A study on the Efficiency of Dandora Domestic and Industrial Wastewater Treatment Plant in Nairobi

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This project is dedicated to my husband Dr Sewe, and children Stella, Robert, Benter and Joyce, for patience, moral, spiritual, psychological and financial support.

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LIST OF ABBREVIATIONS

A	Anaerobic ponds
AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
BOD_5	BOD is measured in a five-day test of oxygen consumption
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
Cd	Cadmium
Cr	Chromium
Cu	Copper
Dandora D & IWTP	Dandora Domestic and Industrial Waste Treatment Plant
DO	Dissolved Oxygen
DoE	Department of Environment
EPA	Environmental Protection Agency
F	Facultative ponds
FAS	Ferrous Ammonium Sulfate
FEPA	Federal Environmental Protection Agencies
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
H_2SO_4	Sulfuric acid
ISAB	Ionic Strength Adjustment Buffer

KCl	Potassium Chloride
KIRDI	Kenya Industrial Research and Development Institute
Km	Kilometres
LCA	Life Cycle Assessment
M	Maturation ponds
MCL	Maximum contaminant levels
Mn	Manganese
NCWSC	Nairobi City Water and Sewerage Company
NED	Naphthyl Ethylenediamine Dihydrochloride
NH_3-N	Ammonia-Nitrogen
NO_3-N	Nitrate-Nitrogen
NO_2-N	Nitrite-Nitrogen
O-N	Organic-Nitrogen
Pb	Lead
PCBs	Polychlorinated biphenyls
SPSS	Statistical Package for Social Scientists
SS	Suspended Solids
TDS	Total Dissolved Solids
TFCC	Total Feacal Coliform Count
T-N	Total Nitrogen
T-P	Total Phosphorus
TSS	Total Suspended Solids

UV	Ultra-Violet
WHO	World Health Organization
WSP	Waste Stabilization Ponds
WTP	Wastewater Treatment Plant
WTPs	Wastewater Treatment Plants
WWTPs	Wastewater Treatment Plants
Zn	Zinc

ABSTRACT

Nairobi's wastewater stabilization ponds (also known as Dandora Wastewater Treatment Plant) are located 30 km to the East of the city, and they discharge into Nairobi River, and finally into Athi River. The plant has eight series, comprising of 38 ponds, and has expanded significantly since its establishment in 1978. Treatment in ponds is achieved by waste stabilization. In 2009, a study was done to establish the efficiency of this wastewater treatment plant and to assess whether the final effluent met the required standards for Kenya. Grab samples were collected at the inlet and outlet of the treatment plant, and also from the discharge points of each pond in 4 series. Wastewater samples from the ponds were analyzed in the chemistry laboratory of Jomo Kenyatta University of Agriculture and Technology (JKUAT), at Kenya Industrial Research and Development Institute (KIRDI) laboratories, Nairobi City Water and Sewerage Company (NCWSC) laboratories and also at the Mines and Geology labs. Dissolved Oxygen (DO) content in the dry season was below the 5.0 mgO_2/L requirement for discharge into surface waters. DO content during the wet season ranged between 2.76 and 19.77 mgO_2/L. The Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) in the final effluents did not meet the design expectation of 20 mgO_2/L, 280 mgO_2/L and 30 mg/L respectively. BOD_5 concentration ranged between 29.90±8.20 and 92.44±5.08 mgO_2/L and removal efficiency from the series ranged between 90.12 and 97.10 %. TSS in the final effluent ranged between 46.10 and 107.8 mg/L in dry season and 78.22 and 120.89 mg/L in the wet season. The % reduction was from 76.70 to 90.00%. The Total-Phosphorus (T-P)

concentration ranged between 7.00 and 75.80 mgP/L (compared to a standard of 2 mgP/L), and the removal efficiency was 13.70% to 78.26 %. Total-Nitrogen (T-N) ranged between 29.11 and 61.35 mgN/L in the dry season (compared to a standard of 2 mg N/L), and 92.73 and 366.42 mgN/L in the wet season. Nitrates (NO3-N) ranged from 50.33 to 334.42 mgN/L in the wet season (compared to a standard of 18 mg N/L). Cd, Mn and Pb levels were above the Kenya guideline standards of 0.01, 0.2 and 0.01 mg/L respectively, for discharge into the environment and surface water. Cd ranged from 0.025 to 0.033 mg/L, Mn concentrations were from 0.085 to 0.748 and Pb concentrations were between 0.083 and 0.332 mg/L. The treated effluent failed to meet the required standards for discharge into surface water bodies. It is recommended that measures should be put in place to improve the final effluent quality. Separation of industrial waste from domestic waste and regular maintenance of the plant are necessary.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Sewage is the wastewater that is contaminated with feaces or urine and includes domestic, municipal, or industrial liquid waste products. Sewage comprises 99.94 % water, with only 0.06 % being dissolved and suspended solids (Karen, 1996). Sewage may drain directly into major watersheds with minimal or no treatment. Treatment is necessary since untreated sewage can have serious impacts on the quality of an environment and on the health of people. Most water borne diseases are as a result of feacal contamination of drinking water supplies and remain a major hazard in many parts of the world (Brook, 1999; Mara and Feachem, 1999). Pathogens which may result from inadequately treated sewage, hide in pollutants (BOD, TSS, COD) and produce waterborne diseases in either human or animal hosts (EPA, 2009). It is therefore necessary that raw municipal wastewater be treated before it can be discharged into natural system or used for agricultural, landscape irrigation or for aquaculture purposes. The most appropriate wastewater treatment to be applied before effluent is discharged or used in agriculture is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines (WHO, 1989, 1993 and 1996; Muller and Lane 2002).

In Kenya (Figure 1a), most major towns have conventional wastewater treatment plants, but most of them have broken down. Dandora Domestic and industrial waste treatment plant in Nairobi (Figure 2) was constructed in 1978 with only two series (phase one), the treatment performed is by waste stabilization. Due to population increase, the plant was expanded in 1990 to a total of eight series, with one phase of anaerobic ponds for experimental purposes along series 3. In 2005, phase 2 anaerobic treatment ponds were constructed along series 5 (Figure 3). However, since the new anaerobic ponds were introduced, no research has been done to evaluate the efficiency of the plant. It is on this basis that the study evaluated the efficiency of the treatment plant.

1.2 Statement of the problem

A study done by Budambula and Mwachiro (2006) revealed bioaccumulation of heavy metals in fish in the seven Falls of Nairobi River, which is the final recipient of the final product of Dandora plant. Although the concentrations were still below the WHO standards, the occurrence of such toxins could be linked to pollution of water from sewage and industrial treatment plant. Hence there is need to establish existing and potential sources of pollution. It is on this basis that this study was conceived. The study aimed at establishing whether the sewage and industrial treatment meets the design expectation and the treated wastewater is safe for human consumption, wildlife and river ecosystem.

1.3 The Purpose of Parameters Analysed

Physico-chemical parameters alone are not sufficient in obtaining reliable information on state of treated wastewater. Inorder to study impacts on receiving water body, routine analysis of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Nutrients tests must be performed in combination with other pollutants like heavy metal (Movahedian et al., 2005). These parameters play a big role in health and diseases. The specific contaminants leading to pollution in water include a wide spectrum of chemicals, pathogens, and physical such as elevated temperature, change in pH, electrical conductivity and eutrophication. High phosphorus, nitrogen and nitrates lead to eutrophication, which causes anoxia, affecting fish and other animal populations. Methemoglobineamia is also caused by ingesting high concentrations of nitrites and nitrates. Many of the heavy metals and industrial chemical substances are toxic to plants and animals. For instance, high levels of lead, manganese and cadmium can respectively cause kidney, nerve and respiratory problems (EPA, 2009).

1.4 Design Expectation

The design expectations of the treatment plant included; in the anaerobic ponds BOD_5 removals are designed to be 68 %. The treatment plant is designed to receive influent of 512 mgO_2/L BOD_5, and to reduce BOD concentration in the effuent to 20 mgO_2/L. As for TSS, the plant is designed for influent and effluent TSS concentrations of 655

and 30 mg/L respectively. The treatment ponds are expected to reduce COD below 280 mgO_2/L (Alexander *et al.*, 1988).

1.5 Hypotheses

1.5.1 Null hypothesis

i. The treatment process has no significant impact on levels of Biological Oxygen Demand (BOD), Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD)

iv. The nutrient levels do not meet the required standards.

v. The levels of selected heavy metals are not significant to the receiving environment.

1.5.2 Alternative Hypothesis

i. The treatment process has an impact on levels of BOD_5

ii. The nutrient levels meet the required standards before discharge into the river

iii. The heavy metals discharged are significant to Nairobi River

1.6 Significance of the study

The data generated from the study will provide useful information on the state of wastewater treatment works and whether the various stages meet treatment discharge

standards. The information generated from the study will also provide critical and timely information on the management of wastewater treatment works in Kenya.

1.7 Objectives

The main objective of the study was to evaluate the perfomance of Dandora Domestic and Industrial Waste Treatment Plant. Specifically, the study focused on the following objectives:

i. To establish removal efficiency of BOD_5, COD and TSS in the treatment ponds

ii. To determine the physico-chemical properties of wastewater at different stages of the treatment process.

iii. To evaluate the heavy metals and nutrient (nitrogen, phosphorus) removals or conversion at different stages of treatment process.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Highly efficient wastewater treatment plant is an important water resource. Discharge of highly treated effluent provide an important water supply to augment stream flows and support beneficial uses such as fish and shellfish rearing; water supply; recreational use; wildlife habitat; and commerce and navigation. The most serious environmental threats are due to inadequate or absence of facilities for the disposal of solid and domestic sewage, which has lead to pollution of water. Untreated wastewater has a higher possibility of transferring heavy metals to humans through food chains. However, in order to achieve high standards of effluent quality and higher efficiencies, it is very important to carry out routine operation and maintenance of the system. Hence it is necessary to revisit factors that affect the performance of the system to have improved treatment standards and mitigate any possible dangers that may result due to these factors (Kigobe and Nalubega, 2001).

A study done on performance assessment of a wastewater treatment plant producing effluent for irrigation in Egypt indicated that the concentration of the raw wastewater was considered moderate and the mean values of the Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5) and Total Suspended Solids (TSS) were

around 250, 102 and 142 mg /L, respectively (Fatma *et al.,* 1998). Fatma *et al* (1998) attributed this to the high quantities of wastewater from industrial sources. The overall efficiency of the treatment facility was good, and the mean residual of COD, BOD_5 and TSS were 25, 8 and 21 mg/L respectively, with percentage removals of 90, 92 and 85%, respectively. Analysis of the Ni, Cu, Pb and Cr in the dried sludge indicated that their concentrations were within the permissible limits of Egypt. Zinc exceeded the standards by 50%.

A study done in Iran on toxicity evaluation of wastewater treatment plant effluents using water flea Daphna magna showed that the efficiency levels of preliminary, primary, and secondary units for removal of toxicity were 6%, 38.9% and 8%. In overall, the investigation indicated that toxicity removal by up to 50% might be achieved in Isfahan Wastewater Treatment Plant (Movahedian *et al.,* 2005). The results of the study showed that physico-chemical parameters alone were not sufficient in obtaining reliable information on treated wastewater toxicity and that toxicity tests must be performed in combination with routine analyses such as BOD_5 and SS in order to guarantee the safety of aquatic organisms (Movahedian *et al.,* 2005).

A survey conducted on the types and efficiencies of various treatment technologies used at major Wastewater Treatment Plants (WWTPs) in the state of Georgia, found that Effluent requirements for BOD_5, TSS, NH_3-N, and effluent T-P varied with facility (Mines *et al*., 2006). Average effluent parameter concentrations versus month

indicated the effectiveness of wastewater treatment as a function of type of treatment technology and temperature. Out of 24 facilities evaluated, fourteen met all the permitted requirements, whereas ten facilities reported violations with regard to flow and/or effluent parameters (Mines *et al*., 2006).

Studies carried out by Almudena *et al.*, (2004) in Leiden, Netherlands at Leiden University on environmental performance of a Municipal Wastewater Treatment Plant indicated that eutrophication and ecotoxicity arose due to high pollutant load at the watercourse discharge.

According to Council of the European Communities (CEC) (1991), effluent limits characterize the required and accepted quality of the discharged wastewater. CEC quality requirements for Waste Stabilization Pond (WSP) effluents being discharged into surface and coastal waters include; BOD of 25 mg/L, COD of 125 mg/L, Suspended solids of 150 mg/L, and for discharge into designated sensitive areas subject to eutrophication; Total nitrogen of 15 mgN/L, and Total phosphorus of 2 mgP/L.

Research in China, Japan and Taiwan indicated that rice accumulated high concentrations of cadmium and other heavy metals when grown in soils contaminated with irrigation water containing substantial industrial discharges (Fernandez, 1991). A more dangerous consequence of raw municipal effluent is transmission of heavy metals

into human beings through animal milk as fodder grown by polluted water accumulates higher quantities of heavy metals (Fernandez, 1991).

Studies carried out by Dixit and Tiwari (2007) on Impact Assessment of Heavy Metal Pollution of Shahpura Lake, in Bhopal, India, indicated that the lake is subjected to enormous anthropogenic stress because of heavy inputs of domestic waste and sewage. This resulted in eutrophication because of nutrients from untreated sewage. In India, the general standards for the discharge of treated wastewaters into inland surface waters are given in the Central Pollution Control Board (CPCB) found in Environmental Protection Agency (EPA) rules. The more important of these for Waste Stabilization Ponds (WSP) rules are as follow: BOD 30 mgO2/L (non-filtered), Total Suspended solids 100 mg/L, Total Nitrogen as100 mgN/L, Total ammonia 50 mg N/L, Free ammonia 5 mg N/L, pH 5.5 – 9.0 amongst others (CPCB, 1996).

A Study done on selected pathogens in Municipal Wastewater Treatment Plant effluents in Jordan classified these effluents as moderate in strength in terms of BOD_5, COD, Total Feacal Coliforms Count (TFCC) and TSS. It was also concluded that the effluents of the treatment plants could be reused for irrigation purposes ranging from unrestricted irrigation to irrigation for animal feed (Kayyali and Jamrah, 1999).

In physicochemical determination of pollutants in wastewater and vegetable samples along the Jakara Wastewater Channel in Kano Metropolis, Nigeria, Akan *et al* (2003)

established that Levels of pH, conductivity, temperature, nitrate, nitrite, sulphate, phosphate, TSS, TDS, DO, BOD and COD were higher than the maximum permissible limits set by Federal Environmental Protection Agencies (FEPA) Nigeria. The concentrations of the metals in the wastewater samples were higher than limits set by WHO and the maximum contaminant levels (MCL). The concentration of nitrite, sulphate and phosphate were determined using spectrophotometric method (Akan *et al.,* 2003).

A study carried out on performance of the anaerobic ponds of Phase II Dandora waste stabilization ponds in Kenya (Pearson *et al.,* 1996) showed that effluent quality was good and met WHO guidelines for unrestricted irrigation. The system was performing to predictable efficiencies for the existing organic load and retention times (> 90% BOD_5 removal). A pilot anaerobic pond study showed BOD_5 removal in excess of 80% in the single celled anaerobic against a design prediction of 53% removal (Pearson *et al.,* 1996).

According to Omoto (2006), the efficiency of Dandora treatment plant fell below design levels of treatment. Nutrients (Nitrates, nitrites) being discharged into Nairobi River were still above the Kenyan standards.

A study carried by Gatundu (1991) on a number of wastewater treatment plants in Thika and Nairobi revealed that the effluents from all the treatment plants had BOD

levels above the WHO standard (20mg/L).

In Kenya, the Fourth Schedule Monitoring Guide for Discharge into the Environment of Environmental Management and Co-ordination (water quality) Regulations, 2006 indicates that every local authority or person(s) operating a sewage system should not discharge any pollutant into the environment, and that they should comply with the standards set out for discharge into the environment. These standards include a BOD concentration of 30 mgO_2/L, TSS of 30 mg/L, Pb and Cd of 0.01 mg/L, temperatures of 20 – 35 ^oC, T-P and T-N of 2mg/L amongst others (Water Quality Regulations, Kenya, 2006).

2.2 The purpose of domestic sewage treatment

The principal objective of wastewater treatment is to allow human and industrial effluents to be disposed without danger to human health or unacceptable damage to the natural environment. This is done by reducing its BOD, the number of pathogenic organisms and the toxic metals (Massoud and Ahmad, 2005).

2.3 Theory of System

Treatment of waste water is achieved by means of biological process in the series of ponds which include: i) Anaerobic ii), Facultative and iii) Maturation in which anaerobic, aerobic and facultative bacteria and production of algae with the help of sunlight (photosynthesis) neutralize or stabilize the wastewater (i.e. reduction of

BOD_5) to a considerable degree. The whole process is based on symbiotic relationship and requires low energy, power, and maintenance cost (Mara, 2001; Mara *et al.*, 1992; Kigobe and Nalubega, 2001).

2.4 Process Description

Sewage wastewater is directed to the screen chamber (main pump house) from an intercepted channel with the help of penstock gates. The sewage is pumped to the splitting chamber and distributed over two anaerobic ponds and facultative ponds, and the removal of BOD_5 is achieved (about 60 per cent). The wastewater is then sent to Maturation Ponds (Figure 3), where the final treatment is achieved (Boutin *et al.*, 1987; Bucksteeg, 1987; Council of the European Communities, 1991).

2.5 Preliminary treatment

When sewage enters the treatment works, it first passes through preliminary treatment whose objective is removal of coarse solids, grit and other large materials often found in raw wastewater. In grit chambers, the velocity of the water through the chamber is maintained sufficiently high, or air is used, so as to prevent the settling of most organic solids. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment units (Boutin, *et al.*, 1987; Bucksteeg, 1987; Council of the European Communities, 1991).

2.6 Pollution Indicators in Wastewater

2.6.1 pH

pH represents the effective concentration (activity) of hydrogen ions (H^+) in water. The pH of domestic wastewater typically ranges from 6.5 to 7.5. Significant departures from these values may indicate industrial or other non- domestic discharges. Changes in pH can affect aquatic life indirectly by altering other aspects of water chemistry such as acidity or alkalinity. Low pH levels accelerate the release of metals from rocks or its sediments in the stream. These metals can affect aquatic life like fish's metabolism and ability to take water through the gill (IDEQ, 2006; USEPA, 1991). Electrode methods have been widely used in determination of pH (APHA, 2005).

2.6.2 Temperature

Temperature is basically important for its effect on other properties of wastewater. Respiration of organisms is temperature-related; respiration rates can increase by 10% or more per 1^oC temperature rise. Therefore, increased temperature does not only reduce oxygen availability, but also increases oxygen demand, which can add to physiological stress of organisms (Giller and Malmqvist, 1998).

2.6.3 Conductivity (EC)

EC of water is a useful and an easy indicator of its salinity or total salt content. Wastewater effluents often contain high amounts of dissolved salts from domestic sewage. High salt concentrations in waste effluents can increase the salinity of the

receiving water, which may result in adverse ecological effects on the aquatic biota (Ademoroti, 1996).

