THE EFFICIENCY OF NAIROBI'S KARIOBANGI WASTEWATER TREATMENT PLANT

BY

ANDERE CLEMENT MIRUKA

REG. NO: I56/69022/2013

A RESEARCH THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL CHEMISTRY OF THE UNIVERSITY OF NAIROBI

AUGUST, 2016

DECLARATION

This thesis is my original idea and has never been presented for award of a degree at any other University

Sign……………………………………. Date……………………………………

Andere Clement Miruka.

This thesis is submitted with our approval as research supervisors

Sign……………………………………. Date……………………………………….

Prof. David K. Kariuki.

Department of Chemistry,

University of Nairobi

Sign……………………………………. Date………………………………………

Prof. Amir O. Yusuf

Department of Chemistry,

University of Nairobi

Sign……………………………………. Date………………………………………

Dr. John O. Onyatta

Department of Chemistry,

University of Nairobi

ABSTRACT

Kariobangi Sewerage Treatment Plant in Nairobi City County is a conventional mechanical wastewater treatment plant with an installed capacity of 32,000 m^3/day and has an in built methenation unit. It is the only available conventional mechanical wastewater treatment plant in the city and its efficiency is therefore, of paramount importance. A total of 48 samples from three sites within the plant namely the Inlet (I), the Clarifier(C) and the Outlet (O) were analyzed for various parameters. Development activities within the treatment plant's catchment area were assessed with view to establish their effects on the performance of the plant. Physico-chemical parameters, chemical parameters, heavy metals, oil & grease and bacteriological presence analyses were carried out so as to evaluate the efficiency of the plant. The physico-chemical parameters analyzed included settleable solids (SS), chemical oxygen demand (COD), and biochemical oxygen demand after five days (BOD_5). The chemical parameters analyzed were nitrates and phosphates. The heavy metals analyzed included cadmium (Cd), lead (Pb), and chromium (Cr). Oil & grease was also analyzed while Total coliforms were analyzed as the bacteriological parameter. Imhoff cone was used to determine the level of settleable solids. Potassium dichromate titration method was used to determine the COD. Sample incubation process which gave daily readings of BOD for five days was used to determine the concentrations of BOD_5. Ascorbic acid method was used for phosphate determination. Flame Atomic Absorption Spectrometry was used to analyze the samples for cadmium, chromium and lead presence. Solvent extraction was used to determine the concentration of oil & grease. The nutrient-culture method was used to establish the concentrations of total coliforms. The results for various parameters, for I, C and O were: settleable solids; 6.5-15.7 ml/l, 0.2- 0.9 ml/l, 0.25- 1.9 ml/l respectively; COD; 600- 4000 mg/l, 80- 120 mg/l, 70-115 mg/l respectively; BOD_5 ; 310-650 mg/l, 60-290 mg/l, 60-210 mg/l respectively; nitrates; 0.158-1.437 mg/l, 0.167-1.178 mgl, 0.132-1.00 mg/l respectively; phosphates; 76-200 mg/l, 82.5-179 mg/l, 86-127 mg/l respectively; Cd; 0.505- 0.723 mg/l, 0.1543- 0.2893 mg/l, 0.8500-1.4465 mg/l respectively; Cr; 4.625- 58.568 mg/l, 0.0743- 0.9432 mg/l, 10.16 mg/l respectively; oil & grease; 1.012- 1.901 mg/l, 1.1246-1.349 mg/l, 0.923- 1.032 mg/l respectively; Total coliforms; 253,000- 590,000 counts/100 ml, 180,000 -561,000 counts/100 ml, 160,000- 783,000 counts/100 ml respectively. Percentage reduction efficiency for settleable solids was found to be in the range of 74.7- 96.7 % while COD and BOD_5 had percentage reduction efficiency ranging from 88.3- 98 % and 43.6-

84.5 % respectively. Nitrates and phosphates had percentage reduction efficiency of the range -17-36.5 % and -13.2- 36.5 % respectively. Oil & grease had percentage reduction efficiency in the range of 14.4 -92.6 % while total coliforms had percentage reduction efficiency of -32.7 -66.9 %. With the average outflow volume of 109.3 litres/second the pollution loadings were of 139,357 mg/s, 35,303.9 mg/s, 20,493.76 mg/s, 22.36 mg/s, 111.78 mg/s, 82.78 mg/s, 375,718,750 counts /s for settleable solids, COD, BOD_5, Cd, Cr, Oil & grease and total coliform respectively. Cottage industries involving paint making, metal works and construction of residential and commercial buildings due to population upsurge were some of the development aspects established in the plant's catchment area. In conclusion, the quality of the effluent that emanated from the plant was wanting and the pollution load discharged into Nairobi River was in large figures.

DEDICATION

I dedicate this thesis to my late parents Mr. and Mrs. Miruka, my lovely wife Lucy and son Curran for their support.

ACKNOWLEDGEMENT

I would wish to express my sincere gratitude to my lead supervisor, Prof. David Kariuki, for his immense contribution in formulating, monitoring and guidance during this research project. My special appreciation also goes to Prof. Amir Yusuf for his constant encouragement and guidance throughout the study and for finding time to proof read this work. Many thanks to Dr. John Onyatta for his time to proof read this work. I also acknowledge NUFFIC for funding this project, thanks to Mr. Bobby Russell and Prof. Shiundu, the coordinators of the NUFFIC project-Technical University of Kenya - Chapter.

I am also indebted to the Director Kenya Water Institute (KEWI), Mrs. Doris Situma, Head of Department of Water Resources Management at Kenya Water Institute (KEWI); Mrs Maundu, Chief Technician Biological Labaratory (KEWI); Mr. Makose, Technologist at Kenya Water Institute for having allowed me to use their laboratory to carry out this study.

I wish also to acknowledge the support from staff of Nairobi Water and Sewerage Company at the Kariobangi Sewerage Treatment Works (KSTW) especially Mrs. Miriam Khamala. My appreciations also go to Nairobi City Water and Sewerage Company (NCWSCO) for having allowed me to carry out this research work at one of their facilities; the Kariobangi Sewerage Treatment Works (KSTW).

I also express my thanks to Dr. Austin Aluoch, Chairman of the Department of Chemical Science and Technology, Technical University of Kenya for his support during this study.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
APHA	American Public Health Association
AQP	Accrued Quality Points
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CP	Compulsory Parameter
DO	Dissolved Oxygen
DNA	Deoxyribonucleic Acid
DWF	Dry Weather Flow
EDP	Effluent Discharge Points
FAO	Food and Agriculture Organization
FC	Facility Code
H.U	Hazen Units (for measuring color)
Jua Kali	Informal industrial set-ups
KSTW	Kariobangi Sewerage Treatment Works
msl	Metres above sea level
NCWSC	Nairobi City Water and Sewerage Company
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Units
ROK	Republic of Kenya
PLP	Pollution Loading Points
SS	Suspended Solids
PV	Permanganate Value
TDS	Total Dissolved Solids
TGWC	The Global Water Crisis
TSS	Total Suspended Solids
TPH	Total Petroleum Hydrocarbon
WHO	World Health Organization
WRMA	Water Resources Management Authority

CHAPTER ONE

INTRODUCTION

Kenya is classified a country with limited water supply with per capita accessible water presently at 650 m^3 per year and future outcrop shows a likely drop to 359 m^3 per year by 2020, due to population increase. This number is far-off the internationally acknowledged value of 1000 m^3 per year per capita level. Imperative action is thus required to boost the water capacity to advance the availability and ease of access to clean and safe drinking water. Water pollution is a limiting factor for development in Nairobi City and other parts of the country. It is therefore prudent to pay more attention to wastewater as a major water source if well treated to suit a given purpose. Nairobi City Water and Sewerage Company is the body charged with the responsibility of collection and treatment of wastewater in the city. However, the city's wastewater management systems have not been able to keep up with the increase in demand for cleaner water from the ever growing population which is estimated to be at 4 million currently. The systems have proved insufficient to handle the amount of municipal and industrial effluent released into Nairobi River and other surface waters. Nairobi is no longer the "place of cool waters" but one in which the surface water is no longer potable or fit for many other useful purposes. A good number of industries located in Nairobi's industrial area discharge their wastes directly into the environment particularly into Ngong River thus making it the most polluted river in Kenya. The amount of untreated effluent discharged into the river has made it a flowing effluent. Petro-chemicals and metal compounds from micro-enterprises and "Jua-kali" sector are some of the industrial wastes that are always released into the environment. Oil & grease from the busy roads and Jua Kali garages are usually washed into adjacent water systems. Due to poor sewage systems, some of these wastes usually find their way into the available sewer lines making the treatment processes ineffective. Untreated or partially treated sewage and uncollected garbage have immensely contributed to a vicious cycle of water pollution, water-borne diseases, poverty, and environmental degradation. It also poses environmental and health risks to people living in Nairobi and its environment, especially the poor who usually use contaminated waters and raw sewage for irrigation, subjecting both farm workers and consumers of the food crops to possible health problems (UNEP 2008).

Wastewater refers to a mixture of the liquid wastes transported from business buildings, residential areas, institutions, industries, ground, surface and storm water that may be directed to or just flows into the sewers (Metcalf and Eddie, 1972). Huge industries release large volumes of wastewater and it is therefore, it is essential to treat contaminated water before release for the safeguard of the surroundings and human being. Contaminated water when directly released into existing water bodies such as rivers has detrimental effects on fisheries and other aquatic organisms. Inorganic ions of nitrogen and phosphorus often present in wastewater can cause algal blooms, and great harm to aquatic organisms. Wastewater when not appropriately treated, can carry disease causing organisms, which, when ingested by humans through food chain, may result to grave health problems such as typhoid and cholera. It is also necessary to remove solid wastes from wastewater because as it decomposes, it consumes oxygen and depletes the oxygen in the water body it is added to, resulting to death of the aquatic life. Wastewater that has been treated can be used in so many ways such as, for domestic chores, in industrial settings, re-used in agricultural setting such as for irrigation (Melissa *et al* 2007). The first known wastewater removal sewer scheme was constructed very early in history and was a Babylonian seal cylinder which dated back to the seventh century (Noyes, 1994). The gutters and open channels which served as sewers for storm waters were constructed a few centuries later. Nowadays, water is pumped from wells, rivers, streams, and reservoirs to water treatment plants in today's cities, where it is treated and distributed to consumers. Wastewater resulting from the various uses collected via sewer pipes to wastewater treatment plants, where it is either treated and returned to streams, rivers, and oceans or re-used for irrigation and landscaping. Harmful materials, such as chemical compounds, and microorganisms are removed from the wastewater at the treatment plant. (Melissa *et al* 2007).

