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School of Engineering

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

Carbon Abatement in Wastewater Stabilization Ponds

Case Study of Dandora Waste water stabilization Ponds in Kenya

BY

Kihanya Stephen Mwangi

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Thesis supervisor: Dr. Zablon I. Oonge

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DECLARATION

I, Kihanya Stephen Mwangi, hereby declare that this thesis study is my original work. To the best of my knowledge, the work presented here has not been presented for a thesis study in any other university

Name of Student**. Kihanya Stephen Mwangi** Date…………………

This thesis study has been submitted for review with our approval as university supervisors

Name of Supervisor **Dr. Zablon I. Oonge** .Date............................

Name of Supervisor **Dr. Semion Dulo** **.** Date...................................

ABSTRACT

Wastewater treatment plants (WWTPs) operate on natural processes in removal of Biochemical oxygen Demand (BOD), Oxygen chemical (COD), nutrients organic carbon, and pathogenic microorganisms from wastewater. Wastewater treatment produce considerable amount of greenhouse gases largely methane during their operations. Reducing these emissions from the treatment process and the contribution of the wastewater treatment plants is important in reducing green house gas effects into the environment. This can also allow recuperating energy, and nutrients, thus reclaiming of treated wastewater in less developed countries can be of importance in boosting the energy sources as well as improve in Economies of these countries. It is therefore important to understand how these emissions can be computed and get documented. This research has attempted to estimate and compute the greenhouse gases, primarily methane, emissions from Dandora Sewage Treatment Plant (DSTP) in Nairobi Kenya using the Intergovernmental Panel in Climate Change (IPCC) Guidelines (1996) and IPCC Good Practice Guidance (2000).Operations data from year 2007 to year 2013 was obtained from Nairobi City Water and Sewerage Company (NCWSC), the operator at the plant and analysed to determine the average BOD loading rate and flows to the Plant as well as the BOD removal rate across the anaerobic ponds from which the amount of methane being generated by the DSTP was computed.

The average BOD loading rate and effluent to and from the anaerobic ponds of DSTP was 454.11mg/l and 120.82 mg/l respectively between year 2007 and 2013.This was 88.7% of the design capacity of 512mg/l. The plant received an average of 83,648.30 m^3/day which was 52.28% of the design capacity of 160,000m3/day from year 2007 to year 2013.This represented a BOD mass loading of 37,985.53kg/day

against a designed capacity of 81,920kg/day which was 46.37%.Thus DSTP has been operating at about 50%.

The plant generated an average of 11.29m^3/day of methane from year 2007 to year 2013 at the current flows and can generate an average of 14.1m^3/day of methane at a full capacity of 160,000m^3/day at a BOD loading of 512mg/l.

Methane generated from the anaerobic ponds at the plant can be collected using floating covers and be used to generate electricity that can be imported into the national grid at a feed in tariff ,be used in operations of the plant or be sued for carbon credits. This would increase revenue to the operator as well as prevent methane being released into the atmosphere as it is the case now.

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ACRONYMS

AWSB	Athi Water Services Board
B_o	Maximum Methane Production Potential in kgCH4/kgBOD
BOD	Biochemical oxygen demand
BOD_5	Five days Biochemical oxygen demand
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CH_4	Methane
DSTP	Dandora Sewage Treatment Plant
DWF	Dry Weather Flow
EF	Emission factor in kgCH4/kgBOD
EM	Methane Correction Factor
g	Grams
GHGs	Green House Gases
HRT	Hydraulic Retention Time
H_2S	Hydrogen Sulphide
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilograms
LTI	Long Term Intervention

NCC	Nairobi City Council
N_2O	Nitrogen Oxide
NaRSIP	Nairobi River Sewage Improvement Project
SRT	Sludge Retention Time
TOW	Total Organic in Wastewater kgBOD/yr.
Yr.	Year
UNFCCC	United Nations Framework Convention on Climate Change
RCH_4	Recovered Methane
^oC	Degrees Centigrade

CHAPTER ONE:

1.0 INTRODUCTION

1.1 General

The solution to making decisions of controlling and reducing the rate at which Methane increases (CH_4) in the atmosphere is by recognizing and quantifying the sources, both natural and anthropogenic. (Peter M.Czeplel et.al, 1993).

The United Nations Framework Convention on Climate Change is worldwide renowned source for common action on the lessening of greenhouse gas emissions (UNFCCC, 2007). One of the important requirements for participating countries under the UNFCCC is the assemblage of yearly greenhouse gas (GHG) register for the individual countries that covers four broad sectors of Energy and agriculture, Land Uses, industrial processes, and waste among others. Reports on Methane Emissions and nitrous oxide emission from wastewater treatment under the waste sector (IPCC, 2006b). However, computations of GHG emissions is not normally done directly, but rather estimated through the usage and adoption linking emissions to data recoverable from activities linked to these emissions.

It has been concluded by Scientists that the current above normal changes in the weather conditions in the world is as a result of human-generated greenhouse gases emissions. “climate change” refers to a change of climate that is accredited to human activity that changes the composition of the atmosphere globally and that is in addition to natural climate variability observed over comparable time periods as described by the United Nations Framework Convention on Climate Change (UNFCCC),

Baede et al., (2001) has recorded that earth surface average temperature without the effect of greenhouse gases (GHGs) would be -19°C compared to the existing average temperature of 14°C. Therefore, it is a significant atmosphere characteristic. The present concern is a rapid increase in the concentration of these gases which will disrupt the energy flow in the atmosphere of earth and eventually result in the global warming (Kemp, 1994). Incoming solar radiation strikes the surface of the planet and some part of this radiation inform of energy is reflected as infrared radiation from the surface. Clouds and the atmosphere also radiate infrared radiation (IR). Part of this radiation is absorbed by GHGs and it increases the kinetic energy of their molecules. Increased concentrations of GHGs stimulate the atmospheric heat retention capacity and cause GHGs to act as a blanket that keeps solar heat inside atmosphere. As a result, the temperature of the earth increases (Baede et al., 2001)

Increases of GHGs concentrations in the atmosphere have led to further studies of GHGs estimation, sources and sinks. wastewater treatment plants receive wastewater as influent and produces treated waste water for discharge by using different processes such as anaerobic treatment, aerobic treatment, and mix of the two types of treatment. On-site greenhouse gases emissions are generated by solids treatment processes ,liquid treatment processes, and the burning of biogas and remnant fuels for energy production. Off-site greenhouse gases may also be produced because of solids dumping such as transportation and degradation away from site where soilds are from. (Monteith et al., 2005).

1.2 The Effect of Green house gases

Researchers worldwide have come to narrowing conclusion that greenhouse gases emissions caused my human activities are the main source of the current earth's changes in weather conditions that are beyond the normally expected conditions. These conditions have changed and are adversely getting extreme with time as development in the industrial, processing and technology improve and get innovative. These Greenhouse gases that comprises of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone, and water vapour, permit unrestricted passage of the radiation from the sun which are rich in energy, while at the same time to some extent absorb the long-wave radiation that get emitted from the earth after it gets heated by the incoming radiations. Greenhouse gases then re-emit the absorbed energy in the form of infrared radiation, which in turn warms the earth's surface. The amount of this heating is dependent on the amount and type of the green houses gases in the atmosphere. (DEAT, 2009).

1.3 Necessity to Quantify Emissions of Greenhouse Gases

Recently, global warming coupled with climate change have become most important issues in the environment sector because of their effects on environment, economy and energy production (Yerushalmi et al., 2009). It is recognised in the Intergovernmental Panel on Climate Change(IPCC) that excessive generation of greenhouse gases ,mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from anthropogenic sources are partly liable for global warming and climate change (El-Fadel and Massoud, 2001).it is therefore important to note that, the identification and quantification of all sources, both natural and anthropogenic, is needed for developing strategies to control and reduce the rate of increase of the GHGs emissions into the atmosphere. Due to the generation of CO_2, CH_4, and N_2O during the process of treating waste water, wastewater treatment plants (WWTPs) are regarded as a GHGs emissions source in the commercial sector (EIA, 2003). The international protocols and organizations have restricted the GHGs emissions, related regulations, obligatory limitations, carbon taxes, and penalties (EIA, 2003; IPCC 2006; Specified Gas Reporting regulation, 2007). Therefore, the generation of GHGs emissions from wastewater treatment plants must be estimated before any meaningful mitigation and reduction strategy can be designed and implemented. There is an interest to identify carbon footprints from wastewater treatment plants in terms of GHGs emissions, energy and natural gas usage, and energy production.

1.4 Greenhouse Gases and the International Protocol

The Kyoto protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC) which came into force on 16 February 2005 after its adoption on 11 December 1997 in Kyoto, Japan with an aim of reducing emission of greenhouse gases. Beyond this, the UNFCCC is an international environmental agreement which has an objective of stabilization of GHGs concentrations in the atmosphere at concentrations that would cause a preventive measure against intrusion of dangerous anthropogenic into the climate system. Kenya Signed the Kyoto Protocol on 12th Jun 1992 ratified it on 30th Aug 1994 and it became into force on 28th Nov 1994.On 28th April 2014 Kenya became the ninth party to the Kyoto Protocol to accept amendments to the protocol at Doha in Qatar commonly referred to as the Doha Amendment. This amendment makes the commitment formal the second commitment period of the Kyoto Protocol (2013-2020).Adoption of the Doha Amendment to the Protocol was done thorough 1/CMP.8 decision at the eighth session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) in December 2012 in Doha, Qatar.

1.5 Problem Statement

Generally, the type and amount of GHG production in WWTPs are to a large extend depend on amount and type of degradable organic materials in wastewater. According to international agreements each sector in industry should estimate the generated GHGs and establish reduction strategies. WWTPs should also consider different strategies to reduce GHG emission for the protection of environment while avoiding carbon taxes and reducing energy costs. The estimation of total GHGs produced in Dandora Sewage Treatment Plant (DSTP) was based only anaerobic ponds GHG generation.

1.6 Objectives

The objective of this study was to:

Quantify the amount of methane gas being generated at the anaerobic ponds of the Dandora Sewage Treatment Plant (DSTP) and;

To propose a method of collecting and utilizing this gas thus preventing its entry into the atmosphere.

1.7 Scope

The scope of this study mainly concentrated in the 23 No anaerobic ponds at Dandora Sewage Treatment Plant (DSTP) for data collected from years 2007 to 2013.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General

In the last few years, GHGs emissions from wastewater treatment processes and operations have become a significant concern and are increasingly being measured and assessed while determining the long term sustainability of a treatment scheme (Scanlan et al., 2008). Atmospheric concentrations of greenhouse gases have gone up due to human induced activities such as production and use of fossil fuels and other agricultural and industrial activities during the last 200 years (El-Fadel and Massoud, 2001). According to the U.S. EPA (1997), wastewater treatment plants (WWTPs) are one of the larger minor sources of GHGs emissions. These plants produce the three important GHGs namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) during the treatment processes, both directly and indirectly. Direct emissions occur during the treatment process through gaseous by-products such as CO_2, CH_4, and N_2O, while indirect emissions occur during the use of energy and ancillary activities. Specifically, aerobic biological treatment plants emit a significant quantity of greenhouse gases because of using considerable amounts of power (Shaw et al., 2008).

2.2 Global Warming Potential (GWP) and CO_2 equivalence

Gases contained in the atmosphere have the potential of causing green house effect directly and indirectly with direct effects happening when absorption of radiations is done by the gas itself absorbs radiation. On the other hand, Indirect effects happens when the lifetime of other gasses get changed by the gas itself which brings about chemical transformations of the substance produce other greenhouse gases, and/or when a gas affects atmospheric processes (EPA, 2004). In order to have a comparison on the capability of each greenhouse gas to capture heat in the atmosphere in relation to another gas capbility, the IPCC developed the Global Warming Potential (GWP) concept. The GWP of a greenhouse gas gives the ratio of time integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Thus, the GWP is a relative measure that can be used to make a comparison of the radiative effects of different gases. It also means that, the GWP of a GHG is the ratio of heat trapped by one unit mass of the gas compared to one unit mass of CO_2 over a certain time period, usually 100 years. The N_2O and CH_4 gases are capable of absorbing more infrared radiation or heat per unit mass and this property translates into their greater global warming potential (EI-Fadel and Massoud, 2001). For example, the GWP of N_2O is 296 which mean that N_2O is able to absorb infrared radiation 296 times of a comparable or rather the same mass of CO_2 over 100 years. According to Wallington et al., (2004) the present atmospheric concentration of CH_4 is 1750 ppb, which means that 1750 molecules of CH_4 are present in one billion molecules of ambient air. The relative GWP, radiative forcing, residence time, and atmospheric concentrations of the three major GHGs related to municipal WWTPs operations are shown in Table 1 below.

Table 1: The GWP, radiative forcing, residence time, and atmospheric concentrations of GHGs produced in the WWTPs

GHG	Radiative Forcing(W/m^2)	Global warming potential over 100-year period	Atmosphere Residence time(years)	Atmospheric concentration(ppb)
CO2	0.000018	1	5-200	370,000
CH4	0.00037	23	12	1750
N2O	0.0032	296	114	314

The radiative forcing is an absolute measure of the strength of a GHG on a per volume basis, whereas the GWP is a relative measure on a per mass basis.

2.2.1. Carbon Dioxide Emissions

Sahely,2006 suggested that CO_2 is generated from the oxidation of organic material during wastewater treatment and combustion of fossil fuel on-site for heating. IPCC method includes the CO_2 emissions from wastewater treatment processes and burning of fuels in boilers within the "Energy" sector (Sahely, 2006). The alkalinity consumption is considered as the other main source of off-site CO_2 production, which has carbon dioxide resulting from conversion of the inorganic carbons into the gas (Diagger et al., 2004). Alkalinity consumption is mostly in the bicarbonate form ($HCO3^-$) at near neutral pH. The reaction is in the following form:

$$CHO_3^- + H^+ \rightarrow CO_2 + H_2O \quad (1)$$

2.2.2. Methane Emissions

Methane gas is usually produced under anaerobic condition during organic matter decomposition. Untreated wastewater may also generate CH_4 if anaerobic condition is maintained there (Scheehle and Doorn, 2001). The CH_4 emissions rate from wastewater management practices varies from country to country and depends on organic fraction, level of treatment and estimation method (El-Fadel and Massoud, 2001). The methane gas can be emitted from four types of sources. Energy, agriculture and waste management are three major sources and industrial process is a minor source.

2.2.3. Kinetics of BOD Removals

At any time the BOD remanning in wastewater is the difference between the ultimate BOD and the BOD removed. This can be illustrated as:

$$y = Lo - L \tag{2}$$

Where Lo is the initial BOD at time t=0

and L is the BOD removed which is

$$L = Loe^{-kt} \tag{3}$$

Therefore

$$y = Lo(1 - e^{-kt}) \tag{4}$$

The equation for BOD removal can also be written as

$$L = Lo10^{-kt}$$

(5)

2.3. History of Dandora Sewage Treatment Plant

The Dandora East Sewage Treatment Plant (DSTP) is located about 30km from the Nairobi CBD along the Kangundo road. According to records, the original Dandora Estate Sewage Treatment Works was designed by M/S Viak E.A Ltd., and Phase 1 works was commissioned in 1980 to treat a Dry Weather Flow (DWF) of 30,000 m^3/day. The treatment plant was constructed after the sewage treatment plants of Kariobangi Sewage Works and Industrial Area Ponds, had been commissioned in 1963 and 1974 respectively(Otieno Odongo et.al,1998).

Due to increased sewage flow to the DSTP from connections to the trunk sewers and overflows from Kariobangi and Industrial Area Ponds, the Nairobi City Council (NCC) commissioned Sir Alexander Gibb & Partners (Africa) in 1984 to carry out the expansion of the Dandora Works, which is hereafter referred as Phase II Works (Otieno Odongo et.al, 1998).

The design and construction of the DSTP (Phase II works) was subsequently carried out between 1984 to 1989 and expanded the capacity of the plant from a DWF of 30,000 m^3/day to a DWF of 80,000 m3/day. (Sir Alexander Gibb,1988).

The refurbishment involved the construction of the following main works at the plant:

Inlet works with capacity to treat up to 3 x DWF (i.e. 240,000 m^3/day);

Eight linear series of ponds each comprising one facultative pond followed three maturation ponds for Series 3 to 8, and Construction of experimental anaerobic ponds prior to Series 3 ponds.

In early 1990's, the NCC engaged Lagoon Technology Inc. (LTI, Mara et.al) to carry out monitoring and evaluation of the performance of the stabilisation ponds at the DSTP. In their Fourth Mission Report (August 1994), LTI proposed the sizing of the anaerobic ponds to increase the capacity of the DSTP up from 80,000 m3/day to 160,000 m^3/day based on the following design criteria.

DWF of 23,333 m3/day for pond Series 3 to 8, and

DWF of 10,000 m3/day for pond Series 1 and 2.

LTI therefore proposed 2 duty and 1 standby pond per line with each pond having a capacity of 31,818 m^3.

Based on the LTI recommendation, NCC commissioned Gibb Africa in 1996 to carry out design and to supervise the construction of anaerobic ponds prior to Series 5 ponds. These are referred as Phase III Works. The construction of three ponds comprising 2 duty and 1 standby prior to Series 5 ponds was completed and commissioned in 1999.

After the enactment of the Water Act 2002, the mandate of water and sewerage provision in Nairobi was transferred from the NCC to Athi Water Services Board (AWSB). Consequently, AWSB carried out design of anaerobic ponds prior to Series 1, 2 & 7 ponds and engaged Gibb Africa in 2009 to supervise the construction works.

In addition, AWSB are in the process of constructing the remaining anaerobic ponds prior to series 2, 4, 6 and 8 ponds under the Nairobi River Sewage Improvement Project (NaRSIP).

According to the Dandora Estate Sewage Treatment Works, Final Design Report (June 1988) by Sir Alexander Gibb & Partners (Africa) and subsequent design calculations by Gibb as shown in Table 2 below.

Table 2: Hydraulic design parameters for DSTP

Parameter	Value
DWF capacity without anaerobic	80,000 m3/day
DWF capacity with anaerobic ponds	160,000 m3/day
BOD of influent sewage	512 mg/l
Suspended Solids (SS) content at	655 mg/l
Design Temperature	16 0C

Table 3: Series 1and 2 ponds

Parameter	Anaerobic	Facultative	Maturation
Number of ponds per	2 in parallel	1	3 in series
Surface size of each	70 m x 35 m	700 m x 300	300 m x 300
Depth below TWL	4 m	1.75 m	1.2 m
Hydraulic retention	2.3 days	37 days	10 days
Approximate volume	6,000 m3	358,000 m3	105,000 m3

Table 4: Series 3 ponds

Parameter	Anaerobic	Facultative	Maturation
Number of ponds	3 in parallel	1	3 in series
Surface size of each	65 m x 65 m	700 m x 300	300 m x 150
Depth below TWL	4 m	1.75 m	1.2 m
Hydraulic retention	2.3 days	37 days	5 days
Slope of	1:3	1:3	1:3

Approximate volume	11,800 m3	358,000 m3	52,000 m3

Table 5: Series 4 to 8 ponds

Parameter	Anaerobic	Facultative	Maturation
Number of ponds	3 in parallel	1	3 in series
Surface size of each	120 m x 90 m	700 m x 300	300 m x 150
Depth below TWL	4 m	1.75 m	1.5 m
Hydraulic retention	2.3 days	37 days	5 days
Slope of	1:3	1:3	1:3
Approximate volume	34,000m3	358,000m3	52,000m3

The general layout of the wastewater stabilisation ponds at DSTP is indicated in the Photo Plate 1below.