2.6.4 Dissolved oxygen (DO)

The analysis for dissolved oxygen is a key test in water pollution and waste treatment processes. While dissolved oxygen concentrations are necessary to carry out the BOD determination, DO levels are also important in determining how satisfactory a biological wastewater treatment plant is operating. For example, for satisfactory biological wastewater decomposition some dissolved oxygen must be present. Although some microorganisms can survive in anaerobic conditions, many of the beneficial microorganisms that stabilize wastewater require aerobic conditions. If oxygen is not enough, the system will be inefficient (Marais, 1970).

2.6.5 Biological Oxygen Demand (BOD)

BOD is taken as a measure of the concentration of organic matter present in any water. The greater the decomposable matter present, the greater the oxygen demand and the greater the BOD_5 values (Ademoroti, 1996). Liu and Yang (2009) noted that it was significant to further research and develop the simple, rapid method for the determination of BOD_5. The developed methods included dilution and respirometric Technique. Determination of BOD_5 in water was obtained by dilution and incubation method because respirometric is a proposed method which has not been fully

developed and validated (IDEQ, 2006; Lenore et al., 1998; USEPA, 1991; Liu and Yang, 2009; APHA, 2005).

2.6.6 Chemical Oxygen Demand (COD)

COD is often used as a measure of pollutants in wastewater and natural waters as it evaluates the effects of organic and inorganic waste materials on dissolved oxygen in receiving waters (APHA, 2005). For many years, the strong oxidizing agent potassium permanganate ($KMnO_4$) was used for measuring chemical oxygen demand but Potassium permanganate's effectiveness at oxidizing organic compounds varied widely, and in many cases biochemical oxygen demand (BOD) measurements were often much greater than results from COD measurements. Since then, other oxidizing agents such as ceric sulfate, potassium iodate, and potassium dichromate ($K_2Cr_2O_7$) have been used to determine COD. Of these, potassium dichromate has been shown to be the most effective. It is relatively cheap, easy to purify, and is able to completely oxidize almost all organic compounds (Clair *et al.,* 2003; Lenore *et al.,* 1998; APHA 2005).

2.7 Nutrient Removal

2.7.1 Total phosphorus (T-P)

Human excreta and detergents are the largest contributors to phosphorus in domestic wastewater. Phosphorus (P) occurs in natural waters and in wastewaters almost solely

as phosphates. It is essential to the growth of organisms and can be the nutrient that limits the primary use of a body of water. In the case where phosphate is a growth-limiting nutrient, the discharge of raw or treated wastewater or industrial waste as well as non-point source runoff to a body of water may result in the stimulation of growth of photosynthetic aquatic macro and micro-organisms in nuisance quantities. Orthophosphate sometimes referred to as "reactive phosphorus," is the most stable kind of phosphate, and is the form used by plants. (Liu *et al.*, 2007). In phosphorus determination, different analytical methods had been applied which includes; Acid persulfate, vanadomolybdophosphoric acid, stannous chloride, photodecomposition and many others. vanadomolybdophosphoric acid method was chosen because it is simple, cost-effective, less time consuming and both low and high concentration of phosphorus can be determined (APHA, 2005).

2.7.2 Ammonia-nitrogen (NH_3-N)

When plants and animals die, proteins (which contain organic nitrogen) are broken down by bacteria to form ammonia (NH_3) through ammonification. Nitrification occurs where ammonia is broken down by *Nitrosomonas* (eq 2.1 and 2.2) bacteria to form nitrite (NO_2), which is then converted by bacteria *Nitrobacter* (eq 2.3) to form nitrate (NO_3). Nitrates are reduced to gaseous nitrogen by the process of "denitrification," performed by organisms such as fungi and *Pseudomonas* bacteria (eq 2.4). These organisms break down nitrates to obtain oxygen. Un-ionized ammonia (NH_3) found in

certain types of wastewater effluent is toxic to many aquatic organisms (Soares *et al.,* 1996). Ammonia determination by electrode method and Kjeldahl have been used. However, the Kjeldahl method has been widely used in determination of ammonia-nitrogen as it eliminates many interferences in sewage wastewater (Jones, 1991; Kjeldahl, 1883; USEPA, 1991; APHA, 2005).

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O \ (nitrosomonas\ bacteria) \quad \textbf{(2.1)}$$

$$NH_3 + O_2 \rightarrow NO_3^- \ (nitrosomonas\ bacteria) \quad \textbf{(2.2)}$$

$$NO_2 + O_2 \rightarrow 2NO_3^- \ (nitrobacter\ bacteria) \quad \textbf{(2.3)}$$

$$NO_3^{2-} \rightarrow NO_2^- \rightarrow N_2 + O_2 \ (pseudomonas\ bacteria) \quad \textbf{(2.4)}$$

2.7.3 Organic-nitrogen (O-N)

Organic nitrogen is found in the cells of all living things and is a component of proteins, peptides, and amino acids (Raymond and Cem, 1982). The Kjeldahl method has been widely used in determination of organic- nitrogen as it facilitates the removal of bound organic nitrogen in water and preoteins (Jones, 1991; Kjeldahl, 1883; USEPA, 1991; APHA, 2005).

2.7.4 Nitrites-nitrogen (NO_2-N)

Nitrite (NO_2) is relatively short-lived in water because it is quickly converted to nitrate by bacteria. Excessive concentrations of nitrate and/or nitrite can be harmful to humans and wildlife (Rodda and Urbatini, 2004). Wild life especially fish succumb to nitrate poisoning - particularly if levels remain high. The resulting stress will leaves them more susceptible to disease and inhibits their ability to reproduce (Unanimous, 2010). Methods used for nitrite analysis include; UV-visible spectrophotometer, phototube and colorimetric methods. UV-Visible method was selected because of accuracy, ease of use and high precision (APHA, 2005).

2.7.5 Nitrates-nitrogen (NO_3-N)

Nitrates are the oxidized forms of nitrogenous compounds in inorganic form. Nitrate is a nutrient, and is found in sewage discharge, fertilizer runoff, and leakage from septic systems. Nitrate (NO_3) is highly soluble (dissolves easily) in water and is stable over a wide range of environmental conditions. It is easily transported in streams and groundwater (Liu *et al.*, 2007). Available methods for determination of nitrate include; cadmium reduction, uv spectrophotometer and ion electrode analysis. Ion electrode was chosen because of simplicity, less time consuming and both low and high nitrate concentrations range (0.14 -1400 mgNO3-N/L) are detected (APHA, 2005).

2.7.6 Total Nitrogen (T-N)

Nitrogen (N) is a major component of municipal wastewater, storm water runoff from urban and agricultural lands, and wastewater from various types of industrial processes. Environmental and health problems associated with excessive amounts of N include, high concentrations of nitrate in drinking water supplies which can cause methemoglobinemia, in infants. Nitrogen is found in many forms in the environment.

In sewage treatment plants, nitrogen is found in four forms namely; organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Inorganic forms include nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and nitrogen gas (N_2). The Kjeldahl method is a means of determining the nitrogen content of organic and inorganic substances. The method has been refined and tested for a wide variety of substances and approved by various scientific associations including: AOAC International (formerly the Association of Official Analytical Chemists), Association of American Cereal Chemists, American Oil Chemists Society, Environmental Protection Agency,International Standards Organization and United States Department of Agriculture. Both macro-Kjeldahl and sermi micro-Kjeldahl methods are available for nitrogen determination. Sermi micro-Kjeldahl method was chosen because it determines both low level and high level nitrogen (Jones, 1991; Kjeldahl, 1883; USEPA, 1991; APHA, 2005).

2.8 Removal of Solids

2.8.1 Total Suspended Solids

TSS includes all particles suspended in water which will not pass through a filter. Suspended solids absorb heat from sunlight, increasing water temperature and subsequently decreasing levels of dissolved oxygen (warmer water holds less oxygen than cooler water). Some cold water species, such as trout, are especially sensitive to changes in dissolved oxygen. Photosynthesis also decreases, since less light penetrates the water. As less oxygen is produced by plants and algae, there is a further drop in dissolved oxygen levels. The TSS is removed in the ponds when the solids settle with sludge (Mumba *et al.*, 1999; Olivia *et al.*, 1980). The method which has been widely used for determination of TSS is vacuum filtration and oven drying between 103 ^{o}C to 105^{o}C (APHA, 2005).

2.8.2 Total Dissolved Solids (TDS)

TDS measurements are often used to express the degree of contamination or amount of impurities in water and wastewater. A wide variety of inorganic ions and organic compounds, many of which may not be considered contaminants, contribute to the sum total of dissolved solids. A number of these are biologically utilized or chemically reactive in wastewater. TDS often includes relatively high concentrations of dissolved compounds, which are not removed in wastewater and can add a laxative effect to water or cause the water to have an unpleasant mineral taste. It is also possible for

dissolved ions to affect the pH of a body of water, which in turn may influence the health of aquatic species. Inorganic salts comprise the great majority of TDS. TDS are removed as other pollutants are reduced in the treatment plant (Sequitur, 2003).

2.9 Heavy Metals Pollution

Heavy metal pollutants are introduced into sewage treatment plants significantly as a result of various industrial operations. Some of the pollutants of concern include lead, chromium, zinc, cadmium, copper and manganese. Most heavy metals are carcinogenic and cause ill health. These toxic materials may be derived from refining ores, the processing of radioactive materials, etc. A number of metals are required in small amounts for plant or animal growth. Some of these micronutrients are toxic at higher concentrations, and may be found in certain types of wastewater. Metals, such as cadmium, mercury and lead, are toxic even at relatively low concentrations. Some heavy metals have biomagnification 's effect (Trivedi, 1989). According to Nouri and Naghipour (2002), and Shinya and Tsuruho, (2003) heavy metals do not break down in the treatment plants. The reductions achieved are believed to be due to sedimentation. Some of the methods used for metal determination include; Inductile Coupled Plasma-Mass Spectrophotometer (ICP-MS), X-ray Flourescence (XRF), Anodic Stripping Voltammetry (ASV) and Atomic Absorption Spectrophotometer (AAS). AAS was chosen because of availability and ease of operation.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study Area

The Dandora Treatment Plant is located within Nairobi in Kenya (Figure 1a and Figure 1b). It is situated 30 km to the East of the city centre of Nairobi (Figure 2). The effluent from the plant is discharged into Nairobi River (Figure 3). A flow chat showing the ponds layout in Dandora D and IWTP is given in Figure 3. 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*)*

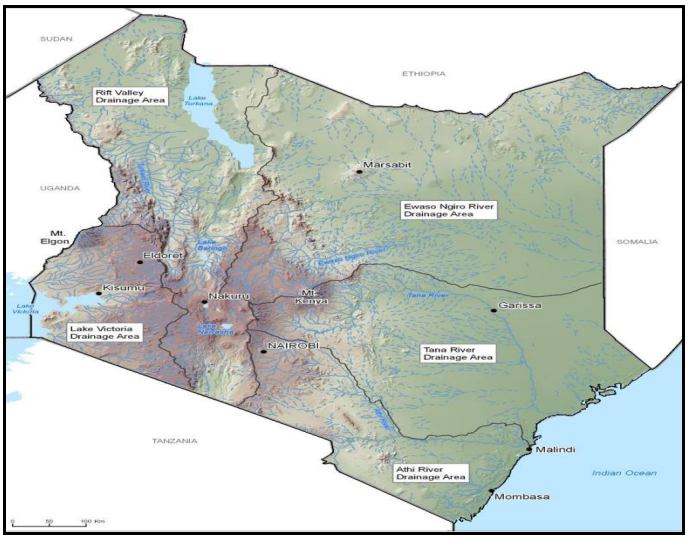

Figure 1a: The Map of Kenya

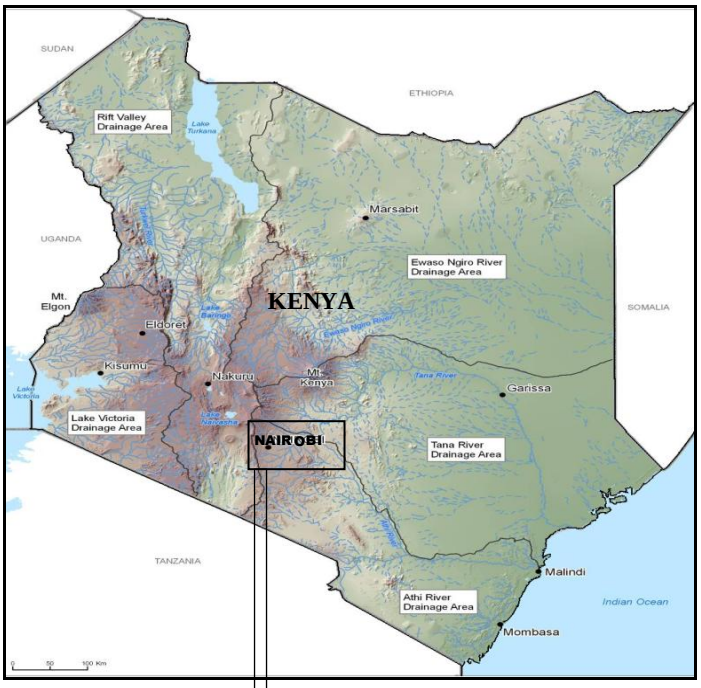

Figure 1b: Map of Kenya showing Nairobi

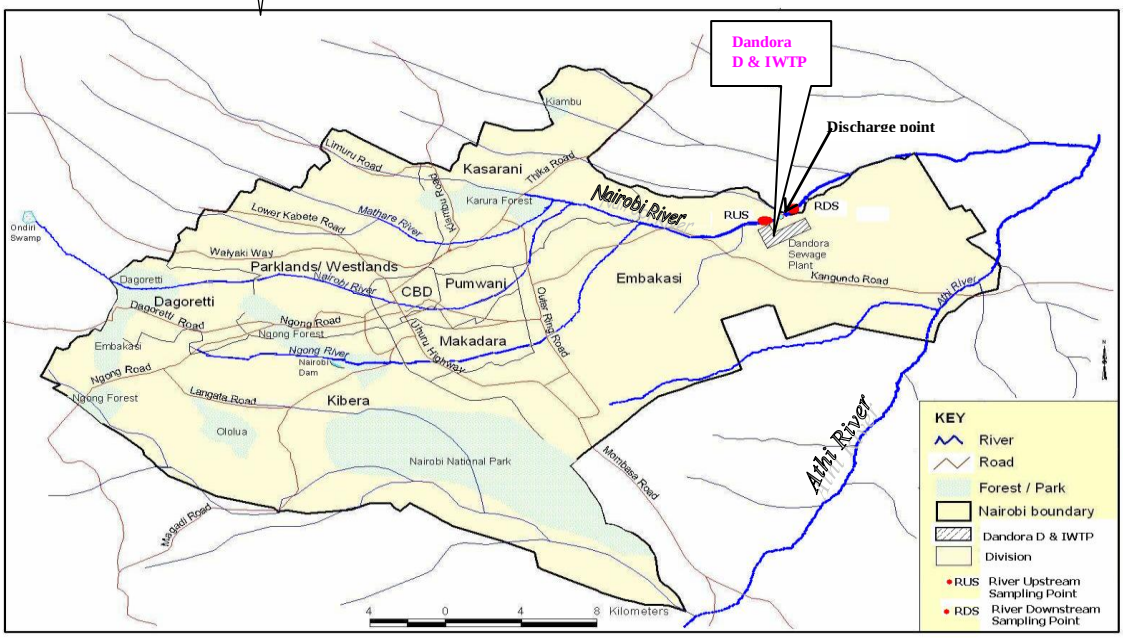

Figure 2: Map of Nairobi showing the location of Dandora D and IWTP

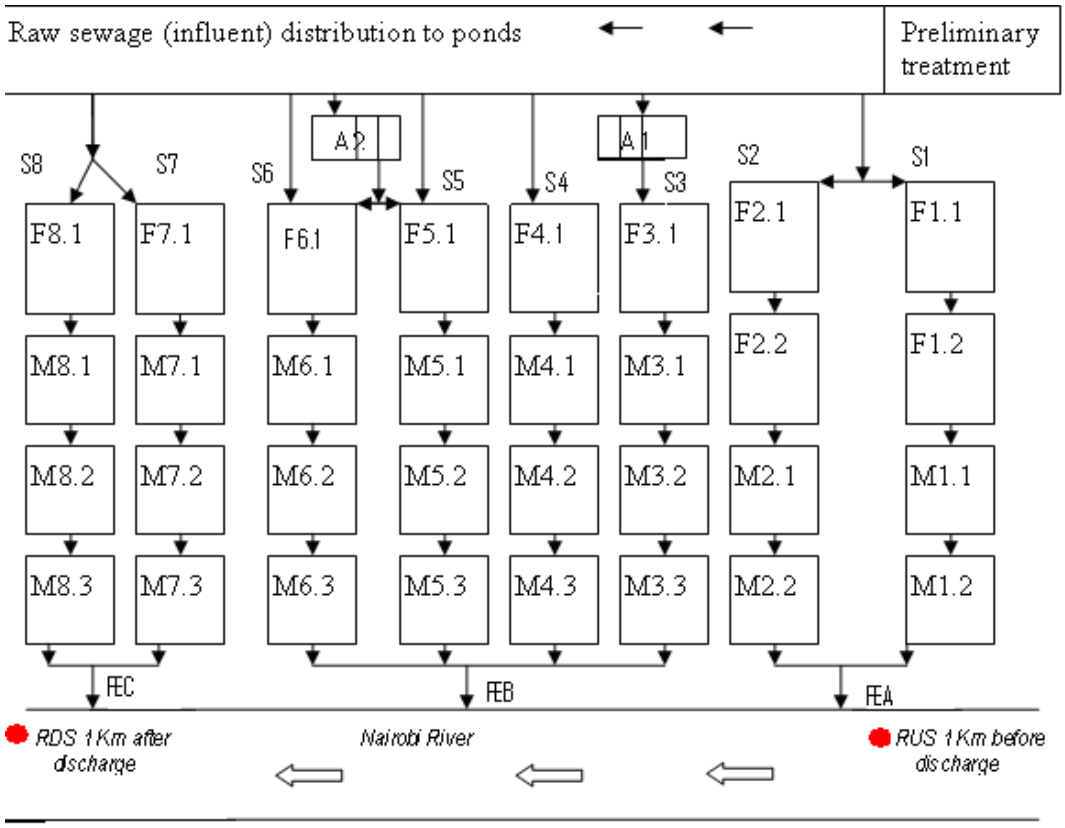

Figure 3: Ponds Layout at Dandora D and IWTP

KEY:

⇦ Direction of flow of Nairobi River

A1 Anaerobic ponds along series 3; A2 Anaerobic ponds along series 5

F Facultative ponds; M Maturation ponds

S 1 – S 8 -Series (1 - 8) FEA- Final effluent (S1+S2);

FEB - Final effluent (S3+S4+S5 +S6); FEC – Final effluent (S7 +S8);

RUS- Sampling point River upstream;

RDS –sampling point River downstream.