1.1 LOCATION OF NAIROBI CITY

Nairobi is the capital city of Kenya and is situated towards the edge of South-Eastern of Kenyas's agricultural rich region. It is at approximately 1° 9'S, 1° 28'S and 36° 4'E, 37° 10'E and it covers an area of about 696 km^2 (CBS, 2001). The variations in altitude are between 1,600 and 1,850 metres above sea level (Mitullah, 2003). The parts of the city towards the Western side is on the high ground of approximately 1700-1800 metres above sea level with rugged landscape, the eastern side is generally low, approximately 1600 metres above sea level and flat (Saggerson, 1991).

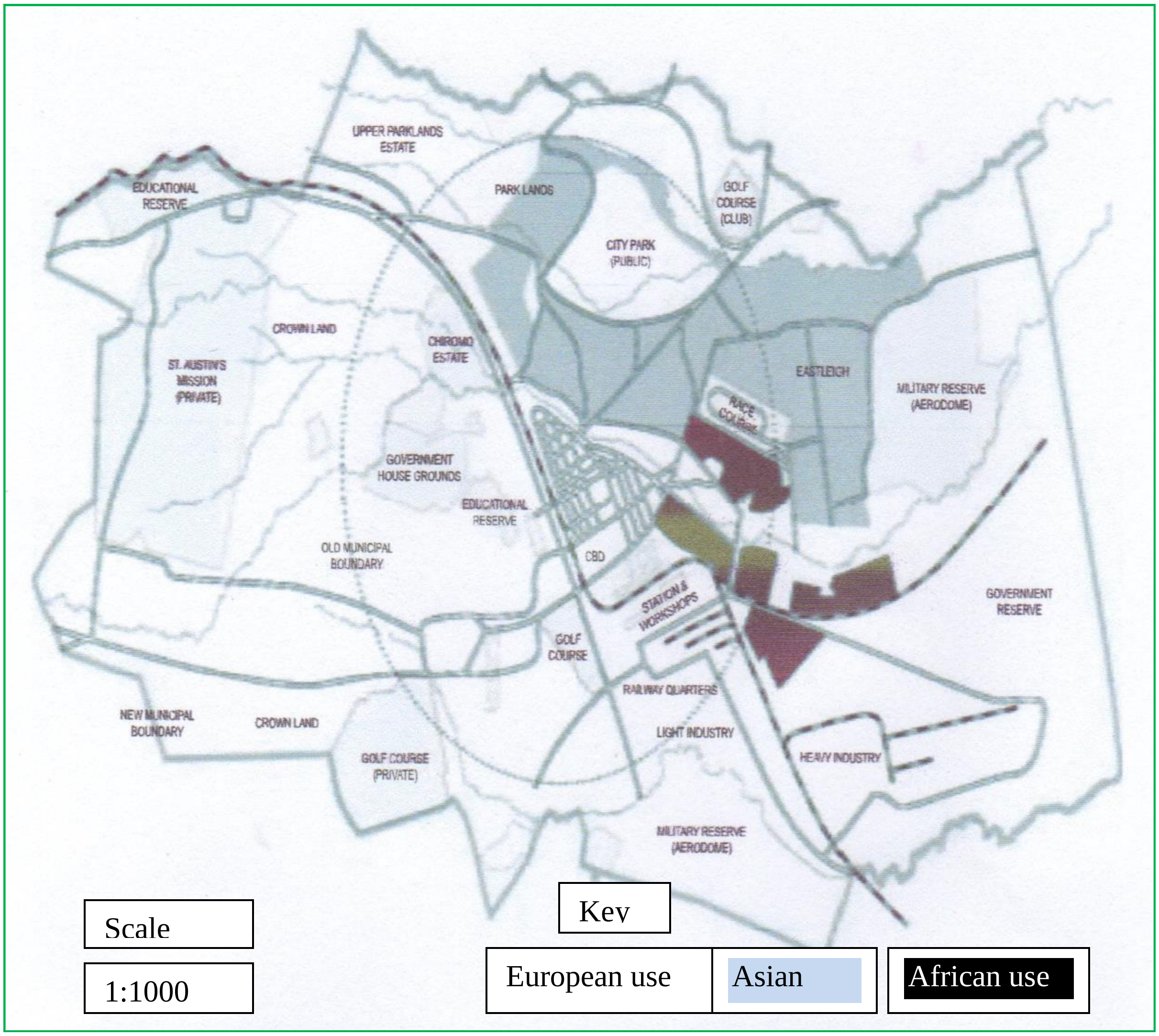
1.2 PLANNING OF CITY OF NAIROBI

1.2.1 The First Master Plan

The earliest arrangement of the current city of Nairobi was drawn by Arthur Frederick Church in 1898 (JICA, 2014). The plan drafted by Church had the following features: Nairobi City was about the same location as it is today, and the railway line was laid out where the Uhuru highway is currently towards the West. There was a main street that was running from the railhead, which was called Station Road (today's Tom Mboya Street), which was laid out from the railway station to North, with a design to be wide enough for three-axled oxcart wagons to turn. There was another street parallel to Station Road, called Victoria Street (renamed as Government Street in 1901, and today's Moi Avenue) which was laid out with the same width as the Station Road. Along the Victoria street were thirteen commercial plots called European Bazaar. Off Victoria Street were ten streets along which houses for railway workers were built. Along the rise that bordered the flat land were a half dozen sites for upper grade houses for senior railway employees, which is today's railway golf course, and Nairobi river was dammed up to create a impounding pond (ETH Studio, 2008). There was no sewer line or waste treatment plant (s) that was put in place then.

1.2.2 Plan for a Settler Capital 1927

The Settler Capital Plan was the second master plan of the city of Nairobi and was drafted by F. Walton James and designed by Eric Dutton in 1927 under the colonial government. The area of the city was extended to 77 km^2 to put up with the increasing populace. The main objective of the plan was to improve the drainage and assist in clearance of swamps as well as regulation of buildings. Traffic regulations were introduced so as to cover up to the extended residential area though the residential area was by and large segregated by racial groups. There was no wastewater or solid waste management strategies that were put in place (JICA, 2014). Figure 1.1 shows the 1927 plan of Nairobi City.

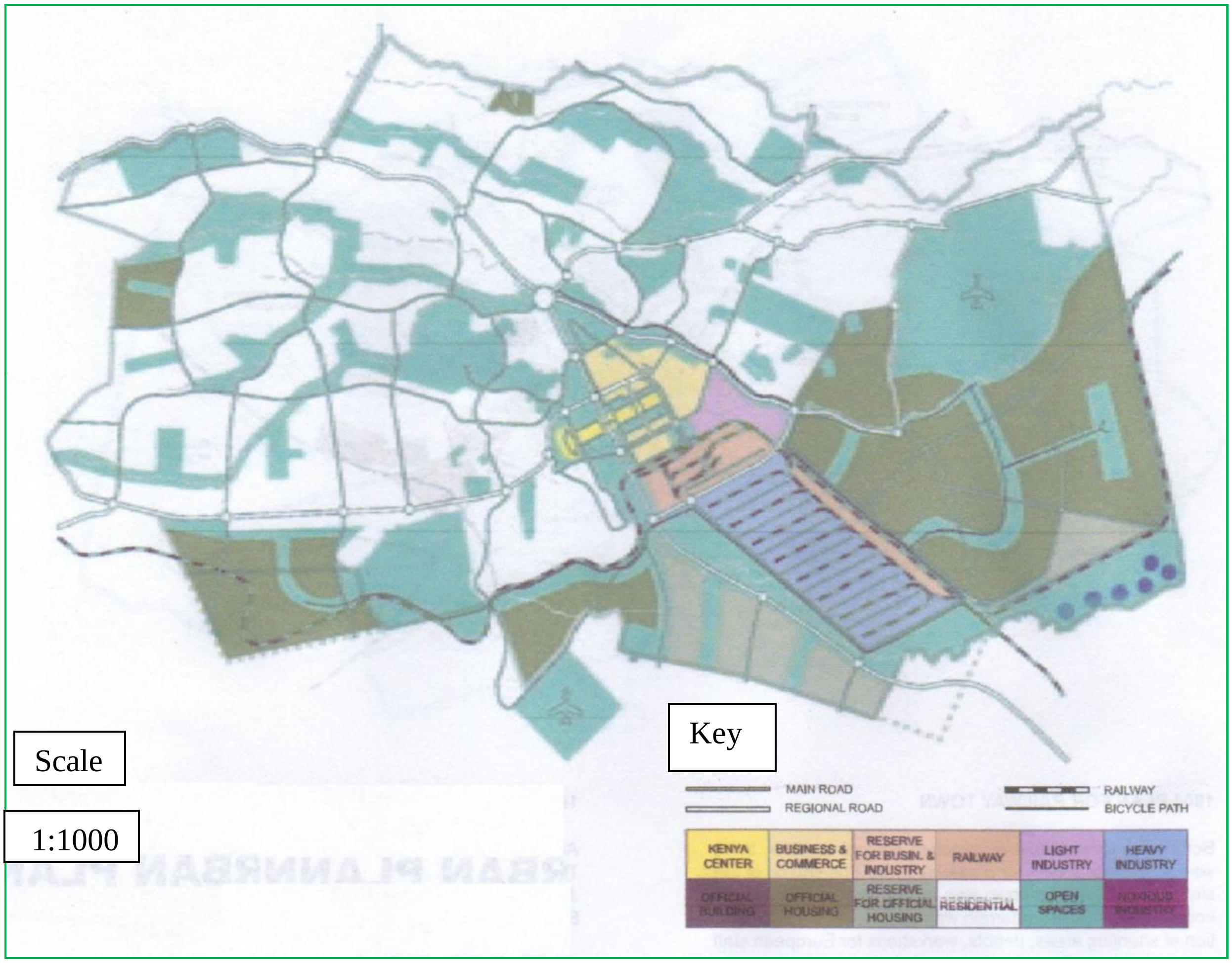


Source: ETH Studio Basel, History of Urban Planning in Nairobi, 2008

Figure 1.1: The settler capital plan of Nairobi, 1927

1.2.3 Master Plan for colonial Capital

The third master plan was developed in 1948. A zoning scheme was introduced in this plan with zones for administrative buildings, trade and commercial, industry, railway, residential, official housing, open space, forest reserve and parks. One of the goals of the plan was to set up neighborhood units for the employed with intentions to foster exclusivity. The plan was also intended to attract more industrial investments to Nairobi. The alignment of the railway had also been changed to the present one along the western part of the town, which gave way for the expansion of the Uhuru Highway today. The area to the south of the railway station was converted to an extensive industrial zone (JICA, 2014). Figure 1.2 illustrates these details.



