USE OF SLOW SAND FILTRATION TO IMPROVE TREATED EFFLUENT AT BOUNDARY SEWAGE TREATMENT PLANT (ELDORET) FOR IRRIGATION

BY

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DECLARATION

Declaration by the Candidate

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Declaration by the Supervisors

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TO MY DEAR PARENTS:

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ABSTRACT

Food insecurity in Kenya due to dependence on rainfall, coupled with drying up of rivers and wells during the dry season make it impossible to grow crops throughout the year. These factors have increased the demand on this scarce water and led to people living in urban and peri-urban areas resort to using sewage treated water to irrigate their crops. This informal practice raises concerns on health issues both to the farmers and consumers of the crops. The objectives of the present study were to determine the microbiological and physicochemical parameters at the various stages of sewage treatment at Boundary Sewage Treatment Plant during dry and wet seasons, if the treated water met national and international standards for wastewater to be used in irrigation and if slow sand filters were able to improve the quality of the water for irrigation. The study was undertaken at Eldoret Water and Sanitation Company and University of Eldoret Laboratories in February to early March 2012 for dry season and in June to July 2012 for the wet season. The BOD_5 technique was used in determining Biological Oxygen Demand, total coliforms and total aerobic bacteria were determined, COD digestion method and colorimetric method for COD, gravimetric method for both Total Suspended Solids and Total Dissolved Solids, temperature, pH and conductivity were determined. Slow sand filters made of sand sizes of 0.1 mm, 0.05 mm and another one made of 0.1 and 0.05 mm were put in a pipe of 2.6 feet in length. The data was analysed with one way Analysis of Variance (ANOVA), one sample t- test and dependency t- test using SAS 9.2 and 9.3 software and proportions. ANOVA showed that there was significant difference ($p < 0.05$) in BOD, COD, pH, total coliforms, TDS, TSS, conductivity, temperature during the two seasons at all the stages of treatment however total aerobic bacteria were not significantly different ($p > 0.05$) during wet season. The one sample t –test showed that the treatment plant was efficient for some of the parameters. Dependent t test analysis revealed that the sand filters improved the final effluent of Boundary Treatment Plant. The treatment Plant reduced COD by 89.23%, BOD by 86.27%, Total Suspended Solids by 58.46%, temperature by 6.73%, total coliforms by 99.68% and total aerobic bacteria by 26.73% however, Total Dissolved Solids, pH and conductivity increased by 79.02%, 3.74%% and 79.12% during dry season. Similar trends were also observed during wet season. Boundary Sewage Treatment Plant and the slow sand filters were capable of improving wastewater quality to the level that can be used for irrigation. Total coliforms was compared with irrigation standard of ≤ 1000 MPN/100 ml, pH with a range of 6.5 – 8.5, BOD with ≤ 30 mg/l, COD with ≤ 100 mg/l, TDS with ≤ 1200 mg /l and TSS with ≤30 mg/l. The means of the influent during dry season were; 4500 for total coliforms, 8.05 for pH, 82.67 for BOD, 169 for COD , 722.7 for TDS and 90 for TSS against the mentioned standards. The findings of the effluent during dry season were 33.33, 27.67, 28.33 for BOD from the 3 filters, 74.33, 62.33, 70 for COD, 81.67, 23.33, 26.33 for TSS and 960, 600, 813 for total coliforms against the standards. Means of the influent during wet season; 28 for BOD, 76.67 for COD, 1600 for total coliforms, 357.3 for TDS, 62 for TSS and 8.03 for pH in comparison with the standards and the means of the effluent were; 706.7, 400 and 440 for total coliforms and 55, 15, and 26 for TSS against the standards for irrigation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA:	Analysis of Variance
BOD:	Biological Oxygen Demand
COD:	Chemical Oxygen Demand
DO:	Dissolved Oxygen
ELDOWAS:	Eldoret Water and Sanitation
EMB:	Eosine Ethylene Blue
ES:	Effective Size
GMO:	Genetically Modified Organism
MPN:	Most Probable Number
N / A:	Nutrient Agar
NEMA:	National Environmental Management Authority
SAR:	Sodium Absorption Ratio
SSF:	Slow Sand Filtration
SS:	Suspended Solids
TAB:	Total Aerobic Bacteria
TDS:	Total Dissolved Solids
TF:	Trickling Filter
TSS:	Total Suspended Solids
UC:	Uniformity Coefficient
USEPA:	United States Environmental Protection Agency
WHO:	World Health Organization
WSP:	Waste Stabilization Pond

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CHAPTER ONE

INTRODUCTION

1.1 Wastewater

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry and / or agriculture and can encompass a wide range of potential contaminants and concentration (http://en.wikipedia.org/wiki/wastewater, 2009). Wastewater generated from agricultural and food operations have distinctive characteristics that set it apart from common municipal wastewater: it is biodegradable and non-toxic, but has high concentration of BOD and suspended solids (EPA, 2001). Sometimes, industrial wastewaters are treated partially before their discharge into sewers, or else are treated separately through suitable treatment processes so that the treated effluent is safe (Punmia, 1998). The amount of sewage that flows in the sewers is dependent upon the habit of the people. For instance, if the people use more water during a certain time during the day, there will be more sewage at that particular time of the day. More often, people tend to use more water in the morning. Therefore there is a greater quantity of sewage flowing during mornings than at mid-day. This flow becomes a lot again during the evening (Ramesh, 2004).

1.2 Wastewater reuse

The term wastewater reuse is often used synonymously with the terms wastewater recycling and water recycling (McCornick *et al.,* 2004) but they are actually different terms. Wastewater reclamation involves the treatment or processing of wastewater to make it reusable (Asano, 1998). Wastewater reuse or water reuse is the beneficial use of treated water (Asano, 1998) and wastewater recycling or water recycling is the use of wastewater that is captured and redirected back into the same water use scheme (Metcalf and Eddy, 2003). EPA (2004) defines wastewater reuse as “using wastewater from one application to another application.”

Wastewater use is a growing precise worldwide. As fresh water sources become scarce, wastewater has become an attractive option for conserving and expanding available water supplies. Wastewater can have many types of applications, including irrigation of agricultural land, aquaculture, landscape irrigation, urban and industrial uses, recreation and environmental uses and artificial ground water recharge (Asano *et al.,* 2007). Principally, all wastewater can be used for all purposes for which fresh water is used, given appropriate treatment and reliable operation. With a few exceptions worldwide, wastewater applications are restricted to non-potable uses, or at most to indirect potable uses. Wastewater use in agriculture is by far the most established application and one with the largest tradition (Jimenez and Asano, 2008). In most cases the irrigated land are located in or near the urban areas where the wastewater is generated. Estimates on wastewater use worldwide indicate that about twenty million hectares of agricultural land is irrigated with treated and untreated wastewater (Jimenez and Asano, 2008).

Wastewater reuse can become a significant source of non-point source (NPS) pollution (Huang and Zia, 2001), including water pathogens. This can cause serious health risks when people are exposed to the contaminated wastewater.

Wastes are treated by a variety of sewage treatment processes that are aimed at reducing the Biological Oxygen Demand (BOD) and removing nutrients that could cause eutrophication of the receiving waters. Sewage treatment can involve physical removal of solids, biological decomposition of organic compounds, chemical, physical or biological removal of the other constituents such as heavy metals, nitrogen and phosphates and disinfection to remove potentially pathogenic micro organisms (Ramesh, 2004).

1.4 Statement of the problem

Increased population, urbanization, improved living conditions and economic developments have driven the generation of increased volumes of wastewater by the domestic, industrial and commercial sectors (Lazarova and Bahri, 2005; Asano *et al.*, 2007; Qadir *et al.*, 2009).

There has been food insecurity in Kenya due to overdependence on rainfall which may be experienced twice in a year, once in a year, may be inadequate, and may not fall at all or sometimes even delay. Furthermore, due to global warming, the climate of the country and the world at large may change obstructing the normal pattern of climate leading to food insecurity. Genetically Modified Organisms (GMOs) that were intended to solve food insecurity have raised a lot of public concern on their consumption hence not solving their intended purpose.

Kenya, including some of the residence within Eldoret town experience water rationing especially during dry season. This shortage could be partly due to the rapid expansion of the town and also due to farmers within Eldoret town who earn their livelihood by producing vegetable and tree seedlings using treated water from Eldoret Water and Sanitation Company (ELDOWAS). These factors have increased the demand on the diminishing water and led to people living in urban and peri-urban areas to resort to using sewage treated water to irrigate their crops. This practice raises concerns on health issues both to the farmers and consumers of the crops and has raised questions on the microbiological quality of this water. This study investigated both microbiological and physicochemical aspects of Boundary Sewage Treatment Plant and whether slow sand filters could improve the quality of wastewater to meet the recommended standards to be used for crop irrigation.

1.5 Justification

Water scarcity in many parts of Kenya is a limiting factor against many development activities. Hence, there is need for water enhancement strategies. The current water availability is estimated at 650 m^3/ year per capita, and could drop to about 350 m^3/ year by the year 2020 (Ngigi and Macharia, 2006). With dropping per capita of fresh water availability, there is increase dominance of wastewater in the water balance and this makes wastewater a very important source of irrigation water for urban agriculture (Githuku, 2009).

Wastewater provides a reliable alternative source of water during dry season, permitting production of multiple crops throughout the year. Production in the off-season, when larger scale dry farming is limited, gives urban and peri-urban agriculture a competitive advantage. Wastewater also contains valuable plant nutrients such as cobalt, iron, manganese, molybdenum. Crop yields are higher when crops are irrigated with undiluted wastewater than with fresh water (Buechler *et al.,* 2002; Drechsel *et al.,* 2002; Scott *et al.,* 2004).

The trend towards growing water stress is likely to accelerate due to climate change. Changes in weather (temperature, precipitation, drought, timing of thaw, frequency of hurricane, rising of sea level and elevated storm) are all physical processes that have implications on the development and well being of human settlements (Lemmen *et al.,* 2008). Global warming is destabilizing the world's weather system with the most severe negative agriculture impacts expected in developing countries where food is produced mainly under rainfed agricultural system and are least capable to adjust technologically to its effects (Vorosmarty *et al.,* 2000).

Treated wastewater is a significant part of marginal water in many countries. However, possible high concentration of salts, heavy metals or pathogenic microorganisms in wastewater may result in negative effects on plant growth and quality (Morales *et al.,* 2001).

Eldoret gets its water from two sources; Two river dam in Kaptagat and Chebara dam in Elgeiyo – Marakwet county. The two sources produce over 20,200 m^3 / day of water. While most of the water distributed to consumers is treated, water from wells remains untreated. The water reticulation system is inadequate with only about 180,000 households within the municipality being covered (Cheserek *et al.,* 2012).

In fact it has been argued that " in terms of quantity, the greatest potential for wastewater reuse is through using properly treated wastewater for irrigation purposes, as a substitute for conventional ground and surface water sources" (AHT Group AG, 2009).

1.6 Objectives

1.6.1 Main objective

To determine if use of slow sand filtration can improve treated effluent at Boundary Sewage Treatment Plant (Eldoret) for irrigation

1.6.2 Specific objectives

1. To determine the microbiological and physico-chemical parameters of the treated wastewater from all stages of Boundary Sewage Treatment Plant during dry and wet seasons.
2. To determine if the treated wastewater meets national and international standards for irrigation.
3. To determine if the use of slow sand filters can improve the quality of treated wastewater for irrigation.

1.7 Hypotheses

1. H_O: The microbiological and physico – chemical parameters do not differ at all stages of Boundary Sewage Treatment Plant during dry and wet seasons.

   H_A: The microbiological and physico – chemical parameters differ at all stages of Boundary Sewage Treatment Plant during dry and wet seasons
2. H_O: The treated wastewater does not meet the recommended national and international standards for wastewater for irrigation.

H_A: The treated wastewater meets the recommended national and international standards for wastewater for irrigation

3. H_O: Slow sand filters may not improve the quality of the treated wastewater for irrigation

   H_A: Slow sand filters may improve the quality of treated wastewater for irrigation

CHAPTER TWO

LITERATURE REVIEW

2.1 Sewage and wastewater microbiology

Wastewater is derived from domestic sewage or industrial processes, which for reasons of public health and for recreational, economic and aesthetic considerations cannot be disposed off merely by discarding into convenient lakes or streams. Rather, the undesirable and toxic materials in the water must first be either removed or rendered harmless. Inorganic materials such as clay, silt and other debris are removed by mechanical and chemical methods, and microorganisms participate only casually or not at all. However, if the material to be removed is organic in nature, treatment usually involves the activities of microorganisms, which oxidize and convert the organic matter to carbon dioxide. Wastewater treatment also results in the elimination of pathogenic microorganisms, thus preventing this organism from getting into rivers or other supply forces (Brock *et al.*, 1994).

2.2 Composition of sewage

Sewage contains 99.9% water. Solids which barely comprise 0.1% are partly organic and partly inorganic or partly in suspension and partly in solution. In addition, sewage is charged with numerous living organisms derived from faeces, some of which may be agents of diseases (Ramesh, 2004).

2.2.1 Chemical characteristics

An understanding of the chemical composition of wastewater is important since this allows an understanding of reactions and interactions with the organic and inorganic compounds (Roila *et al.*, 1994). Chemical characteristics of wastewater include the amount or concentration of carbohydrates, fats, oils and grease, pesticides, phenols, proteins, surfactants and volatile organic matter, alkalinity and chlorides, heavy metals, nitrogen, phosphorous, sulphur, hydrogen sulphide and methane (Tchobanoglous and Burton, 1991)

2.2.2 Microbiological characteristics

Since the composition of wastewater varies, it is to be expected that the types and number of organisms will fluctuate. Fungi, protozoa, algae, bacteria and viruses are present. Raw sewage may contain millions of bacteria per mililitere including the coliforms, *Streptococci*, anaerobic spore-forming bacilli, the *proteus* group and other types originating in the intestinal track of humans (Pelczer *et al.*, 1993). Sewage is also a potential source of pathogenic protozoa, bacteria and viruses. The causative agents of dysentery, cholera and typhoid fever may occur in sewage. The poliomyelitis virus that causes infectious hepatitis and the coxsackie viruses are excreted in the faeces of infected hosts and thus appear in the sewage (Pelczer *et al.*, 1993).

