bacteria which can adapt themselves to growth in the presence, as well as in the absence, of oxygen. Sometimes referred to simply as facultative bacteria.

Facultative pond: wastewater treatment pond in which aerobic and anaerobic treatment occurs. The anaerobic treatment occurs in the upper one meter or so of the pond where dissolved oxygen levels are higher. Anaerobic treatment occurs in the lower depths of the pond.

Filter: A screening device or porous substance used to remove solid material from liquids. Filters, made out of a layer a coal and a layer of sand, trap dirt or bacteria in the water treatment process.

Grab Sample: A single sample collected at a particular time and place that represents the composition of the water, air, or soil only at that time and place.

Grit chamber: A chamber or tank that used in primary treatment where wastewater slows down and heavy, large solids (grit) settle out and are removed.

Imhoff Cone: A clear, cone-shaped container used to measure the volume of settleable solids in a specific volume of water.

Incubator: A small oven-like appliance that is used to heat and grow bacteria samples.

Indicator organism: testing for the presence of a particular organism, i.e. testing for fecal coliform or *E.coli.* The presence of such organisms would indicate a degraded water quality.

Influent: the flow of raw sewage entering the plant.

Kjeldahl Nitrogen: The combined amount of organic and ammonia nitrogen. Also called total Kjeldahl nitrogen (TKN).

Lagoon (oxidation ponds or stabilization ponds): A pond containing raw or partially treated wastewater in which aerobic or anaerobic stabilization occurs. Algae grow within the lagoons and utilize sunlight to produce oxygen, which is in turn used by micro organisms in the lagoon to break down organic material in the wastewater. Wastewater solids settle in the lagoon, resulting in effluent that is relatively well treated, although it does contain algae.

Milligrams per liter (mg/L): The weight of a substance measured in milligrams contained in one liter. It is equivalent to 1 part per million in water measure.

Monitoring: Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

Municipal Sewage: Wastes (mostly liquid) originating from a community; may be composed of domestic wastewaters and/or industrial discharges.

Nitrate: a form of nitrogen found in oxygenated wastewater. Nitrate is a nutrient for plants so it can contribute to prolific weed growth in waterways.

Nutrients: key nutrients associated with wastewater are nitrogen and phosphorous. Nutrients are an important contaminant in wastewater as they cause prolific weed growth in waterways, adversely affecting ecology.

Parasite An organism which lives on or in another living organism of a different species (the host), from which it obtains food and protection, e.g. tapeworms, greenflies.

Parts per million (PPM): A measurement of concentration of one unit of material dispersed in one million units of another.

Pathogens: organisms that can cause diseases. Pathogens include bacteria, viruses and worms.

pH: An expression of the intensity of the basic or acid condition of a liquid; may range from 0 to 14, where 0 is the most acid and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5.

Phosphorus: Phosphorus is an essential element in the metabolism of biological organisms. A minimal concentration is necessary to achieve optimum operation of biological treatment systems. Because it has been implicated as a contributing factor in the development of noxious algal blooms, more emphasis is being placed on controlling the amount of phosphorus discharged in the treatment plant effluent. Phosphorus may exist in many different forms in aqueous solution. These forms may be classified as [a] orthophosphate, [b] pyro-, poly-, and metaphosphate (condensed phosphates), and [c] organic phosphorus. The orthophosphates are of most concern because they are freely available for biological metabolism.

Primary treatment: The first stage of wastewater treatment that removes settle able or floating solids only; generally removes 40% of the suspended solids and 30-40% of the BOD in the wastewater.

Pump: Mechanical device that allows water to be lifted or raised.

Sampler: A device used with or without flow measurement to obtain an aliquot portion of water or waste for analytical purposes. May be designed for taking single sample (grab), composite sample, continuous sample, or periodic sample.

Sampling Frequency: The interval between the collection of successive samples.

Screen: A device to remove large suspended or floating debris from wastewater.

Screening: The removal of relatively coarse floating and suspended solids by straining through racks or screens.

Secondary treatment: the wastewater process where bacteria are used to digest organic matter in the wastewater.

Settleable Solids: Material heavy enough to sink to the bottom of a wastewater treatment tank.