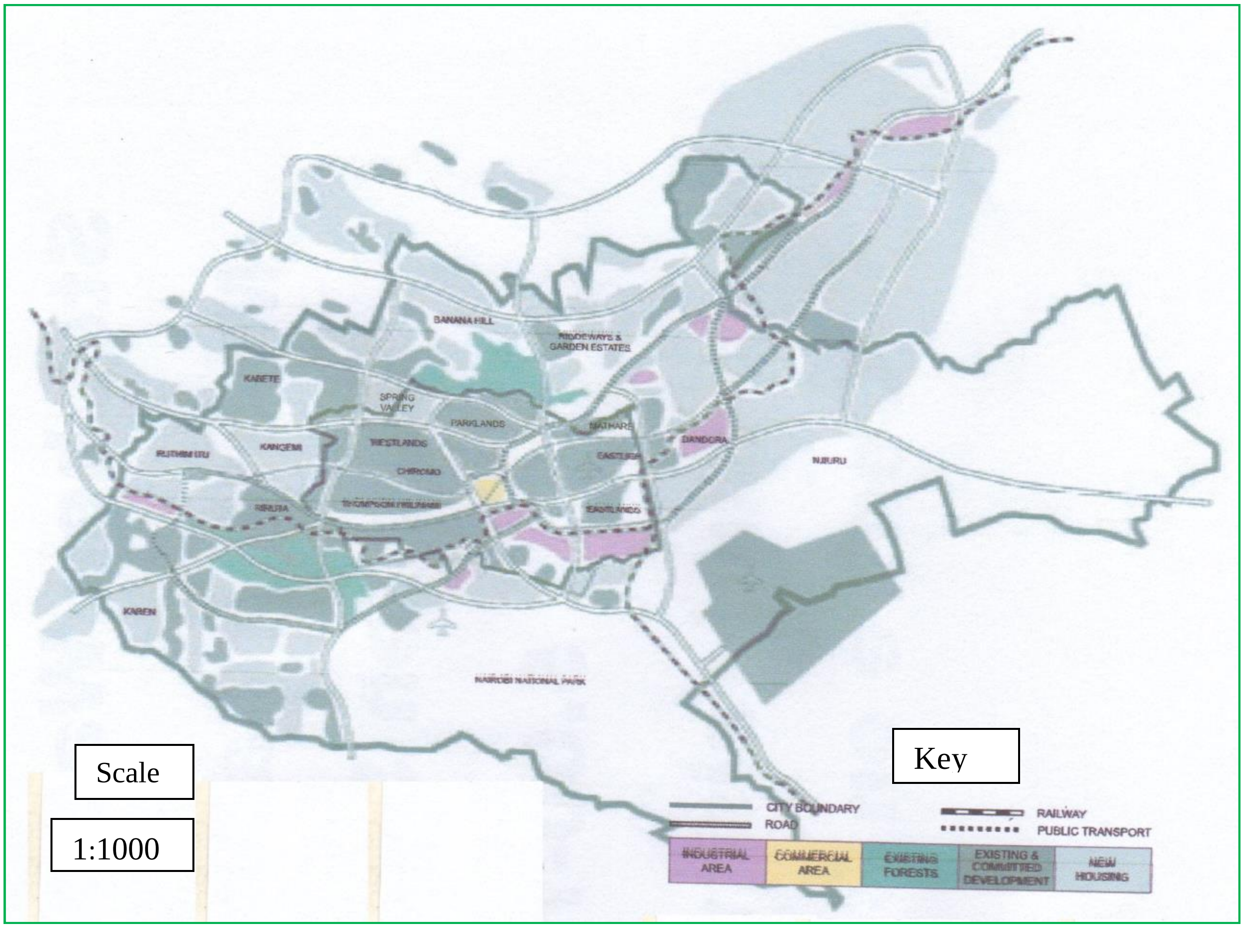
Source: ETH Studio Basel, History of Urban Planning in Nairobi, 2008

Figure 1.2: Master Plan of Nairobi, 1948

1.2.4 Nairobi Metropolitan Growth Strategy 1973

In 1971, the United Nations helped in the formulation of Metropolitan Growth Strategy in collaboration with the UN experts, urban planners in the City Council of Nairobi and urban planning consultants to form a Nairobi Urban Study Group (JICA, 2014). In 1973, Nairobi Metropolitan Growth Strategy as shown in Figure1.3 was published and the Team Leader was Charu Gupta (1971-72) and Donald Monson (1972-73) (JICA, 2014). In the 1973 Strategy, a number of proposals were made in relation to the urban planning of Nairobi and the major components were:

Central Business District (CBD) was already congested, and it was proposed that some functions of CBD to be supplemented in some suburban centres to avoid excessive concentration in the CBD. A wide road network surrounding CBD was proposed with bus ways to connect to residential and industrial areas, and use of private cars was to be controlled so that the increasing number of population would shift to public transport. The industrial area which was close to CBD was providing a large number of employment opportunities, but was already heavily concentrated. To avoid excessive concentrations, expansion was to be limited to capital-intensive urban industry type with limited employments. For other existing industries, expansion of production was recommendable in suburban locations. The northern part of the City, which then had mostly been planned for coffee plantation and estates, was expected to be urban area by the turn of the century. Since some areas were steep-sided hills that could not be easily converted to high or medium density housing area or industrial area, they were to be used mainly for low density housing development. The southern part of the City, which includes Kibera and Wilson Airport was to be used chiefly as residential area for low to medium income population. Wilson Airport was to be relocated to a site outside of Nairobi. The site after the relocation was to be converted to an industrial area. Karen and Langata areas were to continue being used for moderate to lofty earning population. Dagoretti, located to the West of the City was expected to have rapid population growth in order to create job opportunities to the anticipated increasing population within the zone, provision of industrial area and commercial centres was necessary. The eastern part of the city was to continue to serve low to middle income population except in a few of high end estates ((JICA, 2014).



Source: ETH Studio Basel, History of Urban Planning in Nairobi, 2008

Figure 1.3: Master Plan of Nairobi, 1973

1.3 POPULATION GROWTH

In 1901, the population of Nairobi was 8 000, this figure increased to 118 000 in 1948 and by 1962, the city's population was 343 500 persons (Rakodi 1997, CBS 2001). Today the population is estimated to be about 4 million. The average population density for Nairobi is 5714 people per km^2. Rural migrants influenced the early growth of Nairobi. Major increase in population was observed in the period ranging from the year 1979 to 1989 when about 772 624 new people came to the city (NEMA, 2003). Several motivation factors were behind the rural-urban movement of people to Nairobi and they include; enhanced economic prospects, higher education facilities, higher wage employment, and the readily available market for goods and services. Table 1.1 gives the historical population growth of the Nairobi city since its inception to the last population census in the year 2009 (ROK, 2010).

2 Table 1.1: Historical change of Population of Nairobi

Year	Population(1,000)	Average Annual Growth rate (%)	Remark
1906	11		1st Master Plan (1898) 2nd Plan for settlers Capital (1927)
1948	119	6.84	3rd Master Plan 1948
1963	342	7.29	Independence 1963
1969	509	6.85	1st Census
1979	828	4.99	4th Master Plan (1973) 2nd census
1989	1325	4.81	3rd Census
1999	2,143	4.93	4th census
2009	3,138	3.89	5th census

Source: Nairobi City County

2.1 WATER SOURCE

The Nairobi River Basin is made up of three rivers namely; Nairobi, Ngong, and Mathare. The catchment of these rivers is located within Limuru and Kikuyu Hills. The principal sources of water for Nairobi are Ndakaini, Ruiru, and Sasumua dams on rivers originating from the Aberdare ranges, one of the five Kenya's water towers. Nairobi city water and sewerage company (NCWSC) is the body that is solely responsible for water collection and distribution to the residents of the city as well as for wastewater management. Water quality of the city is being compromised by several factors which includes natural phenomenon such as the high fluoride content in groundwater to human activities such as poor management of wastewater and environmental deterioration within the city and in the surrounding suburbans (NCC, 1995).

2.2 SEWERAGE SYSTEMS

Nairobi has two main wastewater treatment plants namely Kariobangi sewerage treatment works and Dandora sewerage treatment. These plants serve approximately 48 percent of Nairobi's population (ROK, 2002). The sewerage systems are facing numerous challenges which include but not limited to poor upholding, unlawful acquaintances, disposal of garbage in toilets garbage, and intentional blocking of sewage lines so as to tap water for irrigation. For example, at Maili Saba in Kibera, manhole covers were removed and the city's main sewer line blocked, diverting raw sewage on to their land to water their crops (Scott *et al* 2004). A research works carried out in the year 2000 showed that 3,700 farmers in Nairobi practice irrigation and that of these 36 percent use wastewater (Ayaga *et al* 2004). Total coliform counts increase downstream in all the three rivers running through Nairobi and there seems to be no dilution effects taking place which means that there are several human waste and other sewage discharge points along the rivers. (UON/UNEP.2005). Research has also shown that fifty percent of all the preventable diseases are related to water and sanitation (Practical Action, 2005).