2.3 Wastewater reuse in Kenya

Although the urban poor continue to use wastewater for irrigation purposes, wastewater reuse in Kenya is illegal. A study undertaken in 2006 and 2007 by Githuku (2009), for example, revealed that only 50% of the wastewater generated in Nairobi ends up in the treatment facilities while the rest is used for cultivation of over 720 ha using raw sewage. The study established that over 100,000 households in Kahawa, Soweto, Kibera, Mailisaba, Maringo and Kariobangi South use raw sewage for cultivation.

The crops grown at Kibera using wastewater include sugarcane, fodder crops (napier grass), maize and vegetables (kales, spinach and indigenous African leafy vegetables such as amaranth and black nightshade) (Githuku, 2009).

Polluted water might expose people to health risks such as increased vulnerability to cancer as some chemicals in wastewater are carcinogenic, viral infections and exposure to aerosol transmitted diseases (Ongerth and Ongerth, 1982). Further, Poucher *et al.* (2007) noted that although land application of sewage sludge can improve soil physical properties and increase soil organic matter content, there are also disadvantages such as the possible transfer of pathogenic microorganisms to the soil that may include *Escherichia coli*, *faecal coliforms* and *enterococci*. In a study on the mineralization of the herbicide Atrazine in slurries from soils irrigated with treated wastewater, Mesaphy and Mandelbaum (1997) noted that the rate of herbicide mineralization decreased significantly when soils were irrigated with wastewater. This indicated that the herbicide, which could be present in wastewater, had capacity to interfere with biochemical processes in the soil.

Scott *et al.* (2000) summarized the major environmental threats of wastewater reuse. The authors observed that percolation of nutrient-rich waters through the soil could lead to the degradation of ground water. The biggest health risk associated with the use of wastewater for irrigation is the microbial risk which arises due to the pathogens like disease causing organisms that are usually present in untreated or partially treated and at some level also in treated wastewater (Feachem *et al.*, 1983).

2.4 Water guidelines in Kenya

Kenya's National Environmental Management Authority (NEMA) has set out guidelines on irrigation water quality and quality requirements discharge into the environment. Schedules eighth and ninth schedules of the NEMA water quality standards give the quality standards for water to be to be used for irrigation (Tables 2.1 and 2.2). (Government of Kenya, 2006). EPA guidelines for selected states in the United States are summarised in table 2.3, while Jordan allowable water reuse standards are given in table 2.4.

Table 2.1: National Environmental Management Authority microbiological quality guidelines for wastewater use in irrigation

Reuse conditions	Exposed group	Intestinal nematodes	Coliforms MPN /100 ml
Unrestricted irrigation (crops likely to be eaten uncooked, sports field, public parks)	Workers, consumers, public	< 1	< 1000**
Restricted irrigation Cereal, crops, industrial crops, fodder crops, pasture and trees***	Workers	< 1	No standard recommended

***** Ascaris lumricoides, Trichuris trichura and human hookworms

****** A more stringent guideline (< 200 coliform group of bacteria per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

******* In the case of fruit trees, irrigation should cease two weeks before fruits are picked and fruit should be picked off the ground. Overhead irrigation should not be used.

Table 2.2: National Environmental Management Authority standards for irrigation water

Parameter	Permissible levels
PH	6.5 to 8.5
Aluminium	5 (mg/l)
Arsenic	0.1 (mg/l)
Boron	0.1 (mg /l)
Cadmium	0.5 (mg/l)
Chloride	0.01 (mg/l)
Chromium	1.5 (mg/l)
Cobalt	0.1 (mg/l)
Copper	0.05 (mg/l)
E.coli	Nil / 1000 ml
Fluoride	1.0 (mg/l)
Iron	1 (mg/ l)
Lead	5 (mg/l)
Selenium	0.19 (mg/l)
Sodium Absorption Ratio (SAR)	6 (mg/l)
Total Dissolved Solids	1200 (mg/l)
Zinc	2 (mg/l)

Table 2. 3: Guidelines for agricultural, food crops and reclaimed water in the states of US

	Arizona	California	Florida	Hawaii	Navada	Texas	Washington
Treatment	Secondary treatment, filtration and disinfection	Oxidized, coagulated, filtered and disinfected	Secondary treatment, filtration and high level disinfection	Oxidized, filtered and disinfected	Secondary treatment, filtered and disinfected	NS (1)	Oxidized, coagulated, filtered and disinfected
BOD 5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5 mg/l	NS	NS	NS	30 mg/l
Turbidity	2NTU(Avg) 5NTU(Max)	2NTU(Avg) 5NTU(Max)	NS	2NTU (Max)	NS	3NTU	2NTU(Avg) 5NTU(Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	None detectable (Avg) 23/100 ml (max)	2.2 / 100 ml (Avg) 23/100 ml (Max in 30 days)	75% of samples below 25/ 100 ml (max)	2.2/100 ml (Avg) 23/100 ml (max in 30 days)	200/100ml (Avg) 400 / 100 ml (max)	20/ 100 ml (Avg) 75/ 100 ml (max)	2.2 / 100 (Avg) 23/ 100 ml (max)

NS – Not Specified by State Regulation

Source*: EPA*, *Guidelines for Water Reuse*, *September* 2004, EPA / 625/R- 04/108; Table 4-5 page 155.

Table 2. 4: Allowable limits of wastewater, reuse and criteria for reuse in Jordan

Parameter	UNIT	A[1]	B[2]	C[3]
Biological Oxygen Demand	Mg/l	30	200	300
Chemical Oxygen Demand	Mg/l	100	500	500
Dissolved Oxygen	Mg/l	>2	-	-
Total Suspended Solids	Mg/l	50	150	150
pH	Unit	6 -9	6 – 9	6-9
Turbidity	NTU	10	-	-
Nitrate	Mg/l	30	45	45
Total Nitrogen	Mg/l	45	70	70
Escherichia coli	Most probable number or colony forming unit/ 100 ml	100	1000	-
Intestinal helminthes eggs	Egg/l	≤1	≤1	≤1

[1]A cooked vegetables, parks, playgrounds and sides of roads within city limits.

[2]B Fruit trees, sides of roads outside city limits and landscape

[3]C Field crops, industrial crops and forest trees

Source Mediware, 2005a

2.5 Wastewater treatment

The systematic treatment of wastewater was started in the late 1800s and early 1900s (Tchobanoglous and Burton, 1991). Wastewater often contains high levels of organic matter from industrial and agricultural wastes and from human wastes. It is necessary to remove organic matter by the process of wastewater treatment. Depending on the effort given to this task, it may still produce waters containing nutrients and some micro organisms which can be released to rivers and streams (Prescott *et al.*, 2002).

Modern methods of liquid waste treatment are aimed at reducing the amount of organic matter in the waste so that its oxygen demand is lessened before it is discharged into a water body. This must be done to maintain acceptable water quality (Atlas, 1995). There are several different approaches to reducing the amount of organic matter, and hence the requirement of oxygen. These methods employ combinations of physical, chemical and microbiological means (Atlas, 1995).

2.6 Conventional sewage treatment

Effluent treatment is conventionally divided into five levels; pre-treatment, minimal treatment, preliminary treatment basic (primary) treatment, full (secondary treatment) and advanced (tertiary) treatment (Richard and Hirji, 2003).

2.6.1 Pre-treatment

Industrial activities or agricultural processing may create pollutants that can be most effectively treated at the point of generation. Such treatment prior to discharge into a sanitary sewer is pre-treatment. In many countries, licenses for industrial discharges to sewers require that the influent meet certain water quality standards. When an influent concentration of some particular pollutant is unusually high, pre-treatment is usually necessary and cost-effective (Richard and Hirji, 2003). This process is used in the treatment of industrial wastewater such as textile wastewater.

2.6.2 Minimal treatment

Raw wastewater typically contains materials that clog or impair pumps or other equipments needed to discharge wastewater reliably and causes unsightly conditions in the receiving water. Solid waste inappropriately dumped in sewers is another common problem. Minimal treatment removes this material and is used as first step in nearly all wastewater treatment facilities. Septic tanks are a form of minimal treatment (Richard and Hirji, 2003).

2.6.3 Preliminary treatment

Sewage undergoes preliminary treatment to make it suitable for the main treatment processes. This includes screening and removing grit, oil and grease (Water UK, 2006). A screen removes large floating objects such as rags, cans, bottles and sticks that may clog pumps, small pipes and downstream processes. The screens vary from course to fine and are constructed with parallel steel or iron bars with openings of about half an inch, while others may be made from mesh screens with much smaller openings (EPA, 2004). The cleared material (screenings) is washed and safely disposed off at a landfill site (Water UK, 2006).

Sewage contains grit and dirt from roads or cleaning activities. These are inert material that cannot be treated and it is removed by a settlement process that allows the lighter organic material to remain in suspension for the next treatment stage (Water UK, 2006).

The grease and fatty oils in sewage forms scum in sedimentation tanks and interfere with oxidation process in aeration tanks. Skimming tanks are about one meter deep and the scum accumulations are removed manually or buried or burnt (Ramesh, 2004).

2.6.4 Primary sewage treatment

This stage follows the preliminary stage of treatment where more solid matter settles out. About 40 -60% of suspended solids are removed from sewage by settling. This settling treatment and flocculating chemicals that increase the removal of solids are sometimes added (Tortora *et al.*, 2010). Primary treatment removes about 25-35% of the BOD of the sewage. They are deep ponds, 3 – 5 meters deep, allowing for low oxygen levels conditions to prevail (Sperling, 2007). The oxygen consumption rate in these ponds is much higher than the oxygen production rates, which creates the anaerobic condition. Particular bacteria have evolved to thrive in oxygen-depleted conditions, as they breakdown organic materials into methane and carbon dioxide (Sperling, 2007). The BOD and solid concentration in the raw wastewater are reduced by sedimentation and anaerobic digestion (Mara, 2003). Anaerobic treatment is more suited to wastewater with high BOD (IETC – UNEP, 2002) and therefore useful at reducing high concentration of BOD and Suspended Solids from agriculture and food industries.

A properly designed anaerobic pond can achieve around 60% of BOD removal at 20^{0}C and one day hydraulic retention time is sufficient for wastewater with a BOD of up to 300 mg/l and temperature higher than 20^{0} C (Mara, 2003). At temperature below 15^{0} C, the digestion process slows down and the dominant process is thought to be sedimentation (Mara and Pearson, 1998). With typical detention times (weeks to months) settling is responsible for the removal of the majority of suspended solids and organic nutrients entering anaerobic ponds (Reed *et al.*, 1995). Gravitational settling can account for removal rates of > 50% for total solids and volatile solids and 30% for nitrogen and phosphorus. A reduction of between 30 – 40% in the number of coliforms is obtained (Ramesh, 2004).

The major problems of anaerobic ponds are the odour and the increase in ammonia and sulphide concentration caused by the anaerobic process (Mara and Pearson, 1998; Crites *et al.*, 2006). Besides BOD, COD and SS removal anaerobic pond is efficient in removal of *Vibrio cholerae* due to their high sulphide concentration (Mara *et al.*, 2001).

Primary treatment can physically remove 20 to 30% of the BOD that is present in particulate form. In this treatment, particulate material is removed by precipitation of small particulates and settling in basins and tanks (Prescott *et al.,* 2002).

2.6.5 Secondary sewage treatment

To achieve an acceptable reduction in BOD, secondary treatment by various means is necessary. In secondary sewage treatment a small portion of the dissolved organic matter is mineralized. The larger portion is converted into removable solids (Atlas, 1995).

Trickling filter (TF) is one of the secondary sewage treatment. It is an aerobic treatment system utilising micro organisms attached to a media to remove organic matter from wastewater that passes over, around, through or by the media (Mackne *et al.*, 1998). In sewage 40 – 80% of BOD is particulate (Parker *et al.*, 2006) and the remainder dissolved. The trickling filter removes 40 – 70% of this BOD (Tchobanoglous *et al.,* 2005). Sewage is distributed by a sprinkler resolving over a media of porous material which is normally an artificially constructed bed consisting of broken stones, bricks or other suitable material (Ramesh, 2004).

In trickling filters, microorganisms establish a strong attachment to the uneven surface of the media (rocks, stones or plastic) and biofilms develop above the plane of the media, to a depth of about 2 mm. Small organic molecules diffuse into microbial cells in the biofilm, providing carbon and nutrients for microbial cell growth. To remove the larger sized molecules and particulate matter BOD, these particles must be trapped in the biofilm, so they can be degraded into small enough particles for diffusion to occur. The larger molecules and particulates become trapped in the biofilm by a ‘glue’ (extracellular polymeric substances EPS) secreted by the microbial cells. The EPS also attach the microorganisms to the media (Boltz *et al.,* 2006). Enzymes bound to the microorganism cells in EPS breakdown the particulates through hydrolysis, into smaller and smaller units (Confer and Logan, 1998), until the compounds are small enough to diffuse across the cell membrane. The organic material is completely mineralised to carbon dioxide, ammonia, nitrate, sulphate and phosphate in the extensive biofilm (Madigan *et al.,* 2009). Trickling filter design also includes an open under drain system that collects the filtrate as well as solids and also serves as a source of air for the micro organisms on the filter (Mackne *et al.,* 1998). The treated wastewater and solids from the trickling filter are piped to a settling tank where the solids are separated. Usually part of the liquid from the settling chamber is recirculated to improve wetting and flushing of the filter medium, optimising the process and increasing the removal rate (EPA, 2000). Trickling filter removes 80 to 85% of the BOD (Tortora *et al.,* 2010).