Photo Plate 1: Satellite Image showing the Layout of DSTP at the time of the study

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Study Area

The Dandora Treatment Plant is located within Nairobi in Kenya as shown in Figure 1below. It is situated 30 km to the East of the city centre of Nairobi .The effluent from the plant is discharged into Nairobi River. Anaerobic ponds are 63 m^2 and 4 m deep; with a retention time of 2 days. Facultative Ponds are 700 by 300 m each and 1.75 m deep; with a retention time of 37 days (series 1-2), and 35 days (series 3 – 8). Maturation Ponds are 300m by 150 m each and 1.2 m deep, with a retention time of 5 days (Alexander et al, 1988) .At the time of the Study,

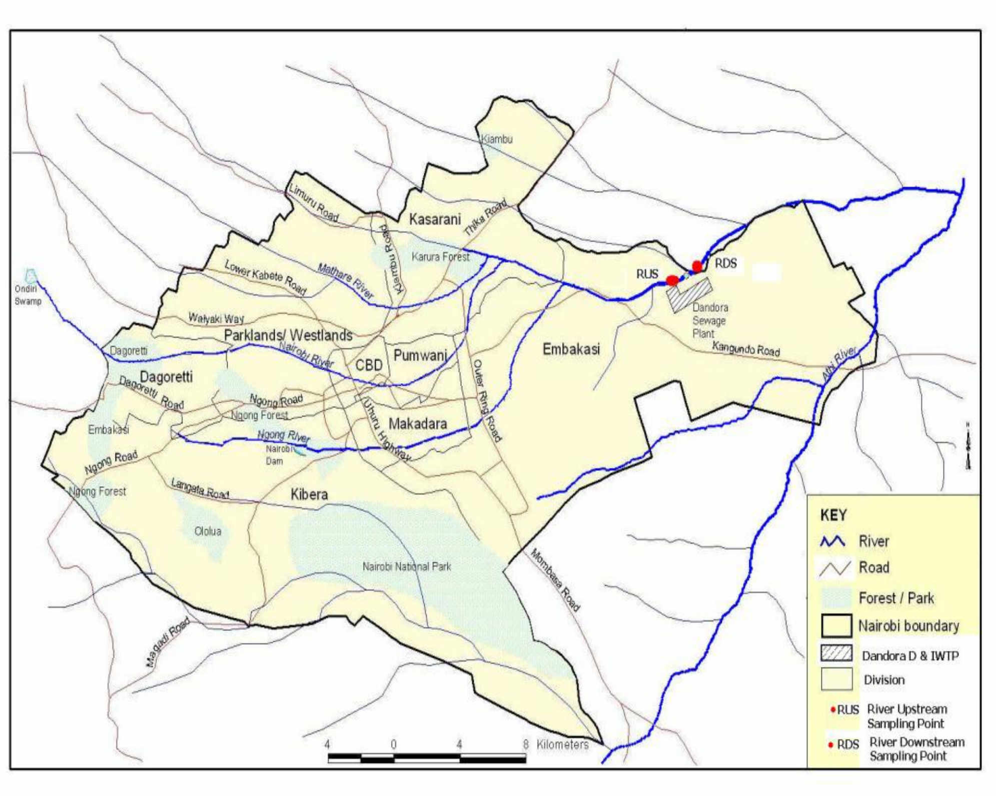

Figure 1: Map of Nairobi showing the location of Dandora Treatment Plant

At the time of the Study,Anaerobic Ponds were only on Series one,Two,Three and Five as shown in Photo Plate 2.However during Implimentation of the Nairobi Rivers Restoration Program in year 2014/2015 as shown in Photo Plate 3 below.

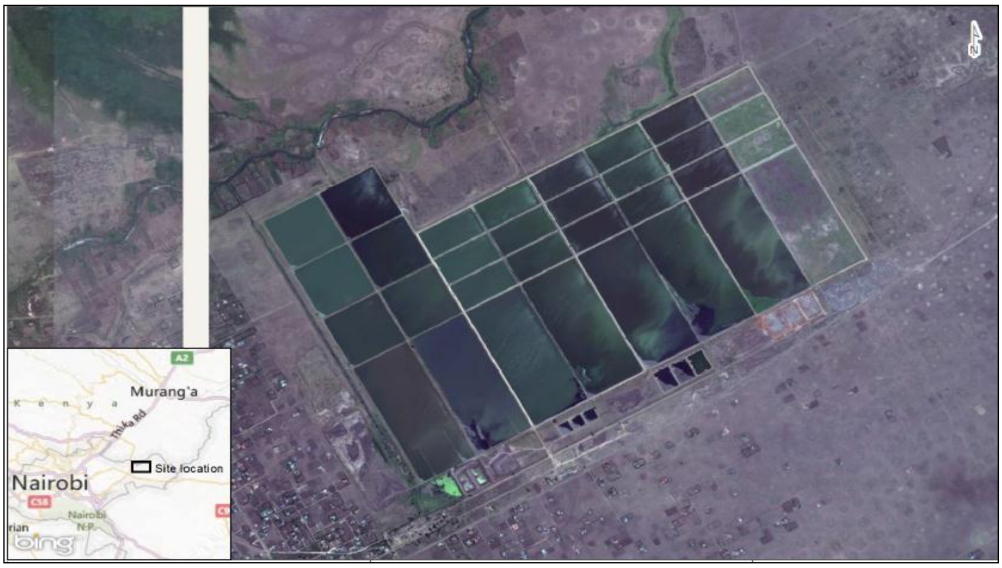

Photo Plate 2: Satellite Image of Ponds arrangement at DSTP during the study Period

Photo Plate 3: Satellite Image of the current Ponds arrangement at DSTP during the study Period

This research was done according to the methods outlined in the GHG protocol and IPCC Guidelines for National Greenhouse Gas Inventories (2006).

3.2. Desk study and review of existing documentation on DSTP

Before the commencement of the project, a desk study was done to have an understanding of the entire anaerobic process in wastewater treatment plants. The design reports and IPCC guidelines were studied to have an understanding of the anaerobic process and the quantification guidelines for methane generation.

3.3. Data Collection and Reconnaissance

Operational data was collected from the operator at DSTP which has been documented from the year 2007.this data was collected in hard and soft copies through visits to the plant on various occasions.

3.4. Computation of BOD loadings

Before attempting to quantify likely biogas generation from the Anaerobic Treatment Ponds at DSTP with any degree of accuracy, it was necessary to first determine the variations in key parameters which influence that estimation. The parameters which were considered included:

Organic load, measured as BOD5, which directly impacts on both the quantity of methane which can be formed, as well as the rate of BOD5 removal;

Daily influent flow, which impacts on the hydraulic retention time of the anaerobic ponds and thus the extent to which the conversion of BOD5 to biogas can be completed; and

Temperature, which influences the rate at which biological activity takes place.

Each of these factors was examined in order to develop a more accurate estimation of biogas generation, especially likely seasonal or monthly variations.

3.5. Organic load as BOD_5

Raw wastewater quality and flow data collected from Nairobi City Water and Sewerage Company operations staff at the DSTP was analysed for the period August 2007 through January 2013. In many cases the influent flow was not recorded at the same time as samples were taken for water quality testing, including determination of BOD5.

In order to ascertain the seasonal variation in the influent BOD5 loading to the DSTP and hence the Anaerobic Pre-treatment Ponds, it was necessary to search through the flow and water quality records to locate co-incident data pairs when influent flow and BOD5 were measured and analysed at the same time. The BOD loading, as kg BOD5/day, was then computed on those occasions.

The BOD_5 loading data were tabulated and the following calculated to examine the variation in the data on a seasonal basis:

minimum;

mean (average); and

Maximum.

According to the design criteria of the ponds by Duncan Mara, the following parameters were used.

Table 6: Design parameters by Mara adopted for the Design of DSTP

Parameter	Value
BOD loading rate (mg/l)	20T-100
BOD removal (%)	2T+20

Where T is the average temperature at DSTP which from statistical data and records from DSTP was observed to be 16^{o}c in the coldest month.

Using this value of the average temperature, the design BOD loading to the DSTP according to Duncan Mara was computed to be 220 mg/l as shown in equation (6) below.

$$20(16) - 100 = 220\ mg/l$$

(6)

With a BOD removal of 52% as shown in equation (7 below:

$$2(16) + 20 = 52\%$$

(7)

This would signify that 114.4g/l of the BOD would get removed from the waste water across the anaerobic ponds.

From observation data of the raw sewage BOD and the volumes of the anaerobic ponds, the actual BOD loading was computed .From the reconnaissance visits to the plant, it was observed that the current operation does not comply to the designed operation in which two ponds were intended to be operational and one pond to be a stand by for the desludging purposes. Therefore the mass BOD loading to each pond was recomputed as follows.

BOD loading into each pond (g/day) = observed raw sewer BOD (mg/l) x pond volume m3

The actual BOD loading rate to the treatment plant was computed by dividing the mass BOD loading by the effective volume of the lagoons.

3.6. Computation of BOD removals

Oxidization of organic matter and the speed at which it gets oxidized by bacteria is a primary factor in the reasonable design of waste water treatment plants. Scientists and researchers have established that BOD removal frequently tends to follow first-order kinetics; which means that the BOD removal rate at any time compares to the amount of BOD present or remaining in the system at that time (D.mara, 2003). This type of reaction is written as:

$$\frac{dL}{dt} = -kL \tag{8}$$

Where k is the first-order rate constant for BOD and L is the amount of BOD remaining at time t.

Integrating Equation (8) above which is the differential form of the first-order equation for BOD yields to Equation (9) below:

$$L = Loe^{-kt} \tag{9}$$

L0 represents the value of L at the time when the reaction is starting, ie at the beginning or rather t = 0. L0 is the ultimate BOD which in other words is the amount of BOD in the system before oxidation happens. The quantity of matter in terms of BOD removed added to the amount of BOD remaining at any time definitely equals the ultimate BOD as shown in equation below:

$$y = Lo - L \tag{10}$$

In which y term represents the BOD that is removed at time *t*. Substituting equation (10) into equation (9) above results into equation (11) below:

$$y = Lo(1 - e^{-kt}) \tag{11}$$

Based on equation (11) above and data analysis from DSTP, the generalised BOD curves for DSTP were plotted as shown in chapter 4 of this report.

If Q is the flow in m3/day to DESTP and Li and Le are the influent and effluent BOD to DESTP, respectively, in mg/l (g/m3), then the quantity of BOD getting into the anaerobic ponds and leaving the anaerobic ponds would be as indicated in equations (12) and (13) below respectively.

$$Quantity\ of\ BOD\ entering\ the\ ponds\ (g/day) = LiQ \tag{12}$$

$$QuantityofBODleavingtheponds(g/day) = LeQ \tag{13}$$

The quantity of BOD removed in bacterial oxidation was calculated by equation (8) as k1L g/m^3 day where L is the BOD of the reactor contents. It was assumed that the ponds were completely mixed so that ponds' contents would be similar to the ponds effluent. Under this condition the BOD of the ponds contents would be Le. When V is the working volume of the ponds in m3, then the BOD removed across the ponds was computed as indicated in equation (14 below:

$$Quantity\ of\ BOD\ leaving\ the\ ponds\ (g/day) = kLeV \tag{14}$$

Combining equations (12), (13) and (14) would yield equation (15 below which on rearranging yielded equation (16) below.

$$LiQ = LeQ + kLeV \tag{15}$$

$$\frac{Le}{Li} = \frac{1}{1 + k(\frac{V}{Q})} \tag{16}$$

The ratio V/Q is the mean hydraulic retention time (θ, days); equation (16) thus resulted into equation (17 below.

$$\frac{Le}{Li} = \frac{1}{1 + k\theta} \tag{17}$$

The first-order rate constant k for BOD removal is temperature dependent as shown in equation (18) below.

$$\frac{k35}{kt} = \varepsilon^{(35-T)} \tag{18}$$

Where T is the pond operating temperatures which were obtained as an average from the temperatures data obtained from DSTP and K35is the reaction rate at 35oc while ε is the temperature coefficient equal to 1.085.for a fixed percentage reduction of BOD, the symmetry of θ and k in equation (17) permits equation (18) to be expanded as equation (19) below.

$$\frac{k35}{kt} = \varepsilon^{(35\theta - T)} = \frac{\theta t}{\theta 35}$$

(19)

Where θ35 is the retention time at 35oc

Data obtained by Suwannakarn &Gloyan (1964) from a series of laboratory-scale ponds treating a synthetic non satellite waste at a number of different temperatures were analysed by Marais (1966),who obtained the values for K35 and ε of 1.2 and 1.085 respectively. Extensive laboratory and field studies (Herman &Glayon , 1985) have shown that certain beneficial green algea seize to function effectively at water temperatures in excess of 35oc.using equation (17) and a measured value for k35 ,therefore the detention time for any percentage reduction at 35^{o}c can be determined. at any temperature (T),the detention time (θ) for the same percentage reduction can be determined using equation (19).

The percentage BOD removal was computed as in equation (20) below.

$$BOD\ Removal\ (\%) = \left(\frac{Lo - Le}{Lo}\right)100 = \left(1 - \frac{1}{kt\theta t + 1}\right)100$$
$$= \left(\frac{\theta t}{\frac{1}{kt} + \theta t)}\right)100$$

(20)

The value of k_t used in equation (20 was computed by plotting a graph of equation (17 with a hydraulic detention time of 2.3 days according to the design of the anaerobic ponds (Gibb,1998).Regression analysis was done on the relationship of the BOD Influent and BOD effluent to achieve the right relationship between the BOD loading and the Effluent BOD. During the actual BOD generation computation, the actual hydraulic detention time was recalculated based on the design flows according to Gibb (1998) of each ponds series and the effective volumes of the ponds. The obtained value of kt was used to develop generalized BOD graphs for DSTP.

Regression analysis was also carried on the data obtained from DSTP to determine the relationship between the BOD removed and Bod loading. These results were compared with the results obtained in equation (20) to determine the adequacy of the developed equation for use in computation of the BOD removal as a percentage and as a function of the BOD of the influent.

Further to the above analysis, the BOD removals were compared from observed data by computing the removal from raw data and applying equations by mara to observe how the BOD removal was behaving in order to come up with an appropriate way of computing BOD removals across the anaerobic ponds.

3.7. Computation of biogas generated

The IPCC good practice default method was utilised for the estimation of methane emissions from DSTP sewage treatment at the anaerobic ponds. The key variable in the methane estimation from domestic and commercial wastewater is the Biochemical oxygen demand (BOD) from wastewater anaerobically treated

From data analysis, the annual, monthly and daily averages of the BOD and COD effluent from the anaerobic ponds was computed to give the annual monthly and daily averages of the BOD and COD removals

The methane emission from wastewater treatment at DSTP was computed in line with the guidelines in the IPCC (1996) together with the guidelines in the IPCC Good Practice (GPG) (2000). In principle, the IPCC has defined remaining methane emission as the total quantity of methane emission less the quantity of methane prevented from getting into the atmosphere through recovery.

Emission getting into the atmosphere = Total generated Emission – Methane prevented from getting into the atmosphere.

In other word;

Emission getting into the atmosphere is the Net emission (NE), Total generated emission is the Gross emission (GE) and Methane prevented from getting into the atmosphere is the Recovered Methane ,methane recovery (MR)

Generally, GE is equivalent to the total amount of organic waste (TOW) multiplied by a Factor of Emission (EF)/Emission Factor (EF):

$$NE = (TOW \times EF) - MR$$

Where the emission factor (EF) has been defined as:

$$EF = B_o \times \text{weighted average MCF}$$

B_o is the maximum capacity to produce methane from a unit of BOD or COD (kg CH_4/kg BOD or kg CH_4/kg COD),

The theoretical maximum yield of methane from organic matter getting into a system can be computed by in view of the conversion of a simple typical sugar like glucose to methane and carbon dioxide anaerobically (Crites and Tchobanoglous, 1998):

$$C_6 H_{12} O_6 \rightarrow 3CO_2 + 3CH_4 \tag{21}$$

Carbon, Hydrogen and oxygen has a mass of 12g, 1g and16g respectively

Similarly, methane requires oxygen commonly known as has an oxygen demand for total break down into water and Carbon dioxide as can be depicted by the equation below.

$$3CH_4 + 6O_6 \rightarrow 3CO_2 + 6H_2 \tag{22}$$

The oxygen demand required by a kilogram of glucose can therefore be expressed as:

$$\frac{KgO_2}{KgC_6 H_{12} O_6} = \frac{192}{180} \tag{23}$$

And the yield of methane per kg of glucose is:

$$\frac{KgCH_4}{KgC_6 H_{12} O_6} = \frac{48}{180} \tag{24}$$

Therefore, the yield of methane per kg of oxygen demand is

$$\frac{KgCH_4}{O_6} = \frac{48}{180} \bigg/ \frac{192}{180} = 0.25$$

(25)

In terms of waste water composition, oxygen demand is quantified in terms of COD or BOD .The BOD value is approximately 2.4 the COD value . Theoretically, the maximum amount of methane produced from COD removed is equivalent to 0.25 kgCH_4 per kgCOD removed or 0.65 kgCH_4 per kgBOD removed (Doornet al., (1997). This factor is unquestionable, because it is governed by the methane's chemical stoichiometry. However, methane correction factor is only an estimation of the likely efficiency in conversion of COD or BOD to CH_4 in a given type of process. IPCC has published Default values and ranges by the for a limited range of wastewater systems, as shown in Table 7 below

Table 7: Default Methane Correction Factors for Domestic Wastewater

Type of Treatment	Comments	MCF	Range	CH_4Production (i.e.EF× MCF)
A Centralised aerobic waste water treatment plant	Managed Well Loaded beyond capacity	0.0 0.3	0.0 – 0.1 0.2 – 0.4	0.00kgCH_4.kgCOD^{-1} 0.08 kgCH_4.kgCOD^{-1}
Anaerobic reactor or digester	Does not include CH4 recovery	0.8	0.8 – 1.0	0.20 kgCH_4.kgCOD^{-1}
A Shallow anaerobic lagoon	Depth below 2m	0.2	0.0 – 0.3	0.05kgCH_4.kgCOD^{-1}
A Deep anaerobic lagoon	Depth beyond 2m	0.8	0.8 – 1.0	0.20 kgCH_4.kgCOD^{-1}

Source: (IPCC, 2006a; after Table 6.3)

B_o Values of 0.25 kg CH_4/kg COD and 0.6 kg CH_4/kg BOD, respectively shall be used in the computation of Methane from the anaerobic ponds at DSTP, for treatment systems that are uncovered, RCH_4 is zero

During this activity, the following assumptions were used. This is based on the preliminary data analysis and existing documentation.

The design wastewater flow into each anaerobic pond is 5,000 m3/d for Series 1 3,333m3/d for Series 2 and is 7,777.78 m3/d for Series 3 through 8 with an influent BOD of 512 mg/L at the 95% percentile level(H.W Pearson,S.TAvery,S.W .Mills,P.Njagga and P.Odhiambo,1996);

All 23 No. anaerobic ponds are in operation i.e. there are no standby ponds;

The current average design flow to the Dandora Estate STP is 65% of design, i.e. 104,000 m3/d(sir alexander Gibb and partners,1988);

BOD removal across the anaerobic ponds is 70% (H.W Pearson,S.TAvery,S.W .Mills,P.Njagga and P.Odhiambo,1996

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Status at DSTP

4.1.1 BOD loading and removal across the Anaerobic Ponds

From the data obtained for the anaerobic ponds, the average BOD loading rate and effluent to the anaerobic ponds was 454.11mg/l and 120.82 mg/l respectively. The plant average BOD loading was 88.7%, of the design capacity of 512mg/l.

The plant received an average of 83,648.30 m3/day which about 52.28% of the design capacity of 160,000m3/day from year 2007 to year 2013. This represented a BOD mass loading of 37,985.53kg/day against a designed capacity of 81,920kg/day. This was 46.37%.Thus DSTP has been operating at about 50% of the design capacity as shown in Table 8 below. The plant received high flows in year 2010/2011which could be attributed to the high rains experienced in the period as shown in **Error! Reference source not found.** below.