2.3 SANITATION

Nairobi City is currently facing a huge challenge as far as provision of sufficient sanitation amenities is concerned. Sewage discarding and garbage gathering are challenges which are on the rise given the ever growing population. Increasing urbanization, rural-urban migration and quick advancement linked to population increase have led to amplified solid waste production by manufacturing, household, and other activities. However, this increase has not been accompanied by corresponding growth in the ability to deal with waste disposal. In 1992, between eight hundred to one thousand tonnes of solid waste were produced in Nairobi every day, of which less than ten per cent was collected by the local authority. The amount of solid waste by the year 2002 had increased to 1500 tonnes per day out of which 40 percent was either not collected, or predisposed off by ablaze or unlawful discarding (Syagga 1992, CCN 2007). Waste administration has been one of the most critical and thorny environmental challenges within the city. The wastes originate from various sources which include households, service and industrial processes (NEMA, 2003). The most common forms of solid wastes are food waste, polyethene bags, and paper. By the year 2007, more than 2 million polyethene bags were being generated in Nairobi every year. These bags suffocate flora and fauna, contaminate the soil, and provide proliferation grounds for mosquitoes once released into the environment. In the footprints of a number of other African countries, as of January 2008, Kenya enforced a nationwide bar on the importation and supply of polyethene bags below 30 microns in thinness (NEMA, 2008). This was to ensure high quality of the imports with long life span thus reduction on the frequency of importation.

2.4 THE DEVELOPMENT ACTIVITIES IN NAIROBI CITY

In the last few years Nairobi City has experienced major expansion in virtually all the sectors of the economy. Rapid population growth coupled with urbanization has been the force behind these development activities with major changes in urban agriculture, housing and infrastructural development. These land use activities have immensely contributed to water contamination tribulations in Nairobi City (Kithiia and Mutua, 2006).

2.4.1 Urban Agriculture

Even though city farming avails opportunities in shore up of substitute source of income strategy, it is not devoid of ecological issues. The challenges include increase in zoonotic ailments, poisonous chemicals, and environmental degradation. Small-scale farmers in Nairobi block sewers so as to tap wastewater and nutrients for irrigating their crops, risking pathogens as well as heavy metals in the wastewater to food chain (CCN, 2007). There exist numerous farming activities in Nairobi some of which are found along the sewer lines and in areas adjacent to the three rivers cutting across the city. Crops grown often include kales, cabbage, maize, tomato and sweet potatoes. These agricultural activities result to increase in suspended solids, turbidity, colour, nitrates and phosphates from detergents and other wastes. These therefore, cause fall in both the sanitized and artistic aspects of water. Contamination of water resulting from agricultural activities lead to higher management costs and a decline in the artistic satisfaction of water resources (Olmstead, 2010)

2.4.2 Land use and land use planning

The biggest impediment to growth of Nairobi City, particularly designed settlement, is the absence of standard and updated substantial expansion plan. Most development activities within Nairobi city are being carried out in a planning emptiness (NEMA, 2003). The current city set up and administration has not successfully presented suitable alternatives to the eminently growing city rot and environmental disaster. The repercussions resulting from non-availability of workable design plan comprises of jumbled patterns of expansion with a mix up of activities which are not companionable with the area such as small cottage industries within the residential areas, concentration of job opportunities within the central business district (CBD) and manufacturing zones, leading to traffic obstruction, environmental contamination, and quick expansion of unofficial settlement. These have severely affected the wastewater treatment plant in the city. Large debris from building sites, industrial wastes and domestic wastes from informal settlements have made the wastewater treatment processes currently in place to be inefficient. Another major impact of lack of planning is the fact that some developments are being made on parcels of land meant for improvement of sewer lines (Kithiia, 2012).

2.4.3 Housing and infrastructural development

Provision of sufficient housing has been a challenge, with the system not capable to cope up with the demand rate with an yearly shelter shortfall of more than 120,000 units due to population increase (Kusienya 2004). Low pace of venture in medium and low-income housing has led to the mushrooming of informal settlements. In the recent years though, housing and road construction in Nairobi have improved. The debris originating from these sites are a threat to the sanitation efforts in the city as the debris find their way to the sewer lines hampering transportation of wastewater to the Kariobangi Sewerage Treatment Works. The debris from construction sites also causes damage to the plant making the treatment process inefficient. The soils dug in the construction sites are carried away alongside wastewater thereby increasing the amount of solids entering the plant. Efficient sewerage network is also a challenge in the new developing sites (NEMA, 2003).

2.5 STATEMENT OF THE PROBLEM

Nairobi City County has experienced speedy urban increase in populace in the last few years as a result of rural-urban migration as well as the natural growth. As a result, social amenities have been overburdened due to increased demand. The city's wastewater management system has not been able to cope with the current demands. The condition is unpleasant particularly in the unofficial residential areas within the city which do not have elaborate sewerage network. Currently, there are only two available sewerage treatment plants in the city; Kariobangi and Dandora. Kariobangi sewerage treatment works was meant to be energy sustaining due to the inbuilt methanation unit, however, non-maintenance and poor management of the plant has led to the collapse of energy generation and subsequent discharge of raw untreated and partially treated sewage into the rivers. This has resulted in heavy pollution of the rivers, poor health and reduced quality of life within the treatment works catchment area and to other users at large. It was therefore, necessary to assess the efficiency of this facility and propose any possible improvement mechanisms.

2.6 JUSTIFICATION

KSTW is one of the two available wastewater treatment plants in Nairobi City County. The population of the city has increased tremendously in the recent year and is estimated to be about 4 million from 3.13million in 2009.The numbers of light industries such as paint making and metal works among others have equally increased. This implies possible deposition of heavy metals and other waste into sewer lines. The plant discharges into Nairobi River which is occasionally used for irrigation in downstream. These coupled with poor maintenance of the sewerage systems implies increased workload for this plant. These therefore, call for the need for efficiency check on the plant to enable necessary improvement mechanisms to be put in place.

2.7 GENERAL OBJECTIVE

The main goal of this study was to assess the efficiency of Kariobangi Sewerage Treatment Works

2.8 SPECIFIC OBJECTIVES

1. To determine the throughput levels of physico-chemical parameters; settleable solids, TSS, TDS, COD, BOD_5, DO, chemical; nitrates, total phosphorous, heavy metals (Cd, Zn, Cr, Pb), Oil & grease and total coliforms
2. To evaluate the efficiency of the plant on the levels of the physico-chemical parameters, chemical parameters, heavy metals, oil & grease and total coliforms
3. To evaluate the pollution loading of the pollutants to the receiving water bodies.
4. To assess the effects of surrounding development activities on the efficiency of the plant.

CHAPTER TWO

LITERATURE REVIEW

2.1 INRODUCTION

The world is currently faced with a universal water quality predicament (TGWC, 2012). Urbanization, continued swift increase in population, rapid industrialization, and elevated need for foodstuff has led to extension and escalation of food production which are all inserting stress on water resources. These have led to rise in release of polluted water to the receiving water bodies posing a worldwide health risks to human beings. Several reasons are propagating this crisis, however, it is apparent that freshwater and coastal eco- systems all over the world, on to which human race has relied on for decades, are progressively more endangered. It is also obvious that future needs for water is almost unachievable as long as wastewater management is not revolutionized (TGWC, 2012).

Just like in the majority of cities in sub-Saharan Africa, sanitation provision in Nairobi is grossly deficient. A large number of the population have no access to toilets and great amounts of human excretes are released to the environment and this poses greater risks to contagious ailment burden and the standards of living (Hutton *et al*. 2007).

2.2 SEWAGE COMPONENTS AND THEIR ENVIRONMENTAL SIGNIFICANCE

The typical component of sewage can be grouped into five main categories namely physico-chemical, chemical, heavy metals, oil & grease and bacteriological parameters. Other than temperature, pH, conductivity the rest are pollutants. Most countries have own standards for discharge in to public sewers as well as discharge in to the environment. Table 2.1 shows quality limits for release into the municipal sewers as recommended by the national environment management authority (NEMA-Keya). The maximum allowable limit for BOD5 and COD discharge into the public sewers are given as 500 mg/l and 1000 mg/l respectively.

Table 2.1: Standards for Effluent Discharge into Public Sewers

Parameters	**Maximum levels permissible**
Total Suspended Solids (TSS) (mg/l)	250
Total dissolved solids (TDS) (mg/l)	2000
Temperature °C	20-25
pH	6-9
Oil and grease (mg/l)-where conventional treatment shall be used	10
Ammonia Nirogen (mg/l)	20
Biological Oxygen Demand (BOD_5) days at 20°C (mg/l)	500
Chemical Oxygen Demand COD (mg/l)	1000
Lead (mg/l)	1.0
Chromium (Total) (mg/l)	2.0
Cadmium (mg/l)	0.5
Zinc (mg/l)	5.0
Nitrates (mg/l)	20
Phosphates (mg/l)	30
Colour (H.U)	<40

Source: (Environmental Management and Co-ordination (Water Quality) Regulations, 2006)

Table 2.2 gives the maximum allowable limits for discharge into the environment as provided for by national environment management authority. BOD_5 is given as 30 mg/l while COD is given as 50 mg/l.

Table 2.2: Standards for effluent discharge into the environment

Parameter	**Maximum Allowable (Limits)**
Biological Oxygen Demand (BOD_5 days at 20°C) (mg/l)	30
Total Suspended Solids (mg/l)	30
Total Dissolved Solids (mg/l)	1200
Total Coliforms (counts/ 100 ml)	30
pH (Hydrogen ion activity, marine)	5.0-9.0
Oil and Grease (mg/l)	Nil
Temperature (in degrees Celsius) based on ambient temperature.	Ambient Temperature ±3
Chemical Oxygen Demand (mg/l)	50
Colour in Hazen Units (HU)	15
Total phosphorus (mg/l)	2 Guideline value
Total Nitrogen (mg/l)	2 Guideline value
Ammonia, ammonia compounds, nitrate compounds and nitrite compounds (mg/l)	100
Chromium VI (mg/l)	0.05
Lead (mg/l)	0.01
Cadmium (mg/l)	0.01
Zinc (mg/l)	0.5

Source: (Environmental Management and Co-ordination (Water Quality) Regulations, 2006)

2.2.1 Physico-Chemical Parameters

These refer to the parameter to which the physical properties of wastewater are attributed. They include Temperature, pH, color, conductivity, turbidity, settleable solids, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD), and biological oxygen demand (BOD). BOD and COD comprise of biodegradable organic compounds which originate from domestic and industrial wastes as well as from agricultural run-off. These wastes may upset the oxygen balance of surface water because their breakdown consumes oxygen. The optimum dissolved oxygen (DO) in natural water is 4-6 mg/l and this is essential for supporting aquatic life (Omoto, 2006). Any alterations on this optimum level may lead to massive destruction of aquatic life.