Settling pond: A structure in which settle able solids are removed by gravity.

Settling tank (sedimentation tank or clarifier): A vessel in which solids settle out of water by gravity during wastewater or drinking water treatment processes.

Sewage: The spend water of a community. This term is now being replaced in technical usage by the preferable term wastewater.

Sewerage system: the complete sewage collection, treatment and disposal system.

Solids: The determinations of various forms of residue are useful in the control of a wastewater treatment plant. Total Solids (TS), Suspended Solids (SS) and Dissolved Solids (DS), and their volatile and fixed fractions, may be used to assess wastewater strength, process efficiency, and unit loadings. Measurements of the various residue concentrations are necessary to establish and assure satisfactory operational control. It is important that the operator develop sufficient knowledge of these measurements and their interpretation so that they become routine daily procedures.

Stabilization: Conversion of the active organic matter in sludge into inert, harmless material.

Standards: Norms that impose limits on the amount of pollutants or emissions produced.

Suspended solids: Solids in suspension in a water or wastewater which can be removed by filtration.

Total Dissolved Solids (TDS): The sum of the inorganic and organic materials dissolved in water.

Total Solids (TS): TS, is a term applied to the weight of material per unit volume of sample remaining in a previously weighed crucible after evaporation of the sample at a temperature of 103° to 105°C. TS is equivalent to the sum of filterable residue (the portion of TS that would have been retained if the sample were filtered before evaporation) and nonfilterable residue. In wastewater work, the term "suspended solids" is taken to correspond to nonfilterable residue. The term "dissolved solids" is taken to correspond to the filterable residue.

Total Suspended Solids (TSS): A laboratory measurement of the quantity of suspended solids present in wastewater that is one of the main indicators of the quantity of pollutants present.

Treated Wastewater: Wastewater that has been subjected to one or more physical, chemical, and biological processes to reduce its potential of being a health hazard.

Volatile solid: Solids, frequently organic, which volatilize at a temperature of 550°C.

Waste stabilization ponds: Waste stabilization is a biological process which takes place in ponds arranged in series.

Waste Treatment Lagoon: Impoundment made by excavation or earth fill for biological treatment of wastewater.

Waste Treatment Plant: A facility containing a series of tanks, screens, filters and other processes by which pollutants are removed from water.

Wastewater: The spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter.

Water-borne disease: a disease spread by contaminated water.

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APPENDIXIES

APPENDIX A

ANALYTICAL RAW DATA

Table A-1: Water temperature measurements (Celsius)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	15.2	15.5	14.9	14.2	14.6	14.4
01/03/2005	19.4	19.3	17.7	16.5	17.9	17.3
15/03/2005	18.9	18.9	17.8	17.6	18.0	18.9
29/03/2005	22.3	22.5	21.7	21.0	20.8	21.2
12/04/2005	23.1	23.6	23.8	21.7	24.5	25.4
26/04/2005	23.9	24.1	23.2	21.8	23.2	22.9
10/05/2005	23.8	24.2	23.4	22.1	23.0	24.0
24/05/2005	25.4	26.1	25.1	24.1	25.7	26.3
Average	21.5	21.78	20.95	19.88	20.96	21.3

Table A-2: DO concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	2.2	1	2.6	3.5	3.2	3
01/03/2005	2	2.6	2.3	3.4	3.1	3.2
15/03/2005	2	2.5	2.4	3.1	2.7	2.6
29/03/2005	2	1.7	2.1	3.1	2.2	2.7
12/04/2005	1.8	1.9	2.1	3.3	2.4	2.5
26/04/2005	1.6	1.8	1.6	2.8	2.3	2.5
10/05/2005	1.7	1.3	1.8	2.9	2.4	2.3
24/05/2005	1.6	1.1	1.7	2.5	1.9	1.8
Average	1.9	1.7	2.1	3.1	2.5	2.6