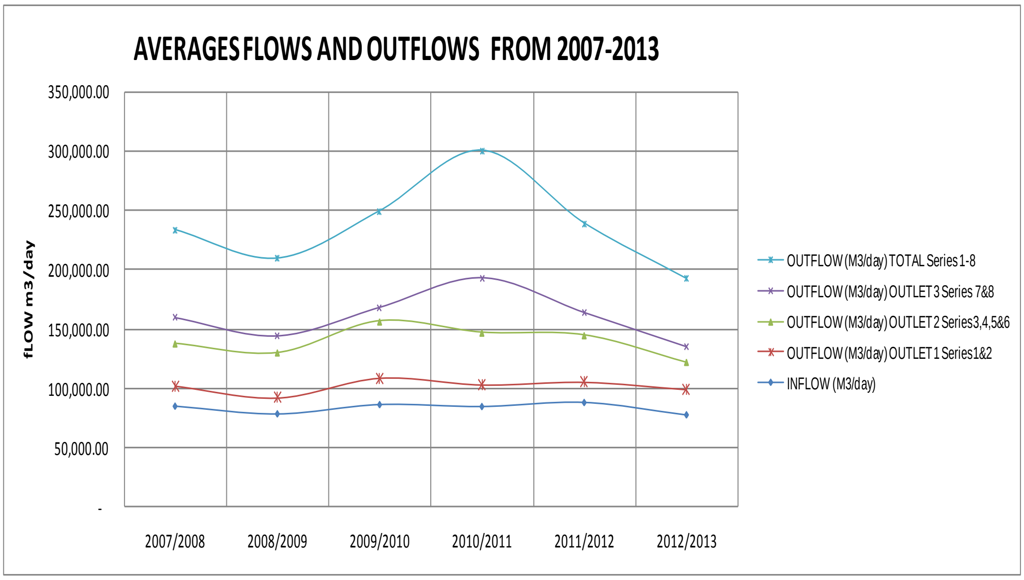

Figure 2: Inflows and outflows and Outflows in and from DSTP year 2007-2013:

Table 8: Inflows and outflows from DSTP year 2007-2013

YEAR	INFLOW (M3/day)	OUTFLOW (M^3/day)			
		OUTLET 1	OUTLET 2	OUTLET 3	TOTAL
		Series1&2	Series3,4,5&6	Series 7&8	Series 1-8
2007/2008	85,226.23	16,315.10	36,267.00	21,510.49	74,092.59
2008/2009	78,885.56	13,252.00	38,031.00	14,021.00	65,304.00
2009/2010	86,522.00	21,233.00	48,734.00	11,404.00	81,371.00
2010/2011	84,919.00	17,521.00	44,560.00	45,512.00	107,593.00
2011/2012	88,265.00	16,293.00	40,234.00	18,834.00	75,361.00
2012/2013	78,072.00	20,676.00	23,372.00	13,093.00	57,141.00

The average BOD removal across the anaerobic ponds was 333.36mg/l at an average design temperature of 16^{o}C and operating temperature of 22^{o}C.This represented a 73% BOD removal across the anaerobic ponds. The results for this analysis are as shown Figure 3 below.

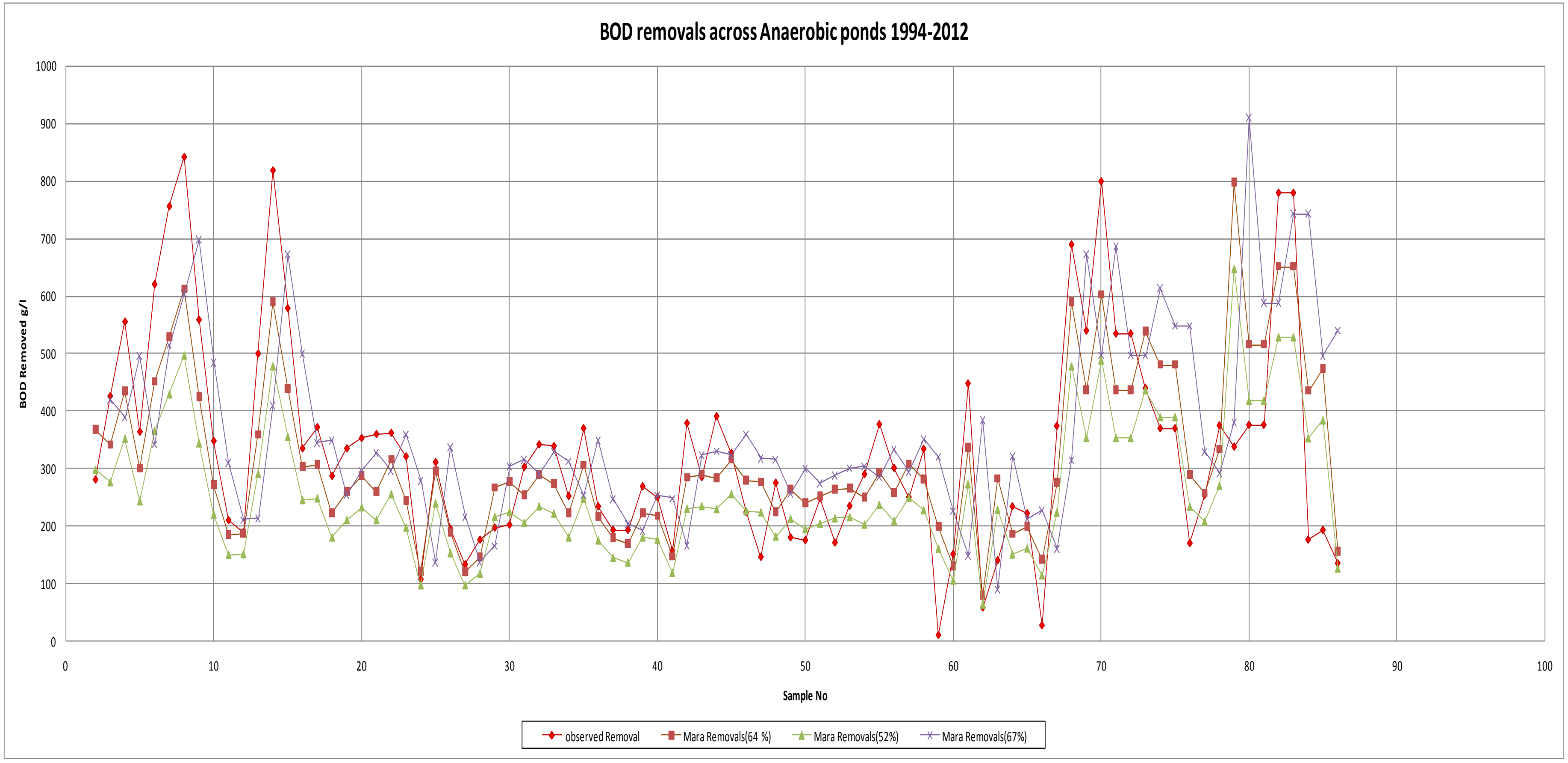

Figure 3: BOD removals at DSTP

The observed BOD removal averaged at 67%.this compared well with the designed BOD removals of 52% at a temperature of 16^{o}C.at the mean temperature of 22^{o}c, which was the mean of the observed temperature at the plant, the designed BOD removal would be 64%.

However, the plant has been operating with three anaerobic ponds against the designed two anaerobic ponds and at an average temperature of 22^{o}C which is above the designed operating temperature of 16^{o}C. This has resulted into reduced volumetric loading to each anaerobic pond under loading the ponds and higher operating temperatures which attributes to the slightly increased efficiency by three percent.

From this analysis it was safe to assume a 65% BOD removal across the anaerobic ponds for computation of Biogas generation across the ponds.

4.1.2. Daily Flows to DSTP

The average flow into treatment plant was 83,648 m^3/day which represents about 50% of the deigned capacity of 160,000m^3/day as shown in Table 9 and Figure 4 below. The DSTP has an inlet capable of handling the design capacity and is expected to be able to handle the anticipated increase in flow from the newly constructed Sewers networks under the Nairobi Rivers Restoration Program.

From the Data analysed its evidence that the Plant has been receiving excess Flows during the Rain seasons a clear indication of Storm water Flows into the Sewers from surface runoff that if with time it goes beyond the capacity of the Inlet works or in case of break down,the Silt washed in the Storm water will cause siltation in the ponds reducing the designed volume capacity and bring about reduced efficiency of the Plant.

Table 9: Daily Flows to DSTP from 2007-2013

Y/M	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
2007/2008	75,422.04	87,856.89	82,112.57	75,485.97	92,791.00	85,980.38	77,239.19	78,911.46	81,952.11	104,251.11	91,039.71	89,672.30
2008/2009	74,547.32	78,882.31	78,658.90	78,658.90	100,454.68	78,528.86	63,091.43	76,218.86	72,072.18	70,888.79	86,915.71	87,708.73
2009/2010	75,381.52	62,910.34	51,303.07	59,029.72	82,627.05	81,692.30	107,163.76	79,671.88	96,303.34	125,068.81	120,738.05	96,377.66
2010/2011	86,374.53	87,125.99	89,420.17	79,561.39	91,020.25	95,458.44	82,443.74	79,244.33	80,783.36	82,643.61	83,212.85	81,743.92
2011/2012	88,290.78	93,633.43	90,686.84	108,262.20	110,790.45	94,175.44	77,035.97	74,507.00	67,109.07	83,014.49	92,145.22	79,525.91
2012/2013	75,944.33	74,656.89	68,335.54	76,507.29	84,709.69	88,278.80						
Ave	79,326.75	80,844.31	76,752.85	79,584.25	93,732.19	87,352.37	81,394.82	77,710.71	79,644.01	93,173.36	94,810.31	87,005.71

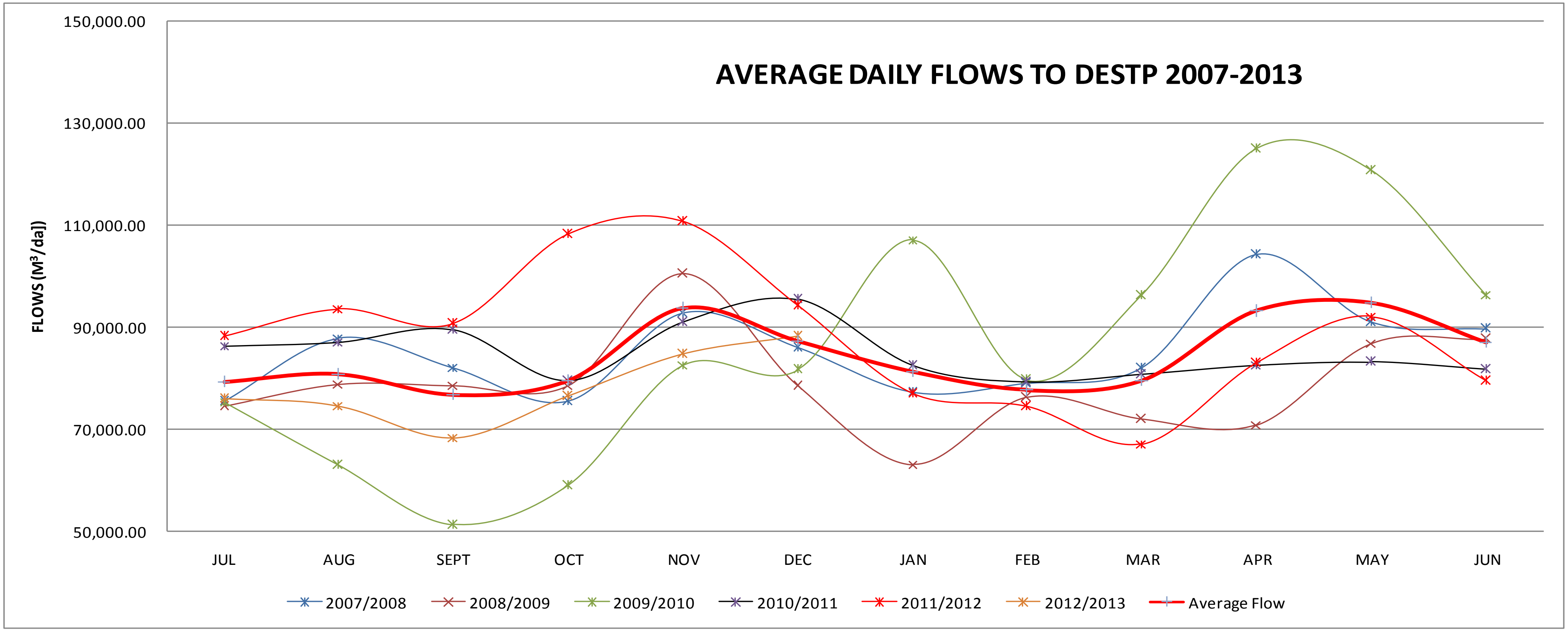

Figure 4: Daily Flows to DSTP from 2007-2013

4.1.3. BOD Loading to DSTP

The average BOD loading to DSTP was 454.11 mg/l for the periods between years 2007 to 2013.This represented 78% of the design capacity of 512mg/l. High loading were observed to occur in the months of January to March and July to October due to less rains which could have resulted into reduced volumetric loadings.

Table 10: Daily BOD loading to DSTP from 2007-2013

YEAR/ MONTH	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
2007/2008	280	480	218	261	282	247	240	270	301	279	232	304
2008/2009	383	416	417	417	403	427	524	586	652	590	518	531
2009/2010	655	784	907	781	650	609	369	540	499	315	331	257
2010/2011	428	523	522	516	272	379	581	517	359	498	477	391
2011/2012	373	387	364	338	287	221	299	442	384	276	163	231
2012/2013	294	306	379	318	247	198						
AVERAGE	402	483	468	438	357	347	403	471	439	392	344	343

The BOD loadings were observed to have gone up in the year 2008/2009 and year 2009/2010 which could be attributed the improvement of the Plant that was carried out including Desludging of the Lagoons .The plant was also fitted with mechanised equipment at the Inlet works including programmable Logic System (PLC) which from the information gathered during the visits to the Plant later failed leading to shutting off of the fine Screens and Grit Chambers.

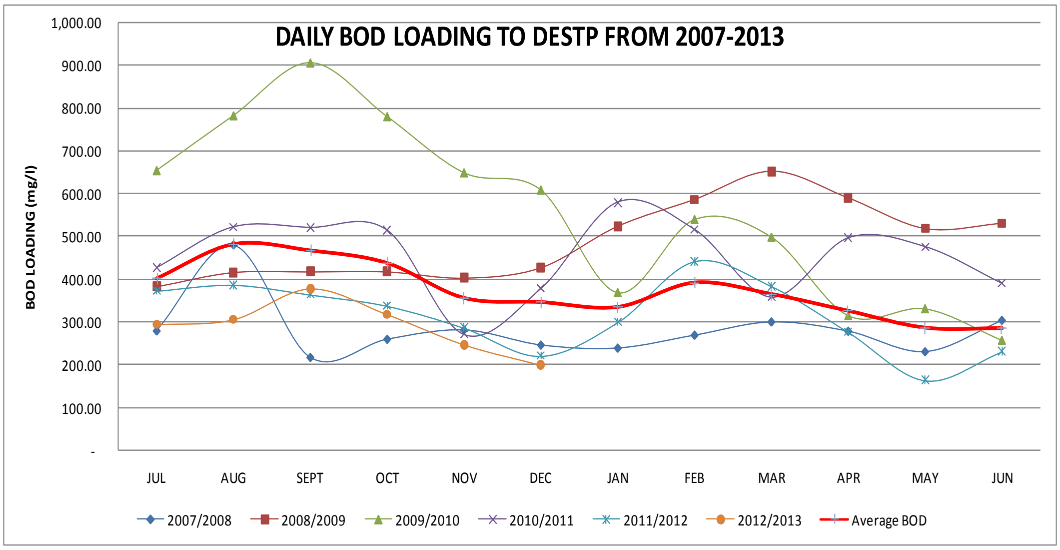

Figure 5: Daily BOD loading to DSTP from 2007-2013

4.1.4. Effluent BOD standards from DSTP

The effluent BOD averaged at 79mg/l from year 2007-2013.The levels were on average 49% higher than the recommended standard of 30mg/l by NEMA as shown in Table 11 below and Figure 6 .This could be attributed to the Failure of the programmable Logic system in year 2010 that led to the shutdown of the intermediate screens, the Fine (cup screens) and the grit chamber which had been automated in the year 2008 when the Inlet works were expanded from a capacity of 80,000m^3/day to the current capacity of 160,000m^3/day.

Table 11: BOD effluent standards (mg/l) from DSTP

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
2007/2008	98	81	55	32	46	62	40	67	57	54	97	79
2008/2009	96	106	117	117	89	101	132	100	110	112	113	118
2009/2010	109	129	158	113	108	83	77	67	79	63	73	59
2010/2011	111	136	150	116	146	51	75	86	62	94	64	86
2011/2012	75	60	64	60	61	34	28	54	50	53	35	29
2012/2013	36	37	51	47	48	35						
Average	88	91	99	81	83	61	70	75	71	76	76	74
% above NEMA Standard of 30mg/l	58%	61%	69%	51%	53%	31%	40%	45%	41%	46%	46%	44%

This led to the increase in flow into the plant and accumulation of sludge in the Ponds which could have reduced the volume of the ponds and thus reducing the efficiency of the Plant.

Accumulated sludge had caused growth of vegetation in the anaerobic ponds further reducing the Volume and causing Short-circuiting in the pond further reducing the efficiency of the ponds. During heavy flows and high organic loadings, the effluent from the plant to DSTP was heavily loading with organics in terms of BOD.

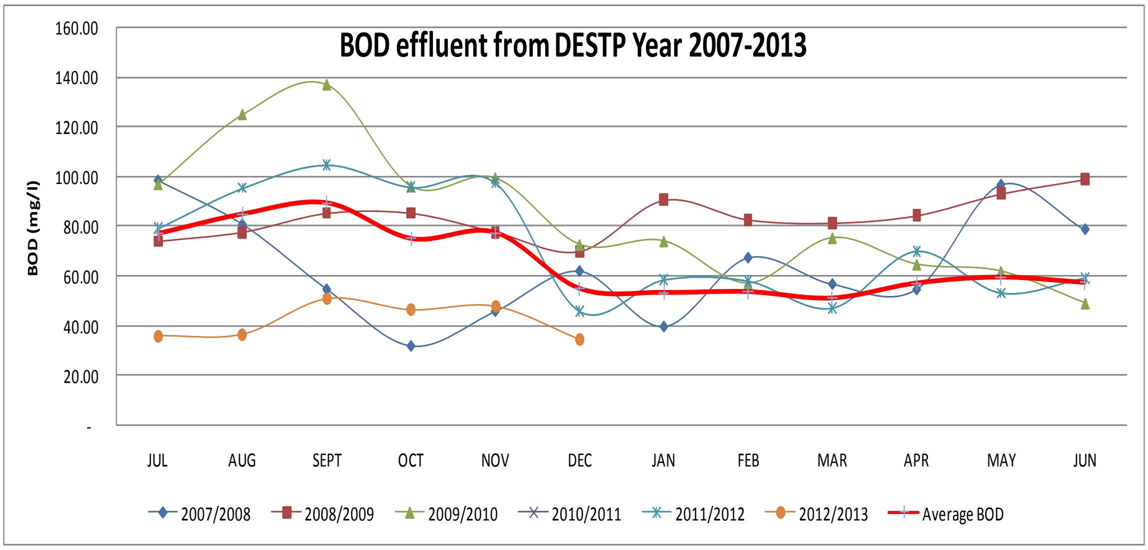

Figure 6: BOD effluent standards from DSTP

4.2. Methane generation year 2007/2008

In year 2007/2008, DSTP received an average of 282.87mg/l of degradable organics measured as BOD_5. This was 55% of the design capacity of 512mg/l of organic loading to the DSTP. Figure 7 below shows the Mean average BOD received at DSTP, the actual BOD received at DSTP against the designed BOD loading capacity of the plant.

Figure 7: Mass BOD loading to DSTP in the in Year 2007/2008

During this period, the average mass loading to the plant was 24,193.54 kg/day against the designed capacity of 81,920 kg/day. This was 30% of the plant designed capacity. Figure 8 below shows how the daily mass loading varied in this period.