3.2 Sampling Design

This study was conducted at Dandora Domestic and Industrial Waste Treatment Plant. Potentially the plant has the capacity to cater for 340 000m^3/day**.** This plant is the largest in East and Central Africa (Pearson *et al*, 1996) (Figure 2 and Figure 3).

All field meters and equipment were checked and calibrated according to the manufacturer's specifications. The pH meter was calibrated using buffers of pH 4.0, 7.0 and 10.0. Dissolved oxygen (DO) meter was calibrated prior to measurement with the appropriate traceable calibration solution (5%HCl) in accordance with the manufacturer's instruction. The conductivity meter was calibrated using 0.01mmol KCl solution.

The sampling plastic bottles were previously cleaned by washing in non-ionic detergent, rinsed with tap water and then soaked in 10% HNO_3 for 24 hours and finally rinsed with deionised water prior to usage. The sampling bottles for phosphate analysis were soaked in hot dilute HCl and rinsed three times with tap water, and finally with distilled water. During sampling, sample bottles were rinsed with wastewater three times and then filled from each of the designated sampling points.

Grab (simple random) samples were collected from the inlet and discharge points of the 4 series in the treatment ponds of the anaerobic, facultative and maturation.

Samples from the influent (raw), the combined series, the river upstream before discharge and downstream after discharge from the plant were also collected. The collected data was sufficient to make conclusion on efficiency of the treatment plant. The samples of treated wastewater were collected during dry and wet seasons of the year 2009. Pilot sampling gave the average values of the quality of the effluent between 9.0am and 4.0pm hence the samples were collected within this time. Physico-chemical parameters i.e. conductivity, pH, temperature and dissolved oxygen were analyzed on site. Triplicate samples of one litre were collected, labeled, and transported to the laboratory, where they were preserved (APHA, 2005).

The four treatment series and the river totals to twenty-four sampling points with a total of 432 samples for both seasons. The total number of series is eight, series 1 and 2 are similar hence only series 1 was selected; series 3 and 4 were selected because only one of them has its waste passing through anaerobic ponds. Series 5 and 6 are similar hence series 5 was selected. Series 7 and 8 were left out since series 8 is not operational, and series 7 is similar to series 4. The sampling points were any of the outlets of each pond, the influent after screening, and in case of the river, upstream and downstream before and after discharge from the plant were sampled.

BOD samples were collected on clean plastic bottles and stored in cool box. Analysis for BOD_5 and Nutrients were immediately done in the laboratory. Samples for heavy metals determination were treated with 1% nitric acid and kept in the refrigerator for

analysis, COD samples were preserved with concentrated sulfuric acid and refrigerated at 4^{o}C (APHA, 2005).

3.3 Field Studies

pH, Electrical conductivity, temperature and dissolved oxygen were determined by a multitester, Sensor module WMS-24-01 (DKK – TOA CORPORATION, Japan).

3.4 Laboratory Studies

3.4.0 Analysis of Biochemical Oxygen Demand

BOD_5 was determined as the difference between the oxygen concentration of an appropriately diluted sample before and after incubation for 5 days at 20 ± 1^{o}C. BOD_5 was obtained by equation 3.1 (APHA, 2005);

$$BOD_5\ (mgO_2/L) = \frac{D_1 - D_2}{P} \quad \textbf{(3.1)}$$

Where D_1 = DO of diluted sample immediately after preparation

D_2 = DO of diluted sample after 5 days incubation at 20± 1^{o}C, mg/L preparations

P = Decimal volumetric fraction of sample

3.4.1 Analysis of Chemical Oxygen Demand (COD)

Closed reflux, titrimetric method outlined was used. The sample was refluxed with potassium dichromate and sulfuric acid in presence of silver sulfate, which neutralized the effects of chloride and also acts as a catalyst. The quantity of Potassium dichromate used was directly proportional to the oxidizable organic matter in the waste water sample. COD was obtained by equation 3.2 and 3.3 (APHA, 2005);

$$Molarity of\ FAS\left(ferrous ammonium sulphate\right) = \frac{volume of\ 0.01667 K_2CrO_7\ solution\ titrated mL\ x\ 0.1000}{volume of\ FAS\ used\ in\ titration mL} \quad \textbf{(3.2)}$$

$$COD(mgO_2 / L) = \frac{(A-B)\,x\,M\,x\,8000}{mL\ sample} \quad \textbf{(3.3)}$$

Where A = mL FAS used for blank, B = mL FAS used for sample, M = Molarity of FAS, 8000 = milliequivalent weight of oxygen x 1000 mL/L

3.4.2 Analysis of Total phosphorus

The sample was digested on low heat (on sand) on the hot plate for 30- 40 minutes, filtered using prewashed Whatman filter and topped to 100 mls with distilled water. The conversion of phosphorus to orthophosphate was done by vanadomolybdophosphoric acid digestion method. In the presence of Vanadium, yellow vanadomolybdophosphoric acid is formed. The intensity of yellow colour was

determined using Varian UV- Visible spectrophotometer (CARY 50) at a wavelength 430 nm with a path length of 1cm. Phosphorus was obtained by equation 3.4 (APHA, 2005);

$$Phosphorus(mgP/L) = \frac{mgP/L\,(in\,50\,mls\ final\,volume)\,x\,1000}{mL\,sample} \quad \textbf{(3.4)}$$

3.4.3 Analysis of Ammonia-nitrogen and Organic-nitrogen

Ammonia-free distilled water was used for all reagents, rinsing and sample dilution. The Sermi-Micro-Kjeldahl digestion apparatus equipped with heating elements was used to digest and distil the samples for ammonia-nitrogen and organic-nitrogen. The samples were rendered alkaline with sodium hydroxide, which also facilitated the removal of **ammonia-nitrogen**, and distilled into a solution of boric acid with bromo cresol green indicator. This was titrated against 0.02M hydrochloric acid to original greenish-yellow colour.

Alkaline potassium permanganate was added to the sample in the flask to produce **organic-nitrogen**. This was titrated against 0.02M hydrochloric acid to original greenish-yellow colour. The NH_3-N and O-N were obtained by equation 3.5 and 3.6

$$Ammonia-nitrogen(mgN/L) = \frac{(Titre-Blank)\,x\,0.02\,x\,14\,x\,1000}{Aliquot} \quad \textbf{(3.5)}$$

$$Organic\text{-}\,Nitrogen(mgN/L) = \frac{(Titre-Blank)\,x\,0.02\,x\,14\,x\,1000}{Aliquot} \quad \textbf{(3.6)}$$

Where Titre = volume of the titrant used

0.02 = Molarity of acid used

14 = atomic weight of nitrogen

Aliquot = a portion of a total amount of a solution (APHA, 2005).

3.4.4 Analysis of Nitrite-nitrogen

Nitrite (NO_2^-) was determined through formation of a reddish purple azo-dye produced at pH 2 to 2.5 by coupling diazotized sulfanilamide with N-(I-naphthyl)-ethylenediamine dihydrochloride (NED). The dye formed was analyzed in the Varian UV- Visible spectrophotometer (CARY 50) at wavelength 543nm, and a light path of 1cm (APHA, 2005).

3.4.5 Analysis of Nitrate- Nitrogen

The samples for nitrate (NO_3^-) were filtered through Whatman filter paper No 1, buffered with 4M ammonium sulfate (ISAB) and analyzed using Jenway ion meter 3345. The ion electrode responds to nitrate ion activity by developing a potential across inert membrane. Calibration standards were prepared and a curve drawn. Nitrate concentrations were read from calibration curves.

3.4.6 Analysis of Total Nitrogen

Total-Nitrogen in the pond was obtained by the sum of organic-nitrogen and inorganic

nitrogen **ie** sum of organic-nitrogen, ammonia-nitrogen, nitrite-nitrogen and nitrate-nitrogen.

3.4.7 Analysis of Total Suspended Solids

A well mixed sample was filtered through a weighted standard glass fiber filter. The residue retained on the filter was dried (103^0C to 105^0C) to a constant weight. The increase in weight of the filter represented the total suspended solids as in equation 3.7 (APHA, 2005).

$$TSS\,(mg/L) = \frac{Difference in\ weight\ x\ 10^6}{mL sample} \tag{3.7}$$

3.4.8 Analysis of Total Dissolved Solids

A well mixed sample was filtered through a standard glass fiber filter into a weighted crucible, and the filtrate was dried at 180^0C to a constant weight. The increase in weight of crucible represented the total dissolved solids as in equation 3.8 (APHA, 2005).

$$TDS\,(mg/L) = \frac{Difference in\ weight\ x\ 10^6}{mL sample} \tag{3.8}$$

3.4.9 Analysis of Heavy Metals

Samples for the analysis of metals (Cd, Zc, Mn, Lead, Cu and Cr) were digested with

nitric acid subsequently before aspirating into Variance SpectrAA-10 Atomic Absorption Spectrophotometer flame (APHA, 2005).

3.5 Quality Assurance of Data

All reagents used were of analytical grade. Ultra pure water of conductivity 1 µS/cm was used in this study for the blank and the preparation of standard solutions. All glassware and plastics used for the experiments were previously soaked in 10 % hydrochloric acid in case of phosphates and 10 % nitric acid (v/v), for the rest of the parameters. The glassware were rinsed with distilled water.

3.6 Data Analysis

The data collected were subjected to statistical analyses using Statistical Package for Social Scientists (SPSS) and Microsoft Excel package. Microsoft Excel package was used to determine the mean, standard deviation and error bars. Population mean, standard mean, degree of freedom and population was used to calculate statistical differences. SPSS was used to establish correlation between effluents and to establish whether any significant difference existed between selected parameters at different stages of treatment process.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The tables show results obtained for the influent, ponds and the river upstream and downstream. The highest and lowest levels are also presented. The reductions or conversions of individual parameters in each pond are displayed. Each of the 24 sampling points had 9 data values from which the standard deviations were calculated.

4.1 pH of the Ponds and the River

The pH of the ponds and the River are discussed in this section. pH values are presented in Table 1. pH influences waste stabilization pond reactions amongst other factors. The mean pH for influent wastewater during dry and wet seasons were 7.37 ± 0.30 and 8.06 ± 0.30 respectively. The Water Quality Regulations, Kenya (2006) accepts wastewater of pH 6.00 – 9.00 to be discharged in the domestic wastewater through sewer line. Generally, the wet season exhibited high pH values as compared to dry season. The high values may indicate industrial or other non- domestic discharges (IDEQ, 2006).

High pH values were obtained in series 1 during wet season, with secondary maturation pond (M1.2) recording the highest value (9.27±0.16). The high pH values are attributed to reactions of carbonate and bicarbonate ions which provide carbon dioxide for the algae, leaving an excess of hydroxyl ions (Marais, 1970). Although

Lagoon Technology International (1992) indicates that a properly functioning facultative and

Table 1: Means and Standard deviations of pH and temperature during dry and wet seasons.

Sampling points	Mean pH		Mean Temperature (^{o}C)	
	DRY	**WET**	**DRY**	**WET**
Influent	7.37±0.30	8.06± 0.30	24.10±0.00	23.45±0.06
F1.1	7.60±0.12	9.00±0.18	24.10±0.02	23.20±0.21
F1.2	7.66±0.05	9.09±0.11	24.30±0.00	23.40±0.10
M1.1	7.67±0.30	9.22±0.16	24.20±0.15	23.10±0.21
M1.2	**7.93±0.08**	**9.27±0.04**	**24.20±0.12**	**23.33±0.12**
A1	6.71±0.08	7.52±0.14	24.50±0.12	23.60±0.10
F3.1	7.90±0.04	8.05±0.65	24.30±0.12	23.17±0.15
M3.1	8.06±0.03	8.34±0.22	24.60±0.15	23.50±0.20
M3.2	7.99±0.03	8.47±0.20	24.50±0.15	23.40±0.26
M3.3	**8.04±0.06**	**8.48±0.19**	**23.00±0.20**	**24.20±0.10**
F4.1	7.62±0.11	8.45±0.36	23.50±0.20	24.70±0.53
M4.1	7.93±0.13	8.60±0.14	23.50±0.20	24.77±0.25
M4.2	7.62±0.04	8.48±0.15	23.50±0.06	24.67±0.29
M4.3	**7.49±0.06**	**8.43±0.11**	**23.10±0.10**	**24.16±2.89**
A2	6.91±0.03	8.57±0.15	24.80±0.06	27.27±0.11
F5.1	7.52±0.11	8.33±0.00	23.70±0.06	22.90±0.00
M5.1	7.64±0.05	8.67±0.10	24.10±0.10	23.07±0.21
M5.2	7.40±0.01	8.89±0.13	23.30±0.25	24.40±0.90
M5.3	**7.63± 0.06**	**8.61±0.09**	**23.80±0.10**	**24.33±0.29**
FEA	7.93±0.03	8.50±0.04	24.00±0.15	23.10±0.00
FEB	7.75± 0.05	8.43±0.00	23.50±0.15	23.10±0.00
FEC	7.62±0.14	8.43±0.10	23.70±0.17	23.10±0.00
RUS	7.61±0.05	9.43±0.00	24.60±0.31	23.50±0.00
RDS	7.91±0.09	7.91±0.09	24.60±0.15	23.60±0.00

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series.*

maturation ponds should have a pH between 7 and 10, IDEQ (2006) noted that

industrial effluent could be responsible for pH deviation from 6.5 to 7.5 in waste stabilization ponds.

It was noted that the anaerobic ponds A1 and A2 recorded the lowest pH during the dry season. This is attributed to optimum pH between 6 and 8 for methanogenesis (McGarry and Pescod, 1970). Lettinga *et al* (1993) reported that pH of 6.0 constitutes the lowest limit for anaerobic reaction. This is because products from the preceding acidogenesis reaction may accumulate and lead to a pH decrease (Gambrill *et al.,* 1986).

The mean pH (Table 1) in the river upstream during dry season was 7.61 as compared to 9.43 recorded in the wet season. The high pH of the river during wet season is attributed to the storm and agricultural runoff from point and non point sources of pollution during. Human activities such as accidental spills, sewer overflows and discharge of chemicals by communities and industries can possibly have significant effect on pH levels (Gambrill *et al.,* 1986). The pH of the river down stream increased during dry season probably due to discharge from the plant.

There was a significant difference in overall pH between the two seasons since the value of t calculated was found to be 9.173 while t tabulated is 2.07 at 95% confidence level. The difference could be attributed to the storm runoff explained above.

4.2 Temperature of ponds and the River

The temperatures obtained are presented in Table 1. Both seasons recorded temperatures above 20 ^{o}C with little or no increases down the ponds. These are ambient temperatures in hot-climate countries and are conducive to anaerobic reactions (Gambrill, *et al*., 1986). Gambrill *et al* (1986) noted that 60% of BOD_5 removals can be achieved in anaerobic ponds having temperatures above 20°C. This complies with BOD_5 results of A1 and A2 during the wet season (Table 3). The highest Temperature was recorded in anaerobic pond A2 during the wet season. This is attributed to the difference in sampling time. The temperatures of the effluents discharged were within water quality regulations, Kenya (2006), for discharge (20 – 35 ^{o}C) into surface water.

4.3 Conductivity

The conductivities are presented in Table 2. Generally, wet season recorded high conductivity values as compared to dry season. The highest conductivity was observed in influent of the wet season. This is attributed to storm runoff which can have a variety of salt content.

The influent conductivity of 1503.00 ± 123.80 and 1977.3± 5.51 µS/cm were obtained during dry and wet seasons respectively (Table 2). The recommended conductivity by Kenyan standard should be less than 2000 µS/cm (Water Quality Regulations Kenya,

2006). Thus the influent conductivity for both seasons met the recommended values. However, the influent conductivity was lower than 2520 µS/cm recorded at City of Davis treatment plant in California (having similar system as Dandora) during a study on selected plants (Asano and Tchobanoglous, 1987). The differences in the

Table 2: Means and Standard deviations of conductivity and DO during dry and wet seasons.

Sampling points	**Mean Conductivity (µS/cm)**		**Mean DO (mgO_2/L)**	
	DRY	**WET**	**DRY**	**WET**
Influent	1503.00±123.80	1977.30±5.51	1.80±0.10	2.76±1.45
F1.1	1130.00±37.70	1517.50±10.41	2.32±0.30	12.02±3.17
F1.2	970.00±20.00	1638.30±8.50	2.81±0.18	14.05±1.05
M1.1	1022.00±20.20	1413.00±6.08	3.14±0.34	9.28±1.16
M1.2	**928.00±29.61**	**1418.33±2.80**	**4.23±0.09**	**19.77±0.50**
A1	1273.00±00.91	1651.67±1.53	3.23±0.50	1.82±0.06
F3.1	1003.00±2.86	1630.00±5.00	3.59±0.18	3.38±0.32
M3.1	976.00±97.57	1521.00±6.57	3.26±1.40	8.69±0.22
M3.2	743.00±188.80	1550.33±5.03	3.90±1.56	6.31±0.21
M3.3	**900.0 0±70.00**	**1454.00±5.29**	**3.90±0.47**	**9.65±0.45**
F4.1	1122.00±56.89	1581.33±1.53	3.32±0.52	0.79±0.15
M4.1	1063.00±26.62	1610.00±5.00	3.32±0.20	6.82±0.89
M4.2	903.00±06.93	1551.67±2.89	2.73±0.31	4.00±1.96
M4.3	**1043.00±19.30**	**1631.67±2.89**	**2.66±0.11**	**3.16±0.96**
A2	1033.00±66.58	1601.67±2.89	2.90±0.08	0.72±0.53
F5.1	1108.00±55.96	1613.33±5.77	3.09±0.21	1.05±0.09
M5.1	1043.00±118.45	1592.67±54.42	3.04 ±0.50	2.30±1.11
M5.2	1145.00±138.11	1633.33±4.16	3.45±0.44	14.27±5.06
M5.3	**1030.00±43.59**	**1598.00±27.54**	**2.91± 0.83**	**2.76±1.45**
FEA	943.00±40.41	1460.00±10.00	3.67±0.35	9.60±0.10
FEB	949.00±35.80	1466.00±10.00	2.78±0.65	12.02±3.17
FEC	1003.00±135.77	1455.00±10.00	3.30±0.28	5.75±0.09
RUS	503.00±39.95	942.50±2.12	3.40±0.10	2.60±0.10
RDS	1134.00±72.29	1134.00±9.60	3.30±0.10	5.79±0.00

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series.*

conductivity observed at Dandora and California wastewater treatment plants could be due to different quantities of salt contents discharged into treatment plant by the two localities. There was a significant difference in overall conductivity between the two seasons since the value of t calculated was found to be 17.112 while t tabulated is 2.07 at 95% confidence level. There was a correlation coefficient of 0.6966 between the two seasons.

4.4 Dissolved Oxygen

The dissolved oxygen (DO) concentrations are presented in Table 2 and appendix 7. Generally, wet seasons recorded higher DO as compared to dry season. The highest DO was observed in maturation pond M1.2 (19.77 mgO_2/L), during wet season. It is suggested that photosynthetic activities of algae (Marais, 1970), and surface turbulence during the wet season contributed to high DO content in the ponds. Addition of DO by the rain cannot be ruled out. The high DO was due to reduction in BOD_5 levels (greater than 94 %) in the corresponding ponds. This is because bacteria use oxygen in breaking down organic matter.