Chemical Oxygen Demand (COD) test measures not only the oxygen equivalent of the waste organic matter but also that of the microbial cells. The oxygen demand associated with microbial cells is only partially exerted during a BOD test, also some of the organic compounds measured by the COD determination may not be metabolized by the microorganism in either the BOD bottle or the biological treatment process (Ramesh, 2004). A drawback of this method is that nutrient overload may lead to excess microbial slime reducing aeration and percolation rates and leads to removal of trickling filter bed. Trickling filter method cannot be used during cold winters when the temperatures are very low since the growth rate of the organisms becomes very low (Atlas, 1995).

Nitrogen generally present in wastewater is reduced form of ammonia, is removed during conventional wastewater treatment by two sequential biological processes; nitrification and denitrification (Osada *et al.,* 1995; Wicht and Beier, 1995; Tallec *et al.,* 2006a; Kampschreuer *et al.,* 2008b). The nitrification process produces acid. This acid formation lowers the pH of the biological population in the aeration tank and causes a reduction of the growth rate of nitrifying bacteria. Denitrification occurs where oxygen levels are depleted and nitrate becomes the primary oxygen source of microorganisms (Mackne *et al.,* 1998). The nitrate is reduced to nitrous oxide (N_2O), and in turn, nitrogen gas (N_2). Since nitrogen gas has low water solubility, it escapes into the atmosphere as gas bubbles. Denitrification is an alkalinity producing process (Mackne *et al.,* 1998).

2.6.6 Oxidation ponds (stabilization ponds or lagoons)

The presence of algae in the aerobic and facultative zones is essential for the successful performance of facultative ponds (US EPA, 2002b). In aerobic treatment ponds, aerobic microorganisms use dissolved oxygen to degrade the organic matter into CO_2, water and cell biomass. Passive or naturally aerated ponds rely on oxygen produced by phytoplankton during photosynthesis and to a lesser extend diffusion of oxygen from the air into surface layers (Shilton, 2005). Their major function is to ensure the removal of pathogens, excess nutrients and algae (Mara, 2012). Waste stabilization pond technology is quite useful natural method for wastewater treatment as it is cost effective with a high efficiency for removing pathogenic microorganisms. Waste stabilization ponds (WSP) are intensively used for treating domestic sewage in tropical and subtropical countries due to sufficient sunlight and temperature that are normally key factors for the efficient removal of potential pathogens (Nascimento, 1987).

Maturation ponds are generally shallower than the other types of ponds. They range in depth from 0.9 – 1m (Mara, 2012). This is to allow light penetration to the bottom and aerobic conditions throughout the whole depth and ensure that there are substantial amounts of treatment of wastewater.

The position of oxypause (the depth at which the dissolved oxygen concentration reaches zero) similarly changes, as does the pH. This is so, since at peak algal activity carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, leaving an excess of hydroxyl ions with the result that the pH can rise to above 9 which kills faecal bacteria (Mara and Pearson, 1998). This also creates conditions favourable for ammonia removal via volatilisation (US EPA, 2002b). Anaerobic fermentation occurs at the bottom layer of the lagoon (US EPA, 2002b).

The size and number of maturation ponds needed in a system is normally determined by the required retention time to achieve a specified pathogen concentration and organic matter (The water treatment, 2012). For phosphorous removal aerobic and anaerobic conditions are used alternatively in a series of treatments and phosphorous accumulate in specially adapted microbial biomass as polyphosphate (Prescott *et al.*, 2002).

The principal factors involved in bacterial reduction are retention time (Lloyd *et al.*, 2002), exposure to sunlight (Curtis *et al.*, 1992) and temperature.

2. 6.7 Tertiary treatment

This stage purifies wastewater more than is possible with primary and secondary treatments. The goal is to remove such pollutants as non-biodegradable organic material like polychlorinated biphenyls, heavy metals and minerals (Ramesh, 2004). Tertiary treatment is typically used to remove nutrients particularly nitrogen and phosphorous or to protect waters for example, mountain lakes – with limited natural ability to degrade organics (Richard and Hirji 2003). Organic pollutants can be removed with activated carbon filters. Phosphate is usually precipitated as calcium or iron phosphate by addition of lime. Excess nitrogen may be removed by “stripping”, volatilization as ammonia at a higher pH (Prescott *et al.,* 2002). Ammoniacal nitrogen can also be removed by breakpoint chlorination by adding hypochlorous acid in 1:1 ratio. Removal of ammonical nitrogen lowers the BOD because nitrification would consume oxygen dissolved in the remaining water. Removal of heavy metals like mercury, lead, chromium and cadmium also occur at tertiary treatment (Ramesh, 2004). The adsorbed metal ions are generally converted into either toxic products residues that are associated with the microbe biopolymer matrix and are either released during sludge treatment or are remobilized after sludge disposal (Ramesh, 2004). The general tendency of bacteria to concentrate heavy metals in their biomass is favourable to effluent quality, but it complicates the disposal of the sludge. Heavy metals can be subsequently fed and reprocessed for use or permanently immobilized (Ramesh, 2004). Tertiary treatment is expensive and usually not employed except where necessary to prevent obvious ecological disruption (Prescott *et al.,* 2002).

2.6.8 Disinfection

This is the final stage of conventional sewage treatment process. It is designed to kill the pathogenic bacteria and viruses that were not eliminated during the previous stages. It is normally accomplished by chlorination; using chlorine gas, or hypochlorite. Chlorine reacts with water to yield hypochlorious and hydrochloric acid, the actual disinfectants. Hypochlorite is a strong oxidant, which is the basis of its antibacterial action (Atlas, 1995). Pathogen removal is an extremely important aspect of wastewater treatment as bacteria, viruses, protozoa, and helminthes may be present in treated wastewater.

Pathogens can be destroyed by natural processes such as high pH levels that occur in the anaerobic parts of some pond treatment systems. Pathogens also die naturally or are killed by predation. Longer retention times and higher temperatures in pond systems and other aquatic systems promote these processes (Richard and Hirji, 2003). Protozoa and microscopic invertebrates present in wastewater feed on bacteria and fungi (Ramesh, 2004).

2.7 Slow sand filtration (SSF) technique

Slow sand filtration is a long established technique for reducing turbidity and bacteria in water (Huisman, 1974; James and Evison, 1979; Tebutt, 1999). It has been in large – scale use for a hundred years. Slow sand filtration as a system of water purification has been in continuous use since the beginning of the twentieth century and has proved effective under widely differing circumstances. It is simple, inexpensive and reliable, and still the chosen method of purifying water supplies for some of the major cities of the world (Huisman, 1974; James and Evison, 1979; Tebutt, 1999).

2.7.1 Filtration techniques

There is a wide range of filtration systems that can be used for treating irrigation water (Morel and Deiner, 2006). For on-farm installation, sand filters with slow application rates (slow sand-filters) are a possible option. However, sand should be of correct configuration i.e. effective size (ES) of 0.15 – 0.40 mm and uniformity coefficient (UC) of 1.5 – 3.6 (Metcalff and Eddy, 1995). The sand size is characterized by its effective size (ES or d_{10}) and uniformity coefficient (UC or d_{60} / $d_{10)}$ (Ellis, 1985). Sand filters remove pathogenic microorganism from polluted water by first retaining them in the filtration media before they are eliminated (Stevic *et al.,* 2004).

Using a laboratory scale model has shown that slow sand filters can be applied effectively as tertiary treatment for relatively clean secondary effluents (Ellis, 1987). Its study showed 88% removal of suspended solids, 76% removal of BOD and 97% removal of coliform organisms. It has been reported that most of the removal occurred at about the surface sand layer, also Schmutzdecke (Bellamy *et al.*, 1985 and Ellis, 1987). The authors reported the average percent removal of total coliform bacteria as 97% using sand size of 0.29 mm and sand depth of 97 cm. Bellamy *et al.* (1985) have reported that the removal of standard plate counts ranged from 88% to 91%. In a follow up study, Bellamy *et al.* (1985) reported that the removal was 99.9%.

Several mechanisms for the removal of particles, microorganisms and organic matter exist in slow sand filters. The raw water to be purified enters the supernatant and moves through the sand bed due to gravity. As water percolates through the sand, organic material and microorganism are removed by both mechanical (absorption, diffusion, screening and sedimentation) and biological processes (predation, natural death and metabolic breakdown (Huisman, 1974; Ellis and wood, 1985; Haarhof and Cleasby, 1991; Fogel *et al.*, 1993; Lloyd, 1996; Bahgat *et al.*, 1999). The improvement in water quality by the sand filtration differs for different quality of the raw water, sand grain size, rate of filtration, temperature and the oxygen content of the water (UNEP / SOPAC, 2002). SSF do not improve sulphate, sodium and total dissolved solids and that additional treatment processes are required for water that is high in dissolved solids, such as sodium, nitrite, sulphate and fluorite (Mah, 2001).

The slow sand filter system is a highly biologically active unit, therefore, the filter has to be operated for several days to develop a biological film (Schmutzdecke) on the grain of the filter until the purifying bacteria become well established and plays an important role in treatment process (Ellis and Kov, 1985). The biological conditions governing the effectiveness of the slow sand filter are; the degree of scum formation and the microbiological maturity of the sand bed (Bellamy *et al.*, 1985).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was conducted at Boundary Sewage Treatment Plant, Eldoret municipality, Uasin –Gishu County. Boundary Sewage Treatment Plant is located at latitude of 0.52^0 N and longitude of 35.28^0 E (Fig3. 2), humidity of 64%, temperature of 23.4^0C, altitude of 1992 m above sea level and it receives rainfall of 1140 mm per year (Eldowas company profile and performance, 2003).

3.2 Efficiency of Boundary Sewage Treatment Plant and slow sand filters

The present study aimed at determining the use of slow sand filtration to improve treated effluent at Boundary Sewage Treatment Plant (Eldoret) for irrigation.

Slow sand filters were used to polish the final effluent from Boundary Sewage Treatment Plant. Two different sizes of sand were used; 0.1 and 0.05 mm. The sand was obtained from the Estate Department within University of Eldoret. The sand was sieved with the 0.05 and 0.1 mm sieve size and put on 2.6 feet slow sand filter having a diameter of three inches. The third filter was obtained by putting 0.1 mm sand size to 1.3 feet height then the remaining 1.3 feet height was topped up with 0.05 mm sand size. The filters were washed with sterile distilled water then suspended vertically (Fig 3.1).

One and a half litres of final effluent sample from Boundary Sewage Treatment Plant was passed through each of these three filters. The respective filtrate was used to test for the microbiological and physico- chemical parameters.

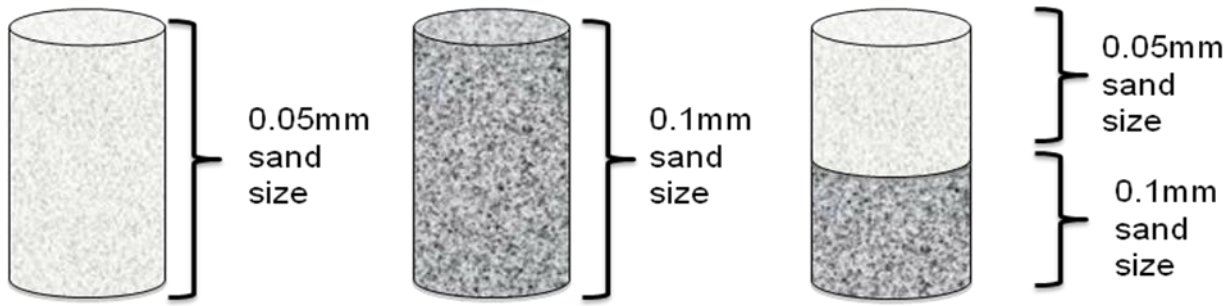

Figure 3.1: The slow sand filters which were used in the study to polish the final effluent from Boundary Sewage Treatment Plant. Source: Author, 2014

3.3 Research design

Boundary Sewage Treatment Plant relies almost entirely on microbial treatment of waste. It uses physical, trickling filters and pond system to remove and degrade wastes. It has 1 screen, 2 primary ponds, 1 secondary pond, 1 sedimentation pond, 1 tertiary pond and 2 trickling filters (Fig 3.2).

Sewage treatment at Boundary Treatment Plant takes 13 days from the inlet to outlet. It takes four days at the primary pond, approximately two minutes at the filter, few minutes at the sedimentation tank, four days at secondary pond, and five days at the tertiary pond. In the present study, samples for analysis were collected as follows: inlet sample on day one, primary pond sample after four days, filter sample same day as primary pond sample and final effluent after nine days. Five litres of the final effluent was taken to the laboratory and passed through the three sand filters. Sampling for dry season was done in the month of February to March 2012, and for wet season were done in the month of June to July 2012.

The samples of influent and effluent of the SSF, were analysed in terms of removal of colour; turbidity, Biological Oxygen Demand (BOD), total aerobic bacteria; Chemical Oxygen Demand (COD); Total Suspended Solids (TSS); Total Dissolved Solids (TDS), total coliform count, and *E-coli*; conductivity, temperature and pH; to determine the efficiency of the SSF in reducing the level of concentration of the selected parameters. All the parameters were tested in three replicates; Temperature and pH were tested at the point of sampling and the rest at the Eldoret Water and Sanitation Company laboratories and others at University of Eldoret Laboratory.