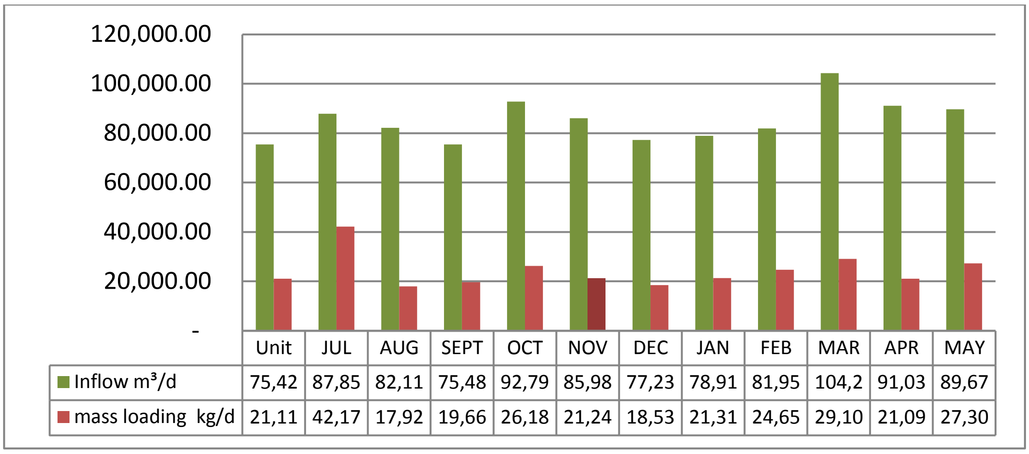

Figure 8: Mass BOD loading to DSTP in the in Year 2007/200Methane Generation Series one anaerobic ponds

During this period, an average of 0.767m^3/day was generated in series one anaerobic ponds. This ponds are two and each generated an average of 0.389m^3/day of methane. The daily and average generated methane in this series was as shown in Table 12 and Figure 9 below.

Table 12: Daily Methane gas generated from Series one ponds in 2007/2008

Month	Ju	Au	Se	Oc	No	De	Ja	Fe	Ma	Ap	Ma	Ju
Daily Gas Production	0.7	1.3	0.5	0.7	0.7	0.6	0.6	0.7	0.8	0.7	0.6	0.8
Mean Production	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

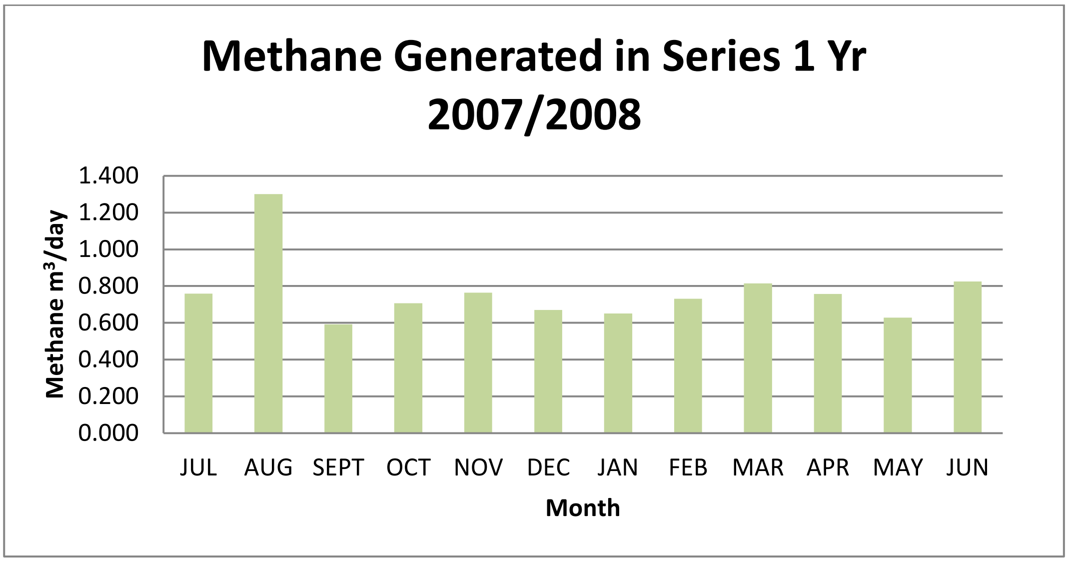

Figure 9: Daily Methane gas generated from Series one ponds in 2007/2008

4.2.1. Series Two anaerobic ponds

An average of 0.472m^3/day was generated in series two anaerobic ponds in year 2007/2008. The daily and average generated methane in this series was as shown in Table 13 and Figure 10 below. The production in this series was less than series one due to reduces mass loading to each pond since the ponds are operated as three ponds compared to series one which receive the same flow as series two.

Table 13: Daily Methane gas generated from Series two ponds in 2007/2008

	JU	AU	SE	OC	NO	DE	JA	FE	MA	AP	MA	JU
DAILY GAS	0.4	0.8	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.3	0.5
MEAN PRODUC	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

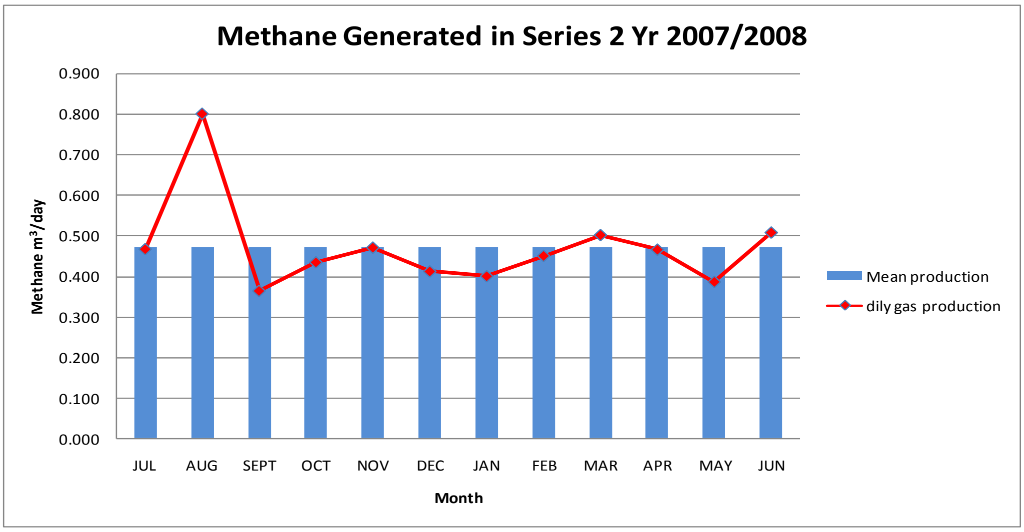

Figure 10: Daily Methane gas generated from Series Two ponds in 2007/2008

4.2.2. Series Three anaerobic ponds

An average of 1.101m^3/day was generated in series three anaerobic ponds in year 2007/2008. This ponds are three measuring 65m by 65m at the top and each generated an average of 0.389m^3/day of methane. The daily and average generated methane in this series was as shown in Table 14 and Figure 11below.

Table 14: Daily Methane gas generated from Series Three ponds in 2007/2008

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
DAILY GAS PRODUCTION	1.08	1.86	0.85	1.01	1.09	0.96	0.93	1.05	1.170	1.08	0.900	1.18
MEAN PRODUCTION	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.100	1.10	1.100	1.10

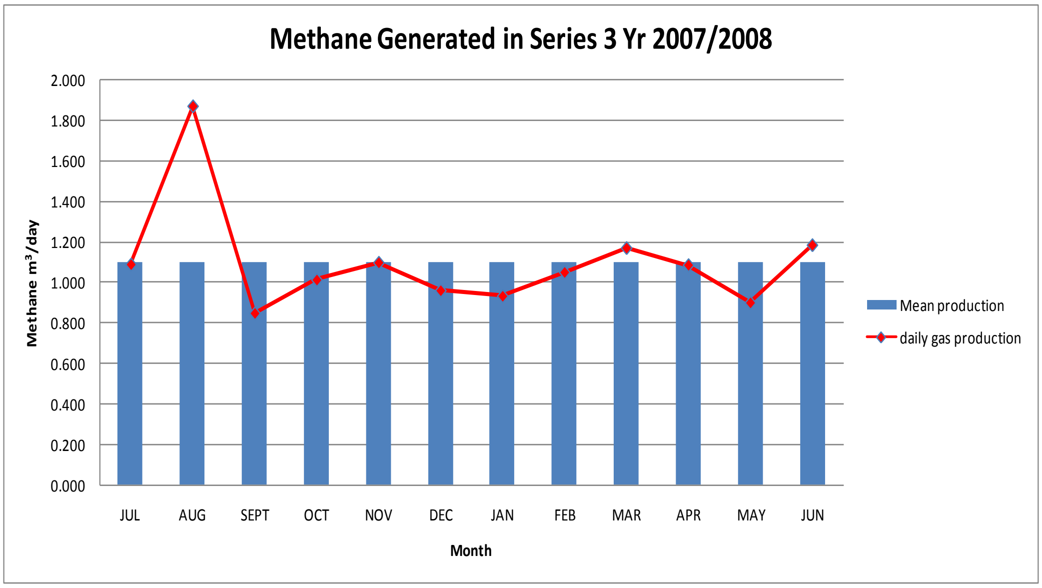

Figure 11: Daily Methane gas generated from Series Three ponds in 2007/2008

4.2.3. Series Four to Eight anaerobic ponds

Series four to Eight are similar in dimensions and the amount of flows they receive. They were therefore analysed together and the total methane generated in the year would be a summation of all the ponds in the five series.

An average of 5.5 m^3/day would be generated in series four to eight which all have three anaerobic ponds in year 2007/2008. This indicated that on average each series wold generated 1.1$m^3$of methane per day. In these Series, the only existing ponds at the time of the study and would have released an approximated amount of 1.1m^3 of methane per day The daily and average generated methane in this series was as shown in Table 15 and Figure 12 below.

Table 15: Methane gas generated from Series Four to Eight ponds in 2007/2008

	Jul	Au	Se	Oct	No	De	Jan	Fe	Ma	Apr	Ma	Ju
One Series	1.0	1.8	0.8	1.0	1.1	0.9	0.9	1.0	1.1	1.0	0.9	1.18
Five Series	5.4	9.3	4.2	5.0	5.4	4.8	4.6	5.2	5.8	5.4	4.5	5.92
Average	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.50

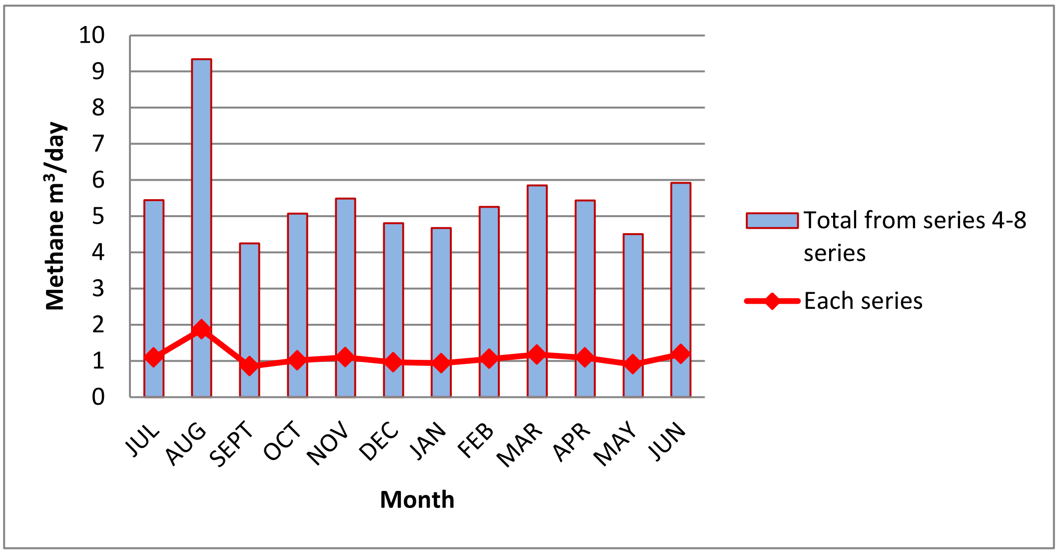

Figure 12: Methane gas generated from Series Four to Eight ponds in 2007/2008

In this year an average of 7.842 m^3/day of methane would be generated from all the anaerobic ponds at DSTP as shown.

4.3. Methane production in year 2008/2009

In year 2008/2009, DSTP received a mean average of 488.52mg/l of degradable organics measured as BOD. This was 49% of the design capacity of 512mg/l of organic loading to the DSTP. Figure 13 below shows the Mean average BOD received at DSTP, the actual BOD received at DSTP against the designed capacity.

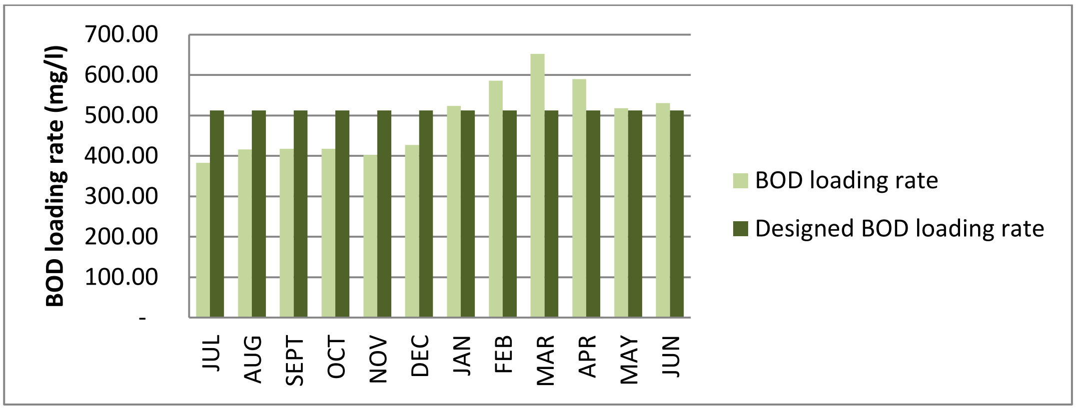

Figure 13: Daily BOD loading to DSTP in the in Year 2008/2009

During this period, the average mass loading to the plant was 38,248.94 kg/day against the designed capacity of 81,920 kg/day. This was 43% of the plant capacity. Figure 14 below shows how the daily mass loading varied in this period.

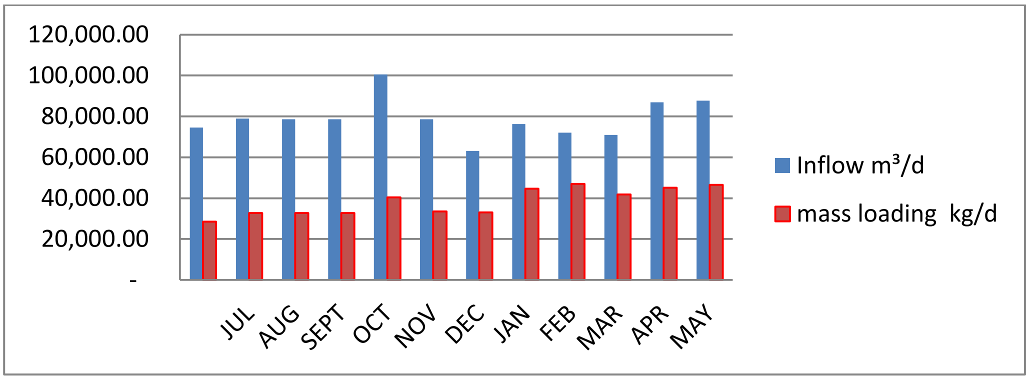

Figure 14: Daily BOD loading to DSTP in the in Year 2008/2009

During this period, an average of 1.324m^3/day was generated in series one anaerobic ponds. This ponds are two and each generated an average of 0.518m3/day of methane. The daily and average generated methane in this series was as shown in Table 16 below.

Table 16: Daily Methane gas generated from Series one ponds in 2008/2009

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.04	1.13	1.13	1.13	1.09	1.16	1.42	1.59	1.77	1.60	1.40	1.44
Mean Production	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32

4.3.1. Series Two anaerobic ponds

An average of 0.815m^3/day was generated in series two anaerobic ponds in year 2008/2009. The daily and average generated methane in this series was as shown in Table 17 below.

Table 17: Daily Methane gas generated from Series two ponds in 2008/2009

	Jul	Au	Se	Oct	No	De	Jan	Fe	Ma	Apr	Ma	Jun
Daily Gas Production	0.6	0.	0.6	0.6	0.6	0.7	0.8	0.9	1.0	0.9	0.8	0.8
Mean Production	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

4.3.2. Series Three anaerobic ponds

An average of 1.901m^3/day was generated in series three anaerobic ponds in year 2007/2008. This ponds are three measuring 65m by 65m at the top and each generated an average of 0.389m^3/day of methane. The daily and average generated methane in this series was as shown in Table 18 below.

Table 18: Daily Methane gas generated from Series three ponds in 2008/2009

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.4	1.6	1.6	1.6	1.5	1.6	2.0	2.2	2.5	2.2	2.0	2.0
Mean Production	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9

4.3.3. Series Four to Eight anaerobic ponds

Series four to Eight are similar in dimensions and the amount of flows they receive. They were therefore analysed together and the total methane generated in the year was a summation of all the three.

An average of 7.44 m^3/day was generated in the five series from series four to eight which all have three anaerobic ponds in year 2007/2008. This indicated that on average each series would generate generated 1.49m3 of methane per day. The daily and average generated methane in this series was as shown in Figure 15 below.

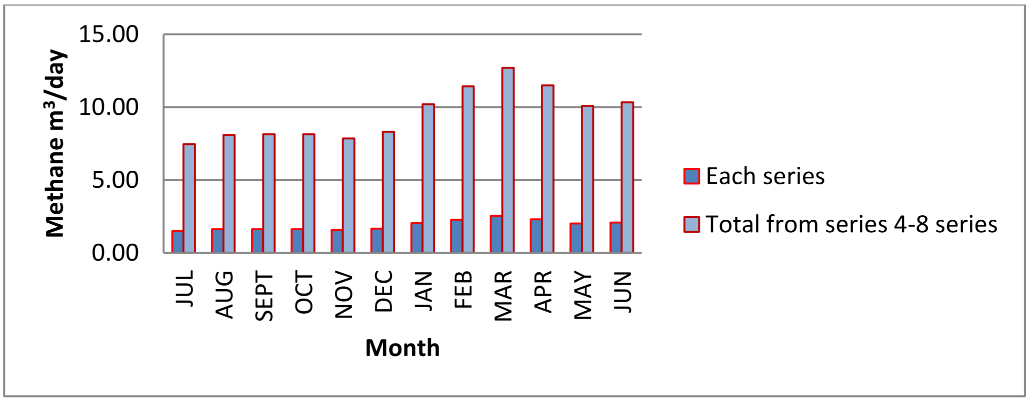

Figure 15: Methane gas generated from Series Four to Eight ponds in 2008/2009

In this year an average of 10.6 m^3/day of methane would have been generated from all the anaerobic ponds at DSTP if all the series had operational anaerobic ponds as is the case today after more anaerobic ponds were constructed on series 4, 6, 7 and 8.

4.4. Methane production in year 2009/2010

In year 2009/2010, DSTP received a mean average of 558.17mg/l of degradable organics measured as BOD. This was 109% of the design capacity of 512mg/l of organic loading to the DSTP. Figure 16 below shows the Mean average BOD received at DSTP, the actual BOD received at DSTP against the designed capacity.