The lowest DO was recorded in anaerobic pond A2 during the wet season. This complied with design expectation of less than 1 mgO_2/L (Alexander *et al.,* 1988). Pescod (1996) also noted that anaerobic ponds are able to maintain a DO concentration of 0.09 ± 0.12 mgO_2/L. However, the low DO was not maintained in A1 during both

seasons and A2 in the dry season. This could be due to DO concentration recorded in these ponds, which may have entered with influent flow hence increased the DO content (Rinzima, 1988). The recommended DO guideline value for support of aquatic life is 5 mgO_2/L (Mitsumasa and Spencer, 2000; WHO, 1993).

There was a significant difference in overall DO between the two seasons since the value of t calculated was found to be 3.442 while t tabulated is 2.07 at 95% confidence level. This difference is attributable to algal activity, surface re-aeration, surface turbulence and re-suspension of the settled sludge during the wet season.

4.5 Biochemical Oxygen Demand

Seasonal concentrations and percent (%) BOD_5 removals are presented in Table 3 and Appendix 8. The mean concentrations of BOD_5 for the influent wastewater during dry and wet season were 927.70 ± 65.60 and 935.56 ± 13.33 mgO_2/L respectively. The influent BOD_5 are higher than the design recommendation of 512 mgO_2/L (Alexander *et al.,* 1988). This variation between applied and designed values could be due to high organic loading, and are likely to cause unexpected fluctuation in plant's efficiency. The influent BOD_5 received was much higher than 102 mgO_2/L recorded at a treatment plant in Egypt (having similar system as Dandora) during a study on the performance assessment of a wastewater evaluation plant producing effluent for irrigation in Egypt (Fatma *et al.,* 1998). The high organic content in Kenya could have been due to high

population in Nairobi.

During the dry season the anaerobic ponds, A1 and A2 achieved BOD_5 removal of 56.90 % and 44.20 % respectively. These reductions were lower than 84.75 % and 88.22 % obtained in the same ponds during the wet season. The recommended period

Table 3: Means, Standard deviations and percentage reductions of BOD_5 during dry and wet seasons.

Sampling points	**Mean BOD_5 (mgO_2/L)**		**% BOD_5 reduction**	
	DRY	**WET**	**DRY**	**WET**
Influent	927.70±65.60	935.56±13.33	-	-
F1.1	123.10±29.70	54.56±4.95	86.70	94.17
F1.2	81.30±8.50	44.89±2.67	91.40	95.20
M1.1	54.70±35.00	43.56±5.81	94.10	95.34
M1.2	**50.70±11.80**	**27.11±4.81**	**94.50**	**97.10**
A1	508.90±53.90	142.67±10.20	56.90	84.75
F3.1	144.00±9.40	73.78±16.50	84.40	92.11
M3.1	93.80±8.00	48.44±4.22	89.90	94.82
M3.2	27.60±4.20	116.67±4.17	97.00	87.53
M3.3	**29.90±8.20**	**92.44±5.08**	**96.80**	**90.12**
F4.1	147.00±13.10	52.00±3.46	84.10	94.44
M4.1	133.40±18.90	68.89±4.81	85.60	92.64
M4.2	114.20±18.50	49.33±5.66	87.70	94.73
M4.3	**54.20±11.30**	**40.44± 8.11**	**94.00**	**95.68**
A2	517.80±51.40	110.22±10.44	44.20	88.22
F5.1	55.10±7.20	49.33±5.33	94.00	94.73
M5.1	77.80±3.50	48.00±4.90	91.60	94.87
M5.2	82.70±11.10	40.00±4.90	91.10	95.72
M5.3	**32.90± 5.20**	**41.78±6.36**	**96.50**	**95.53**
FEA	64.00±14.40	56.00±4.00	-	-
FEB	102.70±16.70	86.00±2.00	-	-
FEC	124.00±4.00	64.00±4.00	-	-
RUS	39.00±4.00	96.89±3.89	-	-
RDS	163.20±6.70	52.22±7.51	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

of de-sludging the ponds is fifteen years (Alexander *et al.,* 1988). The during dry season were lower than the design expectation of 68 % (Alexander *et al.*, 1988), and this could be due to the fact that ponds have not been desludged since construction. Other possible reasons for low BOD_5 removal during dry season may include high sulfides, organo-chlorines (not determined) and heavy metals. Rinzima (1988) also noted a possible toxicity of dissolved oxygen which can enter anaerobic pond with influent (Table 2).

The mean temperature of the ponds obtained were greater than 20 ^{o}C (Table 1), and this could have contributed to high % BOD_5 removal since waste stabilization is achieved by physical, chemical and biochemical reactions influenced by temperature amongst others factors. The temperatures above 20 ^{o}C are conducive for bacterial action on organic matter (Gambrill *et al.*, 1986).

High BOD_5 removals of 84 % - 91 % were achieved in facultative ponds in both seasons as compared to maturation ponds. The BOD_5 reduction in facultative ponds is expected to be higher than maturation ponds, and it is suggested that the high reduction was due to conversion of effluent into carbon dioxide, water and bacterial and algae cells in the presence of oxygen. Since the algae populations require sunlight, they develop and produce oxygen in excess of their own requirements and this excess is used by bacteria to further break organic matter within the effluent.

Thus in secondary facultative ponds (and in the upper layers of primary facultative ponds) sewage BOD is converted into algal BOD (Marais, 1970). Final effluent BOD_5 cumulative reductions of 90 % - 97 % were achieved in maturation ponds in both seasons. The removal in maturation ponds alone amounts to only 7 % and this is because their primary function is to remove excreted pathogens and nutrients (Mara and Pearson, 1986).

The % BOD_5 removals achieved in the maturation ponds (90 % - 97 %) were approximately similar to 98 % achieved in Ramtha (having similar system as Dandora) during a study on performance of wastewater treatment plants in Jordan and suitability for reuse (Al-Zboon and Al- Ananzeh, 2005).

The effluent BOD_5 discharged in both seasons (M1.2, M3.3, M4.3, M5.3, FEA, FEB and FEC) were higher than the design expectation of 20 mgO_2/L (Alexander *et al.*, 1988). The reasons for high BOD_5 may be due to re-suspension of settled solids, algal BOD converted from sewage BOD, outlet blockages and turbulence caused by hippopotamus which live in the ponds. However, series 3 during dry season (29.90 mgO_2/L) and series 1 in the wet season (27.11 mgO_2/L) recorded BOD_5 concentrations lower than WHO and Kenyan guideline standards of 30 mgO_2/L. Series 1 gives the lowest BOD_5 during wet season could be because of relatively high retention time as compared to other series.

The BOD concentrations of the river upstream during dry and wet seasons were 39.00±4.00 and 96.89±3.89 mgO_2/L respectively, and downstream were respectively 163.20±6.70 and 52.22±7.51 mgO_2/L. The increase in BOD_5 concentration of the river from 39.00 to 163.20 mgO_2/L during dry season is attributable to combined effluents discharged from the series (Figure 5). However, the BOD_5 of the river during wet season was higher than the effluent discharged from the plant due to storm and agricultural runoff from point and non point sources of pollution.

There was significant difference in overall BOD_5 between the two seasons since the value of t calculated was found to be 2.425 while t tabulated is 2.07 at 95% confidence level. The difference is attributable to dilution effect during the wet season. There was a strong correlation of 0.839 between the two seasons. The null hypothesis is rejected since the treatment process has an impact on BOD levels by removal of greater than 84 %.

4.6 Chemical Oxygen Demand

Seasonal concentrations and percent (%) COD (mgO_2/L) removals are presented in Table 4. The mean concentrations of COD for the influent wastewater during dry and wet seasons were 2532.80 ± 48.00 and 1489.00 ± 43.15 mgO_2/L respectively. The high COD in the influent could be attributed to wastes mainly from industrial effluents (IDEQ, 2006; APHA, 2005). The plant receives both domestic and industrial effluents.

The influent COD obtained in this study was higher than 250 mgO_2/L recorded at a treatment plant in Egypt (having similar system as Dandora) during a study on the performance assessment of a wastewater evaluation plant producing effluent for irrigation in Egypt (Fatma *et al*., 1998). The low COD observed in one of the treatment

Table 4: Means, Standard deviations and percentage reductions of COD during dry and wet seasons.

Sampling points	**Mean COD (mgO_2/L)**		**% COD reduction**	
	DRY	**WET**	**DRY**	**WET)**
Influent	2532.80±48.00	1489.00±43.15	-	-
F1.1	658.90±57.80	710.33±82.81	74.00	52.30
F1.2	418.30±30.50	377.78±60.00	83.50	74.63
M1.1	353.30±48.20	356.44±57.26	86.00	76.06
M1.2	**376.20±31.20**	**335.44±41.13**	**85.10**	**77.47**
A1	2321.80±47.20	839.22±27.83	8.30	77.47
F3.1	305.60±57.80	303.00±33.94	87.30	79.65
M3.1	376.80±8.50	289.00±32.171	85.10	80.59
M3.2	338.00±39.10	276.50±20.57	86.70	81.43
M3.3	**316.20±49.20**	**304.00±132.84**	**87.50**	**79.58**
F4.1	641.10±58.70	488.11±25.52	74.70	67.22
M4.1	574.00±38.00	463.00±60.30	77.30	68.91
M4.2	221.20±26.70	470.22±14.41	91.30	68.42
M4.3	**512.20±27.30**	**427.33±38.12**	**88.10**	**71.30**
A2	2379.30±172.50	845.44±31.46	6.00	43.22
F5.1	473.70±121.50	358.00±33.11	81.30	75.96
M5.1	473.70±22.90	405.78±40.77	82.70	72.75
M5.2	264.00±37.70	323.56±14.04	89.60	78.27
M5.3	**276.00±65.50**	**283.67±49.15**	**89.20**	**80.95**
FEA	429.30±53.30	199.33±14.19	-	-
FEB	450.70±28.10	489.33±13.20	-	-
FEC	450.70±28.10	307.67±6.43	-	-
RUS	204.30±31.00	472.00±28.31	-	-
RDS	310.80±48.80	358.00±28.31	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

plants in Egypt suggests that very low organic and inorganic waste is discharged into the sewerage system feeding wastewater treatment plant as compared to that feeding Dandora D & IWTP.

During the dry season the anaerobic ponds, A1 and A2 achieved COD removal of 8.30 % and 6.00 % respectively. These reductions were lower than 77.47 % and 43.22 % obtained in the same ponds during the wet season. The low reductions during dry season has been suggested to be due to organic overloading or inorganic toxicity (Alexander *et al.,* 1988). Oxygen toxicity which comes with influent cannot be ruled out (Table 2).

High COD removals from 81.30 % to 87.50 % were achieved in facultative ponds in both seasons. The reductions in facultative ponds are high due to biogradable pollutants and non-biodegradable oxidizable pollutants contained in the effluent (Tchobanoglous *et al.,* 2003). Maturation ponds achieved COD removals between 6.00 % and 89.60 % in both seasons. Fluctuations in COD removals were observed in maturation ponds. The presence of industrial waste and re-suspension could have contributed to COD fluctuations. The % COD removals achieved in these ponds (6.00 % to 89.60 %) were lower than 95 % obtained in Irbid (having a similar system as Dandora) wastewater treatment plants in Jordan (Al-Zboon and Al- Ananzeh, 2005).

The effluents discharged in both seasons were higher than the design expectation of 280 mgO_2/L (Alexander *et al.,* 1988). However, in dry season, series 5 (276.00 ± 65.50 mgO_2/L) recorded COD concentrations lower than the design. The effluent discharged from combined effluent of the plant during dry season contributed to the increase in COD concentration of the river. The mean temperatures of the ponds obtained were greater than 20 ^oC (Table 1) and this could have contributed to high % COD removal.

4.7 Total Phosphorus (T-P)

Seasonal percent (%) T-P removal and concentrations are presented in Table 5. The general trend observed was reduction in T-P concentration down the ponds. Wet season exhibited high phosphorus concentration. The mean concentrations of T-P for the influent wastewater during dry and wet season were 32.20 ± 2.46 and 82.56 ± 2.70 mgP/L respectively. 30 mgP/L of T-P is recommended by Water Quality Regulations, Kenya (2006) for discharge into sewer lines. The influent phosphorus obtained was higher than 9.0 mgP/L obtained in Moeraki (having similar system as Dandora) in New Zealand (Strang, 2001). The differences in the T-P observed at Dandora and New Zealand wastewater treatment plants could be due to different influent quantity, detergents, industrial waste discharged into the treatment plant and environmental conditions in the two localities.

During the dry season the anaerobic ponds, A1 and A2 achieved phosphorus removal of 1.49 % and 63.70 % respectively; this was lower than 74.30 % and 72.14 %

achieved in the wet season. The T-P reduction achieved in both ponds is by sludge formation (McGarry and Pescod, 1970) due to conducive pH between 6.5 – 8.5.

Table 5: Means, Standard deviations and percentage reductions of Total Phosphorus during dry and wet seasons.

Sampling points	**Mean T-P (mgP/L)**		**% reduction**	
	DRY	**WET**	**DRY**	**WET**
Influent	32.20±2.46	82.56±2.70	-	
F1.1	18.90±0.11	37.00±3.00	41.20	55.18
F1.2	24.40±2.10	23.22±2.11	24.22	71.88
M1.1	24.13±1.78	23.75±1.50	25.05	71.23
M1.2	**7.00±0.00**	**43.33±7.65**	**78.26**	**47.52**
A1	31.72±2.70	21.22±1.39	1.49	74.30
F3.1	23.87±7.35	21.89±2.62	25.87	73.49
M3.1	21.61±2.09	20.67±5.50	32.90	74.96
M3.2	25.94±0.94	42.78±2.54	19.44	48.18
M3.3	**11.92±7.38**	**25.00±3.77**	**62.98**	**69.72**
F4.1	7.80±2.16	30.56±5.34	75.77	62.98
M4.1	20.67±1.00	22.67±4.00	35.80	72.54
M4.2	72.20±1.00	57.56±2.35	-124.22	30.28
M4.3	**75.80±1.79**	**21.67±5.50**	**-135.40**	**73.75**
A2	11.70±3.23	23.00±4.50	63.70	72.14
F5.1	12.01±0.12	22.67±3.28	62.70	72.54
M5.1	22.90±1.05	21.11±3.95	28.90	74.43
M5.2	47.10±6.80	37.67±2.50	-46.27	54.37
M5.3	**27.80±0.44**	**46.78±3.93**	**13.7**	**43.34**
FEA	56.00±1.62	35.00±0.00	-	-
FEB	56.00±0.00	29.00±0.00	-	-
FEC	56.00±0.00	24.00±0.00	-	-
RUS	12.00±0.00	12.00±0.00	-	-
RDS	55.90±1.74	11.00±0.00	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

The highest value of 75.80 mgP/L was obtained in M4.3 during dry season, and

possible reasons for increase down the ponds include; pre-concentration due to high evaporation (Kenya meteorological department, unpublished data, 2009), long retention time resulting from the presence of anaerobic ponds, re-suspension, and both droplets and bottom turbulence arising from the hippopopotomus and crocodiles. The lowest concentrations recorded was 7.00 mgP/L in M1.2, possibly due to the anaerobic oxidation and aerobic conversion of sewage BOD to algal BOD such that phosphorus associated with non-biodegradable fraction of the algal cells remain in the sediment (Mara and Pearson., 1986). The highest phosphorus removals in facultative ponds of 75.77 % were approximately similar to cumulative removal of 78.26 % in maturation ponds.

The T-P content in the final effluent discharged were higher than guideline standard of 2 mgP/L by Water Quality Regulations, Kenya (2006) and C,ouncil of European Communities (1991). The effluent discharged (7.00 to 75.80 mgP/L) recorded concentrations higher than 4.0 mgP/L obtained in La Soukra in Tunisia (Bahri, 1988).

The Nairobi river upstream recorded T-P concentrations of 12.00 mgP/L during both seasons. The effluent discharged from the plant during dry season may have increased the T-P concentration of the river. The high concentration in the river upstream during wet season is attributable to storm and agricultural runoff. The phosphorus concentration did not meet the required standards (Kenya) hence null

hypothesis is accepted.

4.8 Ammonia Nitrogen (NH_3-N)

The ammonia-nitrogen (NH_3-N) concentrations are presented in Table 6. There was no significant difference in ammonia recorded in both seasons. The general trend observed

Table 6: Means, standard deviations and percentage reductions of ammonia-nitrogen during dry and wet seasons

Sampling Points	Mean NH_3-N (mgN/L)		% reductions	
	DRY	**WET**	**DRY**	**WET**
Influent	48.50±3.84	58.80±0.00	-	-
F1.1	40.13±1.98	25.20±0.00	17.26	57.14
F1.2	42.04±4.30	25.20±0.00	13.32	57.14
M1.1	6.53±1.40	20.53±1.40	86.54	57.67
M1.2	**11.20±2.43**	**10.27±1.40**	**76.90**	**82.29**
A1	50.40±1.40	46.67±1.40	-3.92	20.63
F3.1	31.42±1.87	5.60±0.00	35.22	90.48
M3.1	5.29±0.93	28.31±2.60	89.10	51.85
M3.2	8.71±0.93	33.60±4.20	82.04	42.86
M3.3	**12.44±1.48**	**19.60±0.00**	**74.35**	**66.67**
F4.1	35.70±1.87	34.53±1.98	26.39	41.28
M4.1	30.49±0.93	36.44±0.20	37.13	38.03
M4.2	35.44±1.43	35.47±1.40	29.92	39.68
M4.3	**28.31±0.93**	**36.40±0.00**	**41.63**	**38.10**
A2	50.40±0.00	54.40±0.00	-3.92	7.48
F5.1	42.00±0.00	36.40±0.00	13.40	38.10
M5.1	46.67±1.40	36.40±1.40	3.77	38.10
M5.2	50.40±0.00	17.73±0.40	-3.92	69.85
M5.3	**36.70±1.68**	**39.20±0.00**	**24.36**	**33.33**
FEA	50.40±0.00	5.60±0.00	-	-
FEB	50.40±0.00	36.40±0.00	-	-
FEC	50.40±0.00	19.60±0.00	-	-
RUS	36.40±0.00	28.00±0.00	-	-
RDS	30.40±0.00	34.44±0.00	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and % reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

was reduction in NH_3-N concentration down the ponds. The highest NH_3-N was observed in influent (58.80±0.00 mgN/L) during the wet season.

During dry season the anaerobic ponds, A1 and A2 increased in ammonia concentration more than the influent. The increase in NH_3-N is attributable to organic-nitrogen which is hydrolyzed to ammonia in anaerobic ponds. Generally, ammonia-nitrogen removal was low in anaerobic ponds. This was also observed by Soares *et al* (1996) who found a very low removal of NH_3-N in anaerobic ponds.

Maturation ponds achieved cumulative reduction of NH_3-N between 24.36 % and 82.29 % with fluctuations noted in all series. The ammonia removal from 24.36 % to 82.29 % was lower than expected net removal of 95 % (Raymond and Cem, 1982).