Temperatures

Reaction rates increases with rise in temperature in anaerobic ponds, the optimum temperature for methane forming bacteria is given as above 20°C and methane production rate increases twice as much for each 10°C to 15°C rise in temperature in the atmosphere. Incidentally, bacteria are grouped in order of their optimal temperature range for development. Mesophilic bacteria develop in temperatures of between 10-400°C while thermophilic bacteria have a range of 45-750°C (Droste, 1997).

pH

The optimal pH for methanogenesis is between 6 and 8. pH of 6 is probably the lowest value for anaerobic ponds and outside the range of 6.5 to 8.5 pH can influence the occurrence and activity of toxic chemicals. According to Van Haandel and Lettinga (1994) acidogenic population are more tolerant to pH variation and as a result, acidogenic fermentation is likely to predominate over methanogenic fermentation which often leads to the reactor contents being sour. Consequently, the system must therefore contain sufficient cushion capacity to counteract the production of unstable acids and carbon IV oxide that dissolve at the working pressure. Normally, the bicarbonate buffer capacity of wastewater is sufficient to prevent acidity and reduce pH, while carbon dioxide production by micro-organisms tends to control the alkalinity of high pH wastewaters. Where industrial discharges force the pH of a municipal wastewater outside the optimum range, addition of a chemical may be required for neutralization (Droste, 1997).

Color

Water color may be due to existence of innate metallic ions such as iron and manganese, humus and peat material, plankton, weeds, and manufacturing waste. Removal of color is very essential as it makes water suitable for general and industrial use. Wastewater from the industries might need color removal prior to discharge into a watercourse. True color refers to the color of wastewater that is turbidity free whereas apparent color involves color as a result of substances in solution as well as that due to suspended matter. Apparent color is established using the initial sample exclusive of filtration or centrifugation (APHA, 1998).

Conductivity

The measure of the capacity of an aqueous solution to transmit electric current is referred to conductivity and is denoted by the letter, *k*. This capacity is dependent on the concentration, mobility and valence of the ions present in the solution as well as on the temperature of measurement. Inorganic compounds usually form solutions which are excellent conductors while solutions of molecules of organic compounds are generally poor conductors in nature. Laboratory conductivity measurements are used to establish extent of mineral formation to evaluate the consequence of overall concentration of ions on chemical equilibrium, physiological impacts on flora and to review the scale of mineral formation of distilled and deionized water (Shoemaker *et al*, 1989). The SI unit for conductivity is Siemen per centimeter (S/cm) or micro Siemen per centimeter (µS/cm) (APHA, 1998).

Turbidity

Turbidity is defined as the computation of the murkiness of the water, resulting from the existence of suspended matter as well as fine colloidal material like clay and microorganism. Nephelometry is the techniques used to evaluate turbidity and it is defined as the measurement of the dispersion of light as it bounces off particles in solution. The technique is simple as the light beam is directed at a sample while the strength of the light is measured at 90^o from the initial angle of the beam (Paul and Bjourn, 1998). The SI unit for measuring turbidity is Nephelometric Turbidity Units (NTU).

Settleable Solids

Settleable solids refer to the particles that stay at the base of a container when a water sample is left to stand for a certain period of time usually one hour. Settleable solids usually come from domestic wastes and storm runoff. Settleable solids create sludge deposits leading to siltation of the water reservoirs and frequent blockages of treatment facilities. Adsorption of heavy metals and othe miro-pollutants onto suspended matter often result to accumulation of the same in sludge. Suspended solids in a water body are most likely to obstruct sunlight which is essential for photosynthesis by the underneath plants (Omoto, 2006).

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) refers to the portion of particles in water which is capable of passing from end to end of a filter of 2µm/ or (lesser) standard aperture dimension satisfying particular condition. TDS usually measures the amount of material dissolved in water. The dissolved substances may include chlorides, sulfates, nitrates sodium, phosphate and other ions. The total amount of TDS in a given water analyte is very important as it influences the amount of water getting in and out of an organism. High concentrations are also responsible for reduced rate of photosynthesis in plants (Clesceri *et al.* 1995)

Total Suspended Solids (TSS)

Total Suspended Solids (TSS) refers to particles present in a given water sample and are trappable with an aid of a filter. High concentrations of TSS in water affects light penetration thus interferes with the aquatic life. Increased level of TSS may in addition elevate the temperatures of surface water since suspended solids absorbs heat. TSS is often composed of different types of materials such as decaying organic matter, industrial wastes and sewage. The aperture size, region and width of the filter, the material nature and the particle size influence the separation of suspended solids from dissolved solids, and amount of material deposited on the filter (Kasima, 2014).

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is indispensable for marine living. The micro-organisms present in water require oxygen to metabolize. The quantity of dissolved oxygen present in a given water body can be established by employing two possible methods namely; oxygen selective electrode which is portable and the Winkler elemental process involving a chain of ionic and redox reactions leading to development of iodine at a concentration comparative to the original concentration of dissolved oxygen in the analyte. The quantity of iodine formed is then evaluated via a redox titration. Dissolved oxygen is vital for any aerobic biochemical action to take place, its levels are thus helpful pointers of biochemical action (Mancy and Jagle, 1966).

Chemical Oxygen Demand

While BOD of sewage measures the oxidation which truly happens in the sewage as a result of biochemical degradation, COD measures the overall magnitude of the oxidisable materials present in a sample. A strong oxidant (potassium dichromate) is used and the degree to which the oxidant has been consumed is determined. The primary step involves acidification of the solution followed by addition of known but excess quantity of dichromate. Any oxidized substance is reduced and a proportionate quantity of the dichromate is used up (Lenore *et al* 1999).

Biological Oxygen Demand for Five Days (BOD_5)

Biological Oxygen Demand (BOD) can be described as the power of sewage that is the quantity of oxygen need to biochemically oxidize a given sewage sample. The BOD is comparative to the sum of organic material available in a sample. Generally, the BOD is computed as the utilization of dissolved oxygen after a period of five days (BOD_5). This is achieved by determining the level of oxygen in a dilute sample followed by incubation in a sterile condition for five days at $20 \pm 1^{o}C$ after which the level of dissolved oxygen content is determined again. Addition of allyl thiourea to incubating material, assist in prevention of oxidation of the unintended compounds such as inorganic nitrogen. BOD can also be described as the amount of milligrams of oxygen necessary to oxidize organic carbon in one litre of water. BOD was initially meant to assess the rate at which a biochemical reaction would occur in a stream to which a contaminating effluent had been discharged (Spiro and Stigliani, 2003). However, predictions of the impact of such a release to watercourse would require involving other factors rather than BOD alone (Portter and Everitt, 1959).

The solubility of oxygen (O_2) in water is only 9 mg/l at 20 °C and decreases with increase in temperature. The oxygen supply can be replenished by contact with the air, as in rapidly flowing streams. In standing water or in waterlogged soil the diffusion of oxygen from the atmosphere is slow relative to the speed of microbial metabolism, implying that the available oxygen is eventually depleted. Temperature above 15 °C favors the process of BOD reduction as Mara (1976) showed that biogas composed of 70 % methane and 30 % carbon dioxide had its generation improved seven times for every 5°C increase in temperature. The biochemical reaction which occurs in oxygen free ponds has been likened to those that take place in anaerobic digesters. Anaerobic digestion serves to reduce odour and bulkiness of sludge to an inert material without obnoxious odour. The process involves two successive processes referred to as acidogenesis and methanogenesis (Warren and Mark, 2005).

Acidogenesis

Acidogenesis involves fragmentation of bulky organic materials and subsequent conversion to organic acids alongside other gaseous by-products such as carbon IV oxide, methane and small quantities of hydrogen sulfide. This process is achieved through the involvement of a range of facultative bacteria working in an oxygen free environment. The facultative bacteria keep using oxygen bound on nitrate and sulphate as it breaks down the organic material to organic acids and alcohol that generate smallest amount of energy (Krzystof and Magdalena, 2012). If the process were to stop there, the accumulated acids would lower the pH and would inhibit further decomposition by preserving the remaining raw sludge. Gasification which is the second step helps to switch organic acids to methane and carbon dioxide and in the course of action dig estion occurs. Acid-splitting methane-forming bacteria perform this last step (Mark, 2012).

Methanogenesis

Acid-splitting methane-forming bacteria are strict anaerobes and quite vulnerable to environmental conditions of temperature, pH and an aerobiosis. The methane bacteria grow at a lower rate compared to their acid forming counterparts, they are also highly specific in food supply rations. It is noted that each species is restricted to the metabolisms of only a few compounds, mainly alcohols and organic acids, while carbohydrates, fats and proteins are not available as energy sources. The steadiness of the digestion progression depends on the accurate poise of the two biological steps (Mark and Hammer, 2003). An increase in organic loading or a sharp rise in operating temperature (the general operating range of temperature and pH for anaerobic sludge digestion are 29-37 °C and 6.7 to 7.4 respectively) may lead to build up of organic acids as the production of organic acids exceeds the assimilation capacity of the bacteria forming methane. This imbalance causes a decrease in gas production and eventual drop of pH. Digesters are said to produce *foam* as a result of overfeeding and accumulation of toxic industrial waste, such as heavy metals which may also inhibit the digestion process. A research carried out on oxygen-free pond treatment of tapioca starch waste suggested that overloading most likely impaired methanogenesis leading to reduction in BOD removal (Omoto, E., 2006).