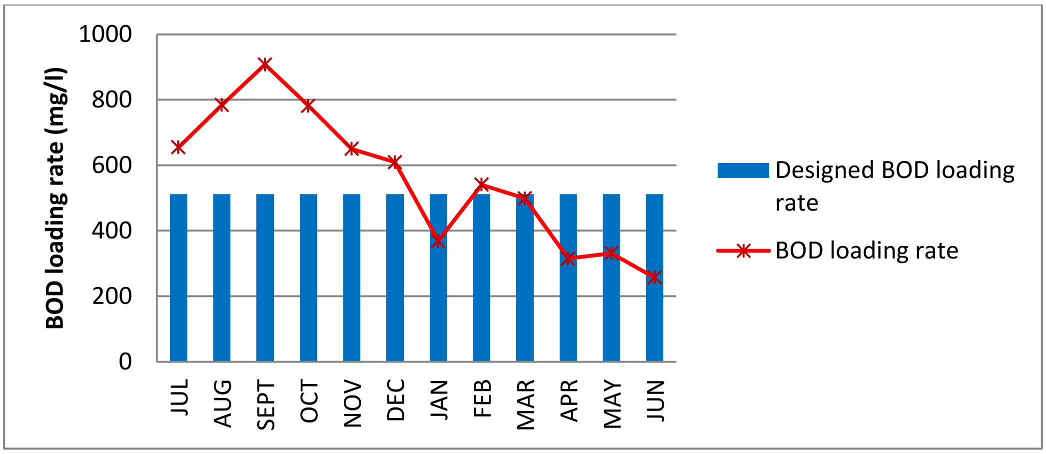

Figure 16: Daily BOD loading to DSTP in the in Year 2009/20010

During this period, the average mass loading to the plant was 44,133.74 kg/day against the designed capacity of 81,920 kg/day. This was 54% of the plant capacity. Figure 17 below shows how the daily mass loading varied in this period.

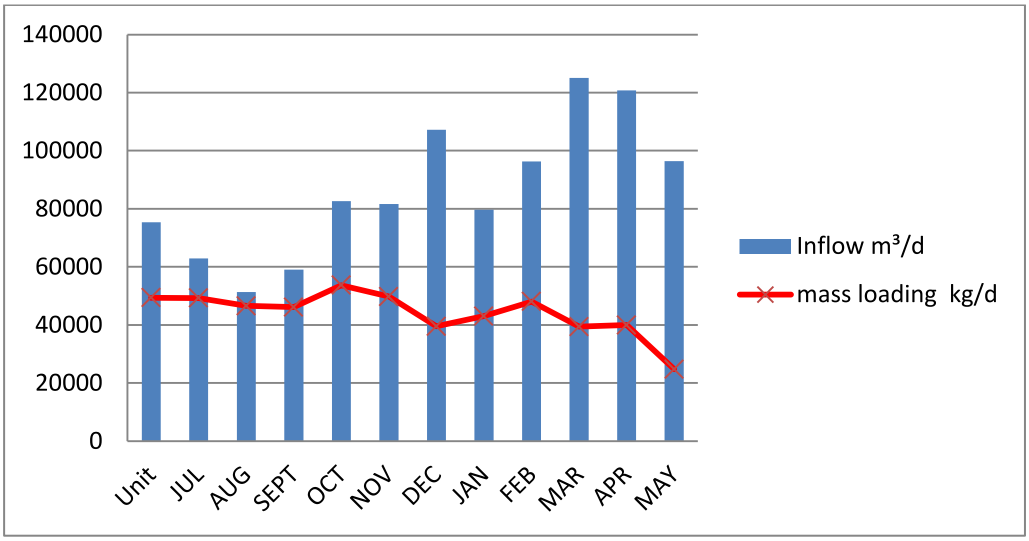

Figure 17: Mass loading and Inflow at DSTP

4.4.1. .Series one anaerobic ponds

During this period, an average of 1.513 m^3/day was generated in series one anaerobic ponds. This ponds are two and each generated an average of 0.757m^3/day of methane. The daily and average generated methane in this series was as shown in Table 19and Figure 18 below.

Table 19: Daily Methane gas generated from Series one pond in 2009/2010

	Jul	Au	Se	Oct	No	De	Jan	Fe	Ma	Apr	Ma	Ju
Daily Gas Production	1.7	2.1	2.4	2.1	1.7	1.6	1.0	1.4	1.3	0.8	0.9	0.7
Mean Production	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

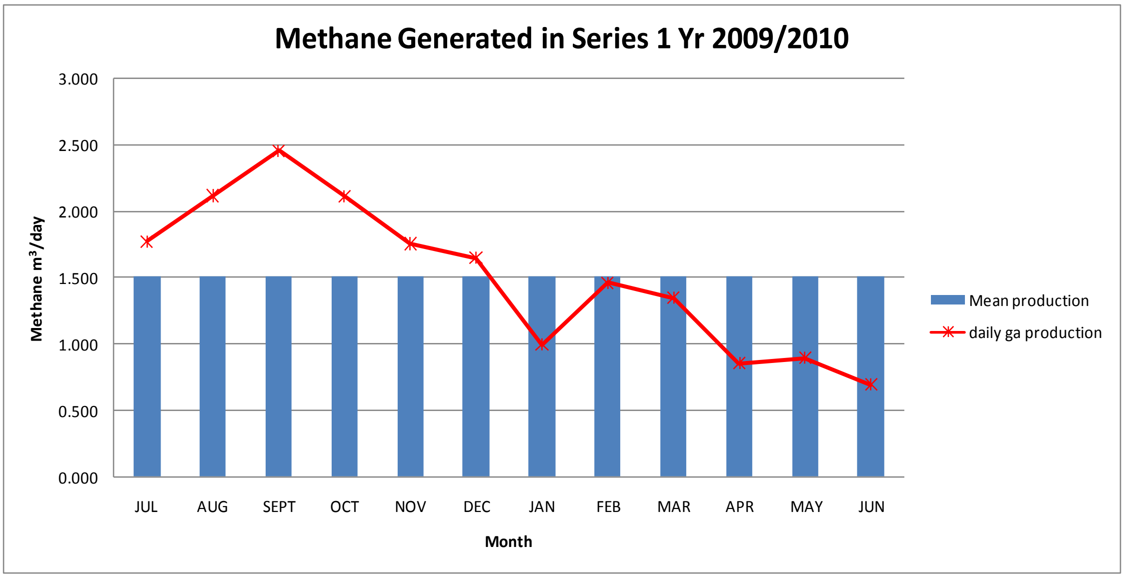

Figure 18: Daily Methane gas generated from Series one ponds in 2009/2010

4.4.2. Series Two anaerobic ponds

An average of 0.93m3/day was generated in series two anaerobic ponds in year 2009/2010. The daily and average generated methane in this series was as shown in Table 20 and Figure 19 below.

Table 20: Daily Methane gas generated from Series Two ponds in 2009/2010

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.09	1.31	1.51	1.30	1.08	1.02	0.62	0.90	0.83	0.53	0.55	0.43
Mean Production	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93

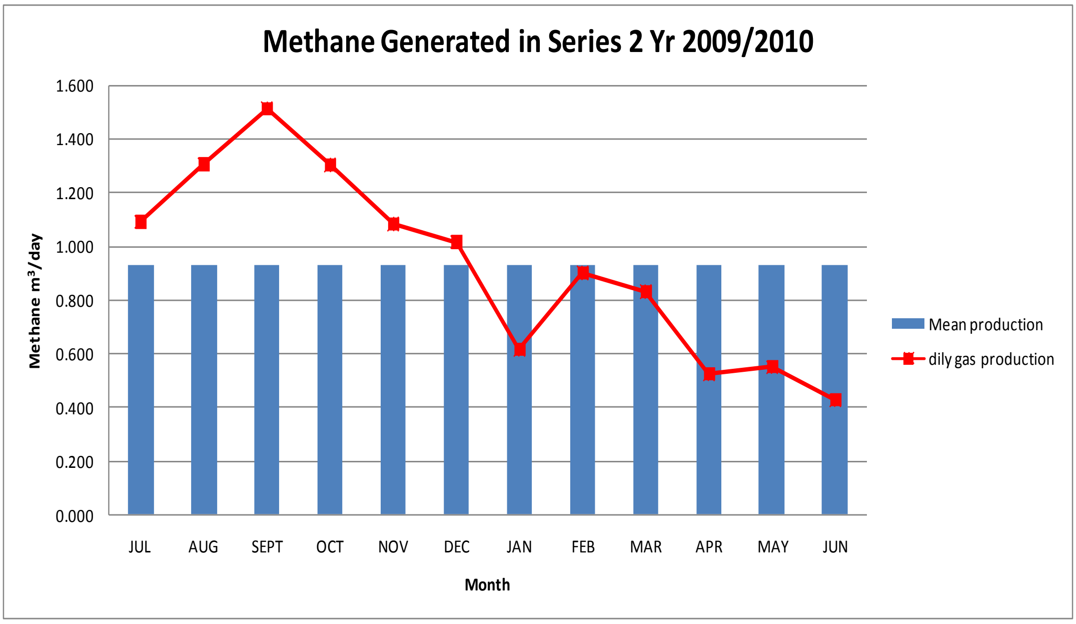

Figure 19: Daily Methane gas generated from Series Two ponds in 2009/2010

4.4.3. Series Three anaerobic ponds

An average of 2,172m3/day was generated in series three anaerobic ponds in year 2009/2010. This ponds are three measuring 65m by 65m at the top and each generated an average of 0.389m3/day of methane. The daily and average generated methane in this series was as shown in Figure 20 and Table 21 below.

Table 21: Daily Methane gas generated from Series three ponds in 2009/2010

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	2.5	3.05	3.53	3.04	2.53	2.37	1.44	2.10	1.94	1.23	1.29	1.00
Mean Production	2.1	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17

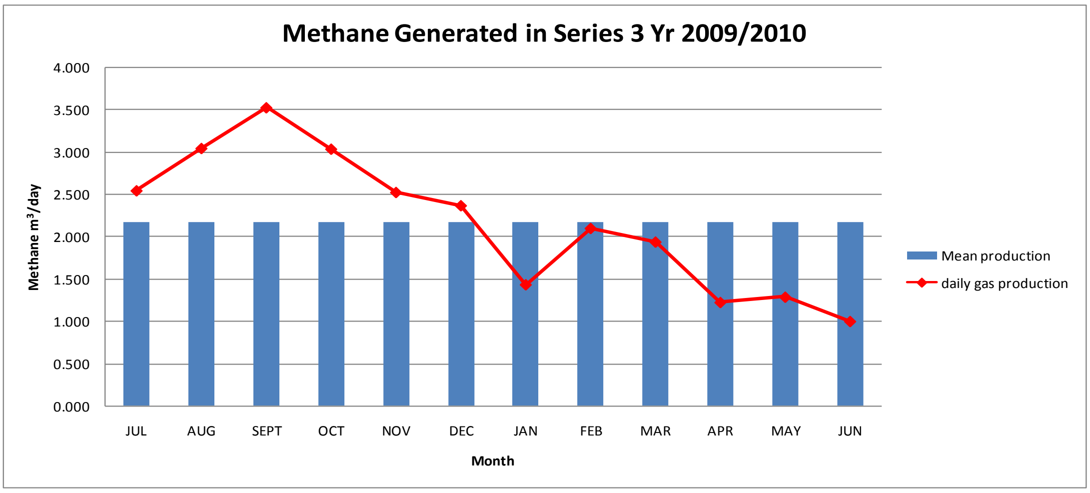

Figure 20: Daily Methane gas generated from Series Three ponds in 2009/2010

4.4.4. Series Four to Eight anaerobic ponds

Series four to Eight are similar in dimensions and the amount of flows they receive. They were therefore analysed together and the total methane generated in the year was a summation of all the three.

An average of 10.85 m3/day was generated in all the five series from series four to eight which all have three anaerobic ponds in year 2009/2010. This indicated that on average each series was able to generate 2.17m3 of methane per day. The daily and average generated methane in this series was as shown in table 22 below

Table 22: Methane gas generated from Series Four to Eight ponds in 2009/2010

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Each Series	2.55	3.05	3.53	3.04	2.53	2.37	1.44	2.10	1.94	1.23	1.29	1.00
Total From Series 4-8 Series	12.74	15.24	17.65	15.20	12.64	11.86	7.18	10.51	9.71	6.13	6.44	5.00
Two Series	5.10	6.10	7.06	6.08	5.06	4.74	2.87	4.20	3.88	2.45	2.58	2.00
Three Series	7.64	9.15	10.59	9.12	7.58	7.11	4.31	6.31	5.82	3.68	3.87	3.00
Four Series	10.19	12.20	14.12	12.16	10.11	9.49	5.74	8.41	7.76	4.90	5.15	4.00
Five Series	12.74	15.24	17.65	15.20	12.64	11.86	7.18	10.51	9.71	6.13	6.44	5.00

In this year an average of 13.544 m3/day of methane was generated from all the anaerobic ponds at DSTP .

4.5. Methane production in year 2010/2011

In year 2010/2011, DSTP received a mean average of 455.46mg/l of degradable organics measured as BOD. This was 89% of the design capacity of 512mg/l of organic loading to the DSTP. Figure 21 below shows the Mean average BOD received at DSTP, the actual BOD received at DSTP against the designed capacity.

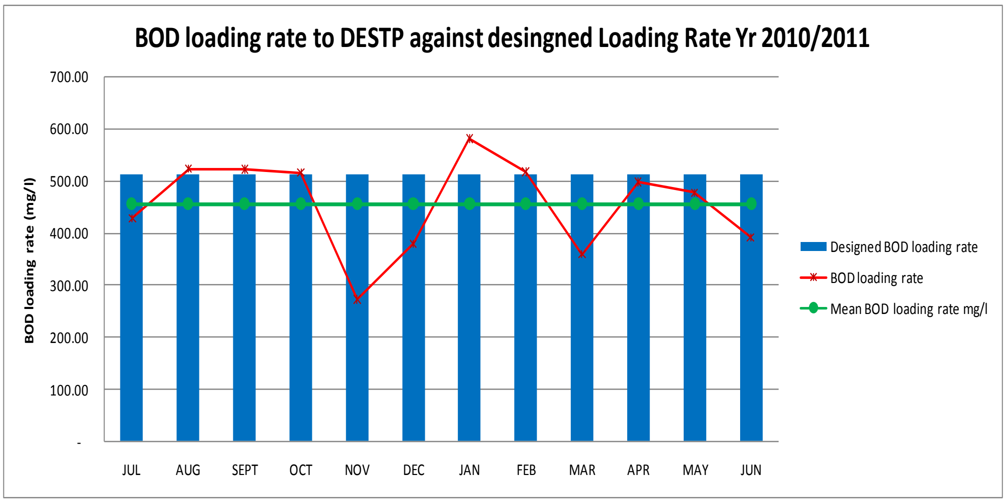

Figure 21: Daily BOD loading to DSTP in the in Year 2010/2011

During this period, the average mass loading to the plant was 38,508.11 kg/day against the designed capacity of 81,920 kg/day. This was 43 % of the plant capacity. Figure 22and Table 23 below shows how the daily mass loading varied in this period.

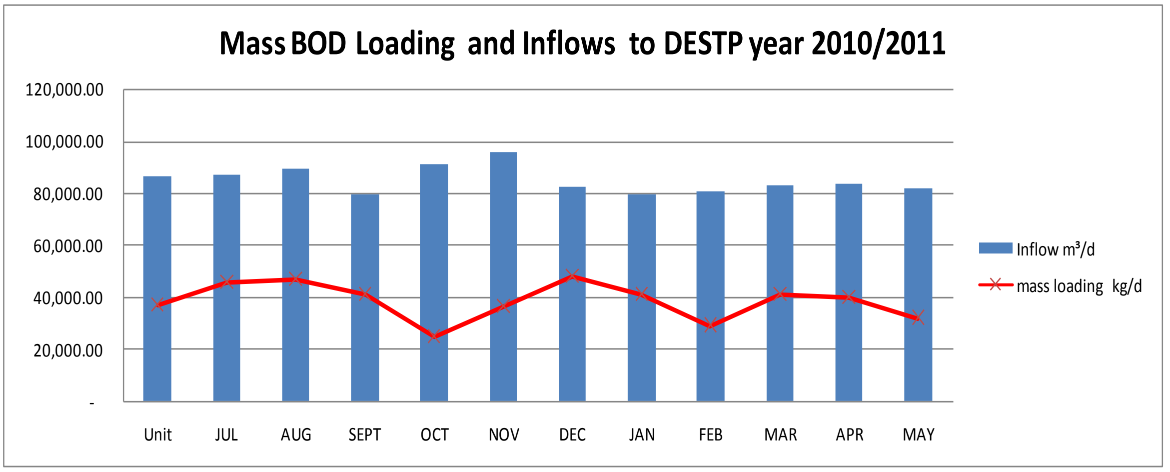

Figure 22: Daily BOD loading to DSTP in the in Year 2010/201

Table 23: Daily BOD loading to DSTP in the in Year 2010/2011

	Unit	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Inflow	m^3/d	86374	87125	89420	79561	91020	95458	82443	79244	80783	82643	83212	81743
BOD loading rate	mg/l	428.14	523.33	522.10	515.83	272.25	379.40	581.25	517.29	359.28	498.07	477.14	391.40
mass loading	kg/d	36980	45595	46685	41040	24780	36216	47920	40991	29023	41162	39704	31994
Designed BOD loading rate	mg/l	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00
Mean BOD loading rate	mg/l	455.46	455.46	455.46	455.46	455.46	455.46	455.46	455.46	455.46	455.46	455.46	455.46

4.5.1. Series one anaerobic ponds

During this period, an average of 1.234m^3/day was generated in series one anaerobic ponds. This ponds are two and each generated an average of 0.662m^3/day of methane. The daily and average generated methane in this series was as shown in Table 24and Figure 23below.

Table 24: Daily Methane gas generated from Series one ponds in 2010/2011

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.16	1.42	1.41	1.40	0.74	1.03	1.58	1.40	0.97	1.35	1.29	1.06
Mean Production	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23

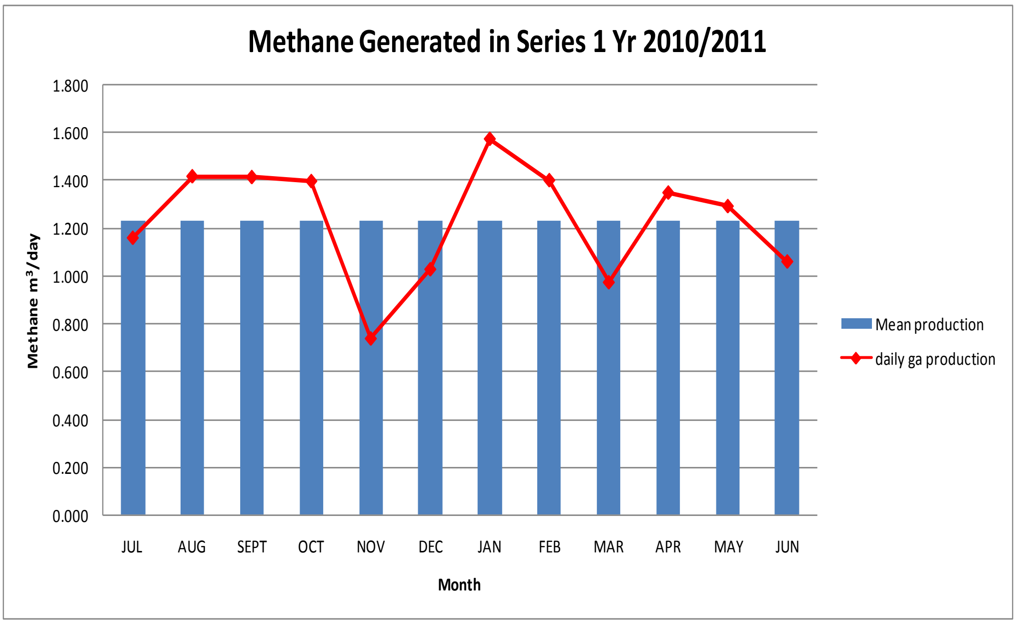

Figure 23: Daily Methane gas generated from Series one ponds in 2010/2011

4.5.2. Series Two anaerobic ponds

An average of 0.76m^3/day was generated in series two anaerobic ponds in year 2010/2011. The daily and average generated methane in this series was as shown in Table 25 and Figure 24 below.