The reductions of NH_3-N in both facultative and maturation ponds are attributable to formation of new algal biomass which eventually become moribund and forms sediment at the bottom of the pond (Mara and Pearson, 1986).

The lowest NH_3-N recorded was in M3.1 (5.29 ± 0.93 mgN/L) during the dry season. The low NH_3-N could be due to volatilization of gaseous ammonia from the pond surface and uptake of organic nitrogen by cells (Raymond and Cem, 1982).

During dry and wet seasons, the River Nairobi upstream recorded 36.40 ± 0.00 and 28.00 ± 0.00 mgN/L respectively, while Nairobi River down stream recorded 30.40

±0.00 and 34.44 ± 0.00 in both seasons respectively. The effluent discharged from the plant during wet seasons may have increased the ammonia nitrogen concentration of the river. The effluents discharged were lower than 50 mgN/L recommended by Central Pollution Control Board (CPCB) found in EPA rules (1996). The NH_3-N met the required CPCB found in EPA rules (1996), hence null hypothesis rejected.

4.9 Organic Nitrogen (O-N)

The organic nitrogen of the series studied are presented in Table 7. Generally, both seasons recorded approximately similar organic-nitrogen concentrations. This is associated with proteins, peptides and amino acids found in human excreta. High O-N concentration was however recorded in F1.1 during wet season (24.27 ±0.00 mgN/L). Generally, reductions were observed down the ponds during both seasons.

The O-N reduction in facultative and maturation ponds (2.8 to 5.6 mgN/L) is suggested to be due to sedimentation (Mara, 2001). Series 1 and 5 recorded effluent slightly above the discharge guideline standard of 5 mgN/L stipulated by CPCB found in EPA rules (1996). The river upstream recorded O-N concentrations of 2.80 mgN/L during both seasons, while the river downstream recorded O-N concentrations of 6.40 mgN/L.

The increase in O-N concentration in the Nairobi river during both seasons is

Table 7: Means, Standard deviations and percentage reductions of O-N during dry and wet seasons

Sampling points	**Mean O-N (mgN/L)**		**% reductions**	
	DRY	**WET**	**DRY**	**(WET)**
Influent	20.16±1.74	18.53±0.00	-	-
F1.1	14.00±0.00	24.27±0.00	31.03	24.45
F1.2	15.64±2.64	11.20±2.64	22.96	15.60
M1.1	5.29±0.93	5.29±0.93	73.94	71.45
M1.2	**5.60±0.00**	**5.60±0.00**	**72.41**	**69.78**
A1	5.60±0.00	5.60±0.00	72.41	69.78
F3.1	5.60±0.00	5.60±0.00	72.41	69.78
M3.1	2.80±0.00	2.80±0.00	86.21	84.89
M3.2	2.80±0.00	2.80±0.00	86.21	84.89
M3.3	**2.80±0.00**	**2.80±0.00**	**86.21**	**84.89**
F4.1	22.40±0.00	22.40±0.00	-11.11	-20.89
M4.1	8.40±0.00	8.40±0.00	58.62	85.61
M4.2	6.22±1.24	6.22±1.24	69.35	66.43
M4.3	**2.80±0.00**	**2.80±0.00**	**86.21**	**84.89**
A2	2.80±0.00	2.80±0.00	86.21	84.89
F5.1	2.80±0.00	2.80±0.00	86.21	84.89
M5.1	2.80±0.00	2.80±0.00	86.21	84.89
M5.2	5.29±0.00	5.60±0.00	72.41	71.45
M5.3	**5.90±0.93**	**5.60±0.93**	**70.89**	**68.16**
FEA	5.60±0.00	5.60±0.00	-	-
FEB	5.60±0.00	4.67±1.62	-	-
FEC	5.60±0.00	5.60±0.00	-	-
RUS	2.80±0.00	2.80±0.00	-	-
RDS	6.40±1.20	6.40±1.20	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required. Negative values indicate increase in concentration.*

attributed to the concentrations from combined effluents (Table 7) discharged from the treatment plant. The concentrations of O-N in the Nairobi river down stream during wet seasons were higher than guideline standard of 5 mgN/L stipulated by WHO (1993) and CPCB (1996). This indicates the inefficiency of the treatment

plant.

4.10 Nitrite Nitrogen

The nitrite-nitrogen (NO_2-N) values and % conversions are presented in Table 8 and Appendix 9. There was no significant difference in nitrite nitrogen recorded in both seasons. The highest nitrite nitrogen was observed in M5.3 (13.00±0.00 mgN/L), during dry season. This is could be due to oxidation of nitrogenous compounds in maturation pond (M5.3). The conversions corresponds to high nitrogen of 61.35 mgN/L (Table 10) obtained in the same pond during dry season. Notable conversions were observed in combined final effluents, which are attributable to contribution from other ponds which were not the subject of study (Appendix 11).

Maturation ponds achieved cumulative conversion between 0.02 % and 18.89 % with fluctuations noted in all series. The NO_2-N conversions in both facultative and maturation ponds were low possibly because nitrite nitrogen is relatively short-lived in water because it is quickly converted to nitrate by bacteria (Rodda and Urbatini, 2004). During dry season, the concentration of NO_2-N in River upstream was 0.10±0.00 mgN/L and River down stream was 4.54±0.05 mgN/L. The effluent discharged possibly from combined effluent of the plant during dry season may have increased the nitrite nitrogen concentration of the river (appendix 9). The effluent discharged was lower than 3 mgN/L recommended by WHO (1993).

Table 8: Means, Standard deviations and percentage reductions of nitrite-nitrogen during dry and wet seasons

Sampling points	**Mean NO_2-N (mgN/L)**		**% conversion**	
	DRY	**WET**	**DRY**	**WET**
Influent	1.039±0.02	0.39±0.03	1.51	0.50
F1.1	0.10±0.00	0.50±0.00	0.15	0.60
F1.2	0.30±0.00	0.50±0.00	0.44	0.60
M1.1	3.04±0.05	0.30±0.00	4.42	0.40
M1.2	**0.77±0.05**	**2.74±0.07**	**1.12**	**3.54**
A1	0.30±0.00	0.30±0.00	0.44	0.40
F3.1	0.17±0.10	0.30±0.00	0.25	0.40
M3.1	0.23±0.10	0.80±0.00	0.33	1.00
M3.2	2.14±1.38	2.40±0.00	3.11	3.10
M3.3	**1.50±1.13**	**0.40±0.00**	**0.02**	**0.50**
F4.1	0.20±0.00	0.40±0.00	0.29	0.50
M4.1	0.30±0.00	0.40±0.00	0.44	0.50
M4.2	0.20 ±0.00	0.40±0.00	0.29	0.50
M4.3	**0.10±0.00**	**0.40±0.00**	**0.15**	**0.50**
A2	0.10±0.00	0.30±0.00	0.15	0.40
F 5.1	0.70±0.00	0.40±0.00	1.02	0.50
M5.1	0.10±0.00	0.30±0.00	0.29	0.40
M5.2	0.10±0.00	0.30±0.00	0.29	0.40
M5.3	**13.00±0.00**	**0.30±0.00**	**18.89**	**0.40**
FEA	9.47±1.62	0.87±0.06	-	-
FEB	5.80±0.10	0.30±0.00	-	-
FEC	12.03±0.15	0.30±0.00	-	-
RUS	0.10±0.00	0.30±0.00	-	-
RDS	4.54±0.05	0.20±0.00	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and % reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

There was a statistical difference in overall NO_2-N conversion between the two seasons since the value of t calculated was found to be 2.192 (0.039) while t tabulated is 2.07 at 95 % confidence level. The statistical difference in the two seasons is attributed to contributions from other ponds not studied but was discharged from

combined effluents (FEA, FEB and FEC). The nitrite nitrogen met the Water Quality Regulations, Kenya (2006) hence null hypothesis is rejected.

4.11 Nitrate Nitrogen (NO_3-N)

The NO_3-N concentrations and conversions are presented in Table 9 and Appendix 10. Wet season recorded significantly high nitrate-nitrogen as compared to dry season. This could be due to storm runoff from fertilizers, animal waste, septic tanks and decaying plant debris. The highest nitrate nitrogen was observed in maturation pond M3.3 (334.44 ± 25.06 mgN/L), during wet season.

NO_3-N conversion from nitrogenous compounds were between 6.13 % and 31.36 % with fluctuations noted in all series. NO_3-N increase was noted in certain ponds ranging between 54.10 % and 101.68%. Although the mean levels of total nitrogen (59.25mgN/l, Table 10) indicates that there is substantial amount of nitrogenous compounds that are yet to be oxidized to nitrate, the incorporation of ammonia into algal biomass contributed generally to low nitrates conversions. It is suggested that the conversion in facultative and maturation ponds were achieved by nitrification.

The lowest NO_3-N recorded in F1.1 (2.70 ± 0.37 mgN/L) during the dry season, is attributable to low DO obtained in this pond (2.32 ±0.30 mgO_2/L, Table 4). The effluents discharged during dry season were lower than 18 mgN/L recommended by

Table 9: Means, Standard deviations and percentage conversions of nitrate-nitrogen during dry and wet seasons

Sampling point	Mean Nitrates (mgN/L)		% conversion	
	DRY	**WET**	**DRY**	**WET**
Influent	3.76±1.82	88.11±3.66	-	-
F1.1	2.70±0.37	48.78±2.68	3.70	29.42
F1.2	3.82±0.87	44.37±4.58	5.19	26.76
M1.1	4.27±1.10	80.44±5.59	5.80	48.50
M1.2	**17.61±3.66**	**255.56±11.58**	**23.92**	**-54.10**
AN 3	3.29±0.46	27.00±1.87	4.47	16.28
F3.1	3.81±0.46	76.56±3.36	5.17	46.16
M3.1	17.45±9.42	260.00±8.66	23.70	-56.79
M3.2	13.91±7.80	257.78±9.05	18.89	-55.45
M3.3	**13.33±7.63**	**334.44±25.06**	**18.10**	**-101.68**
F4.1	5.46±2.15	70.89±4.31	7.42	42.75
M4.1	2.97±1.41	66.78±4.29	4.03	42.28
M4.2	4.28±1.66	68.11±3.52	5.81	41.07
M4.3	**4.51±1.86**	**50.33±4.69**	**6.13**	**30.35**
AN 5	3.89±0.77	55.11±3.30	5.28	33.23
F5.1	7.01±2.22	51.67±5.57	9.52	31.16
M5.1	3.57±0.92	52.33±4.15	4.85	31.56
M5.2	3.50±0.72	62.83±5.83	4.75	37.89
M5.3	**5.75±1.81**	**52.00±5.17**	**7.81**	**31.36**
FEA	13.50±1.00	433.33±28.87	-	-
FEB	14.67±0.29	93.00±6.08	-	-
FEC	15.00±0.50	54.57±4.16	-	-
RUS	3.30±0.09	246.89±10.29	-	-
RDS	3.78±0.14	269.67±1.80	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and % reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

WHO (1993). However, discharges during wet season were much higher than recommended values (Table 10).

The concentration of NO_3-N in the river upstream and down stream during the wet

season was 246.89 ± 10.29 and 269.67 ± 1.80 mgN/L respectively. It is notable that the combined effluent discharged from the plant during wet season may have increased the nitrate nitrogen concentration of the river.

There was a statistical difference in overall nitrate nitrogen conversion between the two seasons since the value of t calculated was found to be 5.363 while t tabulated is 2.07 at 95 % confidence level. The nitrate nitrogen did not meet the required standards (WHO, 1993) during the wet season hence null hypothesis accepted.

4.12 Total Nitrogen (T-N)

The total nitrogen concentrations and removals are presented in Table 10 and Appendix 11. The general trend observed was reduction in T-N concentration down the ponds. Wet seasons recorded significantly high nitrogen as compared to dry season. The highest concentration of T-N was observed in maturation pond M3.3 (366.42 mgN/L), during wet season.

The maturation ponds achieved cumulative reduction of T-N between 16.68 and 60.46 %, with fluctuations noted in all series (Appendix 11). It has been suggested that the T-N reduction in facultative and maturation ponds occur because ammonia is incorporated into new algal biomass, which settles at the bottom (Mara and Pearson, 1986).

The nitrogen removal between 16.68 and 60.46 % was lower than 70 to 90%

Table 10: Means, Standard deviations and percentage reductions of T-N during dry and wet seasons.

Sampling points	Mean T-N (mgN/L)		% reduction	
	DRY	**WET**	**DRY**	**WET**
Influent	73.63±4.06	165.83±8.98	- -	
F1.1	59.25±3.56	100.35±6.36	19.53	39.49
F1.2	61.81±7.30	81.27±9.16	16.05	50.99
M1.1	19.44±8.71	119.74±15.38	73.59	27.79
M1.2	**35.18±6.13**	**275.09±27.43**	**52.22**	**-65.89**
A1	59.59±4.99	79.55±5.14	19.07	52.03
F3.1	41.00±2.42	114.18±9.14	44.32	31.15
M3.1	25.77±10.45	295.96±18.8	65.00	-78.48
M3.2	33.56±10.73	309.65±21.8	54.42	-86.72
M3.3	**29.11±9.69**	**366.42±51.08**	**60.46**	**-120.96**
F4.1	56.84±4.02	185.17±10.67	22.80	-11.66
M4.1	42.16±2.33	120.68±10.48	42.74	27.23
M4.2	46.67±3.34	117.98±8.44	36.62	28.90
M4.3	**35.41±2.79**	**92.73±9.38**	**51.91**	**44.08**
A2	57.22±4.04	115.51±6.60	22.28	30.43
F5.1	52.51±2.20	105.17±11.42	28.68	36.58
M5.1	53.14±3.60	100.33±4.15	27.83	39.50
M5.2	59.60±0.72	94.13±5.83	19.05	43.24
M5.3	**61.35±14.14**	**105.50±5.17**	**16.68**	**36.38**
FEA	78.97±2.62	445.73±28.93	-	-
FEB	70.77±0.39	140.90±6.08	-	-
FEC	83.03±0.55	66.06±4.10	-	-
RUS	42.60±0.09	286.38±20.49	-	-
RDS	48.32±0.19	310.83±5.11	-	

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

achievable in a series of well designed ponds (Mara and Pearson, 1986). Notable increases in T-N concentration between 65.89 to 120.96 % were observed down certain ponds. The increase in nitrogen concentration could be because the nitrogen

associated with the biodegradable fraction of the settled biomass eventually diffuses back into the pond liquid to start the process again (Mara and Pearson, 1986). The lowest nitrogen concentration recorded was 19.44 ± 8.71 mgN/L (M1.1) during the dry season. This is could be due to nitrogen take-up by algal population.

In the dry season, the River upstream and down stream recorded T-N concentrations of 42.6 ± 0.09 and 48.32 ± 0.19 mgN/L respectively, whereas wet season recorded 286.38 ±20.49 and 310.83 ± 5.11 mgN/L respectively. The increase in T-N concentration of the river during both seasons is attributable to the concentrations discharged from the treatment plant. However, the effluents discharged from all ponds were higher than 2 mgN/L recommended by Water Quality Regulations, Kenya (2006).

There was a statistical difference in overall T-N reduction between the two seasons since the value of t calculated was found to be 5.392 (0.05) while t tabulated is 2.07 at 95 % confidence level. The nitrogen did not meet the Water Quality Regulations, Kenya (2006) hence null hypothesis accepted.

4.13 Total Suspended Solids (TSS)

Seasonal mean concentration and percent (%) TSS removals are presented in Table 11 and Appendix 12. Generally, high values were recorded during wet season as

Compared to dry season. The mean concentrations of TSS for the influent wastewater during dry and wet season were 463.30 ± 38.40 and 632.00 ± 23.55 mg/L respectively.

Table 11: Means, standard deviations and percentage reductions of TSS during dry and wet seasons

Sampling points	**Mean TSS (mg/L)**		**% Reduction**	
	DRY	**WET**	**DRY**	**WET**
Influent	463.30±38.40	632.00±23.55	-	-
F1.1	227.80±65.20	330.22±16.14	50.80	47.75
F1.2	92.70±30.40	114.22±6.04	80.00	81.93
M1.1	56.60±17.20	97.78±0.02	87.80	84.31
M1.2	**92.90±18.40**	**78.22±4.05**	**79.90**	**87.62**
A1	132.80±55.40	70.00±10.00	71.30	88.92
F3.1	77.10±35.60	123.78±4.30	83.40	80.42
M3.1	101.60±13.90	132.00±8.00	78.10	79.11
M3.2	100.40±10.80	106.67±1.18	78.30	83.12
M3.3	**70.70±13.60**	**111.33±7.413**	**84.70**	**82.38**
F4.1	134.40±48.80	181.33±41.87	71.00	71.31
M4.1	131.80±39.10	186.89±29.72	71.60	70.43
M4.2	138.90±27.60	106.67±50.60	70.00	83.12
M4.3	**107.80±18.90**	**107.80±18.90**	**76.70**	**82.94**
A2	101.60±11.10	158.67±4.00	78.10	74.89
F5.1	162.70±12.00	186.67±4.00	64.90	70.46
M5.1	122.40±29.70	188.89±6.17	73.60	70.11
M5.2	92.40±38.10	167.11±13.82	80.10	73.56
M5.3	**46.10±9.90**	**120.89±32.54**	**90.00**	**80.87**
FEA	82.70±19.70	160.00±4.00	-	-
FEB	116.00±7.40	352.00±4.00	-	-
FEC	197.30±32.30	366.67±11.55	-	-
RUS	157.80±7.80	157.80±7.80	-	-
RDS	325.30±00.10	325.30±10.10	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

The plant was designed to receive TSS concentration of 655 mg/L (Alexander *et al*, 1988). The influent TSS of 463.30 mg/L was lower than 1040 mg/L obtained in Irbid

WTP during a study on performance of wastewater treatment plants in Jordan and suitabilityfor reuse (Al- Zboon and Al- Ananzeh, 2005). The differences in the TSS observed at Dandora and Jordan wastewater treatment plants are suggested to be due to flow, the performance of the screening system, design, construction and operation simplicity.

During both seasons the anaerobic ponds, A1 and A2 achieved TSS removal of more than 70 %. TSS removals from 47.75 to 83.40 % were achieved in facultative ponds in both seasons as compared to cumulative removal of 76.70 to 90.00 % in maturation ponds. The reduction in facultative ponds may have been achieved by sedimentation. However,TSS removal fluctuated in the Maturation ponds. The fluctuation may have been due to re-suspension of settled solids and algal population.

The effluents discharged from the series studied were all above the design expectation of 30 mg/l (Alexander *et al.*, 1988). The TSS concentrations in the Nairobi river upstream and down stream during dry and wet seasons were 157.80±7.80 and 325.30±0.10 mg/L respectively. The discharge possibly from combined effluent of the plant during both seasons may have increased the TSS concentration of the river (Figure 9). There was a significant difference in overall TSS removal between the two seasons since the value of t calculated was found to be 3.749 while t tabulated is 2.07 at 95% confidence level. There was a coefficient correlation of 0.864 between the two

seasons.