Table A-3: pH measurements (mmole/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	6.22	7.00	7.59	7.87	7.60	7.73
01/03/2005	8.33	7.98	7.69	8.10	7.65	7.77
15/03/2005	8.02	6.89	7.54	7.89	7.55	7.49
29/03/2005	8.00	6.89	7.55	8.03	7.50	7.61
12/04/2005	7.75	6.64	7.31	7.64	7.36	7.59
26/04/2005	5.57	6.76	7.30	7.68	7.40	7.39
10/05/2005	7.50	6.72	7.15	7.59	7.30	7.44
24/05/2005	7.41	6.55	7.14	7.52	7.33	7.54
Average	7.35	6.93	7.41	7.79	7.46	7.57

Table A-4: EC measurements (µs/cm)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	1700	1600	-	1300	1500	1600
01/03/2005	1930	1850	1820	1790	1850	1763
15/03/2005	2280	1756	1645	1562	1634	1734
29/03/2005	1920	1910	1900	1940	1920	1880
12/04/2005	1990	2050	2020	2040	2060	2110
26/04/2005	1890	1950	1990	1950	2010	1980
10/05/2005	1880	1820	1900	1900	1930	1940
24/05/2005	1682	1960	1950	1960	1930	1930
Average	1909	1862	1889	1805	1854	1867

Table A-5: TS concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	1300	1500	1120	980	920	920
01/03/2005	1440	1240	1200	1080	1180	1060
15/03/2005	1460	1120	1160	1040	1000	1040
29/03/2005	1480	1300	1240	1180	1160	1080
12/04/2005	1520	1240	1260	1220	1220	1180
26/04/2005	1300	1120	1100	1020	1080	1100
10/05/2005	1380	1260	1200	1100	1120	1120
24/05/2005	1180	1100	1040	1040	1040	1020
Average	1382.5	1235	1165	1082.5	1090	1065

Table A-6: TDS concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	1020	1000	920	820	880	880
01/03/2005	1177	1040	1083	1005	1060	985
15/03/2005	1220	1040	1000	960	940	1020
29/03/2005	1113	1050	1160	1160	1080	1040
12/04/2005	1100	1060	1120	1050	1100	1160
26/04/2005	1040	980	1020	980	960	1020
10/05/2005	1060	1080	1040	1060	1100	1100
24/05/2005	860	980	940	980	1010	1000
Average	954.6	914.7	920.7	891	903.9	912.3

Table A-7: TSS concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	280	500	200	160	40	40
01/03/2005	263	200	117	75	120	75
15/03/2005	240	80	160	80	60	20
29/03/2005	367	250	80	20	80	40
12/04/2005	420	180	140	170	120	20
26/04/2005	260	140	80	40	120	80
10/05/2005	320	180	160	40	20	20
24/05/2005	320	120	100	60	30	20
Average	308.8	206.3	129.6	80.6	73.8	39.4

Table A-8: TFS concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	720	980	800	740	700	700
01/03/2005	820	820	840	825	800	800
15/03/2005	860	820	900	820	840	860
29/03/2005	820	920	1000	960	920	880
12/04/2005	820	900	980	980	960	920
26/04/2005	720	860	880	840	880	880
10/05/2005	820	880	840	880	800	800
24/05/2005	760	860	840	900	860	920
Average	792.5	880	885	868.1	845	845

Table A-9: TVS concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	580	520	320	240	220	220
01/03/2005	620	420	360	255	380	260
15/03/2005	600	300	260	220	160	180
29/03/2005	660	380	240	220	240	200
12/04/2005	700	340	280	240	260	260
26/04/2005	580	260	220	180	200	220
10/05/2005	560	380	360	220	320	320
24/05/2005	420	240	200	140	180	100
Average	590	355	280	214.4	245	220

Table A-10: Settleable Solids - 1hr (ml/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	7.20	4.50	0.90	1.30	1.60	0.10
01/03/2005	10.5	1.50	0.60	1.80	0.10	0.05
15/03/2005	9.70	1.40	0.60	1.95	0.05	0.07
29/03/2005	10.8	1.10	0.40	1.40	0.02	0.02
12/04/2005	9.80	2.20	0.80	1.90	0.20	0.30
26/04/2005	10.0	3.20	0.50	1.20	0.10	0.05
10/05/2005	10.0	3.00	1.40	1.80	0.05	0.09
24/05/2005	7.30	0.05	0.20	1.10	0.20	0.15
Average	9.41	2.12	0.68	1.56	0.29	0.10