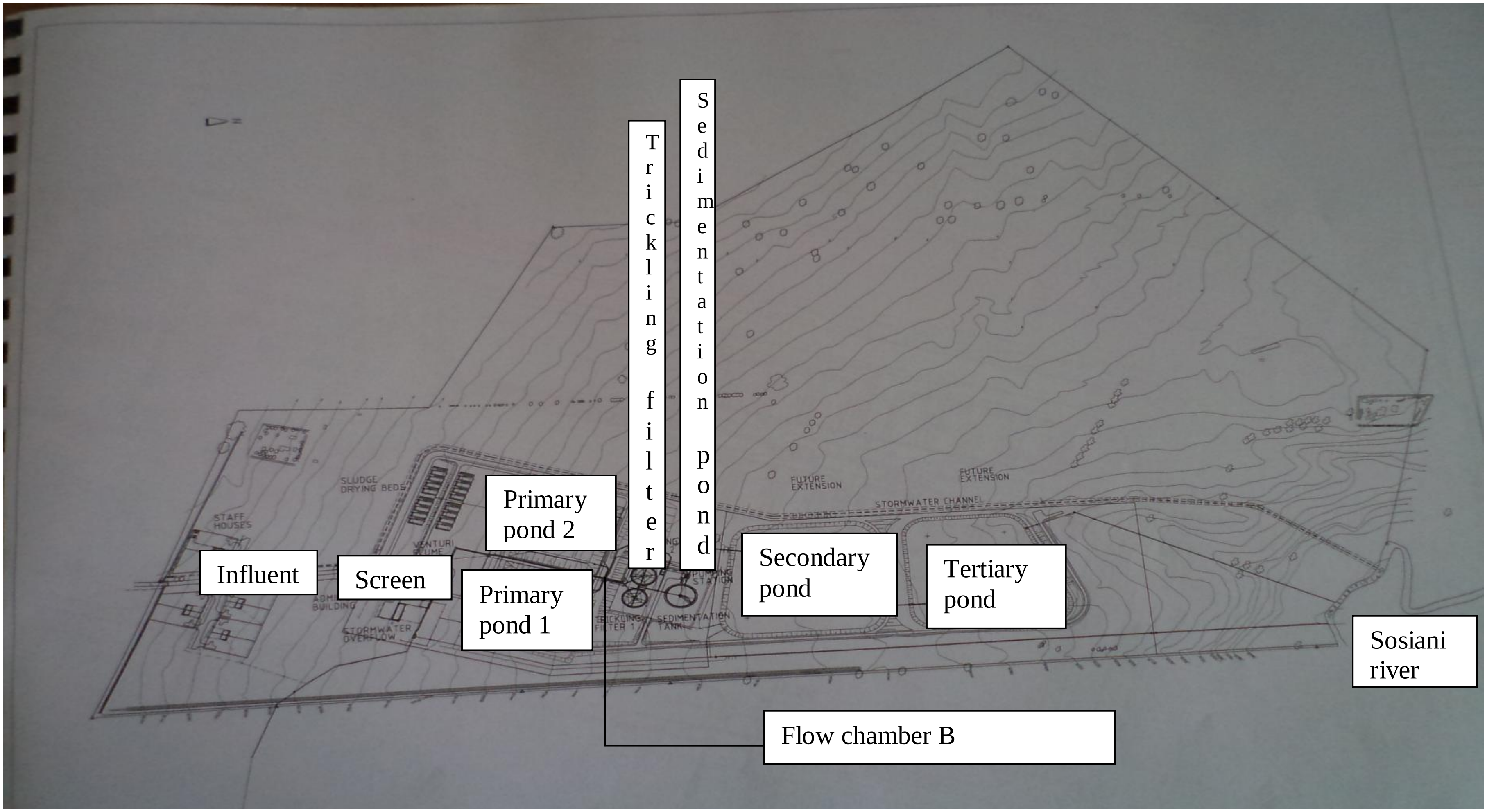

Figure 3.2: Various stages of sewage treatment at Boundary Sewage Treatment Plant. Source: Eldowas, 2000.

3.4 Determination of microbiological and physicochemical parameters

3.4.1 Determination of total coliforms

Samples were collected at the various stages of Boundary Sewage Treatment Plant; influent, primary pond effluent, trickling filter effluent, final effluent and filtrate from the slow sand filters on clean sterile bottles. The sampling bottles were filled to three quarters of their capacities (Ramesh, 2004).

Pour plate technique using a serial dilution of up to 10^{-6} was used. One millilitre of diluted samples were pipetted into a sterile petriplate and melted sterile liquid Eosin Methylene Blue Agar (EMB) was then added and mixed well by gently swirling the plate. The plates were sealed with Parafilm and incubated at 37^{0} C for 24 hours. Colonies that were nucleated with or without metallic sheen and pink in colour (Fig 3.3) were counted with the aid of a Gallenhamp colony counter. The populations of the viable coliforms were obtained using the formula by Madigan *et al.* (2009); Number of counted colonies × dilution reciprocal.

3.4.2 Determination of total aerobic bacteria

The total aerobic bacteria were achieved by using procedure similar to the one described in 3.4.1. The exception was that in this case nutrient agar was used and white and yellow colonies were counted instead of colonies with or without metallic sheen and pink in colour (Fig 3.4).

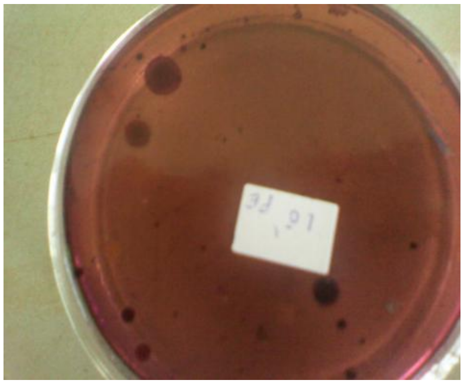

Figure 3.3: Pink nucleated without metallic sheen colonies of total coliforms on EMB media. Source: Author, 2012

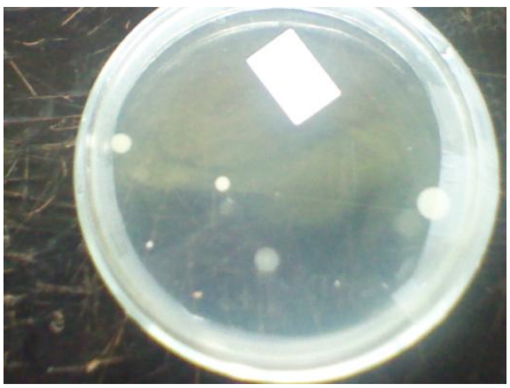

Figure 3.4: White and yellow colonies of total aerobic bacteria on N/A media. Source: Author, 2012.

3.5.3 Determination of Biological Oxygen Demand

The procedure on the BOD track manual 1995 – 1998 was used. Nitrification inhibitor powder was dispensed into the empty sterile BOD bottle. Collected samples of 0.32-1.1 litres were homogenised in a blender for two minutes. The pH of the sample was adjusted to a range of 6.5 and 7.5 with sulphuric acid or sodium hydroxide. Various volumes of the wastewater samples depending on the stage where the sample was collected were measured using graduated cylinder into the BOD bottles; 95 ml of inlet sample was measured into the Biological Oxygen Demand bottle, 160 ml for both primary pond and trickling filter effluent and 355 ml for the final effluent and filtrate samples. A 3.8 cm magnetic stir bar was placed in each sample bottle and stopcock grease was applied to the seal lip of each bottle and to the cap of each seal cap. One gram Lithium hydroxide powder pillow was added to each seal cap. The bottles were incubated for five days in a BOD incubator (Fig 3. 5).

Figure 3.5: Biological Oxygen Demand incubator. Source: Author, 2012.

3.5.4 Determination of Chemical Oxygen Demand

Chemical Oxygen Demand was determined as described in Chemical Oxygen Demand manual (2002) where 100ml of the samples collected from the various stages and from the sand filters were first homogenized in a blender. Two millilitres of the homogenised samples collected from the influent and primary pond effluent were pipetted into the high range reagents (Fig 3.6). The same volume of 2 ml of trickling filter effluent, final effluent and filtrate were added to low range reagents (Fig 3.6). Two millilitres of deionised water was added to each of the two reagents to produce a blank, then the vials were inverted gently several times and placed in a COD reactor digestor (Fig 3.7) which had already been heated to a temperature of 150^0C and left to heat for two hours. After this duration the vials were removed to cool to room temperature and finally a programmed spectrophotometer machine (Fig 3.8) was used to read the COD results.

Figure 3.6: High and low range Chemical Oxygen Demand reagents (low range: 0 – 15,000 mg/l; high range: 15,000 plus mg/l. Source: Author, 2012.

Figure 3.7: Chemical Oxygen Demand Reactor for heating the COD samples at 150 150^0C Source: Author, 2012

Figure 3.8: Spectrophotometer machine for reading COD results.

Source: Author, 2012

3.5.5 Determination of Total Suspended Solids

The TSS was obtained by the procedure of Greenberg *et al.* (1995). A glass filter was dried by placing it in an oven with a temperature of 103^0 C for 60 minutes, removed and then put in a dessicator to cool for 60 minutes and weighed. A 100 ml of the homogenised sample was filtered through the glass filter. The weight of the sample was obtained by using the formula;

Total Suspended Solids (mg) / L = (A – B) × 1000 ÷ Sample volume

Where A = weight of filter plus dried residue in mg

B = weight of filter in mg.

3.5.6 Determination of Total Dissolved Solids

The filtrate obtained from the testing for total suspended solids described in 3.5.5 above was utilized for testing for total dissolved solids by transferring it to weighed evaporating dish and then evaporated to dryness on a steam bath. This was followed by drying for one hour at 180^0 C then cooling for one hour in a dessicator (Greenberg *et al.*, 1995).

Weight of TDS was obtained using the formulae by Greenberg *et al.* (1995)

Total Dissolved Solids (mg) / L = (A – B) × 1000 ÷ Sample volume

Where A = weight of dried residue plus dish in mg

B = weight of dish in mg

3.5.7 Determination of temperature

The temperature of the sample was recorded in situ using an automatic thermometer that was inserted into 250 ml of sewage sample. The thermometer was used to stir the sample for thirty seconds then the results were read and recorded.

3.5.8 Determination of pH

A pH meter was used to determine the pH in situ.

3.5.9 Determination of conductivity

Conductivity was included as one of the parameters in the determination of water quality, due to its usefulness as an early indicator of change in a water system. A conductivity meter was used to determine the conductivity.

3.6 Statistical analysis

One way Analysis of variance procedure using SAS 9.2 and 9.3 software and proportion was used to analyse the microbiological and physico-chemical parameters during dry and wet seasons at the various stages of Boundary Sewage Treatment.

Final effluent data collected during dry and wet season from Boundary Sewage Treatment plant were analysed by one sample t –test procedure using SAS 9.2 software in comparison with national and international standards for wastewater to be used for irrigation.

Dependent t –test procedure was used to analyse the efficiency of slow sand filters by comparing the filtrate with the final effluent. The filtrate was also analysed using one sample t test procedure using SAS 9.2 software in comparison with the national and international standards for those parameters which Boundary Sewage Treatment Plant did not treat to the recommended standard to be used for irrigation. Level of confidence was 95%.

CHAPTER FOUR

RESULTS

4.1 Microbiological and physico-chemical parameters of the wastewater during dry season at Boundary Sewage Treatment Plant

The data collected during dry season at the four stages; influent, primary pond effluent, trickling filter effluent and final effluent were analysed by Analysis of Variance procedure using SAS 9.2 and 9.3 softwares and proportions. This was done for nine parameters; Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), conductivity, pH, total coliforms, Total Dissolved Solids (TDS), temperature, Total Suspended Solids (TSS) and total aerobic bacteria (Table 4.1 and Appendix 5).

4.1.1 Chemical Oxygen Demand

Chemical Oxygen Demand was significantly different ($p < 0.05$) after the wastewater passed through the screen, primary pond, trickling filter, sedimentation, secondary and tertiary pond stages of wastewater treatment (Appendix 5). Chemical Oxygen Demand reduced by 72.27% after the wastewater undergoing treatment at the screen and primary pond, 31.39% after the primary pond effluent was treated at the trickling filters and 43.42% after the trickling filters effluent underwent treatment at the sedimentation, secondary and tertiary ponds respectively (Table 4.1).

4.1.2 Total Dissolved Solids and conductivity

Total Dissolved Solids and conductivity were significantly different ($p < 0.05$) in all the four stages of sampling (Appendix 5). This led to the rejection of the alternative hypothesis that TDS and conductivity were similar at all the four stages where sampling took place.

Table 4.1: Proportions of microbiological and physico-chemical parameters of the wastewater during dry season at Boundary Sewage Treatment Plant

Parameters	Mean ID	Mean PB	Mean FE	Mean TD	% change from ID to PB	% change from PB to FE	% change from FE to TD
COD (mg/l)	1569.67	435.33	298.67	169.00	-72.27	-31.39	-43.42
TDS (mg/l)	403.67	1054.33	793.67	722.67	161.19	-24.72	-8.95
BOD (mg/l)	602.00	238.67	149.67	82.67	-60.35	-37.29	-44.77
TSS (mg/l)	216.67	93.33	105.33	90.00	-56.93	12.86	-14.55
pH	7.76	7.25	8.18	8.05	-6.57	12.83	- 1.59
Temp (0C)	22.30	21.57	15.60	20.80	-3.27	-27.68	33.33
Cond (µs)	576.33	1506	1133.67	1032.33	161.31	-24.72	-8.94
TC (counts)	1419526	667164	339459	4500	-53	-49.12	-98.67
TAB (counts)	8392331	2726668	7799360	6149015	-67.51	186.04	-21.16

- Shows reduction of the parameter in percentage, + shows increase of the parameter in percentage.

Abbreviations used for the stages: ID – Influent, PB- Primary pond effluent, FE – Trickling filter effluent, TD- Final Effluent

COD – Chemical Oxygen Demand

TDS – Total Dissolved Solids

BOD – Biological Oxygen Demand

Cond – Conductivity

TSS – Total Suspended Solids

pH – Potential Hydrogen

Temp – Temperature

T.C – Total Coliforms

T.A.B – Total Aerobic Bacteria

These two parameters increased by 161% after the influent underwent treatment at screen and primary pond. Total dissolved solids and conductivity reduced by 24.72% after the primary pond effluent undergoing treatment at trickling filter, and further reduced by 8% after the trickling filter effluent underwent treatment at the sedimentation, secondary and tertiary ponds (Table 4.1).