4.14 Total Dissolved Solids (TDS)

The TDS concentrations are presented in Table 12. Wet seasons recorded higher

Table 12: Means, Standard deviations and percentage reductions of TDS during dry and wet seasons

Sampling points	**Mean TDS (mg/L)**		**% Reduction**	
	DRY	**WET**	**DRY**	**WET**
Influent	1019.80±31.50	1226.00±3.46	-	-
F1.1	700.70±23.10	737.00±6.25	31.30	39.89
F1.2	601.30±12.50	1016.00±5.00	41.00	17.13
M1.1	633.30±12.70	866.67±18.15	36.60	29.31
M1.2	**575.70±18.60**	**879.00±1.73**	**43.50**	**28.30**
A1	789.00±186.40	024.00±1.00	22.60	16.48
F3.1	592.00±51.10	1011.00±3.00	41.90	7.54
M3.1	605.00±60.60	936.67±11.67	40.70	3.60
M3.2	461.00±116.90	53.67±13.05	54.90	22.21
M3.3	**558.00±43.00**	**901.33±3.22**	**45.30**	**25.75**
F4.1	696.00±35.20	950.37±0.58	31.80	22.48
M4.1	659.00±78.60	998.00±3.000	35.40	18.60
M4.2	560.00±65.90	962.00±1.73	45.10	21.53
M4.3	**647.00±74.20**	**1012.00±1.73**	**36.60**	**17.46**
A2	618.00±9.70	18.00±9.70	39.40	49.59
F5.1	601.00±0.00	1002.00±3.46	41.00	18.27
M5.1	603.30±4.00	987.33±33.29	40.80	19.47
M5.2	614.00±0.00	013.00± 2.65	39.80	17.37
M5.3	**622.00±3.50**	**991.33±17.00**	**39.00**	**19.14**
FEA	529.70±2.30	905.00±13.51	-	-
FEB	599.00±3.50	915.00±4.66	-	-
FEC	599.00±3.50	902.00±3.51	-	-
RUS	455.20±24.60	584.00±1.41	-	-
RDS	703.00±46.40	595.00±0.00	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

TDS values than dry season. The highest TDS was observed in the influent during

wet season. The influent TDS of 1019.80 ± 131.50 and 1226.00 ± 3.46 mg/L obtained during dry and wet seasons respectively, was lower than 1404 mg /L obtained in Los Angeles County joint WTPs during a study on quality of raw wastewater and primary effluent at selected plants in California (Asano and Tchobanglous, 1987; Asano *et al.*,1997). The differences in the TDS observed at Dandora and California wastewater treatment plants could be due to variety of inorganic ions and organic compounds in the influent quantity.

In both seasons, TDS reduction was observed down the ponds in facultative and maturation ponds. It is suggested that the reduction of TDS possibly is dependent on the physical, chemical and biochemical reactions within the ponds for example reactions of carbonate and bicarbonate salts, and formation of hydroxyl ions amongst others. There was a statistical difference in overall TDS reduction between the two seasons since the value of t calculated was found to be 9.678 (0.05) while t tabulated was 2.07 at since the value of t calculated was found to be 9.678 (0.05) while t tabulated was 2.07 at 95% confidence level. It is suggested that the difference between the two seasons was the relatively high concentration of TDS during wet season as compared to dry season. However, all the TDS recorded were below 1200 mg/L permissible by Water Quality Regulations, Kenya (2006).

Generally, nitrogen, nitrate-nitrogen, conductivity, TSS and TDS levels were found to be higher during the wet season suggesting that runoff water contributed to their levels

in the ponds.

4.15 Heavy Metals

4.15.1 Cadmium (Cd)

Dry season's mean concentration and percent (%) Cd removals are presented in Table 13 and Appendix 13. The Cd levels were below detection limit during the wet season. High concentrations were recorded during dry season as opposed to wet season which only recorded Cd in the influent. This could be attributable to pre-concentration due to relatively high evaporation during dry season. The anaerobic ponds, A1 achieved Cd removal of 6.41 % while in A2, no removal was noted (Table 13). The low Cd removal in anaerobic ponds is attributable to the fact that heavy metals affect the rate of anaerobic digestion even at very low concentrations (Rinzima, 1988).

Cd removals of 30.65 % were achieved in facultative ponds as compared to cumulative removals of 19.35 % in maturation ponds. However, Cd increased between 19.35% and 22.58 % in series 5 ponds, and concentrations higher than the influent were noted. The river upstream and downstream recorded Cd concentration of 0.015 ±0.003 mg/L and 0.033 ± 0.004 mg/L respectively. The Cd concentrations discharged from the plant were above 0.01 mg/L permissible by Kenyan standards, which could have contributed to increase in Cd concentration of the river.

Table 13: Means, Standard deviations and percentage reductions of Cd and Cu during dry and wet seasons.

Sampling points	Mean Cd (mg/L)	% Cd red	Mean Cu (mg/L)	% Cu red
	DRY	**DRY**	**DRY**	**DRY**
Influent	0.031±0.004	-	0.049±0.003	-
F1.1	0.022±0.003	30.65	0.042±0.002	14.27
F1.2	0.028±0.003	19.68	0.040±0.002	18.37
M1.1	0.024±0.003	22.58	0.030±0.000	38.78
M1.2	**0.025±0.003**	**17.74**	**0.004±0.004**	**91.84**
A1	0.029±0.006	6.45	0.019±0.009	61.22
F3.1	0.026±0.005	16.13	0.002±0.002	95.92
M3.1	0.017±0.003	46.13	0.005±0.001	89.80
M3.2	0.017±0.003	46.13	0.008±0.001	83.67
M3.3	**0.025±0.002**	**19.35**	**0.011±0.002**	**77.55**
F4.1	0.027±0.002	10.33	0.017±0.004	65.31
M4.1	0.026±0.003	14.52	0.010±0.004	79.59
M4.2	0.029±0.007	6.45	0.003±0.003	38.78
M4.3	**0.029±0.004**	**6.45**	**0.001±0.000**	**97.96**
A2	0.031±0.004	0.00	0.009±0.002	81.64
F5.1	0.038±0.003	-22.58	0.065±0.006	-32.65
M5.1	0.037±0.002	-19.35	0.001±0.000	97.96
M5.2	0.036±0.003	-17.10	0.020±0.005	89.80
M5.3	**0.033±0.004**	**-6.45**	**0.024±0.004**	**40.00**
FEA	0.035±0.005	-	0.032±0.001	-
FEB	0.031±0.001	-	0.035±0.005	-
FEC	0.036±0.005	-	0.031±0.004	-
RUS	0.015±0.003	-	0.001±0.000	-
RDS	0.033±0.004	-	0.001±0.000	-

Refer to Figure 3 on page 20. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

There was a statistical difference in series 5 treatment ponds but not in the other series.

This is attributable to fraction of raw sewage that passes directly to facultative pond.

The levels of cadmium in the river increased after discharge of the effluent from the

Dandora treatment plant hence rejection of null hypothesis.

4.15.2 Copper (Cu)

Mean Cu concentration and percent (%) removals are presented in Table 13 and Appendix 14. Concentrations of Cu during the wet season were below detectable limits in the ponds. Cu content was however recorded during dry season while in wet season, trace amounts were obtained in the influent and the river (Appendix 14).

The anaerobic ponds, A1 and A2 achieved Cu removal of 61.22 % and 81.64 % respectively. Reduction between 14.27 and 95.92 % was achieved in facultative ponds as compared to cumulative removal from 38.78 % to 97.96 % recorded in maturation ponds. However, increase of 32.65 % was obtained in F5.1.

Concentration of Cu in the river upstream and down stream after discharge was 0.001 mg/L. The concentration of Cu discharged into Nairobi river met the Water Quality Regulation, Kenya of 1.0 mg/L (2006).

There was a statistical difference between series 1 and 3, and series 1 and 5 treatment ponds. This could be due to the presence of anaerobic ponds along series 3 and 5. The levels of copper in the river did not increase after discharge of the effluent from the Dandora Treatment plant hence acceptance of the null hypothesis.

4.15.3 Zinc (Zn)

Seasonal Zn concentration and percent (%) removals are presented in Table 14 and Appendix 15. Generally, high values were recorded during dry season as compared to

Table 14: Means, Standard deviations and percentage reductions of Zn during dry and wet seasons

Sampling points	Mean Zn (mg/L)		% Zn reduction	
	DRY	**WET**	**DRY**	**WET**
Influent	1.561±0.234	0.503±0.056	-	-
F1.1	0.445±0.030	0.380±0.070	71.48	24.25
F1.2	0.861±0.070	0.148±0.070	44.87	0.58
M1.1	0.328±0.003	0.153±0.018	79.00	69.50
M1.2	**0.746±0.057**	**0.109±0.039**	**52.25**	**78.33**
A1	0.712±0.171	0.130±0.038	54.42	74.16
F3.1	0.708±0.100	0.124±0.024	54.63	75.35
M3.1	0.577±0.106	0.117±0.010	63.06	76.74
M3.2	0.237±0.020	0.110±0.015	84.84	78.13
M3.3	**0.358±0.025**	**0.147±0.029**	**77.07**	**70.77**
F4.1	1.171±0.140	0.133±0.014	74.18	73.56
M4.1	0.996±0.100	0.149±0.009	36.24	70.37
M4.2	0.394±0.020	0.161±0.014	74.77	67.99
M4.3	**0.184±0.050**	**0.167±0.016**	**88.24**	**66.80**
A2	0.238±0.059	0.130±0.021	84.76	74.16
F5.1	0.623±0.054	0.162±0.040	60.12	67.79
M5.1	0.283±0.025	0.232±0.016	88.58	53.88
M5.2	0.238±0.059	0.233±0.040	84.76	53.67
M5.3	**0.232±0.054**	**0.222±0.013**	**85.15**	**55.86**
FEA	0.226±0.082	0.170±0.000	-	-
FEB	0.337±0.020	0.227±0.006	-	-
FEC	0.153±0.010	0.183±0.006	-	-
RUS	0.131±0.016	0.238±0.019	-	-
RDS	0.419±0.143	0.341±0.0120	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

wet season (Appendix 15). During dry seasons the anaerobic ponds, A1 and A2

achieved Zn removal of 54.42 % and 84.76 % respectively as compared to removal of 74.16% during wet season (Table 14). The reductions achieved are believed to be due to the anaerobic pond function which serves to separate out solid from dissolved material (McGarry and Pescod, 1970).

Zn removals of 24.25 % and 75.35 % were achieved in facultative ponds in both seasons while removal in maturation ponds ranged between 53.67 % and 78.33 %. High pH (greater than 7.5) is believed to have allowed pond purification processes to occur (Moshe, 1972).

The Zn discharged into the Nairobi river ranged between 0.184 to 0.746 mg/L in dry season and 0.109 to 0.222 mg/L in the wet season. The values were lower than the effluent discharge concentrations into surface waters of 0.5 mg/l stipulated by Water Quality Regulations, Kenya (2006). The river downstream recorded zinc concentrations greater than river upstream in both seasons (Table 14), suggesting that the discharge from the Dandora plant contributed to the increase in Zn.

There was a statistical difference in overall Zn removal between the two seasons since the value of t calculated was found to be 4.087 while t tabulated is 2.07 at 95% confidence level (n-1= 22). The difference is believed to arise from dilution effect during the wet season, which reduced concentration of Zn.

The levels of zinc in the river increased after discharge of the effluent from the Dandora treatment plant hence null hypothesis reject

4.15.4 Manganese (Mn)

Seasonal mean concentrations and percent (%) Mn removals are presented in Table 15

Table 15: Means, Standard deviations and percentage reductions of Mn during dry and wet seasons

Sampling points	Mean Mn (mg/L)		% Mn reduction	
	DRY	**WET**	**DRY**	**WET**
Influent	0.604±0.047	1.341±0.032	-	-
F1.1	0.065±0.003	1.143±0.317	89.24	14.77
F1.2	0.256±0.220	0.702±0.097	57.62	38.58
M1.1	0.178±0.098	0.806±0.098	70.53	29.48
M1.2	**0.085±0.067**	**0.567±0.041**	**85.93**	**57.72**
A1	0.592±0.190	1.000±0.038	1.99	25.43
F3.1	0.577±0.016	0.736±0.076	4.47	45.12
M3.1	0.102±0.024	0.773±0.010	83.11	42.36
M3.2	0.128±0.066	0.707±0.022	78.81	47.28
M3.3	**0.176±0.053**	**0.523±0.007**	**70.86**	**61.00**
F4.1	0.477±0.088	0.637±0.005	21.03	52.50
M4.1	0.431±0.077	0.709±0.070	28.81	47.13
M4.2	0.399±0.019	0.254±0.115	33.94	81.06
M4.3	**0.356±0.017**	**0.476±0.016**	**41.06**	**64.50**
A2	0.339±0.106	0.809±0.106	43.87	39.67
F5.1	0.010±0.009	0.719±0.154	98.34	46.38
M5.1	0.351±0.025	0.783±0.058	41.89	41.61
M5.2	0.367±0.110	0.812±0.141	39.24	39.45
M5.3	**0.367±0.066**	**0.748±0.032**	**39.24**	**44.22**
FEA	0.192±0.062	0.383±0.006	-	-
FEB	0.299±0.074	0.703±0.006	-	-
FEC	0.328±0.090	0.590±0.000	-	-
RUS	0.134±0.035	2.288±0.0340	-	-
RDS	0.261±0.024	0.481±0.033	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

and Appendix 16. Generally, high values were recorded during wet season as compared to dry season. The anaerobic ponds, A1 and A2 achieved Mn removal between 1.99 % and 43.87 % respectively during dry season as compared to wet season removal between 25.43 % and 39.67 % respectively. Mn removals from 4.47 % to 98.34 % were recorded in facultative ponds in dry season, while 14.77 % to 81.06 % removals were achieved in maturation ponds during the same period.

The Mn discharged (between 0.085±0.067 and 0.748±0.032 mg/L) from the final effluents of the series studied (Table 15) were higher than the effluent discharge concentrations into surface waters of 0.2 mg/l (Water Quality Regulations, Kenya, 2006). However, series 1 and 3 recorded permissible values of Mn during dry season (Table 15).

The Nairobi river upstream (RUS) and downstream (RDS) respectively recorded Mn concentrations of 0.134 ± 0.035 mg/L and 0.261 ± 0.024 mg/L during dry season. The increase in Mn concentration of the river down stream during dry season is suggested to have been due to discharge from the plant. However, the concentration of Mn in the River upstream during wet season (2.288±0.0340 mg/L) was higher than downstream (0.481±0.033); this may be due to storm runoff.

The levels of manganese in the river during dry season increased after discharge (Appendix 16) of the effluent from the Dandora treatment plant hence null hypothesis

is rejected. There was a statistical difference in overall Mn removal between the two seasons since the value of t calculated was found to be 5.449 while t tabulated is 2.07 at 95% confidence level. Manganese was high in the wet season as opposed to other metals. This possibly could be due to the manganese concentrations in soil which could reach 9000 ppm.

4.15.5 Lead

The mean Pb concentrations and seasonal percent (%) removals are presented in Table 16 and Appendix 17. The general trend is reduction in Pb concentration down the ponds. The concentration of Pb was generally high during the dry season, while removal was high during wet season. During dry season and wet season, anaerobic ponds, A1 achieved Pb removal of 2.23% and 9.77 % respectively, while A2 achieved removal of 82.00% and 20.25 % respectively.

Pb removals of 21.26 % to 79.04 % % were recorded in facultative ponds, while 8.16 %to 85.26 % were achieved in maturation ponds. The concentration of Pb discharged (0.083±0.005 to 0.332±0.024 mg/L) from the final effluent (Table 16) were higher than the recommended effluent discharge concentrations into surface waters of 0.01 mg/L (Water Quality Regulations, Kenya, 2006).

The Pb concentrations in the River upstream in dry (0.341±0.044 mg/L) and wet seasons (0.193±0.022 mg/L) were higher than down stream concentration

(0.220±0.010 and 0.127±0.005 mg/L). This indicates that the runoff increased Pb concentration of the river before Dandora plant discharge.

Table 16: Means, standard deviations and percentage reductions of Pb during dry and wet seasons

Sampling points	**Mean Pb (mgL)**		**% Pb reduction**	
	DRY	**WET**	**DRY**	**WET**
Influent	0.539±0.014	0.563±0.021	-	-
F1.1	0.419±0.033	0.369±0.035	21.26	34.46
F1.2	0.464±0.124	0.417±0.041	13.92	25.93
M1.1	0.495±0.028	0.093± 0.028	8.16	83.48
M1.2	**0.117±0.013**	**0.177±0.032**	**78.29**	**68.56**
A1	0.527±0.128	0.508±0.016	2.23	9.77
F3.1	0.194±0.029	0.126±0.023	64.01	77.62
M3.1	0.218±0.030	0.112±0.014	59.55	80.11
M3.2	0.196±0.054	0.163±0.014	63.64	71.05
M3.3	**0.282±0.023**	**0.174±0.013**	**47.68**	**69.09**
F4.1	0.276±0.034	0.140±0.024	48. 79	75.13
M4.1	0.260±0.010	0.163±0.024	51.76	71.05
M4.2	0.327±0.028	0.080±0.014	39.33	85.79
M4.3	**0.332±0.024**	**0.083±0.005**	**38.40**	**85.26**
A2	0.097±0.012	0.449±0.059	82.00	20.25
F5.1	0.355±0.013	0.118±0.041	34.14	79.04
M5.1	0.146±0.026	0.149±0.022	72.91	73.54
M5.2	0.167±0.019	0.152±0.027	69.02	73.00
M5.3	**0.204±0.007**	**0.108±0.032**	**62.15**	**80.82**
FEA	0.239±0.018	0.103±0.023	-	-
FEB	0.259±0.068	0.223±0.080	-	-
FEC	0.243±0.025	0.157±0.012	-	-
RUS	0.341±0.044	0.193±0.022	-	-
RDS	0.220±0.010	0.127±0.005	-	-

Refer to Figure 3 on page 24. ***Bolded*** *are final effluent and percent (%) reduction from respective series. Unfilled spaces are not ponds hence reductions were not required.*

There was a statistical difference in overall Pb removal between the two seasons since the value of t calculated was found to be 2.921 (P=0.05) while t tabulated is 2.07l (n-I

=22). Since the concentrations of Pb in the river decreased after discharge from the Dandora treatment plant, null hypothesis is accepted.

The low heavy metals (elements) reductions achieved in A1 is thought to occur because the ponds have not been desludged as outlined in design (Alexander *et al.,* 1988) since construction. According to Nouri and Naghipour (2002), and Shinya and Tsuruho, (2003) heavy metals do not break down in the treatment plants. The relatively high reductions achieved in A2 are believed to be due to sedimentation. The high removal observed during wet season is attributable to dilution effect. High concentrations of elements recorded during dry season as compared to wet season is thought to occur due to pre-concentration following relatively high temperature and evaporation rate (Kenya Meteorological Department raw data, 2009).

The heavy metals (elements) reduction in facultative and maturation ponds may have been achieved by sedimentation and precipitation due to the alkaline nature of the effluents. Fluctuations in elements removals in maturation ponds are attributable to re-suspension of settled solids. The increase in concentrations (Cu and Cd) more than the influent recorded in series 5 is believed to arise due to the fraction of raw sewage that enters facultative pond directly from the influent and mixes with effluent from anaerobic pond.