Table 25: Daily Methane gas generated from Series Two ponds in 2010/2011

	Jul	Au	Se	Oct	No	De	Jan	Fe	Ma	Apr	Ma	Jun
Daily Gas Production	0.71	0.87	0.87	0.8	0.4	0.6	0.9	0.8	0.6	0.8	0.8	0.6
Mean Production	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

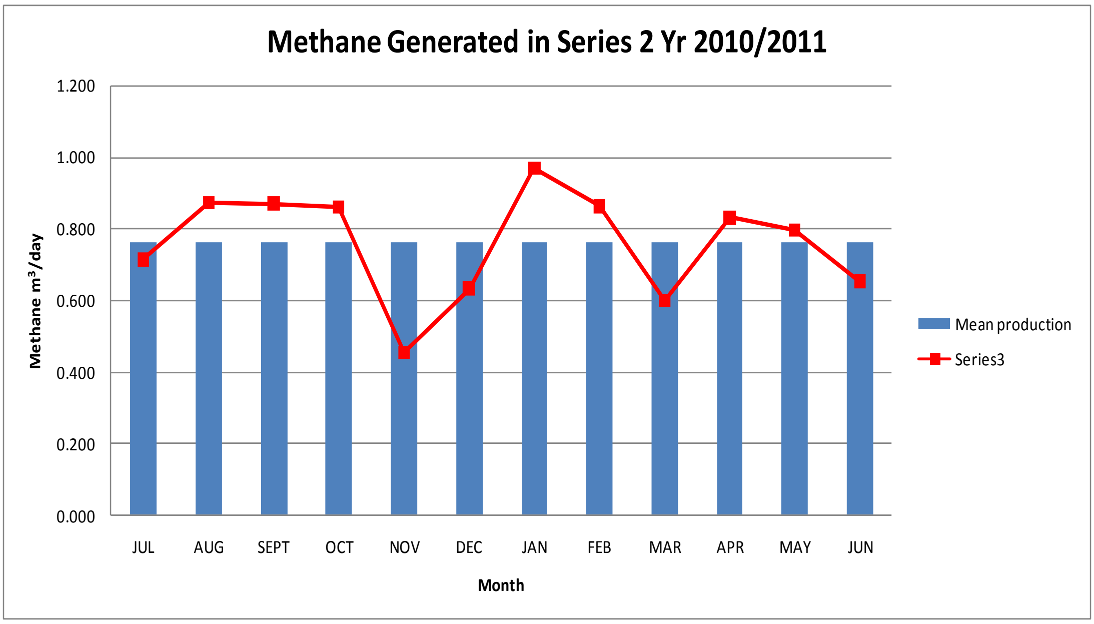

Figure 24: Daily Methane gas generated from Series Two ponds in 2010/2011

4.5.3. Series Three anaerobic ponds

An average of 1.77 m^3/day was generated in series three anaerobic ponds in year 2010/2011. This ponds are three measuring 65m by 65m at the top and each generated an average of 0.59m^3/day of methane. The daily and average generated methane in this series was as shown inTable 26 and Figure 25below.

Table 26: Daily Methane gas generated from Series three ponds in 2010/2011

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.6	2.04	2.03	2.0	1.0	1.4	2.2	2.01	1.40	1.94	1.86	1.52
Mean Production	1.7	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77

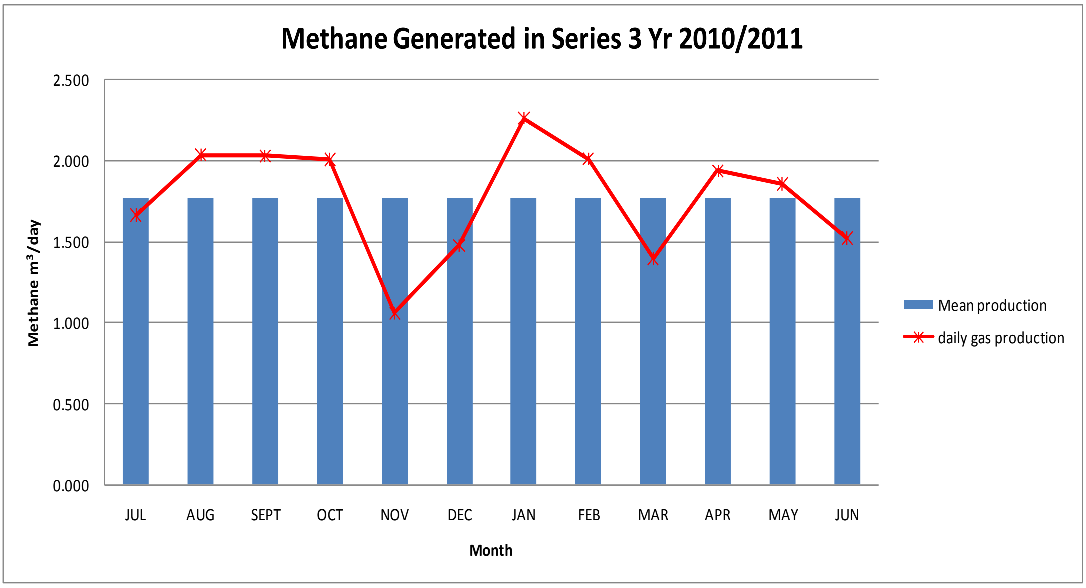

Figure 25: Daily Methane gas generated from Series Three ponds in 2010/2011

4.5.4. Series Four to Eight anaerobic ponds

Series four to Eight are similar in dimensions and the amount of flows they receive. They were therefore analysed together and the total methane generated in the year was a summation of all the three.

An average of 8.8 m^3/day was generated in each series from series four to eight which all have three anaerobic ponds in year 2007/2008. This indicated that on average each series was able to generate 1.76m^3 of methane per day. The daily and average generated methane in this series was as shown in Table 27and Figure 26 below.

Table 27: Methane gas generated from Series Four to Eight ponds in 2010/2011

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Each Series	1.67	2.04	2.03	2.01	1.06	1.48	2.26	2.01	1.40	1.94	1.86	1.52
Total From Series 4-8 Series	8.33	10.18	10.16	10.04	5.30	7.38	11.31	10.06	6.99	9.69	9.28	7.61
Two Series	3.33	4.07	4.06	4.01	2.12	2.95	4.52	4.03	2.80	3.88	3.71	3.05
Three Series	5.00	6.11	6.09	6.02	3.18	4.43	6.78	6.04	4.19	5.81	5.57	4.57
Four Series	6.66	8.15	8.13	8.03	4.24	5.90	9.05	8.05	5.59	7.75	7.43	6.09
Five Series	8.33	10.18	10.16	10.04	5.30	7.38	11.31	10.06	6.99	9.69	9.28	7.61

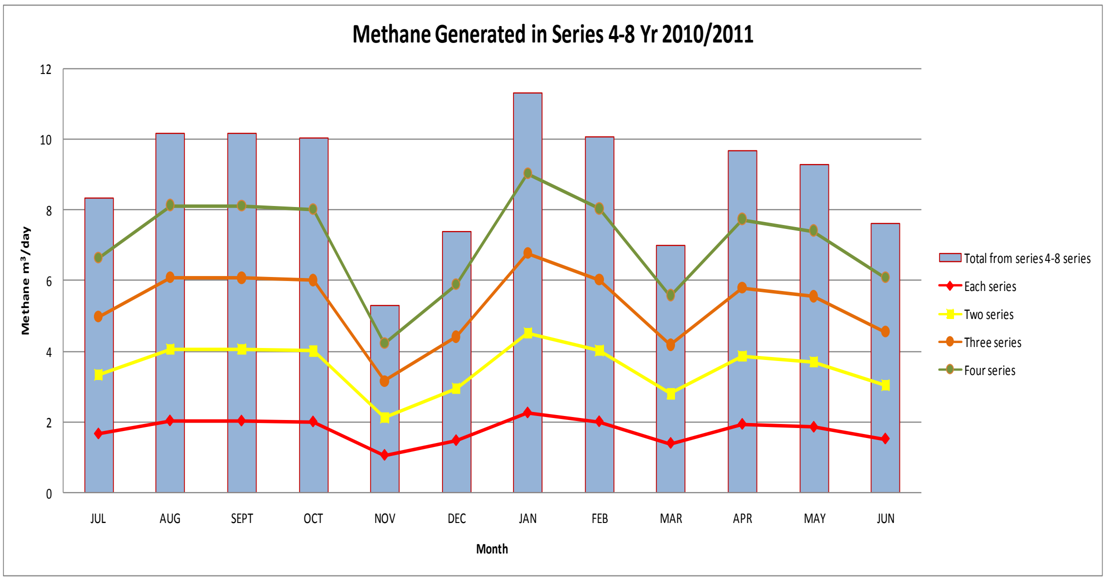

Figure 26: Methane gas generated from Series Four to Eight ponds in 2010/2011

In this year an average of 12.63 m^3/day of methane was generated from all the anaerobic ponds at DSTP as shown in Figure 27and Table 28below.

Table 28: Methane gas generated from Series One to Eight ponds in 20102011

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Total Biogas Generated From Series 1	1.16	1.42	1.41	1.40	0.74	1.03	1.58	1.40	0.97	1.35	1.29	1.06
Total Biogas Generated From Series 2	0.71	0.87	0.87	0.86	0.45	0.63	0.97	0.86	0.60	0.83	0.80	0.65
Total Biogas Generated From Series 3	1.67	2.04	2.03	2.01	1.06	1.48	2.26	2.01	1.40	1.94	1.86	1.52
Total Biogas Generated in Series 4 -8	8.33	10.18	10.16	10.04	5.30	7.38	11.31	10.06	6.99	9.69	9.28	7.61
Mean Gas Production	2.97	3.63	3.62	3.58	1.89	2.63	4.03	3.59	2.49	3.45	3.31	2.71
Total Biogas From All Pond	11.87	14.51	14.47	14.30	7.55	10.52	16.11	14.34	9.96	13.81	13.23	10.85

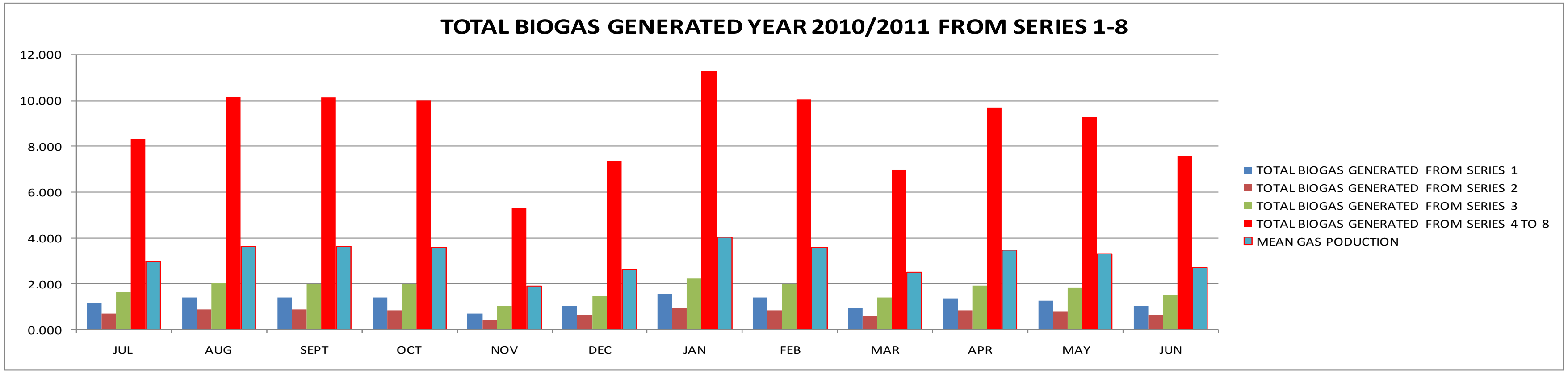

Figure 27: Methane gas generated from Series One to Eight ponds in 2010/2011

4.6. Methane production in year 2011/2012

In year 2011/2012, DSTP received a mean average of 313.73 mg/l of degradable organics measured as BOD. This was 61% of the design capacity of 512mg/l of organic loading to the DSTP. Figure 28 below shows the Mean average BOD received at DSTP, the actual BOD received at DSTP against the designed capacity.

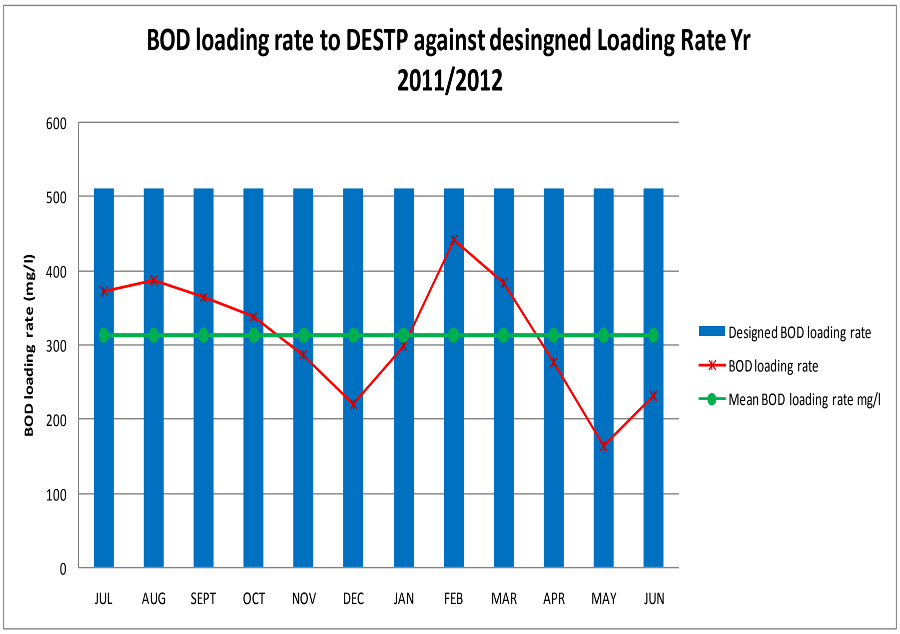

Figure 28: Daily BOD loading to DSTP in the in Year 2011/2012

During this period, the average mass loading to the plant was 27,447.83 kg/day against the designed capacity of 81,920 kg/day. This was 33 % of the plant capacity. Figure 29 and**Error! Reference source not found.**below shows how the daily mass loading varied in this period.

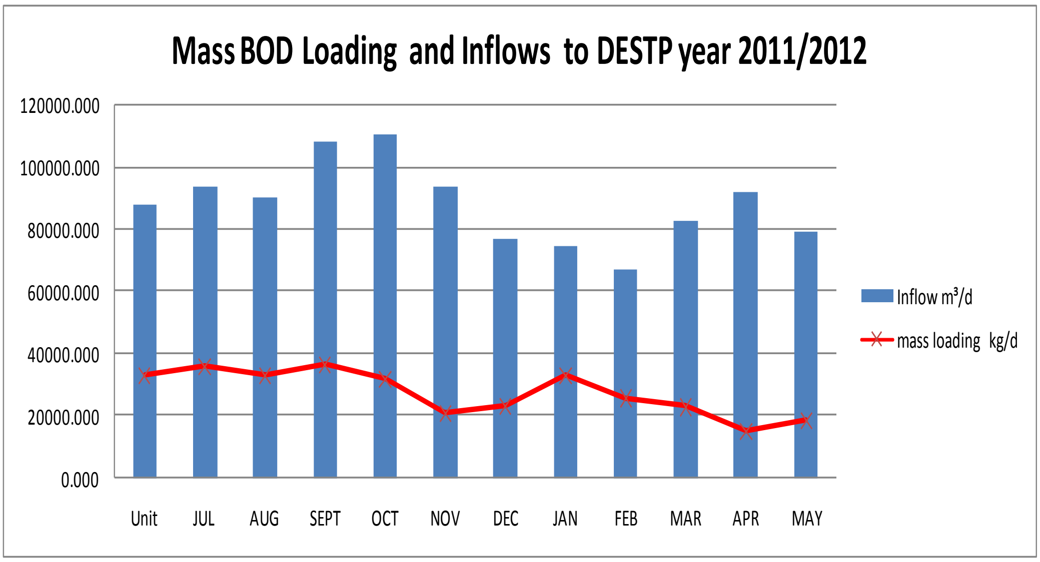

Figure 29: Daily BOD loading to DSTP in the in Year 2011/2012

Table 29:Daily BOD loading to DSTP in the in Year 2011/2012

	Unit	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Inflow	M³/D	88290	93633	90686	10826	11079	94175	77035	74507	67109	83014	92145	79525
BOD Loading Rate	Mg/L	372.90	386.86	364.06	337.78	286.52	220.57	299.37	442.17	383.74	276.38	163.40	230.95
Mass Loading	Kg/D	32924	36222	33015	36568	31744	20772	23062	32944	25752	22943	15056	18366
Designed BOD Loading Rate	Mg/L	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00	512.00
Mean BOD Loading Rate	Mg/L	313.73	313.73	313.73	313.73	313.73	313.73	313.73	313.73	313.73	313.73	313.73	313.73

4.6.1. Series one anaerobic ponds

During this period, an average of 0.85 m^3/day was generated in series one anaerobic ponds. This ponds are two and each generated an average of 0.425m^3/day of methane. The daily and average generated methane in this series was as shown inTable 30 and Figure 30below.

Table 30: Daily Methane gas generated from Series one ponds in 2011/2012

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.01	1.05	0.99	0.92	0.78	0.60	0.81	1.20	1.04	0.75	0.44	0.63
Mean Production	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85

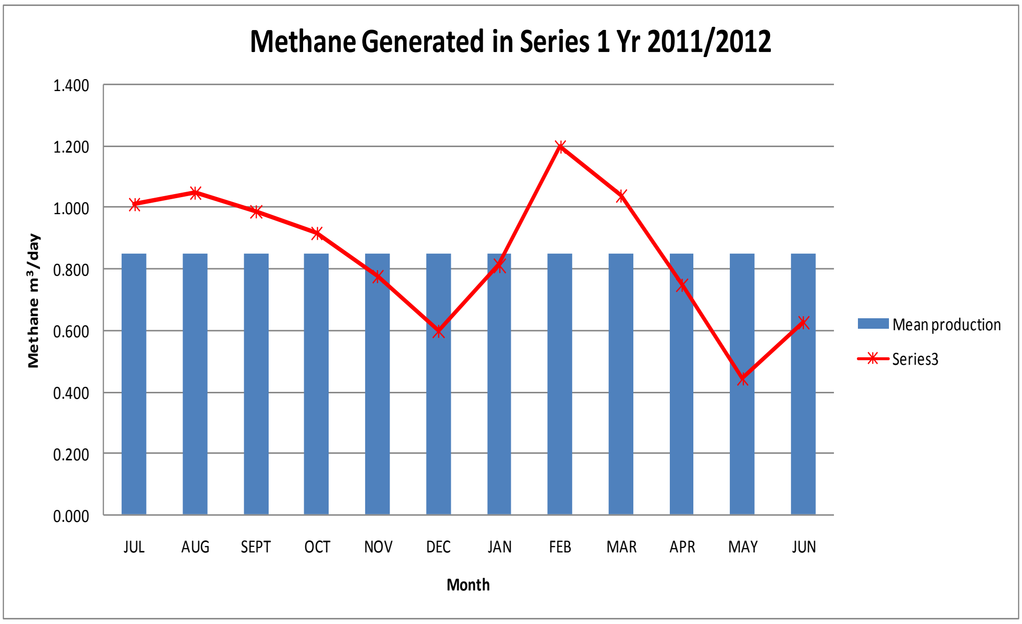

Figure 30: Daily Methane gas generated from Series one ponds in 2011/2012

4.6.2. Series Two anaerobic ponds

An average of 0.52m^3/day was generated in series two anaerobic ponds in year 2010/2011. The daily and average generated methane in this series was as shown in Table 31 and Figure 31 below.