2.2.2 Chemical

Nitrates (NO_3^-)

Almost every rainwater and groundwater aquifers have a little nitrate-nitrogen. Nitrates build up in farming water catchment areas in which farmers apply inorganic fertilizer and animal manure on the crops. In the absence of oxygen, decomposition of organic matter in water containing nitrates reduces the nitrates to ammonia and free nitrogen, consequently, the nitrates are depleted (Wolfgang, 2002). This implies that nitrates are rarely, if ever, found in putrid sewage. However, the composition of sewage could be deeply changed should the industrial effluents be discharged into the public sewerage system. In waste stabilization pond systems, the nitrogen cycle works with the feasible exclusion of nitrification and denitrification. In anaerobic ponds, organic nitrogen is hydrolysed to ammonia after which the concentration of ammonia is found to be higher in anaerobic pond effluents than raw wastewater unless the transit time to the treatment plant is so long. Volatilization for ammonia seems to be the main pathway for nitrogen removal, being reported at very low rates in anaerobic ponds (Soares *et. al*.1996).

Generally, health effects due to nitrate are mainly associated with the presence of methemoglobinemia which is sometimes called the blue baby syndrome. In the stomach, nitrate is changed to nitrites in infants between 0 to 4 months (Lukens, 1987). The nitrite formed then binds to the oxygen carried in the red blood cells resulting to oxygen depletion and subsequently suffocating the young one. The bluish skin color, particularly around the eyes is understandably the symptom of the harmful effects of nitrite. This condition is rarely fatal if detected at an earlier stage as it is easily diagnosed and the situation overturned through medical treatment. Methemoglobinemia ceases to be a threat once the baby is over the age of six months since the nitrite forming bacteria is no longer in the stomach of the baby. Adults may also be affected by nitrate especially in drinking water, expectant mothers can pass the nitrates to the fetus leading to low birth weights (Lukens, 1987).

Phosphates (PO_4^{3-})

Phosphates are largely present in wastewater as inorganic phosphate ions PO_4^{3-}, HPO_4^- and polyphosphates. Inorganic phosphates are present in the non-ionic form in organic molecules such as DNA, RNA and nucleotides (Burks and Minnis, 1994).

Algae and phytoplankton for their growth and for the treatment of water besides silica, utilize phosphates as detergents such as densol and calgon. Phosphates eventually lead to eutrophication of lakes and rivers. Primary inorganic phosphorus is precipitated as an insoluble hydroxyapatite, $Ca_5 (PO_4)_3(OH)$, at pH levels above *9.5*. The mechanism of phosphorus elimination most likely occurs in maturation pond. In general, when nitrates and phosphates are present in natural waters at high levels, excessive algal growth (eutrophication) is likely to result. Drying algae contribute to organic matter which requires oxygen for biodegradation (Mara *et al,* 1992).

2.2.3 Heavy Metals

The consequences of metal ions in wastewater vary as of advantageous to hazardously venomous. A few metal ions are important whereas some might negatively affect water clients, wastewater management systems, and receiving water bodies. In general, metal ions have an effect on the speed of anaerobic systems even at trace amounts. The heavy metal ions present in water are precipitated as hydroxides due to the high pH of the wastewater in the stabilization pond, which settles as sludge (David *et al,* 1994)

Changes in the redox potential can have important consequences for sedimental pollution, especially with respect to cations of cadmium, lead and nickel. Solubility of heavy metals is highest in oxidizing and acidic environments. At neutral to alkaline pH in oxidizing environments, these metal ions adsorb onto the surface of insoluble iron (III) hydroxide and manganese (IV) oxide particles especially when phosphate is present to act as bridging ion. When the redox potential shifts to oxidizing or reducing conditions due to microbial action, and the pH shifts towards the acidic range, $Fe(OH)_3$ and MnO_2 in soils and sediments are reduced and solubilized. The adsorbed metal ions likewise become solubilized and move into ground water when there is $Fe (OH)_3$ and MnO_2 in the sediment. However, if sulfate is reduced microbially to hydrogen sulphide ion, metal ions are immobilized as insoluble sulfides. Exposure of sulfide rich sediments to air through dredging or drainage operations oxidizes HS^- back to sulfate and the heavy metal ions are released (Spiro and Stigliani, 2003).

Chromium

Industrial processes extensively use chromium salts which may enter water supply systems in the course of discharge of wastes. Chromium containing compounds are usually added to the water for cooling for corrosion control purposes. Both hexavalent and trivalent states of chromium may exist in water supplies in trace amounts as chromium does not occur liberally in nature. It is applied in metal surface refinery and in alloys (Lenntech, 2013).

The amount of chromium in the human body is roughly 0.03 mg/l with daily intake heavily dependent on the feed levels normally about 15-200 µg which at times may be as high as 1mg (Dennis and Sush, 1993). Uptake of chromium in the body is between 0.5-1 % with the placenta being the organ with the highest amount of chromium. Not only is trivalent chromium together with insulin helps remove glucose from the blood but also plays important role in fat metabolism thus making it a crucial trace element for humans. Deficiency of chromium possibly will augment diabetes symptoms as chromium is a nutritional requirement for a number of organs, though this is only applicable to trivalent chromium (Lenntech, 2013). Toxicity of chromium (III) is improbable, particularly when taken up via the food chain, instead it may contribute to improving neuropathy and encephalopathy conditions. On the other hand, hexavalent chromium is toxic and carcinogenic and inhaling elevated amounts may result to irritation to the inside layer of the nose. Exposure to chromiumVI over a long period may harm the liver, kidney, circulatory and nerve disorder, and also skin irritation (Lokeshappa *et al*, 2012).

Solubility of chromium (III) oxides in water is very poor and as such only low amounts are found in natural waters. At pH values of more than 5, Cr^{3+} ions are hardly ever present since the hydrated chromium oxide is moderately soluble. The compounds of chromium VI are reduced to chromium III under anaerobic setting though stable under aerobic environment. Chromium is mostly bound to suspended solids in water whereas lime or phosphate in soils may further diminish chromium susceptibility (Mallinson, 1993).

Lead

Lead is a blue-grey metal present on the earth's crust in little amounts. A substantive quantity of lead found on the earth's surface normally originates from anthropogenic activities such as manufacturing, mining and burning fossil fuels. Lead has several uses some of which include manufacture of batteries, ammunitions, soldier and pipes and X-ray shield devices (UNEP/OCHA, 2010).

Lead accumulates in the body and it is very poisonous, natural waters barely contain more than 5µg/l even though much high figures have been documented. Lead may find its way to water supply due to transfer from industrial processes, mining and welder discharges. Running tap waters which are soft, acidic and not well treated may have lead due to attack on the lead pipes and soldier joints (Yi and Wong, 2006).

The effects of lead on human health are similar irrespective of the means by which it reaches the body. Lead affects nearly every organ and system in the human body with the main target being the nervous systems in both children and adults. Exposure of adults to lead over a long period may result to weakness in fingers, wrists, or ankles (Philip *et al*, 2002). The Centers for Disease Control and Prevention (CDC) describes babyhood lead poisoning as a total-blood lead absorption equivalent to or greater than10 µg/dl. Heightened lead poisoning, though not frequent, shows up extra faster and is deemed to be deadly, if pretty large amount of lead is consumed within a short period of which children are the greatest victims (UNEP/OCHA, 2010).

Zinc

Zinc compounds are found almost everywhere in the environment and are present in the earth's crust at concentrations of approximately 70 mg/kg (Thomas, 1991). Zinc as a metal is not freely obtainable in nature, however, it exists in +II oxidation state (Prasad, 2008). Zinc is necessary for human growth and its concentrations of greater than 5 mg/l lead to bitter taste as well as opalescence in alkaline water (Hambidge and Krebs, 2007). Zinc usually finds its way into the household water distribution from deteriorated galvanized iron sheets, dezincification of brass and industrial effluents (FAO/WHO, 2002).

Zinc is a vital constituent of a great amount (>300) of enzymes taking part in the synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids in addition to metabolism of other micronutrients (Heath, 1995).

Acute and chronic zinc toxicity may result due to excessive intake even though there is no confirmation of serious effects from intake of naturally occurring zinc in food that has been documented. The harmful effects observed so far are mainly due to over-feeding on zinc supplements (Fosmire, 1990).

Cadmium (Cd)

The concentration of cadmium on the earth's crust is estimated to be about 0.16 mg/l of which 0.1 to 0.5 mg/l is in soil, 1µg/l in streams and 1-10 µg in groundwater. Cadmium is found in sulfide mineral deposits which hold lead, zinc and copper. It has several uses which include electroplating, manufacture of paints & pigments and alloys with other metals. Its presence in natural waters is controlled by carbonate equilibrium in that the softer the water the lesser the cadmium level allowable. Cadmium is not essential for the growth of plants and animals and it is exceptionally poisonous on accumulation in the liver and kidney. Continued ingestion at small amounts, may lead to dysfunction of the kidney. The United Nations Food and Agriculture Organization suggested highest limit of cadmium in water for irrigation is 10 µg/l. The USEPA principal drinking water standard minimum concentration level (MCL) is 10 µg/l (APHA, 1998). Table 2.1 and Table 2.2 provide standards for discharge into the public sewers and into the environment respectively.

2.2.4 Oil and Grease

Oil & grease cause blockages in sewer lines thereby resulting in overflows and pollution of the environment. It interferes with the light transmission through surface water and gaseous exchange at the surface of the water. Their decomposition also consumes oxygen and sometimes their presence in water provides a habitat asphyxiation of fish and generation of obnoxious gases as a result of anaerobic processes. An asphyxiant is an agent (e.g. CO_2, CH_4, and H_2S) that can compete actively for the body's hemoglobin, crowd out the oxygen environment or damage the central nervous system (Wake, 2005).

The anaerobic sewage treatment processes and the habitat of micro-organisms are affected by both physical and chemical factors. A number of important environmental factors related to anaerobic ponds process include temperature, pH and scale of combination, nutrient necessities, sulfite control, and the occurrence of noxious compounds in the effluent (Van and Lettinga, 1994).

2.2.5 Bacteriological Parameter

Total coliforms.