Table A-11: Settleable Solids - 2hr (ml/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	7.40	4.60	1.00	1.35	1.65	0.10
01/03/2005	10.7	1.55	0.60	2.00	0.12	0.05
15/03/2005	10.1	1.55	0.85	2.20	0.06	0.07
29/03/2005	10.9	1.90	0.65	1.50	0.03	0.02
12/04/2005	9.85	2.70	0.90	1.90	0.22	0.30
26/04/2005	10.5	3.70	0.80	1.50	0.13	0.06
10/05/2005	10.2	3.20	1.50	1.85	0.07	0.10
24/05/2005	7.38	00.1	0.40	1.20	0.26	0.25
Average	9.62	2.41	0.84	1.69	0.32	0.12

Table A-12: BOD_5 concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	410	320	210	155	130	100
01/03/2005	480	460	215	195	-	180
15/03/2005	500	250	185	120	122	220
29/03/2005	250	145	310	140	240	200
12/04/2005	440	410	235	170	215	190
26/04/2005	410	230	205	060	150	140
10/05/2005	560	290	235	095	175	210
24/05/2005	350	220	085	060	215	190
Average	425	290.6	210	124.4	178.1	178.8

Table A-13: COD concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	775	848	406	326	339	279
01/03/2005	734	569	528	427	489	459
15/03/2005	1089	625	502	329	340	342
29/03/2005	914	518	425	393	340	365
12/04/2005	679	585	612	522	470	422
26/04/2005	732	450	413	376	351	341
10/05/2005	1370	700	487	426	368	358
24/05/2005	787	426	390	347	324	232
Average	885	590.1	470.4	393.3	377.6	349.8

Table A-14: COD/BOD ratio

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	1.89	2.65	1.933	2.103	2.608	2.79
01/03/2005	1.529	1.237	2.456	2.19		2.55
15/03/2005	2.17	2.5	2.713	2.742	2.78	1.554
29/03/2005	3.656	3.57	1.371	2.807	1.417	1.825
12/04/2005	1.543	1.427	2.6	3.071	2.186	2.221
26/04/2005	1.785	1.956	2.015	6.267	2.34	2.436
10/05/2005	2.446	2.414	2.072	4.484	2.103	1.705
24/05/2005	2.249	1.936	4.588	5.783	1.507	1.221
Average	2.16	2.21	2.47	3.68	2.13	2.04

Table A-15: COD/TS ratio

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	0.596	0.565	0.362	0.333	0.368	0.303
01/03/2005	0.56	0.4588	0.44	0.395	0.414	0.433
15/03/2005	0.746	0.558	0.433	0.316	0.34	0.329
29/03/2005	0.617	0.398	0.343	0.333	0.293	0.338
12/04/2005	0.447	0.472	0.486	0.428	0.385	0.358
26/04/2005	0.563	0.402	0.375	0.369	0.325	0.310
10/05/2005	0.993	0.556	0.406	0.387	0.329	0.320
24/05/2005	0.667	0.387	0.375	0.334	0.312	0.227
Average	0.649	0.475	0.403	0.362	0.346	0.327

Table A-16: NH3 concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
01/03/2005	44.56	42.26	38.42	40.34	40.72	44.95
15/03/2005	50.45	47.84	43.49	45.67	46.10	50.89
29/03/2005	103.44	83.97	82.89	83.97	83.61	75.68
12/04/2005	129.0	83.32	84.76	85.85	87.65	87.29
26/04/2005	83.05	82.89	84.33	85.77	88.30	92.26
10/5/2005	108.0	86.50	90.10	84.30	90.10	84.70
24/05/2005	70.00	79.00	77.10	82.00	80.40	74.20
Average	84.07	72.25	71.58	72.56	73.84	72.85