Statistical differences observed in elements removal in both seasons are attributed to

dilution effect during the wet season. The wide fluctuations in removals are thought to occur due to variations in precipitations arising from chemical composition, and concentrations in floatable materials.

Chromium was below detection limit in all the ponds in both seasons.

Possible industries discharging heavy metals in the Dandora Treatment Plant include modern lirthographic, sunflag, tanneries, E.A leather, and Regal Pharmauceticals amongst others. Since heavy metals will be likely adsorbed in the sludge and careful handling of the toxic sludge is necessary. Sludge treatment includes stabilization, dewatering, drying and incineration. For sludge which is heavily contaminated with heavy metals, incineration is recommended although prevention of contamination is preferable (Khopka, 2004).

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATION

The overall efficiency of the Dandora treatment plant is given on the basis of the analytical findings. Higher concentrations were obtained in most of the parameters analyzed, and the effluents discharged from the series were above the Water Quality regulations, Kenya. Generally the plant is not efficient in pollutant removal.

i. The removal of BOD_5 was below design expectation of 20 mgO_2/L. The effluent discharged from selected series had BOD concentrations ranging from 27.11 to 92.44 mgO_2/L.

ii. COD concentrations in the final effluent were between 276.0 and 512.0 mgO_2/L against expected 280.0 mgO_2/L, and removal efficiency ranged from 71.30 and 89.20 %.

iii. The TSS concentrations discharged from the final effluent were between 41.10 and 120.89 mg/L against expected 30 mg/L, and removal efficiency ranged between 76.70 and 90.0 %.

iv. The DO determined in the ponds (2.66 to 4.23 mgO_2/L) during dry season fell below limits for support of aquatic life (5.0 mgO_2/L). The concentrations of DO during the wet season were generally high ranging from 2.76 to 19.77 mgO_2/L.

v. In terms of nutrients, the concentrations of phosphorus ranged from 7.00 to 75.80 mgP/L, and these were higher than the Water Quality Regulations of Kenya of 2 mgP/L.

vi. Nitrate discharged concentrations ranging between 50.33 and 334.44 mgN/L. This was higher than the WHO discharge standard of 18mgN/L into surface water. The nitrate conversion from nitrogenous compounds were 6.13 to 31.36 %.

vii. The nitrogen concentrations ranged between 92 to 366.42 mgN/L, and these were higher than Water Quality Regulations of Kenya standards of 2mgN/L. The removal efficiency of 16.68 to 60.46 % was below 70 to 90 % expected.

viii. As far as heavy metals were concerned, Cd, Mn and Pb recorded values higher than permissible limits of Water Quality Regulations, Kenya for discharge into surface water. The required quality of Cd, Mn and Pb were 0.01, 0.2 and 0.01 mg/L respectively. Cd, Mn and Pb concentrations respectively ranged from 0.015 to 0.033, 0.085 to 0.748 and 0.083 to 0.332 mg/L. Their removal efficiency ranged from 6.45 to 19.45, 39.24 to 85.93, and 38.40 to 85.26 % respectively.

The current study indicates that the Dandora Domestic and industrial waste Treatment Plant in Nairobi is not efficient in removing pollutants like BOD, TSS, TP, NO_3-N, TN, Cd, Mn and Pb.

5.1 Recommendation from the study

i. It is advisable to separate the industrial waste from domestic waste to enable efficient treatment. The Industries should be under strict regulations to treat their own wastes to considerable levels before disposal. This is likely to increase the performance of the system.

ii. The entire system should be maintained regularly for increased performance of the plant. This should include desludging the system at appropriate time, an action that is long overdue, and repairing outlet pipes, and screening system to exclude floatable materials, and grit from blocking the pipelines and possibly increasing the concentrations of effluents.

iii. It is necessary to reduce suspended solids to the receiving body possibly by controlling flow since high TSS is known to cause ecological problems. In many cases, TSS influence aquatic life, from phytoplankton to fish. Salmonids and other aquatic species avoid water with high TSS and

emigrate to areas of lower TSS because suspended sediments affect reproductive success.

iv. A wetland should be constructed to stabilize organic matter, nutrients and heavy metals before discharge into environment.

v. The treatment plant should be fenced to prevent animals from grazing into the compound; this would minimize direct contact of animals and wild life with wastewater.

vi. Regular monitoring of the treatment plant should be reinforced to prevent people from blocking the outlets for fishing purposes.

5.2 Recommendations for further studies

i. More studies should be done on sediment and floatables to determine the total contributions of pollutants in both the ponds and the river.

ii. Other possible pollutants such as arsenic and persistent organic polluters (POPs) should be evaluated in the ponds.

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PAPERS

Papers presented during National and International Science Conference

1. **Sewe, H.,** Njenga, J., Oyaro, N., Makayoto, M, OGW, and Mailutha , J. T. (22nd - 25th AUGUST, 2009). The Quality of Wastewater discharged from Dandora Domestic and Industrial Waste Treatment Plant in Nairobi presented at the Sustainable Water Conference at the University of Nairobi, Chiromo, Kenya.

2. **Sewe, H.,** Njenga, J., Oyaro, N., Makayoto, M, OGW, and Mailutha, J. T. (5th -9th OCTOBER, 2009**).** Nutrient Levels in Dandora Domestic and Industrial Waste Treatment Plant: Current Status and Future Prospect presented at the 6th Chemical Society/East and Southern Africa Environmental Chemistry/ 8th Theoretical Chemistry in Africa International Conference at Mombasa Reef Hotel, Kenya.

Papers for Publication

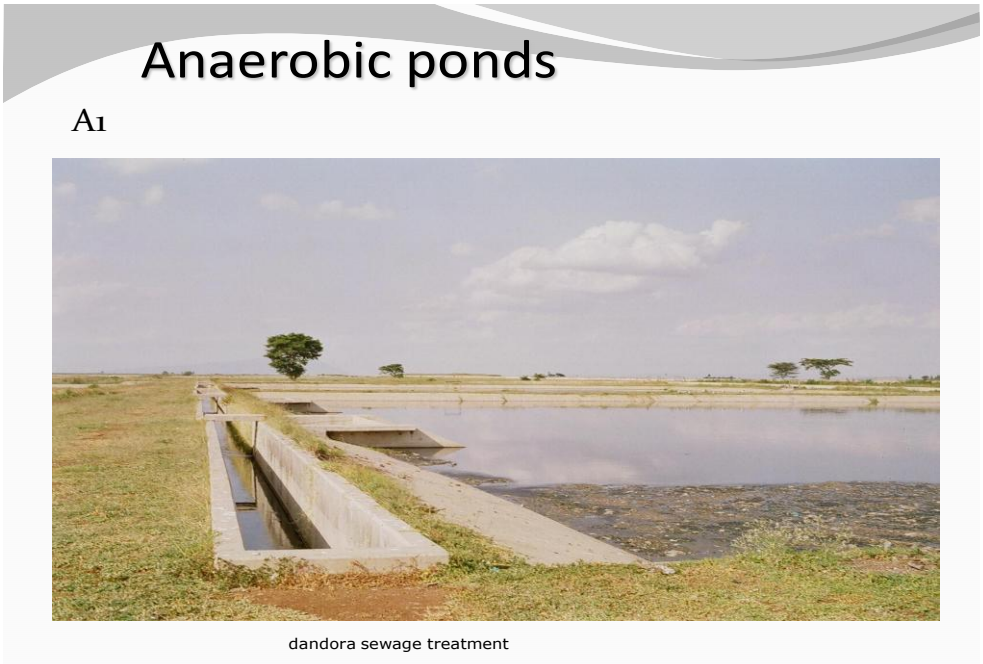
1. **Sewe, H.,** Njenga, J., Oyaro, N., Makayoto, M, OGW, and Mailutha, J. T. Physico-Chemical properties of wastewater in Dandora Domestic and Industrial Waste Treatment Plant. This paper is has been sent to Kenya Chemical Society for publication.

2. **Sewe, H.,** Njenga, J., Oyaro, N., Makayoto, M, OGW, and Mailutha, J. T. Nutrient Levels in Dandora Domestic and Industrial Waste Treatment Plant. This paper has been sent to Egyptian Chemical Society for publication.

APPENDICES

APPENDIX 1

APPENDIX 2



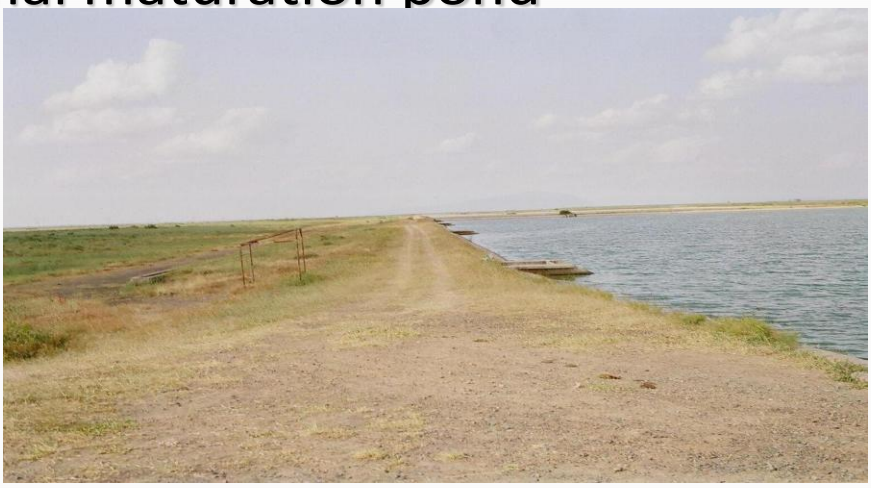
APPENDIX 3

Fucultative pond

dandora sewage treatment

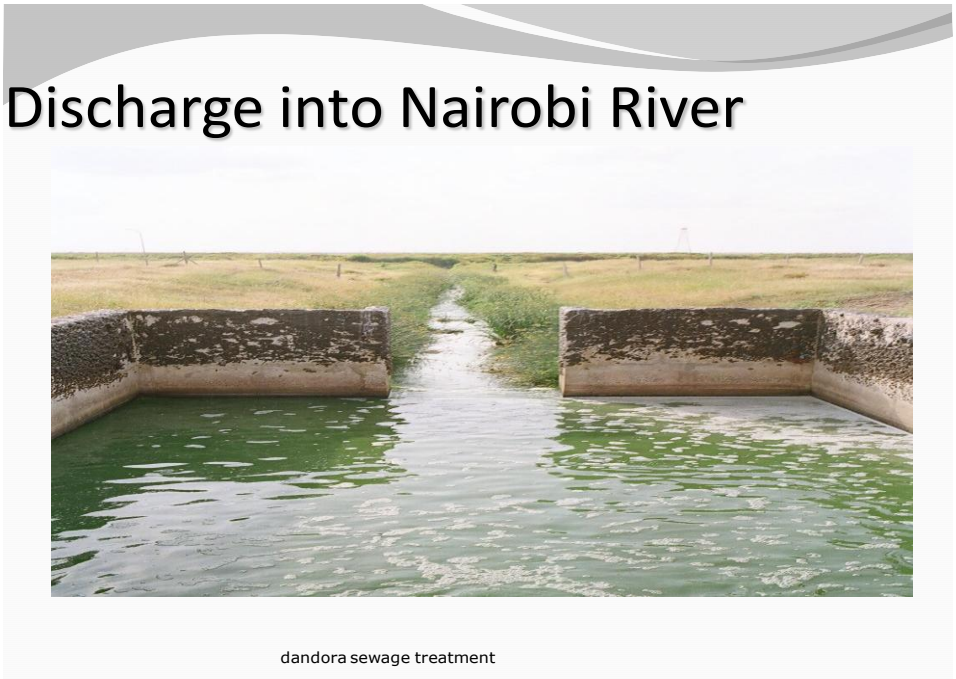
APPENDIX 4

Final maturation pond

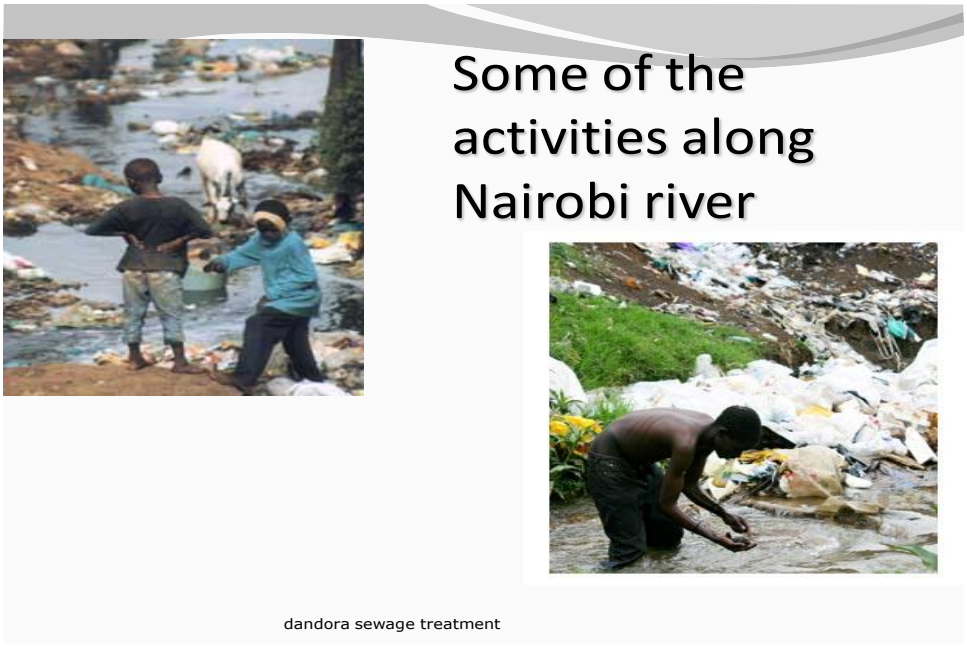


dandora sewage treatment

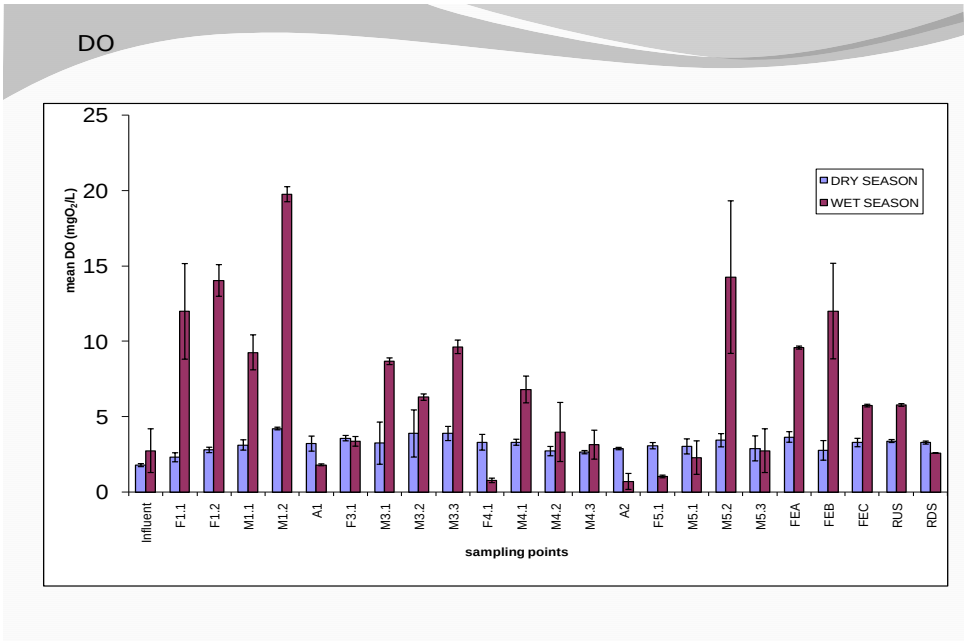
APPENDIX 5



APPENDIX 6



APPENDIX 7



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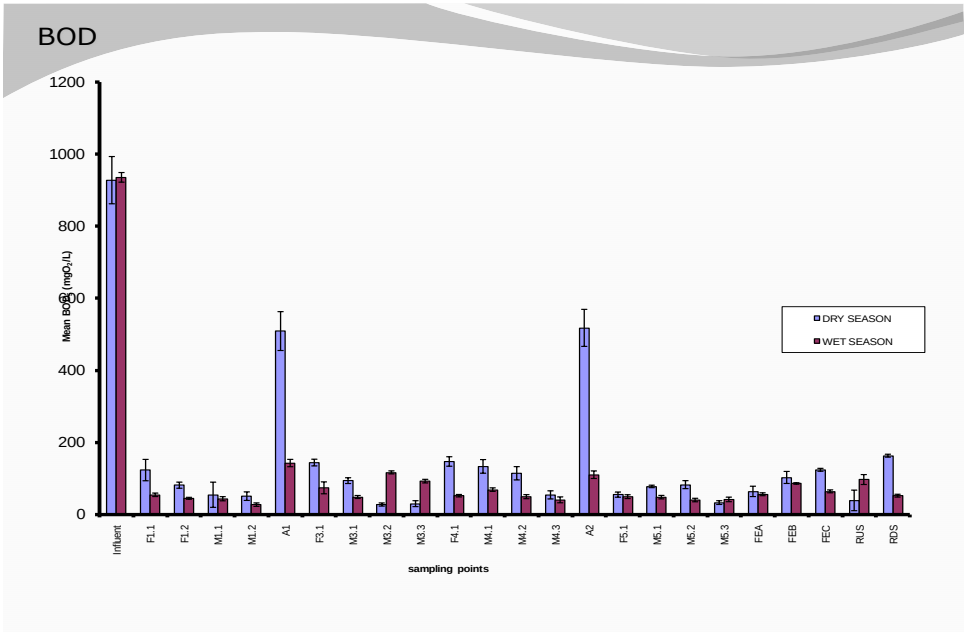