4.1.3 Biological Oxygen Demand

Significant differences ($p < 0.05$) in BOD were observed in all the four stages of sampling (Appendix 5). Biological Oxygen Demand reduced by 60.35% after the raw wastewater passing through the screen and primary pond, 37.29% after the primary pond effluent passing through the trickling filters and 44.77% after the trickling filter effluent underwent through sedimentation, secondary and tertiary ponds (Table 4.1).

4.1.4 Total Suspended Solids

Significant differences ($p < 0.05$) in TSS were observed in all the four stages of sampling (Appendix 5). Total Suspended Solids reduced by 56.93% after the wastewater going through the screen and primary pond, the primary pond effluent, increased by 12.86% after going through trickling filter. The trickling filter effluent reduced by 14.55% after passing through the sedimentation, secondary and tertiary ponds (Table 4.1)

4.1.5 pH

Significance differences ($p < 0.05$) in pH were observed in all the four stages of sampling (Appendix 5). The pH was reduced by 6.57% after the raw wastewater passed through the screen and primary pond, increased by 12.83 after the primary pond effluent undergoing treatment at the trickling filter and reduced by 1.59% after the trickling filter effluent undergoing treatment in sedimentation, secondary and tertiary ponds respectively (Table 4.1).

4.1.6 Temperature

Temperature was significantly different ($p < 0.05$) in all the four stages of sampling (Appendix 5). It reduced by 3.27% after the raw wastewater passed the screen and primary pond. It further reduced by 27.68% after the primary pond effluent underwent treatment at the trickling filter, then it increased by 33.33% after the trickling filter effluent underwent treatment at sedimentation, secondary and tertiary ponds (Table 4.1).

4.1.7 Total coliforms

Significant differences ($p < 0.05$) in the number of total coliforms were observed in all the four stages of sampling (Appendix 5). Total coliforms reduced by 53% after the influent undergoing treatment in screen and primary pond, reduced by 49.12% after the primary pond effluent undergoing treatment in trickling filter, and further reduced by 98.67% after the trickling filter effluent underwent treatment in sedimentation, secondary and tertiary ponds (Table 4.1).

4.1.8 Total aerobic bacteria

Significance differences ($p < 0.05$) in the number of total aerobic bacteria were observed in all the four stages of sampling (Appendix 5). Total aerobic bacteria reduced by 67.51% after influent passed through the screen and primary pond, but it increased by 186.04% after the primary pond effluent passed through trickling filter. It reduced by 21.16% after the trickling filter effluent undergoing treatment at sedimentation, secondary and tertiary ponds respectively (Table 4.1).

4.2 Microbiological and physico-chemical parameters of the wastewater during wet season at Boundary Sewage Treatment Plant

The data collected during wet season at the four stages; influent, primary pond effluent, trickling filter effluent and final effluent were analysed by Analysis of Variance procedure using SAS 9.2 and 9.3 software and proportions. This was done for nine parameters; Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), conductivity, pH, total coliforms, Total Dissolved Solids (TDS), temperature, Total Suspended Solids (TSS) and total aerobic bacteria (Table 4.2 and Appendix 6).

4.2.1 Chemical Oxygen Demand

Chemical Oxygen Demand was significantly different ($p < 0.05$) in all the four stages of sampling (Appendix 6). Chemical Oxygen Demand reduced by 90.84% after the influent passing through the screen and primary pond, 20.23% after primary pond effluent passed through trickling filter and 16.66% after sedimentation, secondary and tertiary ponds respectively (Table 4.2).

4.2.2 Total Dissolved Solids and conductivity

Total Dissolved Solids and conductivity were both significantly different ($p < 0.05$) in all the four stages of sampling (Appendix 6). Total Dissolved Solids and conductivity increased by 9% after the raw wastewater underwent treatment at the screen and primary pond. It reduced by 7% after the primary pond effluent passed the trickling filter and increased by 17% after passing through sedimentation, secondary and tertiary ponds (Table 4.2).

Table 4.2: Proportions of microbiological and physico – chemical parameters of the wastewater during wet season at Boundary Sewage Treatment Plant

Param	Mean ID	Mean PB	Mean FE	Mean TD	% change from ID to PB	% change from PB to FE	% change from FE to TD
COD (mg/l)	1259.33	115.33	92.00	76.67	-90.84	-20.23	-16.66
TDS (mg/l)	299.67	328	303.67	357.33	9.45	-7.42	17.67
BOD (mg/l)	502.00	58.00	54.67	28.00	-88.45	-5.74	-48.78
TSS (mg/l)	240.00	60.00	80.00	62.00	-75	33.33	-22.5
pH	7.02	6.72	7.34	8.03	-4.27	9.23	9.4
Temp (0C)	20.73	15.70	15.47	21.07	-24.26	-1.46	36.2
Cond (µs)	428.33	468.33	434.00	510.67	9.34	-7.33	17.67
TC (counts)	473321	165666	56665	1600	-65	-65.8	-97.18
TAB (counts)	4433333	773333	2102500	2042333	-82.56	171.88	-2.86

Key:
- Shows reduction of the parameter in percentage, + shows increase of the parameter in percentage.

Abbreviations used for the stages: ID – Influent, PB – Primary pond effluent, FE- Trickling filter effluent, TD – Final effluent.

4.2.3 Biological Oxygen Demand

Biological Oxygen Demand was significantly different ($p < 0.05$) after the influent undergoing treatment at the various stages of sewage treatment (Appendix 6). Biological Oxygen Demand was reduced by 88.45% after the influent underwent treatment in screen and primary pond by 5.74% after the primary pond effluent undergoing treatment in trickling filter, and by 48.78% after the trickling filter effluent passed through sedimentation, secondary and tertiary ponds (Table 4.2).

4.2.4 Total Suspended Solids

Significance differences ($p < 0.05$) in TSS were observed in all the four stages of sampling (Appendix 6). Total Suspended Solids reduced by 75% after the raw wastewater underwent treatment at screen and primary pond. It increased by 33.33% after the primary pond effluent passed through the trickling filter and finally reduced by 22.5% after the trickling filter effluent passed through the sedimentation, secondary and tertiary ponds respectively (Table 4.2).

4.2.5 pH

pH was significantly different ($p < 0.05$) in all the stages of sampling (Appendix 6). pH reduced by 4.27% after the raw wastewater underwent treatment at the screen and primary pond. It increased by 9.23% after the primary pond effluent underwent treatment at trickling filter and further increased by 9.4% after the trickling filter effluent underwent treatment at sedimentation, secondary and tertiary ponds (Table 4.2).

4.2.6 Temperature

Temperature was significantly different ($p < 0.05$) at all the four stages of sampling (Appendix 6). This led to the acceptance of the alternative hypothesis that temperature differed at all the four stages of sampling. It reduced by 24.26% after the influent underwent treatment at the screen and primary pond, 1.46% after primary pond effluent passed through the trickling filter and finally increased by 36.2% after the trickling filter effluent underwent treatment at the sedimentation, secondary and tertiary ponds respectively (Table 4.2).

4.2.7 Total coliforms

Significant differences ($p < 0.05$) in the number total coliforms were observed in all the four stages of sampling (Appendix 6). Total coliforms reduced by 65% after the raw wastewater underwent treatment at the screen and primary pond, 65.8% after the primary pond effluent passed through the trickling filter, and by 97.18% after the trickling filter effluent underwent treatment at sedimentation, secondary and tertiary ponds (Table 4.2).

4.2.8 Total aerobic bacteria

The number of total aerobic bacteria was not significantly different ($p > 0.05$) in all the stages of sampling (Appendix 6). Total aerobic bacteria reduced by 82.56% after the raw wastewater undergoing treatment at the screen and primary pond. They increased by 171.88% after the wastewater underwent treatment at the trickling filter and reduced by 2.86% after the trickling filter effluent underwent treatment at the sedimentation, secondary and tertiary ponds (Table 4.2).

4.3 Comparison of the treated wastewater with national and international standards during dry season

Final effluent collected during dry season from Boundary Sewage Treatment Plant was analyzed by one sample t-test procedure using SAS 9.2 software in comparison with the national and international standards for wastewater to be used in irrigation: Biological Oxygen Demand and TSS were compared with United States of America (Washington standards) , COD was compared with standards of Jordan, while total coliforms, pH and TDS were compared with the Kenyan National Environmental Management Authority standards (Table 2.1, 2.2, 2.3 and 2.4).

Table 4.3: Comparison of final effluent from Boundary Sewage Treatment Plant with national and international standards for treated wastewater to be used in irrigation during dry season

Parameters	Mean ± SE	Recommended standards	P - value
BOD (mg/l)	82.67 ± 4.33	≤30 (Washington)	0.0034
COD (mg/l)	169.0 ± 0	≤100 (Jordan)	<.0001
pH	8.05 ± 0.03	≥6.5 (NEMA)	0.9998
pH	8.05 ± 0.03	≤8.5 (NEMA)	0.9982
TC (counts)	4500.0 ± 0	≤1000 (NEMA)	<.0001
TDS (mg/l)	722.7 ± 9.21	≤1200 (NEMA)	0.9998
TSS (mg/l)	90.00 ± 0	≤30 (Washington)	<.0001

4.3.1 Biological Oxygen Demand

Biological Oxygen Demand in the final influent from Boundary Sewage Treatment Plant (BOD = 82.67 mg/l) was significantly ($p < 0.05$) higher than the recommended standard, of ≤ 30 mg/l (Table 4.3). The Null hypothesis was accepted that the treated wastewater from Boundary Sewage Treatment did not meet the standards for irrigation.

4.3.2 Chemical Oxygen Demand

The Chemical Oxygen Demand in the influent (COD = 169.00) was significantly ($p < 0.05$) higher than the compared standard of Jordan of COD of ≤ 100 mg / l. The final effluent mean of 169 ml / l was higher than the Jordan standard of COD ≤ 100 ml/ l (Table 4.3) for wastewater to be used for irrigation leading to the acceptance of the null hypothesis that the wastewater from Boundary Sewage Treatment did not meet the standards for irrigation.

4.3.3 pH

The pH mean of 8.05 was first analysed to see whether it was ≥ 6.5 and it was found to be not significantly different ($p > 0.05$) (Table 7). Secondly the same mean was analysed to see whether it was ≤ 8.5, it was also found to be not significantly different ($P > 0.05$) (Table 4.3). pH mean of 8.05 was within the compared range of 6.5 – 8.5) (Table 7). These two analyses showed that the influent pH (8.05) was not significantly ($p > 0.05$) outside the range of 6.5 - 8.5 from National Environmental Management Authority for the treated wastewater to be used for irrigation.

4.3.4 Total Dissolved Solids

Total Dissolved Solids (TDS = 722.7 mg/l) was not significantly ($p > 0.05$) higher than the compared standard of National Environmental Management Authority of ≤ 1200 mg/l (Table 4.3). This led to the acceptance of the alternative hypothesis that TDS in the final effluent from Boundary Sewage Treatment Plant met the NEMA standards for the treated wastewater to be used in irrigation.

4.3.5 Total coliforms

The number of total coliforms (TC = 4500 count) in the influent from Boundary Sewage Treatment Plant was significantly ($p < 0.05$) higher than the recommended NEMA standard of ≤ 1000 MPN/100 ml (Table 4.3).

4.3.6 Total Suspended Solids

The Total Suspended Solids (TSS = 90.00 mg/l) in the influent was significantly ($p < 0.05$) higher than the recommended standard of United States of America (Washington) of ≤ 30 mg /l (Table 4.3).

4.4 Comparison of the treated wastewater with national and international standards during wet season

Final effluent collected during wet season from Boundary Sewage Treatment Plant was analyzed by one sample t-test procedure using SAS 9.2 software in comparison with the national and international standards for wastewater to be used in irrigation: Biological Oxygen Demand and TSS were compared with United States of America (Washington standards), COD was compared with standards of Jordan, while total coliforms, pH and TDS were compared with the Kenyan National Environmental Management Authority standards (Table 2.1, 2.2, 2.3 and 2.4).

4.4.1 Biological Oxygen Demand

The Biological Oxygen Demand (BOD= 28 mg/l)in the final effluent of Boundary Sewage Treatment Plant was not significantly ($p > 0.05$) higher than the compared standard of United States of America (Washington) of ≤30 mg/l (Table 4.4) for the wastewater to be used for irrigation. This led to the rejection of the null hypothesis that the amount of BOD in the treated wastewater from Boundary Sewage Treatment Plant did not meet the Washington standards for irrigation.

4.4.2 Chemical Oxygen Demand

Chemical Oxygen Demand (COD = 76.67 mg/l) was not significantly ($p > 0.05$) higher than the compared standard of Jordan of ≤ 100 mg /l for treated wastewater to be used in irrigation (Table 4.4). This led to the rejection of the null hypothesis that the amount of COD in the influent of treated wastewater from Boundary Sewage Treatment Plant did not meet the compared standard to be used in irrigation.

Table 4.4: Comparison of final effluent from Boundary Sewage Treatment Plant with national and international standards for treated wastewater to be used in irrigation during wet season

Parameters	Mean ± SE	Recommended standards	P –value
BOD (mg/l)	28.00 ± 0	≤30 (Washington)	1.0000
COD (mg/l)	76.67 ± 0.33	≤100 (Jordan)	0.9999
TC (counts)	1600.0 ± 0	≤1000 (NEMA)	<.0001
TDS (mg/l)	357.3 ± 3.67	≤1200 (NEMA)	1.0000
TSS (mg/l)	62.00 ± 1.00	≤30 (Washington)	0.0005
pH	8.03 ± 0.03	≥6.5 (NEMA)	0.9998
pH	8.03 ± 0.03	≤8.5 (NEMA)	0.9975

4.4.3 Total Suspended Solids

Total Suspended Solids (TSS = 62.00 mg/l) in the final effluent of Boundary Sewage Treatment Plant was significantly ($p < 0.05$) higher than the compared amount of ≤ 30 mg/l of Washington for treated wastewater to be utilized in irrigation (Table 4.4). This led to the acceptance of the null hypothesis that the amount of TSS in the final effluent did not meet the Washington standard for the wastewater to be used in irrigation.