Table A-17: TKN concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
01/03/2005	68.03	64.86	50.62	47.46	42.71	47.97
15/03/2005	98.50	62.68	89.55	77.01	85.96	100.29
29/03/2005	121.11	85.33	87.56	89.04	86.81	89.04
12/04/2005	134.0	99.04	94.59	92.36	96.07	89.33
26/04/2005	-	92.04	105.4	98.72	98.00	95.75
10/5/2005	141.0	-	93.10	89.50	97.60	90.20
24/05/2005	74.23	86.25	81.30	85.50	85.50	77.70
Average	106.14	81.70	86.02	82.80	84.67	84.33

Table A-18: Ortho-phosphorous concentrations (mg/L)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
01/03/2005	10.17	9.77	9.61	8.80	8.88	8.00
15/03/2005	6.71	5.71	5.56	5.71	5.65	5.99
29/03/2005	8.80	3.60	6.20	9.40	2.15	3.10
12/04/2005	2.05	2.20	1.75	2.00	1.85	1.60
26/04/2005	5.28	5.78	5.87	6.16	5.96	6.17
10/5/2005	4.68	4.21	4.87	4.72	4.77	4.83
24/05/2005	8.40	11.1	10.15	8.75	8.63	8.82
Average	6.58	6.05	6.29	6.50	5.41	5.50

Table A-19: FC concentrations (cfu/100ml)

	Sampling Locations					
Date	**1**	**2**	**3**	**4**	**5**	**6**
15/02/2005	1.30E+07	1.20E+07	5.00E+06	6.00E+06	2.00E+06	1.00E+06
01/03/2005	4.00E+06	3.00E+06	6.00E+05	8.00E+04	5.00E+04	3.00E+04
15/03/2005	1.20E+07	3.00E+06	8.00E+05	9.00E+05	3.00E+05	4.00E+05
29/03/2005	1.00E+05	1.50E+04	6.00E+03	2.00E+03	1.00E+04	8.00E+04
12/04/2005	6.00E+05	5.00E+04	6.00E+04	1.50E+04	2.00E+04	1.60E+04
26/04/2005	1.00E+06	2.00E+04	8.00E+04	1.50E+04	6.00E+04	4.00E+04
10/05/2005	1.30E+05	-	-	-	-	4.30E+04
24/05/2005	1.50E+05	4.00E+04	3.60E+04	4.00E+03	9.00E+03	2.00E+04
Average	3.87E+06	2.59E+06	9.40E+05	1.00E+06	3.50E+05	2.04E+05

APPENDIX B

HISTORICAL OPERATING DATA (1999-2001)

DAY	MONTH	YEAR	BOD INFL	BOD EFF	Removal %	COD INFF	COD EFF	Removal %	SS INFF	SS EFF	Removal %
05	09	1999	800	40	95	-	-	-	458	59	87
04	12	1999	480	50	90	970	97	90	380	47	92
02	02	2000	760	65	91	1474	158	89	330	21	94
05	07	2000	360	55	85	665	140	79	232	40	83
12	07	2000	340	55	84	816	180	78	292	34	88
19	07	2000	300	50	83	577	142	75	165	29	82
31	07	2000	680	40	94	1373	136	90	550	32	94
02	08	2000	680	40	94	1373	136	90	550	32	94
09	08	2000	340	40	88	637	174	73	232	33	86
16	08	2000	380	55	86	690	160	77	218	26	88
06	09	2000	420	70	83	1070	148	86	445	32	93
20	09	2000	660	45	93	1330	120	91	580	27	95
18	10	2000	620	25	96	1207	125	90	495	24	95
01	11	2000	680	50	93	1101	118	89	535	14	97
03	12	2000	740	35	95	1582	142	91	652	12	98
13	12	2000	700	35	95	1602	140	91	605	22	96
07	01	2001	465	45	90	1198	124	90	465	21	95
24	01	2001	420	40	90	1078	120	89	417	35	92
29	01	2001	680	50	93	1266	140	89	498	24	95
09	02	2001	600	70	88	1114	162	85	417	27	94
16	02	2001	400	70	83	713	147	79	346	30	91
01	03	2001	340	65	81	693	160	77	522	27	95
08	03	2001	460	75	84	804	160	80	342	29	92
15	03	2001	880	45	95	1642	162	90	810	36	96
22	03	2001	320	85	73	778	228	71	313	23	93
29	03	2001	540	100	81	1041	245	76	447	34	92
05	04	2001	480	95	80	921	232	75	510	34	93
15	04	2001	840	50	94	1376	136	90	620	39	94
25	04	2001	760	35	95	1408	108	92	620	20	97
26	04	2001	640	65	90	1104	194	82	500	33	93
10	05	2001	500	80	84	856	178	79	330	63	81
31	05	2001	420	100	76	633	224	65	318	40	87
21	06	2001	320	50	84	609	160	74	153	25	84
11	09	2001	315	45	86	657	133	80	306	47	85
19	09	2001	481	25	95	1003	107	89	458	55	88
26	09	2001	504	35	93	1052	83	92	232	11	95
02	10	2001	495	40	92	1032	100	90	418	46	89
09	10	2001	536	25	95	1116	107	90	498	60	88
23	10	2001	518	35	93	1079	141	87	482	62	87
30	10	2001	560	43	92	1054	90	91	465	28	94
20	11	2001	500	43	91	-	93	-	-	70	-
27	11	2001	420	34	92	711	101	86	245	45	82
11	12	2001	760	40	95	1348	80	94	710	62	91