Table 31: Daily Methane gas generated from Series Two ponds in 2011/2012

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	0.62	0.65	0.61	0.56	0.48	0.37	0.50	0.74	0.64	0.46	0.27	0.39
Mean Production	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52

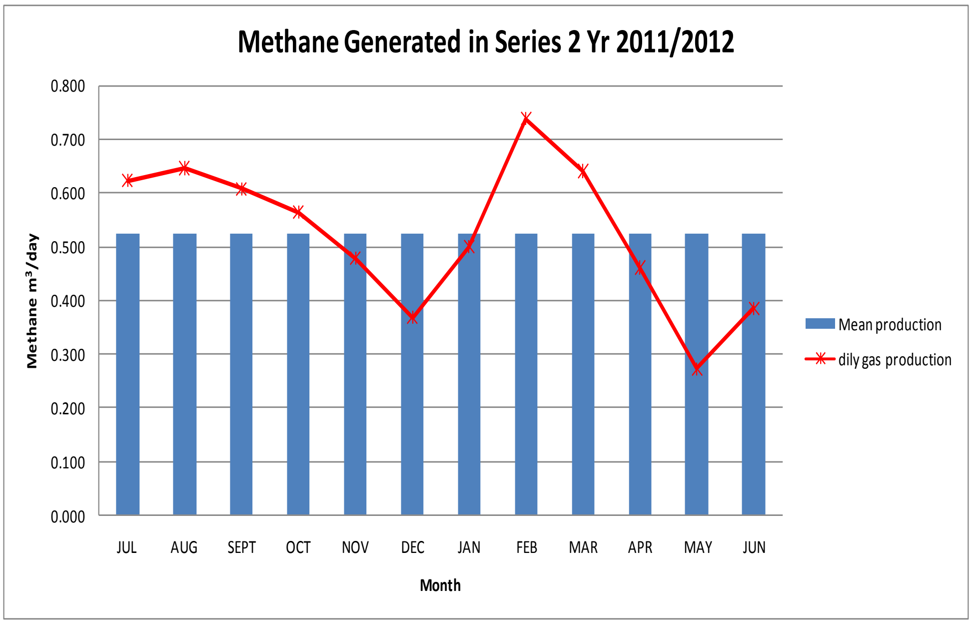

Figure 31: Daily Methane gas generated from Series Two ponds in 2011/2012

4.6.3. Series Three anaerobic ponds

An average of 1.22 m^3/day was generated in series three anaerobic ponds in year 2010/2011. This ponds are three measuring 65m by 65m at the top and each generated an average of 0.41m^3/day of methane. The daily and average generated methane in this series was as shown in Table 32 and Figure 32 below.

Table 32: Daily Methane gas generated from Series three ponds in 2011/2012

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Daily Gas Production	1.4	1.51	1.42	1.3	1.11	0.8	1.1	1.7	1.49	1.0	0.64	0.9
Mean Production	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.2

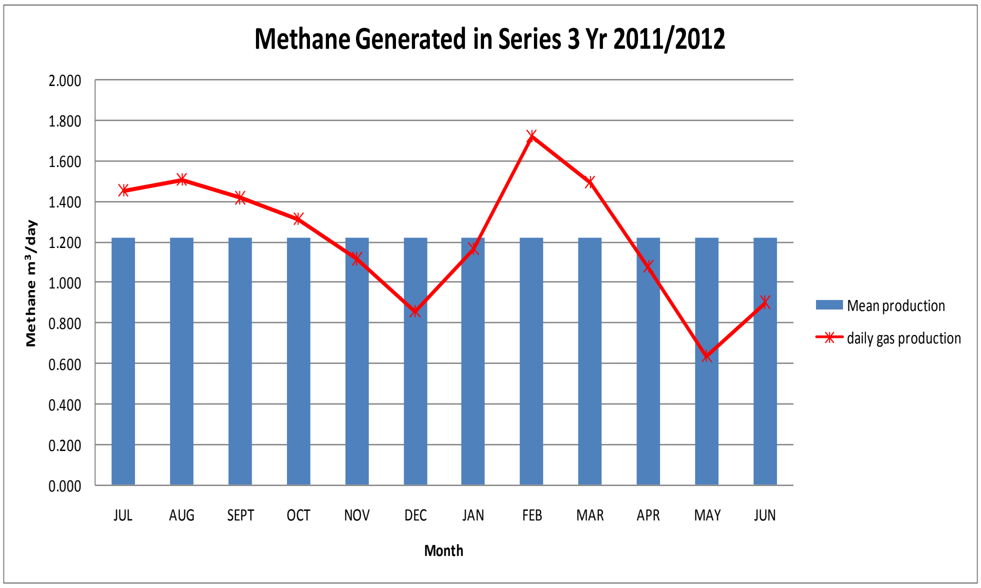

Figure 32: Daily Methane gas generated from Series Three ponds in 2011/2012

4.6.4. Series Four to Eight anaerobic ponds

Series four to Eight are similar in dimensions and the amount of flows they receive. They were therefore analysed together and the total methane generated in the year was a summation of all the three.

An average of 6.06 m^3/day was generated in each series from series four to eight which all have three anaerobic ponds in year 2007/2008. This indicated that on average each series was able to generate 1.21m^3 of methane per day. The daily and average generated methane in this series was as shown in and Figure 33below.

Table 33: Methane gas generated from Series Four to Eight ponds in 2011/2012

	Jul	Aug	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
Each series	1.4	1.5	1.42	1.3	1.1	0.8	1.1	1.7	1.49	1.0	0.64	0.9
Total from series 4-8 series	7.2	7.5	7.08	6.5	5.5	4.2	5.8	8.6	7.47	5.3	3.18	4.4
Two series	2.9	3.0	2.83	2.6	2.2	1.7	2.3	3.4	2.99	2.1	1.27	1.8
Three series	4.3	4.5	4.25	3.9	3.3	2.5	3.4	5.1	4.48	3.2	1.91	2.7
Four series	5.8	6.0	5.67	5.2	4.4	3.4	4.6	6.8	5.97	4.3	2.54	3.5
Five Series	7.2	7.5	7.08	6.5	5.5	4.2	5.8	8.6	7.47	5.3	3.18	4.4
Mean	1.4	1.5	1.42	1.3	1.1	0.8	1.1	1.7	1.49	1.0	0.64	0.9

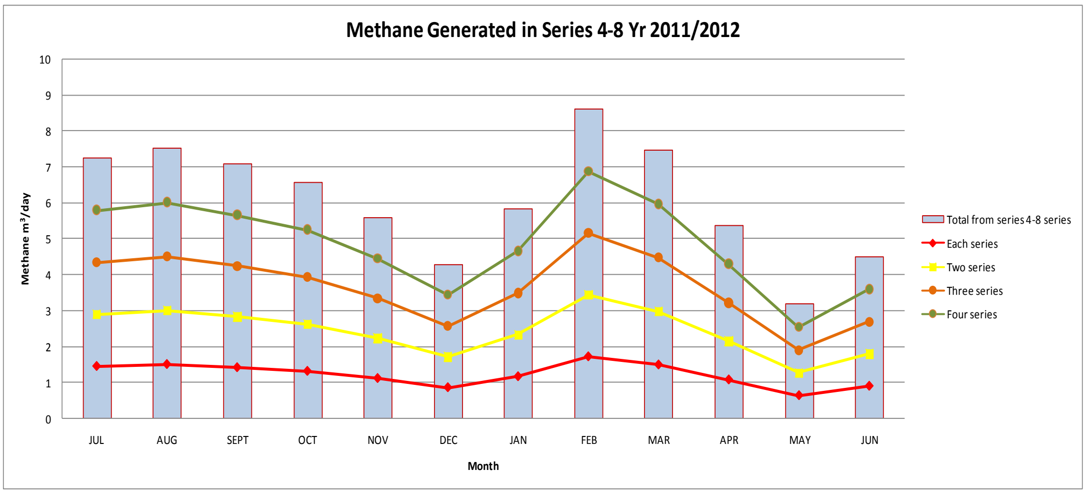

Figure 33: Methane gas generated from Series Four to Eight ponds in 2011/2012

In this year an average of 8.7 m^3/day of methane was generated from all the anaerobic ponds at DSTP as shown in Figure 34 and Table 34 below.

Table 34: Methane gas generated from Series One to Eight ponds in 2011/2012

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Total Biogas Generated From Series 1	1.01	1.05	0.99	0.92	0.78	0.60	0.81	1.20	1.04	0.75	0.44	0.63
Total Biogas Generated From Series 2	0.62	0.65	0.61	0.56	0.48	0.37	0.50	0.74	0.64	0.46	0.27	0.39
Total Biogas Generated From Series 3	1.45	1.51	1.42	1.31	1.11	0.86	1.16	1.72	1.49	1.08	0.64	0.90
Total Biogas Generated From Series 4 To 8	7.25	7.53	7.08	6.57	5.57	4.29	5.82	8.60	7.47	5.38	3.18	4.49
Mean Gas Production	2.58	2.68	2.52	2.34	1.99	1.53	2.07	3.06	2.66	1.92	1.13	1.60
Total Biogas From All Pond	**10.34**	**10.73**	**10.09**	**9.36**	**7.94**	**6.12**	**8.30**	**12.26**	**10.64**	**7.66**	**4.53**	**6.40**

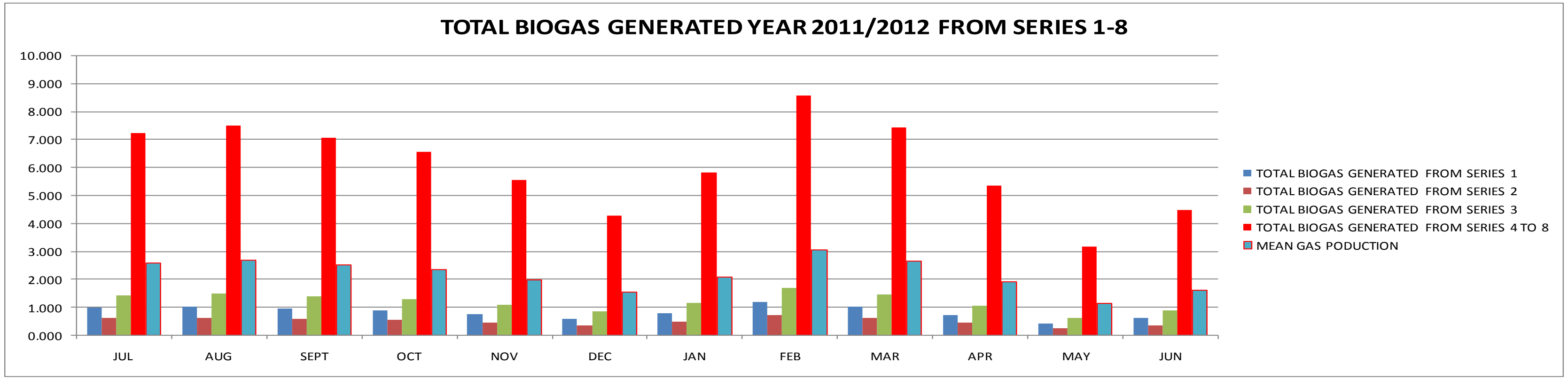

Figure 34: Methane gas generated from Series One to Eight ponds in 2011/2012

4.7. Methane production in year 2012/2013

In year 2012/2013, DSTP received a mean average of 290.37 mg/l of degradable organics measured as BOD. This was 57% of the design capacity of 512mg/l of organic loading to the DSTP. Figure 35 below shows the Mean average BOD received at DSTP, the actual BOD received at DSTP against the designed capacity.

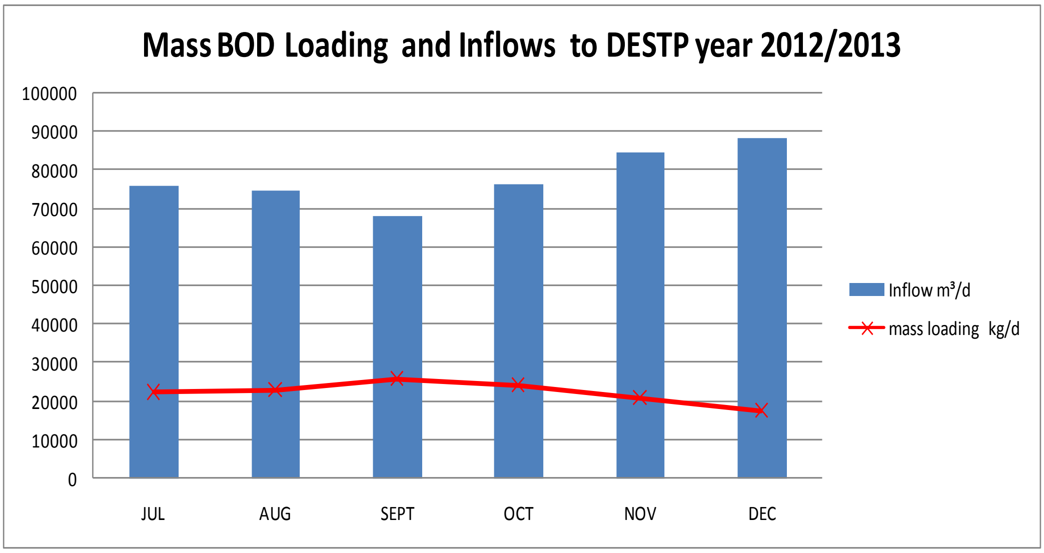

Figure 35: Daily BOD loading to DSTP in the in Year 2012/2013

During this period, the average mass loading to the plant was 22,304.24 kg/day against the designed capacity of 81,920 kg/day. This was 27 % of the plant capacity. Figure 36and Table 35below shows how the daily mass loading varied in this period.

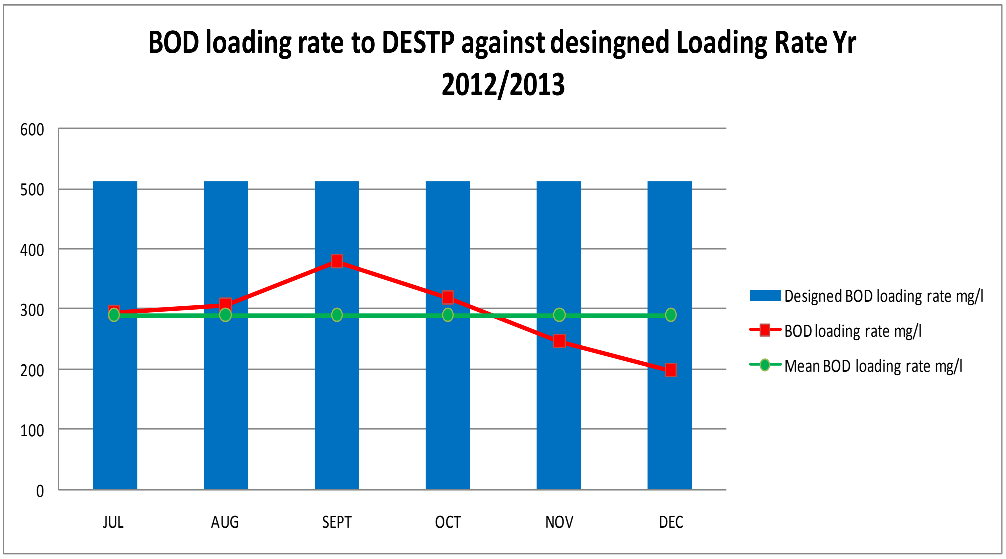

Figure 36: Daily BOD loading to DSTP in the in Year 2012/2013

Table 35: Daily BOD loading to DSTP in the in Year 2012/2013

		Jul	Aug	Sept	Oct	Nov	Dec
Inflow	m^3/d	75944	74657	68336	76507	84710	88279
BOD loading rate	mg/l	294	306	379	318	247	198
mass loading	kg/d	22,349.3	22,845.0	25,887.4	24,335.8	20,888.6	17,519.1
Designed BOD loading rate	mg/l	512	512	512	512	512	512
Mean BOD loading rate	mg/l	290.37	290.37	290.37	290.37	290.37	290.37

4.7.1. Series one anaerobic ponds

During this period, an average of 0.79 m^3/day was generated in series one anaerobic ponds. This ponds are two and each generated an average of 0.395m^3/day of methane. The daily and average generated methane in this series was as shown in Table 36and Figure 37 below.

Table 36: Daily Methane gas generated from Series one ponds in 2012/2013

	Jul	Aug	Sept	Oct	Nov	Dec
Daily Gas Production	0.80	0.83	1.03	0.86	0.67	0.54
Mean Production	0.79	0.79	0.79	0.79	0.79	0.79

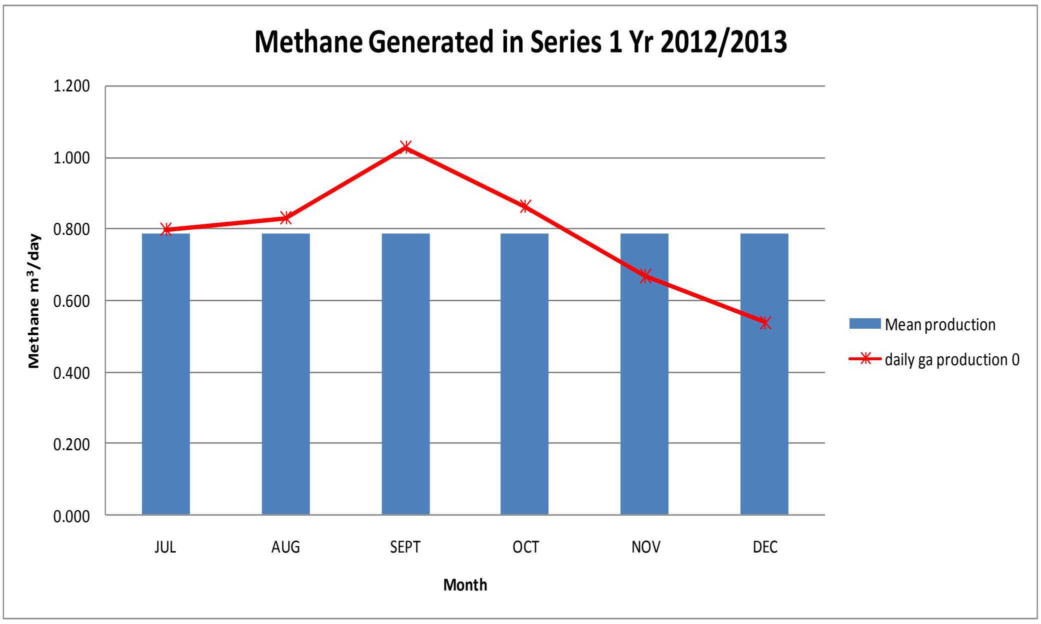

Figure 37: Daily Methane gas generated from Series one ponds in 2012/2013

4.7.2. Series Two anaerobic ponds

An average of 0.484 m^3/day was generated in series two anaerobic ponds in year 2010/2011. The daily and average generated methane in this series was as shown in Table 37 and Figure 38 below.

Table 37: Daily Methane gas generated from Series two ponds in 2012/2013

	Jul	Aug	Sept	Oct	Nov	Dec
Daily Gas Production	0.491	0.510	0.632	0.530	0.411	0.331
Mean Production	0.484	0.484	0.484	0.484	0.484	0.484

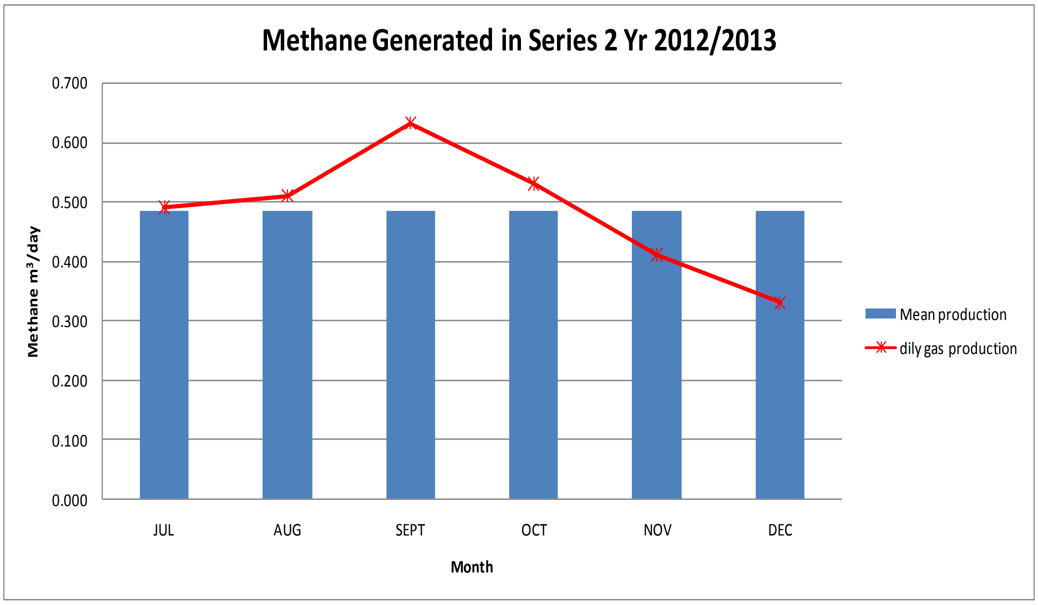

Figure 38: Daily Methane gas generated from Series Two ponds in 2012/2013

4.7.3. Series Three anaerobic ponds

An average of 1.13m^3/day was generated in series three anaerobic ponds in year 2010/2011. These ponds are three measuring 65m by

65m at the top and each generated an average of 0.38 m^3/day of methane. The daily and average generated methane in this series was as shown in Table 38 and Table 38 below.