Wastewater has a varied range of micro-organisms originating not solitary from the human wastes but also from soil and water. Pathogenic micro-organisms like viruses, bacteria, fungi, rotifers, protozoa, and worms which occur chiefly in human excreta and to some extent urine can cause fatal infectious water borne diseases such as cholera, giardiasis, paratyphoid, amoebic dysentery, leprosy, yellow fever, skin infections or malaria. Disinfection is therefore, the prime step in controlling the pathogenic micro-organisms (Tebbut, 1998).

2.3 EFFLUENT DISCHARGE THRESHOLD AND POLLUTION LOADING

The term effluent can be defined as dissipate that is either a liquid which flows away from a containing space, untreated, completely or somewhat treated sewage or other liquid, released straight or indirectly into a watercourse. Load may be defined as a substance that passes a particular point of a water resource in a specified amount of time (Donald, Peter and Steven, 2013). Effluent discharge is therefore a waste disposal process into existing water bodies and is thus one of the many water use activities which need to be regulated. On this basis then, effluent discharge can be grouped into four levels namely A. B, C & D where A implies least harmful effluent while D signifies very detrimental effluent. The categories are based on the level of impact that the effluent will have on the receiving water resource (WRMA, 2009).

2.3.1 Effluent discharge quantity classification

The magnitude of impact that effluent discharge will have on a given water body is dependent on a number of aspects which include the quantity of the effluent and the quantity of the receiving water bodies. The effects of a given effluent released into a water resource will be considerable if very little or no dilution happens upon release. This is most expected to take place when the amount of the effluent discharged is great in comparison with the quantity of the receiving water body. Table 2.3 gives the various categories of effluent discharge and a reflection of the scale of impact on a given water body. These categories are tied to the quantity of the effluent discharged into the receiving watercourse. It is given as a percentage of effluent discharged based on the quantity of the receiving water resource and is expressed as Effluent Discharge Points (EDP). The percentage is ranked to categorize the effluent discharge in terms of EDP. For instance, if the quantity of effluent discharged is less than 5 % of the receiving water resource, then the effluent accrues 10 EDP and hence will fall under Category A. This therefore is the category with the lowest risk of impacts on to water resource. The higher the EDP, the higher the quantity of effluent discharged and the higher the risk of the impact of the effluent to the receiving water resource. This classification allows for a given resource with low water quantity to only accommodate a commensurate low level of effluent discharge, hence preventing it from turning into an effluent flow (WRMA, 2009).

Table 2.3: Effluent Discharge Quantity Classification

Category	**Description**	**Percentage of Effluent Discharge on Water Resource (%)**	**Effluent Discharge Points (EDP)**
A	Effluent discharge believed by virtue of its scale to have a low risk of impacting the water resource.	<5	10
B	Effluent discharge considered by virtue of its scale to have the potential to make a significant impact on the water resource.	5-25	20
C	Effluent discharge estimated by virtue of its scale to have a measurable impact on the water resource.	26-50	50
D	Effluent discharge which involves either international waters, two different catchment areas, or is of a large scale or complexity and which is deemed by virtue of its scale to have a measurable impact on the water resource.	>50	100

Source: **Water Resources Management Authority *effluent discharge thresholds* 2009**

2.3.2 Effluent discharge facility classification

Facilities abstracting water from a given catchment and discharges its effluent into water resources may also be classified according to their pollution impacts potentials. The classification of facilities is based on their activities and the subsequent pollutants likely to come from such activities. Facilities are therefore classified on the basis of parameters likely to be associated with it and then coded. Table 2.4 shows an effluent discharge facility classification with five categories coded as: FC1, FC2, FC3, FC4, and FC5. The codes reflect the increase in potential of pollution impact of the effluent discharge quality through the type and number of parameters present in a given facility. This increase in pollution impact ranges from Code FC1 where only the basic Compulsory Parameters (C.P.) for water quality evaluation should be monitored, to Code FC5 where the parameters to monitored include those for heavy metals and pesticides. The Compulsory Parameters include, pH, Temperature, Turbidity, Total coliforms, DO, BOD, Flow, COD, TDS, Total Nitrogen and Total Phosphorous. Chemical Parameters include fluoride, sulphur, chloride, phosphates, nitrates, sulphates, carbonates, magnesium, calcium, salinity (WRMA, 2009).

Table 2.4: Effluent discharge facility classification

S NO.	Facility	Parameter for Monitoring	Code
1	Domestic waste (WSP_A, Water Service Providers with no industries) Nyeri, Embu, Nanyuki e.t.c, Hospitality industries, Slaughter houses	Compulsory Parameters (C.P) = Feacal coliforms, pH, Temperature, Colour, Turbidity, DO, Flow, TDS, BOD, COD, (Total N, Total P where applicable)	FC1
2	Agro Processing Factories (Tea, Coffee, Sugar, Dairies, Sisal, ,	C.P. + Chemicals (NO_3, PO_4, F,S, SO_4, Cl)	FC2
3	Hydro-electric Generating Power Co. Lodges & Hotels, Paper industry, Fish, Dairies	C.P+ Chemicals + TPH+ Oil & Grease & Surfactants	FC3
4	Oil Refineries, Cement Industry, Tanneries, (Limuru, Thika, Eldoret,)	Compulsory Parameters + Chemicals + TPH+ Oil & Grease & Surfactants + Heavy metals (Mn, Fe, Cr, Cd, Pb, Zn, Se, As, Cu, Sn, Co, Hg,)	FC4
5	Irrigation Schemes, Cities WSP_B (Nairobi, Thika, Nakuru, Kisumu, Mombasa), Geothermal Power Generators, Floriculture	Compulsory Parameters + Colour,+ Chemicals + TPH + Oil & Grease & Surfactants + Heavymetals + Pesticides, Radioactive	FC5

Source: **Water Resources Management Authority *effluent discharge thresholds* 2009**

The facilities are coded according to the parameters to be monitored and therefore the severity of possible shock linked with a given industry. The number and type of parameters show industries that are at a higher risk of impacting on the quality of the water resource. The Facility Code (FC) is related to the superiority of effluent released into a watercourse and by awarding accruing points we may achieve a quality related classification of the effluent discharged. A given FC may upgrade to a less impacting facility if the monitored parameters are nil. Thus if in a given facility classified as FC5, pesticide residues when monitored are not encountered, then the facility may be upgraded to FC4. Similarly, if a facility is classified as FC3 it may be upgraded to FC2 if oil & greases, TPH and surfactants monitored are below the prescribed threshold (tolerance limits). The opposite should hold true.

2.3.3 Effluent discharge quality classification

The integrity of effluent emptied into the water resources can be classified and ranked following the coding done in Table 2.5 This means that the activities of a facility have express connection with the quality of its effluent discharge. The effluent discharge quality just like the effluent discharge quantity is assessed and graded according to parameters to be monitored, thereby gaining Accruing Quality Points (AQP) as shown in Table 2.6. The AQP indicates the severity of the potential impact the effluent discharge can have on the quality of the water resource. The less severe the potential impacts associated with a particular code the low the AQP. Low AQP indicates that the water resource quality is less altered by effluent discharge emanating from facilities classified in that particular code. For example, in Code FC1 (Facility Category 1) only Compulsory Parameters (CP) are to be monitored hence this code has 10 AQP (WRMA, 2009).

Table 2.5: Effluent discharge quality classification

Code	Parameter	Accruing Quality Points
FC1	Compulsory Parameters (C.P)	10
FC2	Compulsory Parameters + Chemicals	20
FC3	Compulsory Parameters + Chemicals + Oil & Grease & Surfactants	40
FC4	Compulsory Parameters + Chemicals + Oil & Grease & Surfactants + Heavy metals	80
FC5	Compulsory Parameters + Chemicals + Oil & Grease & Surfactants + Heavy metals + Pesticides	100

Source: **Water resources Management Authority *effluent discharge thresholds* 2009**

2.3.4 Pollution loading points correlation

Pollution loading on a given water resource can be achieved through a correlation between Effluent Discharge Quantity (EDP), Effluent Discharge Facility (FC) and Effluent Discharge Quality (AQP). This correlation provides the overall pollution loading calculated as pollution loading points (PLP) as shown in Table 2.6. All the three aspects (quality and quantity of effluent discharge, and the quantity of the receiving water resource) have been considered in establishing the pollution loading a given water resource may accommodate. The PLP values allows for the calculation of the tolerance or thresholds of effluent being discharged into a given water resource. A given facility will attain low or high PLP mainly by the quality and quantity of its effluent discharge and the quantity of the receiving water body. Therefore, if a given water resource has low quantity of water compared to effluent discharged into it (high EDP), its threshold, (capacity to accommodate effluent), will be low and only low quantity of 'good quality' effluent can be discharged into it (WRMA, 2009).

Table 2.6: Pollution loading Points correlation

		Quality (Parameter to be analyzed) (AQP)				
QUANTITY (EDP)	Category (Points)	FC1(10)	FC2(20)	FC3(40)	FC4(80)	FC5(100)
	A(10)	100	200	400	800	1000
	B(20)	200	400	800	1600	2000
	C(50)	500	1000	2000	4000	5000
	D(100)	1000	2000	4000	8000	10000

Source: **Water resources Management Authority *effluent discharge thresholds* 2009**

2.3.5 Threshold tolerance range

Thresholds may be defined as the utmost amount of the effluent both in quantity and quality which can be released into a receiving watercourse without causing any grave impacts. The receiving water bodies have diverse water quantities and qualities and thus will have different thresholds. Pollution Loading Points (PLP) may be used to estimate or establish thresholds for each category of effluent to be discharged. The threshold may be expressed as tolerance or range in percentage or PLP. For example, a discharger within the 100 PLP may be allowed a tolerance of 20 % of PLP, hence 120 PLP. The discharger’s threshold will be 0-120 PLP since it is a low impact Class. On the other hand, a discharger within the 10000 PLP is allowed a tolerance limit of 0 % as shown in Table 2.7. This is so because such a facility is likely to cause very high impacts to a water resource into which it discharges (WRMA, 2009).