APPENDIX C

AIR TEMPERATURE AND EVAPORATION DATA

TIME	**TEMPERATURE (C)**							
GMT	15/2/05	1/3/05	15/3/05	29/3/05	12/4/05	26/4/05	10/5/05	24/5/05
0500	11.1	14.6	11.2	12.3	20.7	14.9	16.4	18.6
0600	11.8	16.3	11.6	14.3	23.2	16.9	18.6	21.0
0700	14.0	18.7	14.5	17.0	24.7	18.1	19.3	21.7
0800	16.8	20.7	15.6	18.5	25.7	18.6	19.5	22.5
0900	16.9	23.4	16.1	18.6	25.7	18.9	19.9	22.8
1000	16.8	25.5	16.5	18.8	27.6	19.5	20.2	23.4
1100	16.9	26.7	16.1	18.3	28.5	20.6	20.3	23.6
1200	17.5	27.3	16.4	19.0	29.3	20.7	20.4	23.5

DATE	**EVAPORATION**							
	15/2/05	1/3/05	15/3/05	29/3/05	12/4/05	26/4/05	10/5/05	24/5/05
mm/day	2.9	5.1	3.6	2.9	4.2	3.9	5.0	5.2

APPENDIX D

LOADING CALCULATIONS

Anaerobic ponds

$\lambda_V = L_iQ/V_a$ **Mara and Pearson (1986) & Mara *et al.*(1997) based on Meiring *et al.* (1968)**

where

Li = influent BOD, mg/L (= g/m^3)
Q = flow, m^3/d
Va = anaerobic ponds volume, m^3

Calculation:

$\lambda_V = 425 \times 15{,}000 / 26{,}050 = 244$ g/ m^3 d

θa = Va/Q

where θa = Retention times

Calculation:

θa = 26,050/15,000 = 1.73days

Influent BOD mg/L	Volume m^3	Flow m^3/day	Vol.Org. Load	Detention Time-day
425	26050	15000	244	1.73

Aerated lagoons

$\lambda_V = L_iQ/V_a$

where

Li = influent BOD, mg/L (= g/m^3)
Q = flow, m^3/d
Vae = aerated ponds volume, m^3

Calculation:

$\lambda_V = 210 \times 15{,}000 / 26{,}930 = 117$ g/ m^3 d

Le = Li / (1 + K_T R)

where

Le and Li are the effluent and influent BOD respectively
K_T reaction rate where $K_T = K20\ O_T^{\ T-20}$ where K20 = 1.4/day.
O_T = 1.056 when T ranges between 20-30 °C
O_T = 1.135 when T ranges between 4-20 °C

Calculation:

Average temperature = 19°C.