Table 38: Daily Methane gas generated from Series three ponds in 2012/2013

	Jul	Aug	Sept	Oct	Nov	Dec
Daily Gas Production	1.145	1.191	1.474	1.238	0.959	0.772
Mean Production	1.130	1.130	1.130	1.130	1.130	1.130

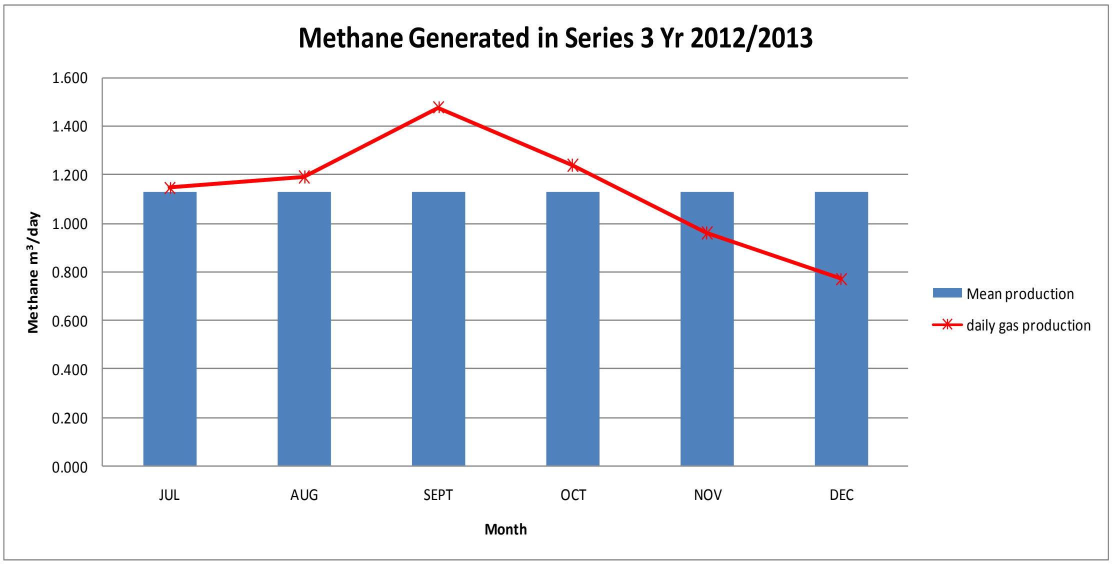

Figure 39: Daily Methane gas generated from Series Three ponds in 2012/2013

4.7.4. Series Four to Eight anaerobic ponds

Series four to Eight are similar in dimensions and the amount of flows they receive. They were therefore analysed together and the total methane generated in the year was a summation of all the three.

An average of 5.65 /day was generated in each series from series four to eight which all have three anaerobic ponds in year 2007/2008. This indicated that on average each series was able to generate 1.13m^3 of methaneper day. This was for the half year from July 2012 to December 2013. The daily and average generated methane in this series was as shown in Table 39 and Figure 40 below.

Table 39: Methane gas generated from Series Four to Eight ponds in 2012/2013

	Jul	Aug	Sept	Oct	Nov	Dec
Each Series	1.15	1.19	1.47	1.24	0.96	0.77
Total From Series 4-8 Series	5.73	5.95	7.37	6.19	4.80	3.86
Two Series	2.29	2.38	2.95	2.48	1.92	1.54
Three Series	3.44	3.57	4.42	3.71	2.88	2.32
Four Series	4.58	4.76	5.90	4.95	3.84	3.09
Five Series	5.73	5.95	7.37	6.19	4.80	3.86
Mean	1.15	1.19	1.47	1.24	0.96	0.77

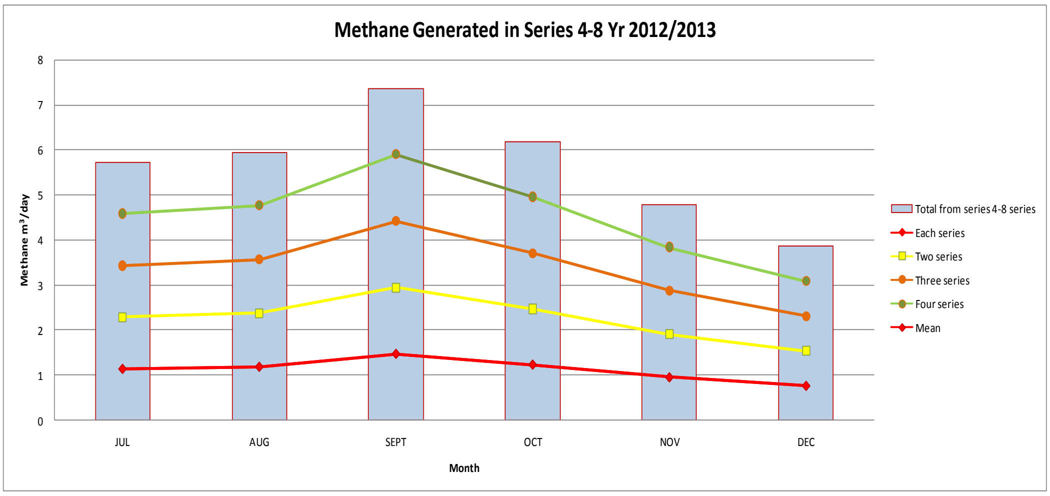

Figure 40: Methane gas generated from Series Four to Eight ponds in 2012/2013

In this year an average of 8 m^3/day of methane was generated from all the anaerobic ponds at DSTP as shown in Figure 41 and Table 40 below.

Table 40: Methane gas generated from Series One to Eight ponds in 2012/2013

	Jul	Aug	Sept	Oct	Nov	Dec
Total Biogas Generated From Series 1	0.797	0.829	1.027	0.862	0.668	0.538
Total Biogas Generated From Series 2	0.491	0.510	0.632	0.530	0.411	0.331
Total Biogas Generated From Series 3	1.145	1.191	1.474	1.238	0.959	0.772
Total Biogas Generated From Series 4 To 8	5.725	5.953	7.370	6.188	4.797	3.861
Mean Gas Production	2.040	2.121	2.626	2.205	1.709	1.375
Total Biogas From All Pond	8.159	8.483	10.503	8.819	6.836	5.502

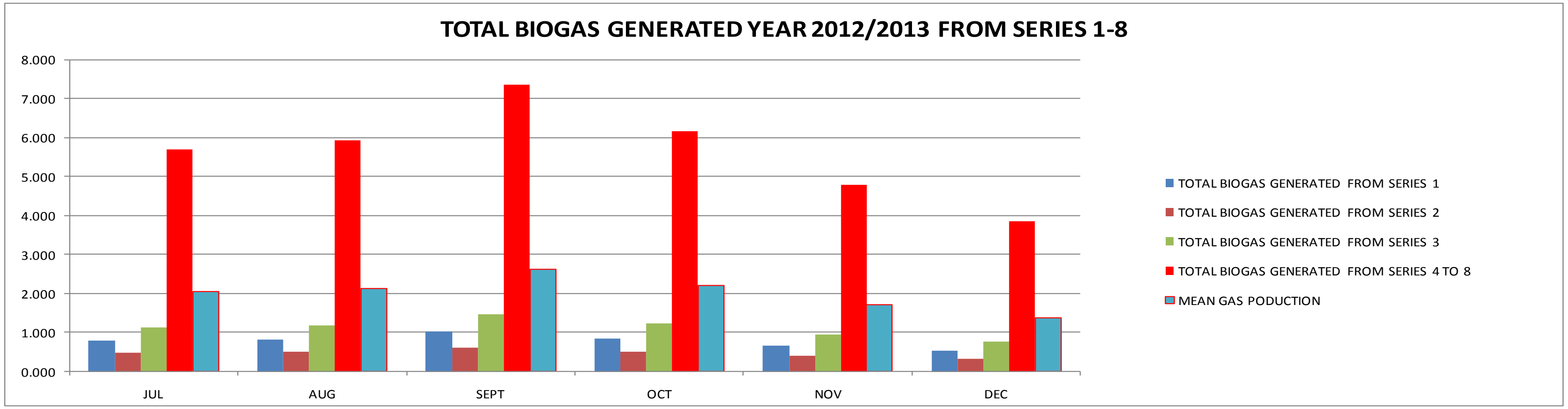

Figure 41: Methane gas generated from Series One to Eight ponds in 2012/2013

4.8. Methane production in year 2007-2013

During the study, data for these years was collected from the operator at Dandora Sewage Treatment Plant and analysed for the amount of methane that was being produced in that was being produced in this period. It was noted that the plant was operating at about 50% of its design capacity and organic loading in terms of BOD.The highest period in which the maximum biogas was produced was from December 2008 to June 2009 when the plant received the highest amount of flows. These flows could be attributed to the high amount of rainfall received in this period due to the elnino phenomenon experienced at the time which could have swept organics accumulated in sewers to DSTP.

This is as depicted in Table 41 and Figure 42 below

Table 41: daily methane generation from 2007-2013

Year	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
2007/2008	7.76	13.31	6.05	7.22	7.82	6.85	6.65	7.49	8.34	7.74	6.42	8.44
2008/2009	10.60	11.52	11.57	11.57	11.17	11.84	14.52	16.25	18.07	16.35	14.37	14.71
2009/2010	18.16	21.72	25.16	21.67	18.01	16.90	10.23	14.98	13.83	8.73	9.18	7.13
2010/2011	11.87	14.51	14.47	14.30	7.55	10.52	16.11	14.34	9.96	13.81	13.23	10.85
2011/2012	10.34	10.73	10.09	9.36	7.94	6.12	8.30	12.26	10.64	7.66	4.53	6.40
2012/2013	8.16	8.48	10.50	8.82	6.84	5.50						
Mean	11.15	13.38	12.97	12.16	9.89	9.62	11.16	13.06	12.17	10.86	9.55	9.51

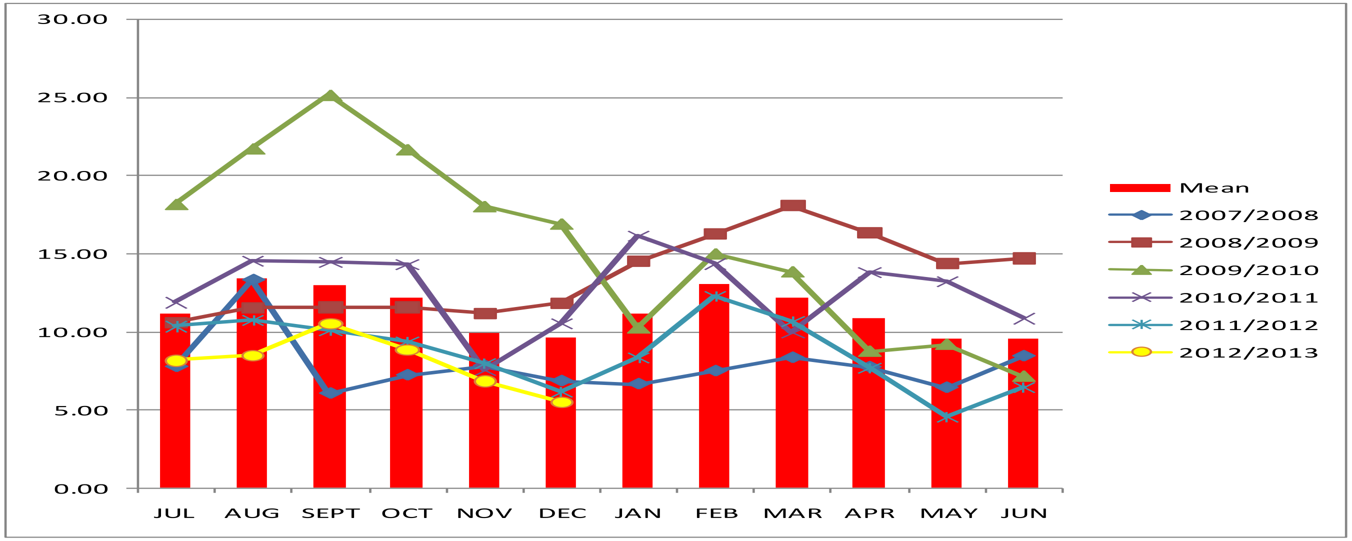

Figure 42: daily methane generation from 2007-2013

4.8.1. Methane production at full capacity

In order to properly estimate the amount of methane that the plant can generate at full capacity, it was necessary to calculate the amount of methane generation at the designed capacity of 160,000m3/day flow and 512mg/l BOD loading to the DSTP.

It was found that an average of 14.1 m3/day of methane would get generated at DSTP with all the anaerobic ponds being operated. Series one would generate 1.39m3/day at a volume of 5000m3/day to each pond. Series two would generate 0.85 m3/day at a volume of 3,333.33 m3/day to each pond and Series three to eight would generate 1.99 m3/day at a volume of 9,333.33 m3/day to each pond.

The amount of methane that can be produced from each series per day is as shown in Table 42 and Figure 43 below.

Table 42:Methane generation at full capacity

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Total Biogas Generated From Series 1	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39
Total Biogas Generated From Series 2	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Total Biogas Generated From Series 3	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99
Total Biogas Generated From Series 4 To 8	9.96	9.96	9.96	9.96	9.96	9.96	9.96	9.96	9.96	9.96	9.96	9.96
Mean Gas Production	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99
Total Biogas From All Pond	**14.1**	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.19	14.19	14.1

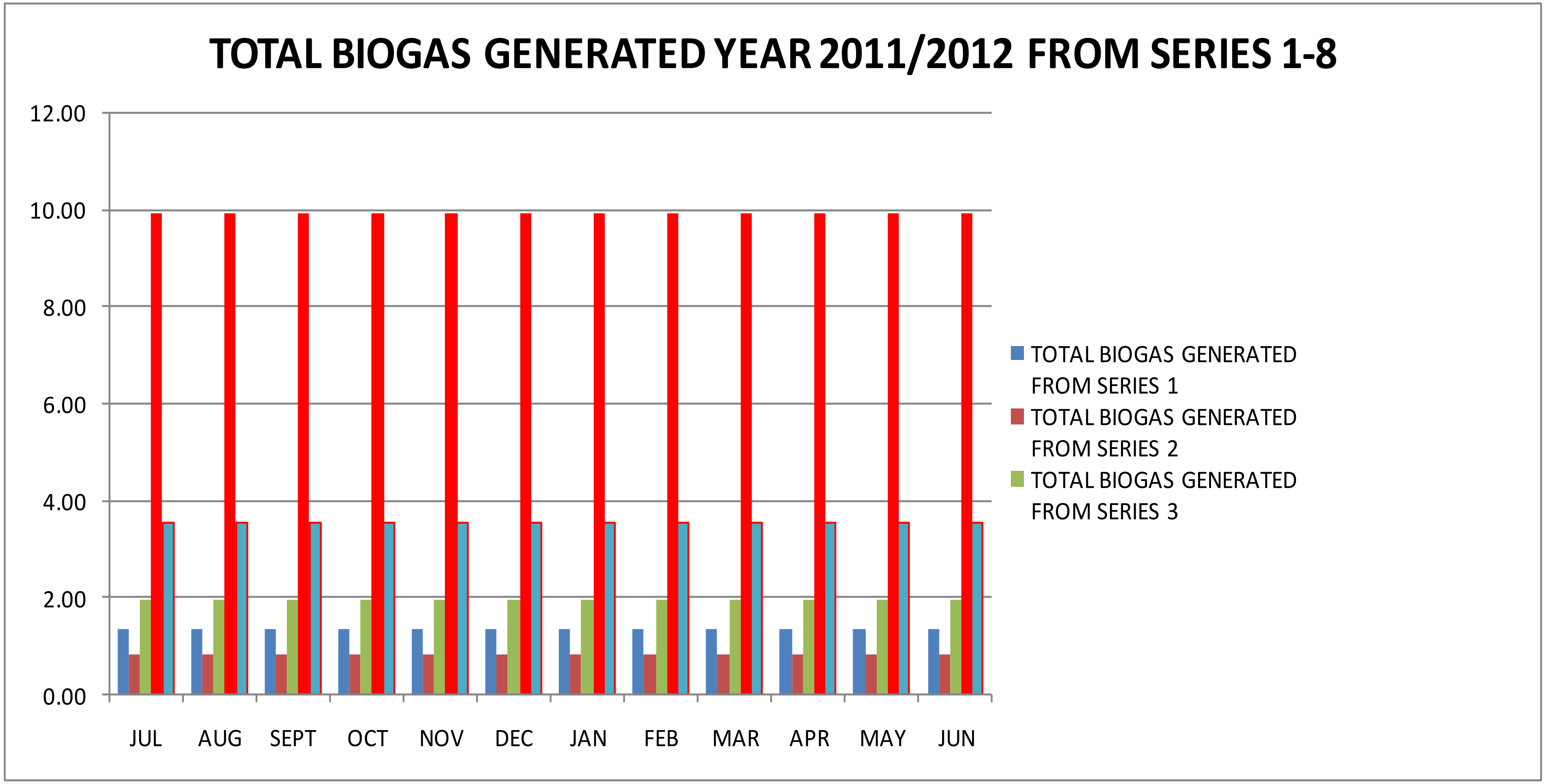

Figure 43:Methane generation at full capacity

CHAPTER FIVE

5.1 CONCLUSION AND RECOMMENDATION

The IPCC calculates the amount of methane emitted by utilising the maximum quantity of methane that a specific quantity of organics can produce with a correction factor showing to what extent to which this methane producing potential is realized in each type of treatment and discharge pathway and system (IPCC, 2006)

The amount of methane production from the anaerobic ponds at Dandora wastewater treatment plant was calculated using the revised 1996 IPCC and 2006 IPCC guidelines and operational data obtained from the treatment plant. The following were the calculated methane volumes from the plant:

The plant is currently producing an approximately 8.3m^3/day of methane at the current flow of 83,648m3/day;

The plant can generate an average of 14.12 m^3/day of methane while operating at full capacity of 160,000m^3/day.

Biogases capture and reuse systems for anaerobic waste water treatment lagoons are the simplest and easiest ways of biogas operation. Instead of investing in a new centralized aerobic treatment plant to avoid anaerobic treatment at DSTP, covering the existing anaerobic lagoons with suitable covers and extracting the captured biogas is an economically feasible means to reduce methane emissions and utilising the gases for economic benefits.

The DESTP can utilise the captured and recovered methane as a source of fuel to produce electric power by employing reciprocating engines and turbines. Power produced at the waste water treatment plant can be utilised on site thereby saving the plant operations from purchased power. DSTP can also treat and refine the captured biogas and sell it as liquefied pressurised gas (LPG) in LPGs cylinders to homesteads or industries to be used as cooking gas and thus generating revenue coupled with prevention of the emissions into the atmosphere.

Through Methane capture and use at wastewater treatment facilities, DSTP can be able to realize the following benefits among others:

- Reduced GHGs and associated air pollutants.
- DSTP can provide an onsite source of energy to run the plant.
- DSTP can convert the emissions into a source of revenue.
- DSTP can create a renewable source of energy to replace power consumption at the plant.
- The capture and conversion of the methane gas at the plant can create jobs related to project construction and operation.
- The capture and utilization of the gas emissions will enhance the Operator’s (NCWSC) image as innovative and Sustainable ways of managing waste water in the city.

CHAPTER SIX

6.1 REFERENCES

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