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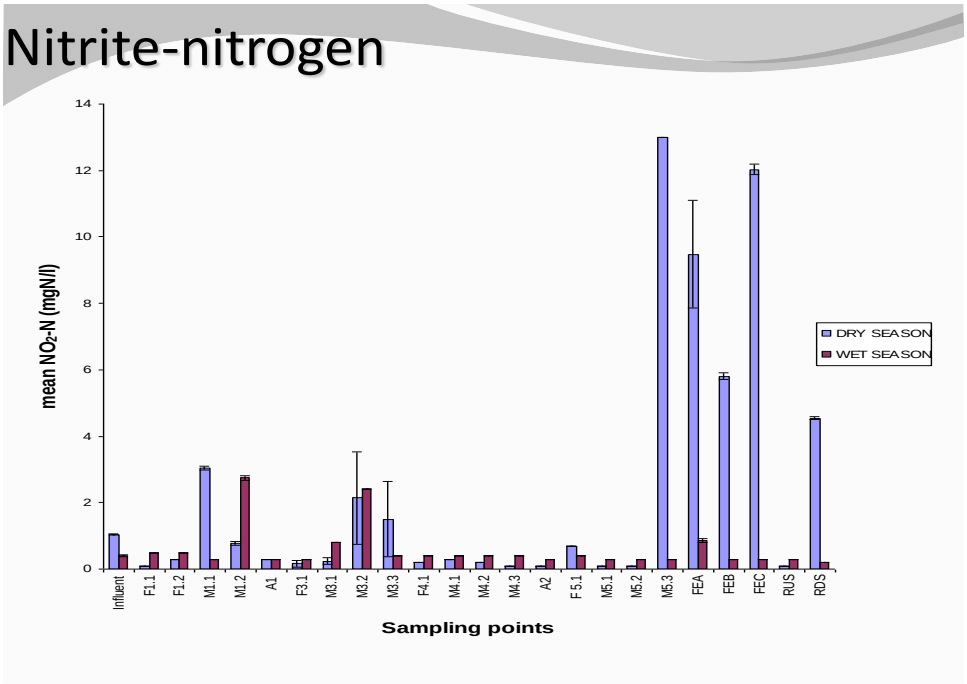

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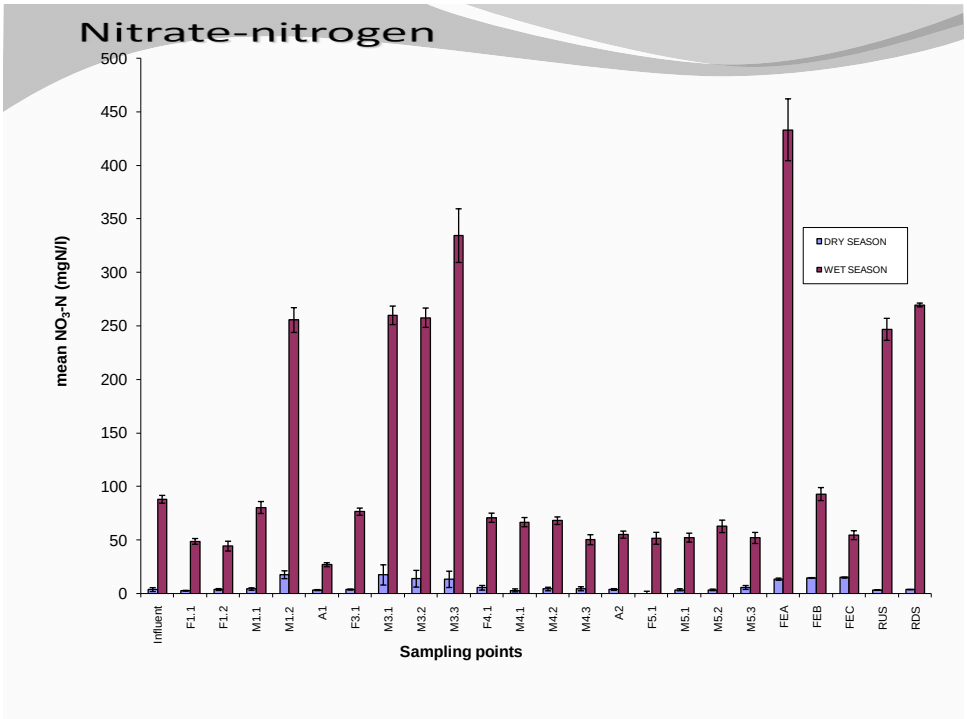

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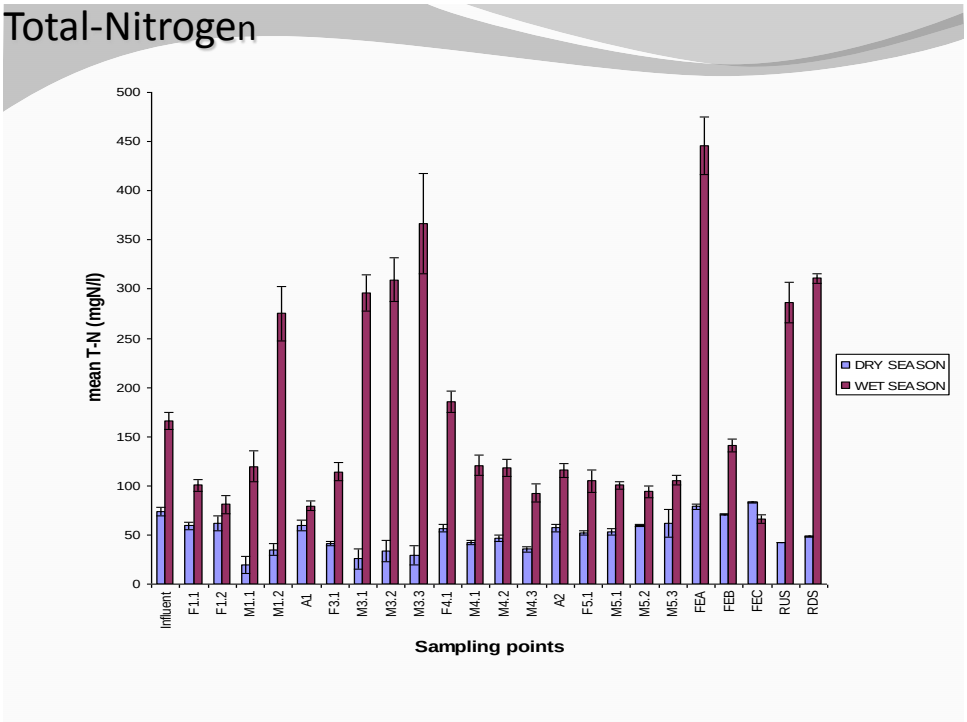

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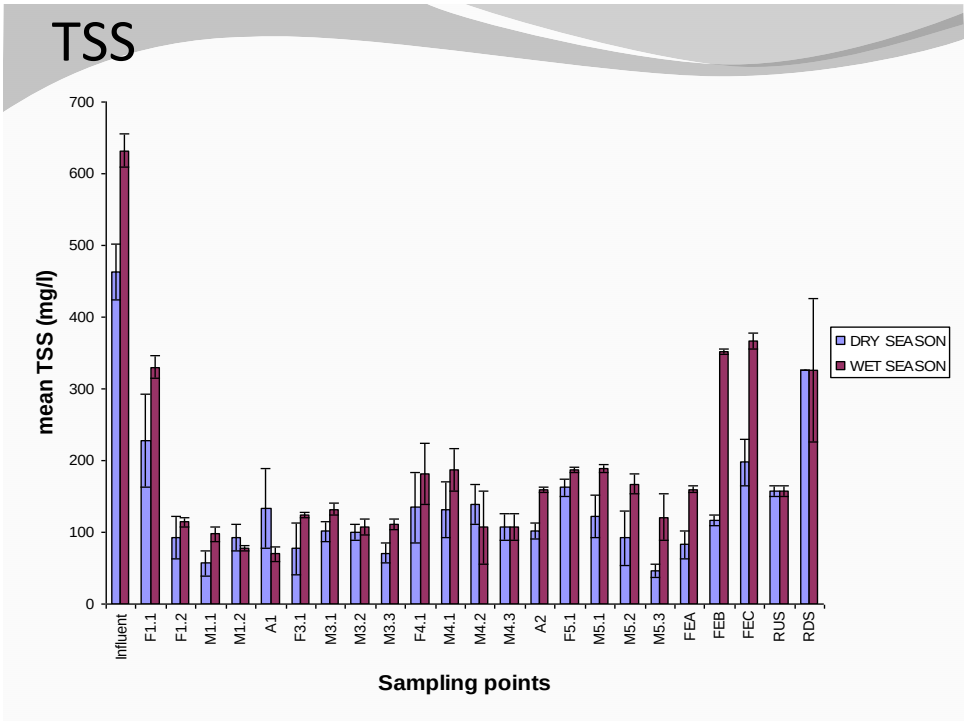

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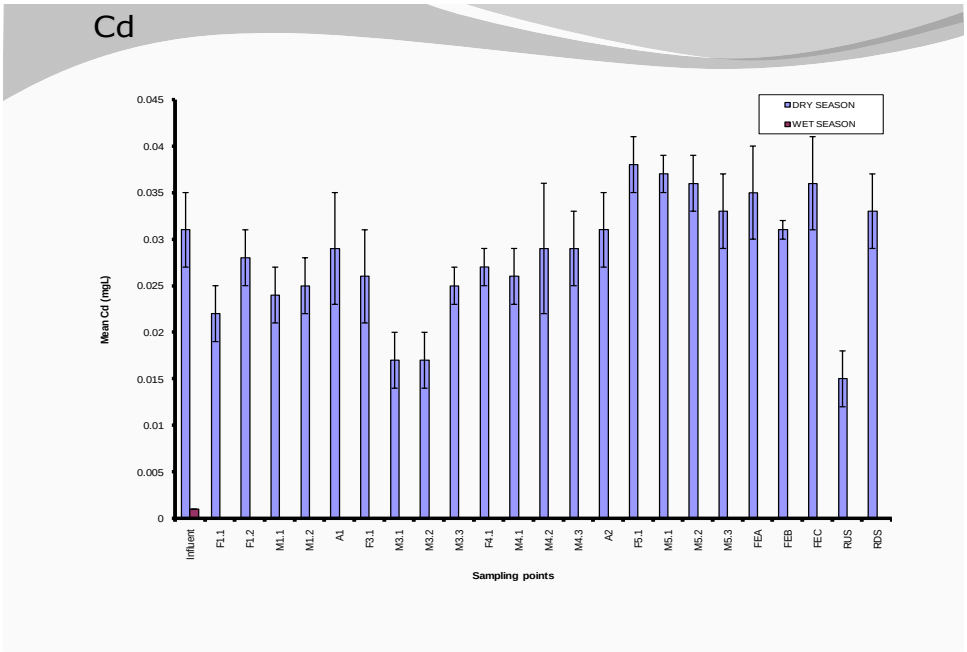
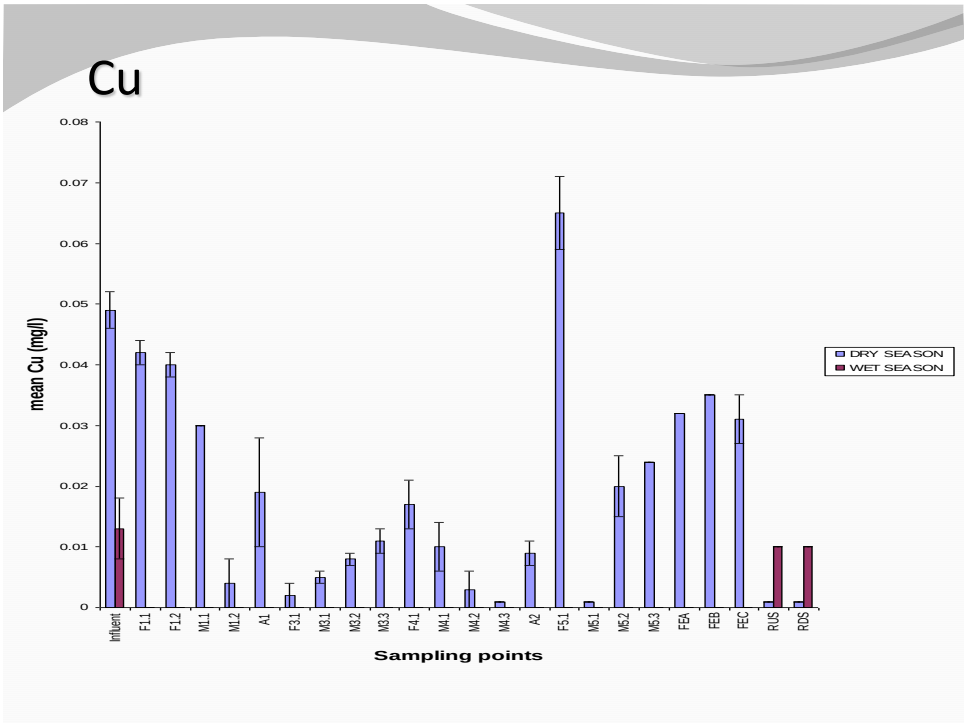


APPENDIX 14



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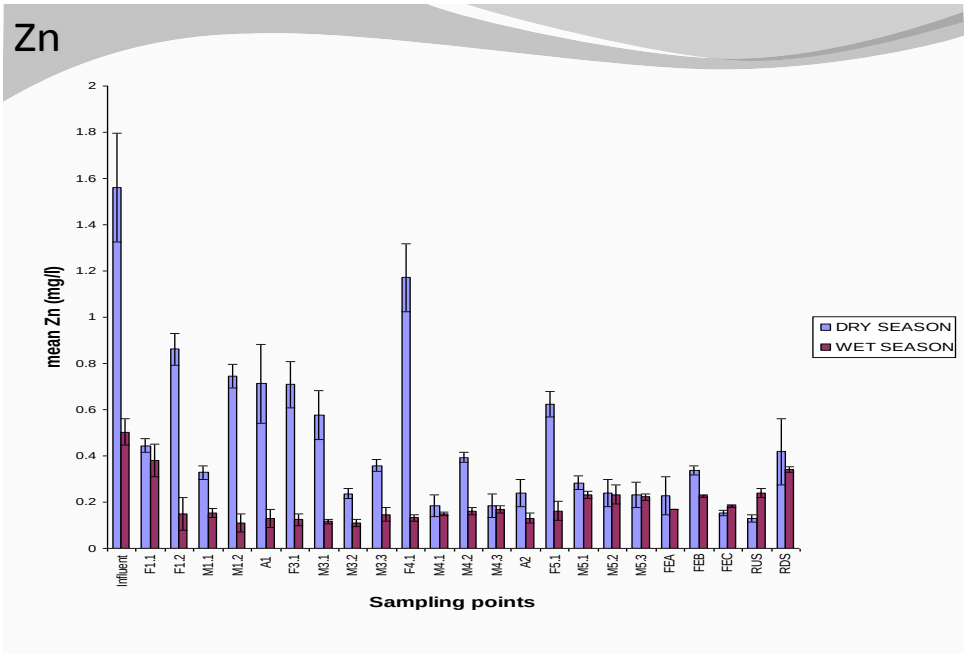
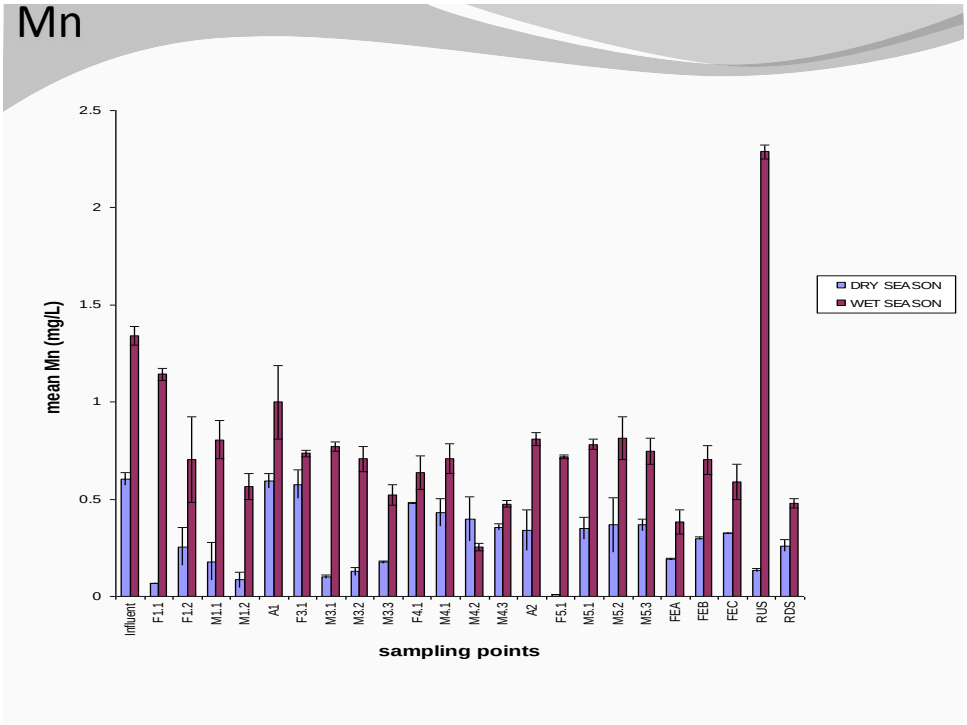
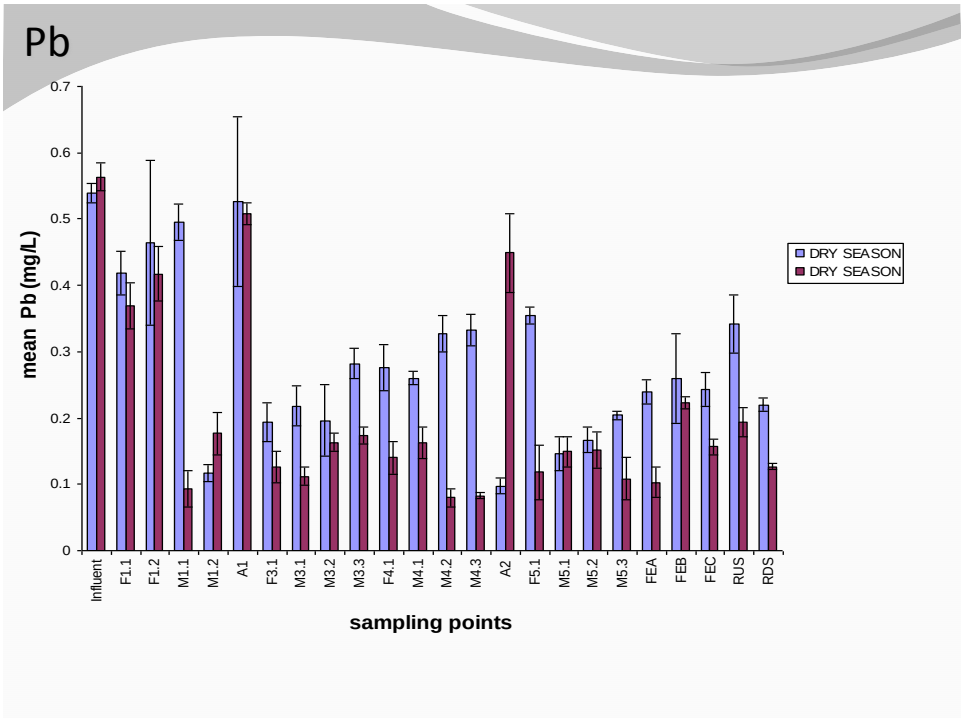


APPENDIX 16



APPENDIX 17


Pb
mean Pb (mg/L)
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0.6
0.5
0.4
0.3
0.2
0.1
0
Influent
F1.1
F1.2
M1.1
M1.2
A1
F3.1
M3.1
M3.2
M3.3
F4.1
M4.1
M4.2
M4.3
A2
F5.1
M5.1
M5.2
M5.3
FEA
FEB
FEC
RUS
RDS
sampling points
DRY SEASON
DRY SEASON