4.4.4 Total coliforms

The number of total coliforms (TC = 1600) in the treated wastewater from Boundary Sewage Treatment Plant was significantly ($p < 0.05$) higher than the recommended standards for irrigation by NEMA of ≤1000 MPN/100ml (Table 4.4). This led to the acceptance of the null hypothesis that the number of total coliforms in the treated wastewater did not meet the NEMA standards to be used in irrigation.

4.4.5 pH

After analysing in two parts, pH (pH = 8.03) in the final effluent from Boundary Sewage Treatment Plant was found to be not significantly ($p > 0.05$) outside the range of 6.5 -8.5 given by NEMA for treated wastewater to be used for irrigation (Table 4.4). This led to the rejection of the null hypothesis that the treated wastewater from Boundary Sewage Treatment Plant was not suitable for irrigation.

4.4.6 Total Dissolved Solids

The Total Dissolved Solids (TDS =357.3 mg/l) in the final effluent from the treated wastewater in Boundary Sewage Treatment Plant was not significantly ($p > 0.05$) higher than the compared NEMA of ≤ 1200 mg / l (Table 4.4). This led to the rejection of the null hypothesis that the amount of TDS in the final effluent from Boundary Sewage Treatment Plant did not meet the compared standard of NEMA for the wastewater to be used in irrigation.

4.5 Comparison of the Boundary Sewage Treatment Plant final effluent with the slow sand filtrate during dry season

The final effluent from Boundary Sewage Treatment Plant during dry season was passed through slow sand filters of two sand sizes (0.05 mm, 0.1 mm and mixture of the two). The efficiency of the slow sand filters were obtained by comparing final effluent from Boundary Sewage Treatment Plant with the filtrate from the three sand filters by dependent t-test using SAS 9.2 software.

4.5.1 Biological Oxygen Demand

Biological Oxygen Demand in the filtered water from all the three filters (BOD T = 33.33mg/l, BOD TT = 27.67 mg/l, BOD TTT = 28.33 mg/l) was significantly ($p < 0.05$)

Table 4.5: Comparison of final effluent from Boundary Sewage Treatment Plant slow sand filtrate during dry season

Parameters	Mean for final effluent	Mean for filtrate	Mean ±SE	P- value
BOD (mg/l)	82.67	T = 33.33	49.33 ± 4.63	0.0087
		TT = 27.67	55.00 ± 4.93	0.0079
		TTT = 28.33	54.33 ± 4.06	0.0055
COD (mg/l)	169.00	T = 74.33	94.67 ± 5.17	0.0030
		TT = 62.33	106.67 ±1.45	0.0002
		TTT = 70.00	99.00 ± 0.58	<.0001
TDS (mg/l)	722.67	T = 635.33	87.33 ± 12.00	0.0184
		TT = 338.67	384.0 ± 7.55	0.0004
		TTT =386.67	336.0 ± 8.02	0.0006
COND (µs)	1032.33	T =907.67	124.7 ± 17.36	0.0188
		TT = 483.67	548.7 ± 10.73	0.0004
		TTT = 552.00	480.3 ± 11.87	0.0006
pH	8.05	T = 8.02	0.03 ± 0.05	0.0247
		TT = 7.98	0.07 ± 0.01	0.0171
		TTT = 8.18	-0.13 ± 0.02	0.6229
TC – (count)	4500.00	T = 960.00	3540.0 ± 11.55	<.0001
		TT = 600.00	3900.0 ± 0	<.0001
		TTT = 813.33	3686.7 ± 3.33	<.0001
TEMP (^{0}C)	20.80	T = 20.60	0.20 ± 0	<.0001
		TT = 21.57	-0.77 ± 0.03	0.0019
		TTT = 20.50	0.300 ± 0	<.0001
TSS (mg/l)	90.00	T = 81.67	8.33 ± 0.67	0.0063
		TT = 23.33	66.67 ± 3.33	0.0025
		TTT = 26.33	63.67 ± 0.33	<.0001
TAB (count)	6149015.67	T = 4844703.67	1304312± 142.1	<.0001
		TT=3364153.67	2784862 ± 91.09	<.0001
		TTT =4032222	2116794 ± 1115.2	<.0001

T – 0.1 mm filter, TT- 0.05 mm filter, TTT- Mixture of the two filters (0.1 and 0.05 mm)

- Shows the parameter was more in the filtrate than in the final effluent lower than the final effluent BOD of 82.67 mg/l (Table 4.5). This led to the rejection of the null hypothesis that slow sand filters did not improve the quality of the final effluent from Boundary Sewage Treatment Plant in terms of BOD.

4.5.2 Chemical Oxygen Demand

Chemical Oxygen Demand from all the three filters (COD T = 74.33 mg/l, COD TT = 62.33 mg/l, COD TTT = 70.00 mg/l) was significantly ($p < 0.05$) lower than Boundary Sewage Treatment Plant final effluent‘s COD of 169 mg/l (Table 4.5). This led to the rejection of the null hypothesis that the filters did not improve the final effluent in terms of COD.

4.5.3 Total Suspended Solids

Total Suspended Solids in the filtered water (TSS T = 81.67 mg/l, TSS TT = 23.33 mg/l, TSS TTT = 26.33 mg/l was significantly ($p < 0.05$) lower than the TSS = 90 mg/l which were in the final effluent obtained from Boundary Sewage Treatment Plant (Table 4.5). This led to the rejection of the null hypothesis that slow sand filters did not improve the quality of TSS from Boundary Sewage Treatment Plant.

4.5.4 Temperature

Temperature in the filtrates from filters (temperature T = 20.60^0 C, TT = 21.57^0 C, TTT = 20.50^0 C, was significantly ($p < 0.05$) lower than 20.80^0 C which was in the final effluent (Table 4.5).

4.5.5 pH

pH of the filtered water from filters (T = 8.02, TT = 7.98) were significantly ($p < 0.05$) lower than 8.05 pH which was in the final effluent from Boundary Sewage Treatment

Plant (Table 4.5). However, the pH which was in the filtrate obtained from filter TTT = 8.18 was not significantly ($p > 0.05$) lower than the pH of 8.05 which was in the final effluent (Table 4.5)

4.5.6 Total Dissolved Solids and conductivity

Total Dissolved Solids and conductivity obtained from the filtered water from all the three filters were significantly ($p < 0.05$) lower from the amount got from Boundary Sewage Treatment Plant final effluent of TDS = 722 mg/l and conductivity of 1032 µs (Table 4.5). Hence rejection of the null hypothesis that the slow sand filters did not improve the TDS and conductivity present in the final effluent of Boundary Sewage Treatment Plant.

4.5.7 Total Coliforms

The number of total coliforms in the filtered water (T = 960 counts, TT = 600 counts and TTT = 813. 33 counts) was significantly ($p < 0.05$) lower than 4500 counts which were in the final effluent (Table 4.5). This led to the rejection of the null hypothesis that slow sand filters did not improve the quality of water in the final effluent from Boundary Sewage Treatment Plant.

4.5.8 Total aerobic bacteria

The number of total aerobic bacteria found in the filtered water was significantly ($p < 0.05$) lower in all the three filters (T = 4844703.67 counts, TT = 3364153.6 counts, TTT = 4032222 counts) than 6149015.57 total aerobic bacteria which were in the final effluent (Table 4.5). This led to the rejection of the null hypothesis that slow sand filters did improve the quality of final effluent from Boundary Sewage Treatment Plant.

4.6 Comparison of Boundary Sewage Treatment Plant final effluent with the slow sand filtrates during wet season

The final effluent from Boundary Sewage Treatment Plant during wet season was passed through slow sand filters of two sand sizes (0.1 mm, 0.05 mm and mixture of the two). The efficiency of the slow sand filters were obtained by comparing final effluent from Boundary Sewage Treatment Plant with the filtrate from the three sand filters by dependent t-test using SAS 9.2 software.

4.6.1 Biological Oxygen Demand

The amount of Biological Oxygen Demand present in the filtrate was significantly ($p < 0.05$) lower in all the three filters (T = 22 mg/l, TT = 19 mg/l, TTT = 21 mg/l) than in the final effluent amount of 28 mg/l (Table 4.6). This led to the rejection of the null hypothesis that the filters did not improve the quality of BOD present in the final effluent obtained from Boundary Sewage Treatment Plant.

4.6.2 Chemical Oxygen Demand

Chemical Oxygen Demand in the filtrate (T = 68.67 mg/l, TT = 67.00 mg/l, TTT = 63.67 mg/l was significantly ($p < 0.05$) lower than that at Boundary Sewage Treatment Plant final effluent of 76.67 mg/l (Table 4.6). This led to the rejection of the null hypothesis that the slow sand filters did not improve the quality of COD present in the final effluent obtained from Boundary Sewage Treatment Plant.

4.6.3 Total Suspended Solids

Total Suspended Solids in the filtrate (T = 55 mg/l, TT = 15 mg/l, TTT = 26 mg/l was significantly ($p < 0.05$) lower than from the final effluent of 62 mg/l (Table 4.6) leading to the rejection of the null hypothesis that slow sand filters did not improve the quality of TSS.

Table 4.6: Comparison of Final Effluent from Boundary Sewage Treatment Plant with the slow sand filtration during wet season

Parameter	Mean for final effluent	Mean for filtrate	Mean ± SE	P -value
BOD (mg/l)	28	T = 22.00	6.00 ± 1.15	0.0351
		TT =19.00	9.00 ± 0	<.0001
		TTT = 21.00	7.00 ± 0	<.0001
COD (mg/l)	76.67	T = 68.67	8.00 ± 1.00	0.0153
		TT = 67.00	9.67 ± 0.33	0.0012
		TTT = 63.67	13.00 ± 0	<.0001
COND (µs)	510.67	T = 935.00	-424.3 ± 16.58	0.0015
		TT =928.00	-417.3 ± 6.44	0.0002
		TTT =724.33	-213.7 ± 11.35	0.0028
pH	8.03	T = 8.21	-0.17 ± 0.03	0.2965
		TT = 8.08	-0.05 ± 0.03	0.0320
		TTT = 8.11	-0.08 ± 0.04	0.1835
TC (count)	1600	T = 706.67	893.3 ± 3.33	<.0001
		TT = 400.00	1200.0 ± 0	<.0001
		TTT = 440.00	1160.0 ± 0	<.0001
TDS (mg/l)	357.33	T = 654.33	-297.0 ± 11.53	0.0015
		TT = 649.67	-292.3 ± 4.37	0.0002
		TTT = 506.67	-149.3 ± 7.97	0.0028
TEMP (^{0}C)	21.07	T = 20.60	0.47 ± 0.03	0.0051
		TT = 20.53	0.53 ± 0.03	0.0039
		TTT = 20.50	0.57 ± 0.03	0.0034
TSS (mg/l)	62	T = 55.00	7.00 ± 1.00	0.0198
		TT = 15.00	47.00 ± 2.08	0.0020
		TTT = 26.00	36.00 ± 1.53	0.0018
TAB (count)	2042333	T =1610000.00	432333 ± 5000	0.0001
		TT =1121750.00	920583 ± 0	<.0001
		TTT =1437511.00	604822 ± 11.00	<.0001

T – 0.1 mm filter, TT- 0.05 mm filter, TTT- Mixture of the two filters (0.1 and 0.05 mm)

4.6.4 Temperature

Temperature was significantly ($p < 0.05$) lower in all the three filters (T = 20.60^{0}C, TT = 20.53^{0}C, TTT = 20.50^{0}C) than in the final effluent of 21.07^{0}C from Boundary Sewage Treatment Plant. (Table 4.6), leading to the rejection of the null hypothesis that the slow sand filters did not improve the temperature in the final effluent obtained from Boundary Sewage Treatment Plant

4.6.5 pH

The pH in the filtrate from slow sand filters (T = 8.21, TTT = 8.11) not significantly ($P > 0.05$) lower than the final effluent mean of 8.03 however the pH in the filtrate from filters (TT = 8.08) was significantly ($P < 0.05$) lower than the one got from final effluent of 8.03 (Table 4.6).

4.6.6 Total Dissolved Solids and conductivity

Total Dissolved Solids and conductivity were significantly ($p < 0.05$) lower in all the three filters (TDS T = 654.33 mg/l, TDS TT = 649.67 mg/l, TDS TTT = 506.67 mg/l, conductivity T = 935µs, conductivity TT = 928 µs, conductivity TTT = 724.33 µs) than the final effluent TDS of 357.33 mg/l and conductivity of 510 mg/l respectively.

4.6.7 Total coliforms

The number of total coliforms (T = 706.67 count, TT = 400 count, TTT = 440) count was significantly ($P < 0.05$) lower in all the three filters than that of final effluent of 1600 count (Table 4.6), leading to the rejection of the null hypothesis that slow sand filters did not improve the number of total coliforms found in the final effluent.

4.6.8 Total aerobic bacteria

The number of total aerobic bacteria in the filtrate (T = 1610000 count, TT = 1121750 count, TTT = 1437511) was significantly ($P < 0.05$) lower from that of Boundary final effluent of 2042333 counts (Table 4.6). This led to the rejection of the null hypothesis that the slow sand filters did not improve the quality of the Boundary Sewage Treatment final effluent

4.7 Comparison of the slow sand filtrate with the national and international standards during dry season

Parameters that were not treated by Boundary Sewage Treatment Plant during dry season to the recommended standards for the treated wastewater to be used in irrigation (Table 4.3) were subjected to slow sand filtration for further treatment for them to be suitable for irrigation. The filtrate was compared with the various recommended standards for treated wastewater to be used in irrigation.

4.7.1 Chemical Oxygen Demand

The amount of Chemical Oxygen Demand (COD T = 74.33 mg/l, COD TT = 62.33 mg/l, COD TTT = 70.00 mg/l) in the filtrate was not significantly ($p > 0.05$) higher than the compared standard of ≤ 100 mg / l (Table 4.7) for wastewater to be used for irrigation. Hence rejection of the null hypothesis that the slow sand filters did not improve the quality of wastewater to be used for irrigation.