$K_T = 1.4\ (1.135)^{19-20} = 1.23$

Le = 210 / (1 + 1.23 * 1.79) = 65.6 mg /L

θae = Va/Q

where θae = Retention times

Calculation:

θae = 26,930/15,000 = 1.79days

BOD in mg/L	Volume m^3	Flow m^3/day	Vol.Org. Load	Detention Time-day	Theoretical efflu. BOD mg /L	Actual efflu.BOD mg /L
210	26930	15000	117	1.79	54	124

Facultative ponds

$\lambda_S = 10\, Li\, Q / A_f$ **(Mara, 1976)**

where

λ_S = surface BOD loading (kg/ha d)

Li = influent BOD, mg/L (= g/m^3)

Q = flow, m^3/d

A_f = surface area of facultative pond, m^2

Calculation:

$\lambda_S = 10 * 124.3 * 15{,}000 / 30{,}460 = 612.1$ kg / ha d

$= 61.21$ g / m^2 d

$\theta a = Va/Q$

where θa = Retention times

Calculation:

$\theta a = 72{,}570 / 15{,}000 = 4.84$ day.

=

Influent BOD mg/L	Ponds volume m^3	Surface Area m^2	Flow m^3/day	Surface BOD Loading	Retention Time (day)
124.3	72570	30460	15000	612.1	4.84

The earliest relationship between λ_S and T is that given by **McGarry and Pescod (1970)**, but their value of λ_S is the *maximum* that can be applied to a facultative pond before it fails (that is, becomes anaerobic). Their relationship, which is therefore *an envelope of failure*, is:

$\lambda_S = 60\, (1.099)^T$

$\lambda_S = 60\, (1.099)^{20} = 396$ kg / ha d = 39.6 g / m^2 d

Maturation pond

$\lambda_S = 10\, Li\, Q / A_m$ **(Mara, 1976)**

where

λ_S = surface BOD loading (kg/ha d)

Li = influent BOD, mg/L (= g/m^3)

Q = flow, m^3/d

A_m = surface area of maturation pond, m^2

Calculation:

$\lambda_S = 10 * 178 * 15{,}000 / 26{,}930 = 991.4$ kg / ha d

$= 99.14$ g / m^2 d

$Ne = Ni / (1 + kT\theta)$ **(Marais, 1974)**

where

Ne = number of FC per 100 ml of effluent

Ni = number of FC per 100 ml of influent

kT = first order rate constant for FC removal, d-1

θ = retention time, d

Calculation:

Average temperature during study period in location 5 = 21 °C.

$Ni = 3.5 * 10^5$ $K_T = 2.6 (1.9)^{21-20} = 4.94$

$Ne = 3.5 * 105 / 1 + (4.94*11.2) = 7.1 * 10^3$.

$\theta_m = V_m / Q$

where θ_m = Retention times

Calculation:

$\theta_a = 135,000 / 15,000 = 9$ day.

BOD in mg/L	Surf. Area m^2	Flow m^3/day	Surface BOD Loading	Retention Time-day	Theoretical Effluent FC conce.	removal %	Actual Effluent FC conce.	removal %
178	26930	15000	99.14	9.0	8.8 E+03	97.8	2.04E+05	41.7

APPENDIX E

AN EXAMPLE ILLUSTRATES THE EFFECT OF SHORT CIRCUITING IN MATURATION PONDS EFFICIENCY

A pond treats a wastewater containing 1×10^{7} cfu/100mL. All but 1/100 of the flow is retained in the pond for enough time to achieve 99.99% treatment. The 1/100 of the flow that short-circuits receives only 60% treatment. So what is the current overall treatment efficiency provided by the pond?

Current efficiency = (99/100) x 99.99% + (1/100) x 60% = 99.59%

Consider if we did something to stop the small fraction of short-circuiting (eg change the inlet/outlet design or add baffles) so that all the flow received 99.99% treatment. It might seem that this is a total waste of time as there is hardly any difference between 99.59% and 99.99%! However, consider the effect on what is actually being discharged:

Original Discharge Concentration = $1\text{x}10^{7}$ x (1 – 0.9959) = 41,000

New Discharge Concentration = $1\text{x}10^{7}$ x (1 – 0.9999) = 1,000

Clearly reducing the discharge concentration from 41,000 cfu/100mL to 1,000 cfu/100mL is a very significant improvement!

Conclusion: A small amount of short-circuiting results in a large reduction in the discharge quality.