Table 4.7: Comparison of slow sand filtrate with the national and international standards for treated wastewater to be suitable for irrigation during dry season

Parameter and filters	Mean ± SE	Recommended Standrds	P- value
BOD (mg/l) - T	33.33 ± 0.33	≤ 30	0.0049
BOD (mg/l) – TT	27.67 ± 0.67	≤ 30	0.9636
BOD (mg/l) – TTT	28.33 ± 0.33	≤30	0.9811
COD (mg/l) – T	74.33 ± 5.17	≤100	0.9808
COD (mg/l) – TT	62.33 ± 1.45	≤100	0.9993
COD (mg/l) – TTT	70.00 ± 0.58	≤100	0.9998
TSS (mg/l) – T	81.67 ± 0.67	≤30	<.0001
TSS (mg/l) – TT	23.33 ± 3.33	≤30	0.9082
TSS (mg/l) – TTT	26.33 ± 0.33	≤30	0.9959
TC (count)– T	960.0 ± 11.55	≤ 1000	0.9629
TC (count) – TT	600.0 ± 0	≤ 1000	1.0000
TC (count) – TTT	813.3 ± 3.33	≤1000	0.9998

4.7.2 Biological Oxygen Demand

Biological Oxygen Demand (BOD = 33.33mg/l) in the filtrate from filter T (0.1mm) was significantly ($p < 0.05$) higher than the recommended standard of ≤ 30 mg /l (Table 4.7). This led to the acceptance of the null hypothesis that filter T (0.1 mm) did not improve the wastewater from Boundary Sewage Treatment Plant to be used for irrigation. However, the (BOD TT = 27.67 mg/l, BOD TTT = 28.33 mg/l) in the filtrate from filters TT (0.05) and TTT (0.1 mm and 0.05 mm) were not significantly ($p > 0.05$) higher than the recommended standard of ≤ 30 mg / l) (Table 4.7) for the treated wastewater to be used for irrigation.

4.7.3 Total Suspended Solids

Total Suspended Solids (TSS T = 81.67 mg/l) in the filtrate from filter T (0.1mm) was significantly ($p < 0.05$) higher than the compared standard of ≤30 mg /l) (Table 4.7) for the treated wastewater to be used in irrigation. This led acceptance of the null hypothesis that the slow sand filter T (0.1mm) did not improve the quality of TSS in the treated wastewater to be used in irrigation. However, the amount of this parameter (TSS TT = 23.33 mg/l, TSS TTT = 26.33 in the filtrate from filters TT (0.05 mm) and TTT (0.1 and 0.05 mm) was not significantly ($p > 0.05$) higher than the compared standard of ≤30 mg /l (Table 4.7) for treated wastewater to be used for irrigation leading to rejection of null hypothesis.

4.7.4 Total coliforms

The number of total coliforms (TC T = 960, TT = 600, TTT = 813.3) in the filtrate were not significantly ($p > 0.05$) higher in all the three filters from the compared standard of ≤ 1000 MPN/ 100 ml (Table 4.7) for wastewater to be used in irrigation. Hence rejection of the null hypothesis that the slow sand filters did not improve the quality of total coliforms in the wastewater to be used for irrigation.

4.8 Comparison of filtrate with the national and international standards during wet season

Parameters that were not treated by Boundary Sewage Treatment Plant during wet season to the recommended standards for the treated wastewater to be used in irrigation (Table 4.4) were subjected to slow sand filtration for further treatment for them to be suitable for irrigation. The filtrate was compared with the various recommended standards for treated wastewater to be used in irrigation.

Table 4.8: Comparison of slow sand filtrate with the national and international standards for treated wastewater to be suitable for irrigation during wet season

Parameter and filters	Mean ± SE	Recommended standards	P- value
TC (count) – T	706.7 ± 3.33	≤1000	0.9999
TC (count) – TT	400.0 ± 0	≤1000	1.0000
TC (count) – TTT	440.0 ± 0	≤1000	1.0000
TSS (mg/l) – T	55.00 ± 0	≤30	<.0001
TSS (mg/l) –TT	15.00 ± 2.89	≤30	0.9825
TSS (mg/l) –TTT	26.00 ± 0.58	≤30	0.9899

4.8.1 Total Suspended Solids

The amount of this parameter (TSS T = 55 mg/l) was significantly ($p < 0.05$) higher than the recommended standard of ≤ 30 mg /l for the wastewater to be used for irrigation, (Table 12). However (TSS TT = 15.00 mg/l, TSS TTT = 26.00) were not significantly ($p > 0.05$) higher than the compared standard (Table 4.8) for the treated wastewater to be used for irrigation. .

4.8.2 Total coliforms

The number of total coliforms (TC T = 706.7, TC TT = 400.00, TC TTT =440.00) in the filtrate were not significantly ($p > 0.05$) higher than the compared standard of ≤ 1000 MPN/100 ml (Table 4.8) for wastewater to be used in irrigation. Hence rejection of the null hypothesis that the slow sand filters did not improve the quality of wastewater to be used for irrigation.

CHAPTER FIVE

DISCUSSION, CONCLUSONS AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Efficiency of Boundary Sewage Treatment Plant during dry and wet seasons

All the parameters except total aerobic bacteria during wet season were significantly different in all the stages of treatment at Boundary Sewage Treatment Plant. This may have been as a result of the various treatment stages at the treatment plant.

Primary sedimentation pond is the first phase of reducing BOD. The BOD was reduced by settlement and anaerobic digestion of organic matter at this pond. This is in line with Mara (2003) who found that the BOD and solid concentration in the raw wastewater were reduced by sedimentation and anaerobic digestion. Anaerobic treatment is more suited to wastewater with high BOD (IETC – UNEP, 2002) and therefore useful at reducing high concentrations of BOD and suspended solids for agriculture and food industries. Furthermore, the four days in which the wastewater spent at this pond exacerbated the reduction of BOD by giving ample time to the anaerobic microorganisms to digest the organic matter to the peak hence reducing the amount of BOD. This is further supported by Mara (2003) who found that a properly designed anaerobic pond could achieve around 60% of BOD removal at 20^0 C and one day hydraulic retention time was sufficient for wastewater with a BOD of up to 300 mg / l and temperature higher than 20^0 C. The reduction of BOD could also be attributed to the settling of organic matter to form sludge at primary pond. Also the availability of two large primary sedimentation ponds of each 21,800 m^2 surface area at Boundary Sewage Treatment Plant, further allowed the large organic load to be degraded hence reducing the organic load enabling the anaerobic microbes to digest them adequately thereby reducing the BOD. Primary treatment can physically remove 20 to 30% of the BOD that is present in particulate form. In this treatment, particulate material is usually removed by screening, precipitation of small particulates and settling in basins and tanks (Prescott *et al.*, 2002).

Flow chamber B may have enhanced the reduction of BOD at the succeeding stage by acting as a stage where primary pond effluent is diluted, aerobic organisms and dissolved oxygen are introduced. .

The trickling filter further reduced the BOD in the wastewater under treatment. The trickling filter media in Boundary Sewage Treatment Plant is made of black coloured polyethylene. Trickling filter (TF) is an aerobic treatment system that utilizes microorganisms attached to a media to remove organic matter from wastewater that passes over, around, through or by the media (Mackne *et al.,* 1998). Moreover, in trickling filters, microorganisms establish a strong attachment to the uneven surface of the media (rocks, stones or plastic) and biofilms develop above the plane of the media, to a depth of about 2 mm (Boltz *et al.*, 2006). Small organic molecules diffuse into microbial cells in the biofilm, providing carbon and nutrients for microbial cell growth (Boltz *et al*., 2006). To remove the larger sized molecules and particulate matter BOD, these particles must be trapped in the biofilm, so they can be degraded into small enough particles for diffusion to occur. The larger molecules and particulates become trapped in the biofilm by a ‘glue’ (extracellular polymeric substances EPS) secreted by the microbial cells. The EPS also attach the microorganisms to the media (Boltz *et al.*, 2006). Enzymes bound to the microorganism cells in EPS breakdown the particulates through hydrolysis, into smaller and smaller units (Confer and Logan, 1998), until the compounds are small enough to diffuse across the cell membrane.

The organic material is completely mineralised to carbon dioxide, ammonia, nitrate, sulphate and phosphate in the extensive biofilm (Madigan *et al.*, 2009), hence reducing BOD. This community absorbs and mineralizes the dissolved organic nutrients in the sewage thus reducing the BOD of the effluent (Ramesh, 2004). The treated wastewater and solids from the trickling filters are piped to a settling tank where the solids are separated (EPA, 2000). Usually part of the liquid from the settling chamber is re-circulated to improve wetting and flushing of the filter medium, optimising the process and increasing the removal rate (EPA, 2000). Trickling filter treatment removes 80 to 85% of BOD (Tortora *et al.*, 2010).

The Sedimentation tank at Boundary Sewage Treatment Plant with a diameter of 34 m, surface area of 900 m^2 and volume of 2,350 m^3 could have further reduced BOD. This is a stage where suspended matter, that include dead organisms from the preceding stage settle down, hence reducing the organic load that would have proceeded to the next stage of treatment. Some organic materials from the trickling filter might have been adsorbed onto the algae on the ridges of this pond hence giving time to the microorganisms present chance to act on the matter, reducing the load, hence BOD.

Secondary and tertiary ponds contributed to degradation of the organic matter by both facultative anaerobic and aerobic digestion of the organic matter respectively, leading to reduction of the BOD. The algae, at the edges of these ponds at Boundary Sewage Treatment Plant could have assisted in degradation of organic matter, hence reducing

BOD. US EPA (2002b) demonstrated that the presence of algae in the aerobic and facultative zones was essential for the successful performance of these ponds, therefore supporting this fact. In aerobic treatment ponds, aerobic microorganisms use dissolved oxygen to degrade the organic matter into CO_2, water and cell biomass. Passive or naturally aerated ponds rely on oxygen produced by phytoplankton during photosynthesis and to a lesser extent, diffusion of oxygen from the air into surface layers (Shilton, 2005). The birds at these ponds in boundary sewage treatment plant may have also contributed to aeration of the ponds as well as reduction of BOD by consuming organic matter in the wastewater. The four and five days spent by the wastewater in these two ponds at Boundary Sewage Treatment Plant exacerbated the reduction of BOD. This is consistent with the observations by The water treatment (2012) that indicated that the size and number of maturation ponds needed in a system is normally determined by the required retention time to achieve a specified pathogen concentration and organic matter.

Chemical oxygen demand is believed to be reduced by the same mechanisms responsible for reduction of BOD. However, this study could not account for the reduction of the non-metabolic matter contributing to the COD, since Boundary Sewage Treatment Plant does not use chemicals to treat the wastewater. Ramesh (2004) defined COD as the amount of oxygen required for the chemical oxidation of the organic matter with the help of strong chemical oxidants. The oxygen demand associated with the microbial cells is only partially exerted during a BOD test; also some of the organic compounds measured by COD may not be metabolized by the micro organisms in either the BOD bottle or the biological treatment process (Ramesh, 2004).

The raw sewage had neutral pH during the two seasons but, the neutrality reduced to near acidic state during dry season and acidic during wet season after screen and primary pond stage of treatment. This reduction of pH could be attributed to the anaerobic degradation of organic matter at the primary pond that produced organic acids and gases like CO_2 and hydrogen ions that dissolves and produce mild acids like organic acid, reducing the pH. This is consistent with the argument by IETC – UNEP (2002) who said that anaerobic digestion occurs in the sludge at the bottom of the pond which results in converting organic load to methane and CO_2 and releasing some soluble by –products into the water column (e.g. organic acids and ammonia). Particular bacteria have evolved to thrive in oxygen-depleted conditions, as they breakdown organic materials into methane and carbon dioxide (Sperling, 2007).

After the primary pond effluent passed through the flow chamber B and the trickling filter the pH increased to alkaline during dry season and to neutral during wet season and this increase could be attributed to increase or introduction of hydroxyl ions to the wastewater at the trickling filter. The algae at the periphery of Boundary Sewage Treatment Plant TF and at the ridges in the sedimentation tank would have released the hydroxyl ions to the wastewater, increasing the pH. This argument is supported by Mara and Pearson (1998) who argued that the position of oxypause similarly changes, as does the pH since at peak algal activity carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, so leaving an excess of hydroxyl ions with the result that the pH can rise to above 9.

Further the pH increased to more alkaline and from neutral to alkaline after the trickling filter effluent passing through the sedimentation, secondary and tertiary ponds. This increase in pH could be attributed to more hydroxyl ions being released into the wastewater under treatment, by the algae at the edges of the sedimentation tank, secondary pond and tertiary pond. Also it could be due to denitrification process in the secondary pond that is associated with facultative anaerobic processes at the boundary sewage treatment plant. A fact supported by Mackne *et al.* (1998). The authors demonstrated that denitrification occurs where oxygen levels were depleted and nitrate became the primary oxygen source of microorganisms and further indicated that denitrification is an alkalinity producing process. Nitrogen present in wastewater is a reduced form of ammonia, and removed during conventional wastewater treatment by two sequential biological processes; nitrification and denitrification (Osada *et al.*, 1995; Wicht and Beier, 1995; Tallec *et al.*, 2006a; Kampschreuer *et al.*, 2008b).

The temperature reduced after the influent passing through the screen and the primary pond. The temperature in the trickling filter effluent further reduced during dry season while it maintained low temperature during wet season. This could be due to cold environment at the filter, where sunshine cannot pass through the media to the cemented floor of the TF to heat the under drain wastewater. The rotating sprinklers at the trickling filters would have brought about cooling effect to the wastewater under treatment.

After the sedimentation pond, secondary pond and tertiary pond, the temperature increased during the two seasons. The increase of the temperature at dry season could be due to heat from the sunshine that heats these ponds directly because they are open.

Total dissolved solids and conductivity increased after the influent undergoing treatment at the screen and primary pond. This could be attributed to the anaerobic breakdown of the organic and inorganic materials hence releasing the dissolved solids and hence the increase in the conductivity and TDS. After the flow chamber B and trickling filter the TDS and conductivity reduced. This could be attributed to removal of nitrate in the wastewater through denitrification process. Mackne *et al.*(1998) showed that nitrate passing through the process of denitrification was reduced to nitrous oxide, and in turn, nitrogen gas. Since nitrogen gas has low water solubility, it escapes into the atmosphere as gas bubbles.

Nitrogen generally present in wastewater is a reduced form of ammonia, and is removed during conventional wastewater treatment by two sequential biological processes; nitrification and denitrification (Osada *et al.,* 1995; Wicht and Beier, 1995; Tallec *et al.,* 2006a; Kampschreuer *et al.,* 2008b). After the stage of sedimentation pond, secondary pond and tertiary pond the TDS and conductivity further reduced during the dry season while it increased during the wet season. The reduction during dry season could be due to further denitrification and the biological reduction of phosphate at ponds through polyphosphate accumulation (Prescott *et al.*, 2002). For phosphorous removal aerobic and anaerobic conditions are used alternatively in a series of treatments and phosphorous accumulate in specially adapted microbial biomass as polyphosphate. The increase of the TDS and conductivity during wet season could be due to more addition of dissolved solids from the the droppings of birds swimming and consuming food at the secondary and tertiary ponds. Generally, carbon and oxygen are major elements in all bird droppings. This is typical of organic material such as bird droppings. In addition to C, N, O, P, Cl, and S farm grow pigeons also have Si and F in their faeces (Lavernburg, 2011).

The number of total coliforms reduced from the first stage to the final stage of wastewater treatment. The first stage of screen removed the large floating objects like rags, cans and sticks (EPA, 2004). This removed material would have been contaminated with microbes including coliforms attached or adsorbed to them. Through this process the number of coliforms in the wastewater would have been reduced. This is consistent with Water UK (2006) who showed that the cleared screenings from the screen is washed and safely disposed off at a landfill site. The safe disposal is practised because of fear of pathogens in the screenings, where total coliforms might be present.

Primary pond is associated with settling of suspended solids to form sludge, it may have settled with some of the coliforms, reducing their number. This fact is supported by Tortora *et al.* (2010). The authors demonstrated that after the primary treatment step of the sewage passed through sedimentation tanks where solid matter settled out with sewage solids collecting on the bottom are sludge. Further reduction of these coliforms could be due to the high temperatures at the primary pond, sedimentation pond, secondary pond and the tertiary ponds which are exposed to direct sunshine resulting to high temperature that is believed to have killed these organisms therefore reducing their population. This reduction was also observed by Nascimento (1987) who showed that waste stabilization ponds technology was a useful natural method for treating wastewater, was cost- effective and was efficient for the removal of pathogenic microorganisms. Waste stabilization ponds (WSP) are intensively used for treating domestic sewage in tropical and subtropical countries due to sufficient sunlight and temperature that are key factors for the efficient removal of potential pathogens.

The wastewater under treatment at boundary sewage treatment plant spent a total of 13 days at the various ponds; 4 days at the primary pond, 4 days at the secondary pond and 5 days at the tertiary pond. This long duration of time could have allowed the various processes to reduce the population of coliforms adequately. This is consistent with the reports by Llyod *et al.* (2002) that among the principal factors involved in bacterial reduction are the retention time. The reduction of these microorganisms could also be due to the varying pH at the various stages at the treatment plant. These effects of pH on coliforms were also observed by Richard and Hirji (2003) who reported that pathogens could be destroyed by natural processes such as high pH levels that occur in the anaerobic parts of some ponds treatment systems. Pathogens also die naturally or are killed by predation. Furthermore, protozoa and microscopic invertebrates that feed on bacteria and fungi are also present in the wastewater (Ramesh, 2004). The rain at wet season could have further led to the reduction of these microorganisms by dilution effect.

The reduction in the number of total aerobic bacteria could also be explained by the same reasons attributed to the reduction of total coliforms. Moreover, their reduction after the wastewater undergoing treatment at the primary pond could be due to the anaerobic conditions associated with the pond. The increase of the total aerobic bacteria at the trickling filter compared with the preceding stage could be due to the favourable environment at the trickling filter where it is thought to have enough oxygen, making these organisms to grow well and multiply fast and comfortably. However the total aerobic bacteria were not significantly different at the stages where sampling took place during wet season.

Total suspended solids reduced after the raw sewage passed through the screen and the primary pond. This could be due to removal of solids at the screen i.e. rags, sticks that could have been having suspended solids adsorbed to them (EPA, 2004). The fine screen could have also removed the suspended solids therefore reducing the TSS in the wastewater (EPA, 2004). The primary pond is associated with settling of suspended solids hence reducing the TSS. Further, primary sewage treatment follows the preliminary stage of treatment where more solid matter settles and about 40 -60% of suspended solids are removed from sewage by settling (Tortora *et al*., 2010). Anaerobic treatment is more suited to wastewater with high BOD (IETC – UNEP, 2002) and therefore useful at reducing high concentration of BOD and SS from agriculture and food industries. The wastewater under treatment spent 4 days at the primary pond. This duration could have also led to further reduction of TSS because it allowed the solids to settle adequately. This is also consistent with findings by Reed *et al.* (1995) observed that with typical retention times (weeks to months) settling is responsible for the removal of the majority of suspended solids and organic nutrients entering anaerobic ponds. Total suspended solids increased after the primary pond effluent passed through flow chamber B and the trickling filter. The increase in the TSS could be due to death flocs from the trickling filter, solids of the media and this construction itself might have peeled out and hence contributed to this increase. Increase of TSS at this stage could also be due to the presence of algae at the floor of the trickling filter especially at the periphery such that when they wither or die or alive at some point they get carried away by the wastewater under treatment. The TSS in the trickling filter effluent reduced after passing through the sedimentation tank, secondary and tertiary ponds due to further settlement of solids, death microbes and decomposition of organic matter. This is consistent with the observations by Atlas (1995) who observed that the bacterial and algal cells formed during the decomposition of the sewage settle at the bottom. And eventually the pond is filled.

5.1.2 Comparison of the influent with the national and international standards

Total dissolved solids and pH met the recommended standards compared with during both dry season and wet seasons for wastewater to be used for irrigation. This could be attributed to the proper treatment of the wastewater at the various stages of treatment at Boundary Sewage Treatment Plant. However, TSS and total coliforms were not treated to the recommended level for the wastewater to be used for irrigation during the two seasons. The lagging of TSS could be due to its increase at the trickling filter stage rather than decreasing hence affecting the efficiency of the treatment plant. Also it may have been contributed by the birds' droppings at the secondary and tertiary ponds. The droppings could have also contributed coliforms into the wastewater hence affecting the performance of the treatment plant to treat total coliforms to the recommended standard. Smith *et al.* (1993) and Kirschner *et al.* (2004) who observed that from the drinking water production standpoint, the presence of aquatic birds at water reservoirs was associated with the decreasing quality of water. Birds residing at waters have been responsible for the deterioration of microbiological quality of this water (Standridge *et al.,* 1979). Waterfowl contribute a substantial amount of fecal indicators to water sources (Standridge *et al.,* 1979; Hussang *et al.,* 1979; Kirschner *et al.,* 2004).

Biological Oxygen Demand and COD were not treated to the recommended standards for the treated wastewater to be used for irrigation during dry season this could be lack of dilution of the wastewater by rainfall to the open ponds at Boundary Sewage Treatment

Plant which took place during wet season. Moreover, the total volume of the influent in during dry season was 5,332 m^3 compared with 7,167 m^3 during wet season.

5.1.3 Efficiency of slow sand filters (SSFs) during dry and wet Seasons

The efficiency of the slow sand filtration (SSF) was determined, in this study, in terms of the removal of impurities from the influent water.

The three slow sand filters improved the quality of the wastewater during both the dry and wet season except for the pH. The improvement of BOD, COD, and TSS by the slow sand filters could be due to physical filtration of the dissolved and suspended organic matter hence reducing the amount of the matter that would have arrived at the filtrate resulting to less BOD, COD and TSS. This explanation is supported by Huisman, 1974; Ellis and wood, 1985; Haarhof and Cleasby, 1991; Fogel *et al.*, 1993; Lloyd, 1996; Bahgat *et al.*, 1999 who reported that several mechanisms for the removal of particles, microorganisms and organic matter exist in SSFs. They indicated that the raw water to be purified enters the supernatant and moves through the sand bed due to gravity. As water percolates through the sand and organic material, microorganisms are removed by both mechanical such as absorption, diffusion, screening and sedimentation and biological processes such as predation, natural death and metabolic breakdown. This is contrary to the findings by Ellis and Kov, (1985) who indicated that the slow sand filter system is a highly biologically active unit.

The total coliforms and the total aerobic bacteria also reduced after the filtering process and this is thought to be because they got adsorbed, screened and sedimented at the filter. This justification is similar to the one by Stevic *et al.* (2004) who reported that sand filters remove pathogenic micro organism from polluted water by first retaining them in the filtration media before they are eliminated. The raw water to be purified enters the supernatant and moves through the sand bed due to gravity. As water percolates through the sand, organic material and microorganism are removed by both mechanical such as absorption, diffusion, screening and sedimentation and biological processes such as predation, natural death and metabolic breakdown (Huisman, 1974; Ellis and Wood, 1985; Haarhof and Cleasby, 1991; Fogel *et al.*, 1993; Lloyd, 1996; Bahgat *et al.*, 1999).

Total dissolved solids and conductivity also reduced and this could be due to adsorption of the dissolved solids at the filter. This finding is inconsistent with the one by (Mah, 2001) who found that slow sand filters do not improve sulphate, sodium and TDS and that additional treatment processes are required for water that is high in dissolved solids, such as sodium, nitrite, sulphate and fluorite.

pH was not improved by filter T during dry season and TT and TTT during wet season. This could be due to lack of ions or any microbial decomposition at the filter that would have altered the pH.

Those parameters that the Boundary Sewage Treatment Plant did not treat to level of the wastewater to be used for irrigation, were treated fully by the slow sand filters to the standards for irrigation. However slow sand filter T (0.1 mm) did not treat BOD and TSS to the recommended standards for irrigation this could be due its large pores which allowed the effluent to just pass through without holding any matter. This is supported by UNEP / SOPAC (2002) who indicated that the improvement in water quality by the sand filtration differs for different sand grain sizes.

5.2 Conclusions

1) The raw wastewater entering Boundary Treatment Plant recorded higher amount in the various parameters during dry season than wet season except for total suspended solids. The treatment plant reduced COD, BOD, TSS, total coliforms and total aerobic bacteria during both the dry and wet seasons. Total dissolved solids, conductivity and pH increased during the two seasons while temperature reduced during dry season and increased during wet season after the raw wastewater undergoing treatment.

   During dry and wet seasons, microbiological and physico chemical parameters reduced at each stage of treatment except for TDS and conductivity which increased after the influent undergoing treatment at the screen and primary pond and total aerobic bacteria and TSS which increased after the primary pond effluent undergoing treatment at the trickling filter.

2) Boundary Sewage Treatment Plant treated pH and TDS during dry season and BOD, COD, TDS and pH during wet season to the recommended national and international standards to be used for irrigation. However, it did not treat BOD, COD, TSS and total coliforms to the recommended standards to be used for irrigation during dry season and TSS and total coliforms during wet season. This treatment plant proved to be more efficient during wet season than during dry season. During wet season the plant achieved the recommended standards for irrigation for most of the parameters than during dry season.

3) Both grain sizes (0.1 mm and 0.05 mm) and a mixture of the two grain sizes in the slow sand filters used in this study improved all the parameters of the effluent from Boundary Sewage Treatment Plant except for pH. Furthermore, the slow sand filters achieved the parameters that the treatment plant failed to achieve to be used for irrigation. Filter T of 0.1 mm failed to reduce BOD and TSS during dry season to the recommended standards for irrigation.

5.3 Recommendations

1. The study recommends the use of slow sand filters of sand size 0.05 mm and another made of two layers of sand sizes 0.05 mm and 0.1mm to further improve on the quality of the final effluent from Boundary Sewage Treatment Plant to be used for irrigation.

2. Study to be initiated on the contribution / s of the birds at the secondary and tertiary ponds to the treatment of wastewater at the Boundary Sewage Treatment Plant

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APPENDICES

Appendix I. Analysis of Variance During dry season

Source	DF	ANOVA SS	Mean Square	P- value
BOD	3	482302.2500	160767.4167	<.0001
COD	3	3977272.250	1325757.417	<.0001
COND	3	1317072.917	439024.306	<.0001
PH	3	2.01995833	0.67331944	<.0001
TC	3	3.2952017E12	1.0984006E12	<.0001
TDS	3	645164.2500	215054.7500	<.0001
TEMP	3	83.18000000	27.72666667	<.0001
TSS	3	33030.66667	11010.22222	<.0001
TAB	3	5.8239083E13	1.9413028E13	<.0001

Appendix II. Analysis of Variance During wet season

Source	DF	ANOVA SS	Mean Square	P- value
BOD	3	466812.0000	155604.0000	<.0001
COD	3	3054283.667	1018094.556	<.0001
COND	3	24252.66667	8084.22222	0.0014
pH	3	2.89993333	0.96664444	<.0001
TC	3	361399555164	120466518388	0.0124
TDS	3	6357.666667	2119.222222	0.0273
TEMP	3	82.86916667	27.62305556	<.0001
TSS	3	67809.00000	22603.00000	<.0001
TAB	3	2.0944448E13	6.9814827E12	0.3736

BOD: Biological Oxygen Demand
COD: Chemical Oxygen Demand
COND: Conductivity
pH: potential Hydrogen
TC: Total coliforms
TDS: Total Dissolved Solids
Temp: Temperature
TSS: Total Suspended Solids
TAB: Total Aerobic Bacteria

Appendix III. Birds at boundary sewage treatment plant pond