Table 2.7: Threshold tolerance range

Pollution loading points	Potential Impact	Threshold /Tolerance range (%)
0-200	Low	20
201-1600	Moderate	10
1601- 4000	High	5
4001-10000	Very high	0

***Source:* Water resources Management Authority *effluent discharge thresholds* 2009**

2.4 WASTEWATER TREATMENT PROCESS

The initial processes in wastewater treatment, starting from the gathering systems to the gravel tanks, is used with the aim of removing the wreckage which are most likely to disturb the flow and subsequently break the gears used in the afterward purification process of wastewater. The processes are mainly four but the first two are usually employed. The processes include; primary treatment, secondary treatment, tertiary treatment and advanced treatment.

2.4.1 Primary Treatment

Primary stage entails physical process which involves mechanical screening, grit removal followed by sedimentation process aimed at simultaneous elimination of oil & fatty acids, settleable, suspended and solids that float like paper bags and related plastics. Biochemical oxygen demand (BOD) and nutrients (N and P) are also taken out though to a small extent. Examples of the facilities used in the primary stage include bar or bow screen, primary sedimentation, pH neutralization and Imhoff tanks. Both primary and secondary treatment stages generate at a volume not more than 0.5 % of the wastewater (Bayer and Lanxess, 2010).

2.4.2 Secondary Treatment

Secondary treatment is the second stage. Here biodegradable organic matter and organic nitrogen are converted to carbon (IV) oxide, water, and nitrates through aerobic and/ or anaerobic microbial processes. Waste stabilization ponds, activated sludge, aquaculture, rotating bio-discs, trickling filters and constructed wetlands are typical examples of secondary treatment processes (Qasim, 1994).

2.4.3 Tertiary Treatment

Tertiary treatment is intended to get rid of nutrients, total nitrogen consisting of organic nitrogen and sometimes ammonia nitrogen and total phosphorus encompassing particulate and soluble phosphorus passed over from the secondary effluent. Tertiary treatment provides additional removal of SS and BOD reduction. Basically, tertiary treatment is aimed at controlling eutrophication in sensitive surface waters and some re-use schemes. Examples include constructed wetlands, aquaculture, chemical precipitation, denitrification and nitrification, disinfection among others (Jern, 2006).

2.4.4 Advanced Treatment

Advanced wastewater treatment uses additional processes beyond those used conventionally to prepare wastewater for direct reuse for industrial, agricultural, and municipal purposes. The advanced treatment processes target specific contaminants. Examples of state of the art techniques usually employed include reverse osmosis, electro dialysis, selective ion exchange, hyper-filtration, chemical treatment and detoxification. Figure 2.1 gives a diagrammatic summary of the conventional wastewater treatment process in which wastewater flowing into the treatment plant is first subjected to pre-treatment where scum is removed. From pre-treatment stage the water passes through the primary stage where the debris are removed. The water is then aerated on its way to the secondary stage where biodegradable organic matter and nitrogen are converted to carbon dioxide, water and nitrates. The sludge removed from the secondary stage is then digested to produce biogas which provides energy used to run the plant. The sludge residues are then dried and transported away where it is used as fertilizers (EPA, 1994).

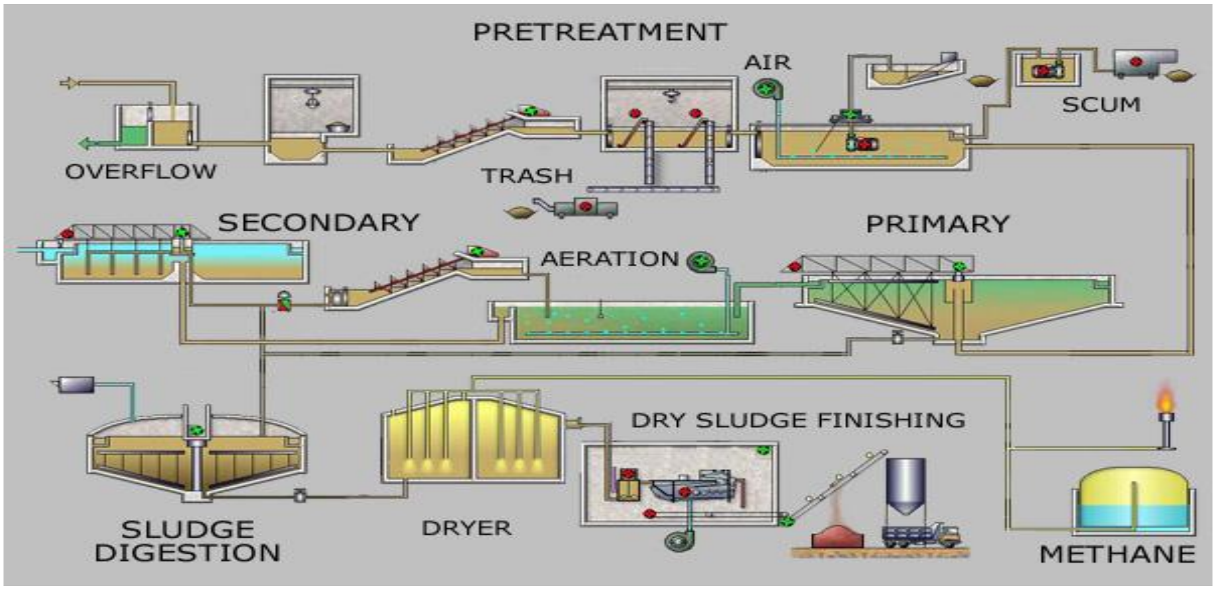


Figure 2.1: Diagrammatic representation of the wastewater treatment process

2.4.5 Inhibition in Biological Treatment

The performance of a wastewater treatment plant is dependent upon several factors one of which is the action of micro-organisms coupled with metabolism which are normally influenced drastically by the existence of venomous materials in the raw wastewater. Constituents of the wastewater undergoing treatment usually dictate the degree to which inhibition is likely to be a threat to a wastewater treatment plant. A good number of substances including but not limited to organic and inorganic solvents, heavy metals and biocides can inhibit the biological activity in the treatment plant (EPA, 1997).

Acute and chronic toxicities are the two forms of toxicity that can occur within a treatment plant. Severe toxicity arises when the amount of toxic substances in the wastewater is sufficient enough to deactivate the biological action. On the other hand, chronic toxicity takes place at slow pace; more than days or weeks leading to process breakdown owing to a steady buildup of toxic substances in the biomass (Mittal, 2011). Industrial discharges may as well pose toxic effect to the micro-organisms. This toxicity is determined by respiration inhibition which is a reduction in the O_2 consumption rate. The measurement resulting from this process should be relied upon in circumstances where the treatment plant could be subject to distress loads of toxic sbstances (EPA, 1997). The biological activity in a plant can also be affected by temperature and pH either individually or in combination. Other stuff such as oils, fats, grease and hair can also affect the operation of mechanical plant (Al-Layla *et al*, 1980).

2.5 NATURAL ALTERNATIVES TO CONVENTIONAL WASTEWATER TREATMENT

2.5.1 Aquatic Floating Plant System:

The living machine

Living Machines in Figure 2.2 consists of a chain of tanks containing plants and some micro-organisms therein, wastewater is then made to flow through the tanks and in the process get treated naturally. This arrangement imitates wetland ecosystem to clean the wastewater even though, it needs small amount of space and does the cleaning process more effectively than wetland since it is possible to control the conditions. This therefore makes them to be more idyllic as the micro-organisms are exposed to extra oxygen compared to a wetland because air is bubbled through the tanks. A number of Living Machines do generate some valuable by-products which include methane gas, edible and decorative plants and fish (Todd, 1994). It is a method worth using as the operation cost is at minimal.

Source:www.livingroutes.org

Figure 2.2: The living Machine

Restorers

Restorers refer to a set of floating plants and some organisms which carry out the cleaning of the water. They, as shown in Figure 2.3 may be used to treat contaminated lakes or wastewater through constructing artificial ponds. The plants provide oxygen required by the microorganism to respire. As these organisms respire they consume any organic matter present in the water thus cleaning it.

Source: Ocean Arks International

Figure 2.3: Restorers

2.5.2 Ecoparque

An Ecoparque refers to an amalgamation of a wastewater treatment plant and a park. An Ecoparqué as shown in Figure 2.4 treats the wastewater generated from a neighborhood without use of any chemicals. Wastewater enters the park through gravity and microcriba filter out bigger macrobiotic material, composted with the help of tiger worms and then re-used in Ecoparqué. The cleaning process entails settling out of solids using a clarifier whilst biofilters which are huge tanks filled with bacteria colonies treat the water. The treated water is re-circulated through the biofilters until it is of the required standards before being released to the entire park for irrigation purposes (Bedar, 2000). One of the significant characteristics of an ecoparque is that small decentralized wastewater treatment units can be successfully used to serve households in groups and the resultant water reused for other functions such as irrigation. The nutrients can be retained in the water if the plants being irrigated can make use of them (Bedar, 2000).

Figure 2.4: Ecoparque

2.6 KARIOBANGI SEWERAGE TREATMENT WORKS

Built in 1961 and extended in 1963, Kariobangi sewage treatment works is a conventional plant (biological filters) with an in-built methanation unit. The treatment involves screening, grit removal, primary sedimentation, biological filtration and secondary sedimentation. The plant is located in Nairobi City County, Kamunde Road off Outer Ring Road behind Kariobangi Light Industries. The plant was to be constructed in four stages of 16,000 m^3/d to ultimately treat a design dry weather flow (DWF) of 64,000 m^3/d. Only two stages of the works so far have been developed giving a DWF capacity of 32,000 m^3/d, and a hydraulic storms capacity of 96,000 m^3/d (Howard, 1985). Currently, the plant discharges about 8,000 m^3 per day of wastewater to the Nairobi River system, about 7 km downstream and North-East of the city centre. The plant receives wastewater from the city's sewerage network. Figure 2.5 shows the treatment process of Kariobangi Sewerage Treatment Works. The incoming water is passed through bar racks then to the grit chamber so as to remove debris. Wastewater free from large debris is then passed through primary clarifier to the trickling filter then to the secondary clarifier before discharge. The resultant sludge is digested to generate biogas used to run the generator, boiler and the incinerator with the final waste dried and sold to farmers specifically those having large tree plantations.

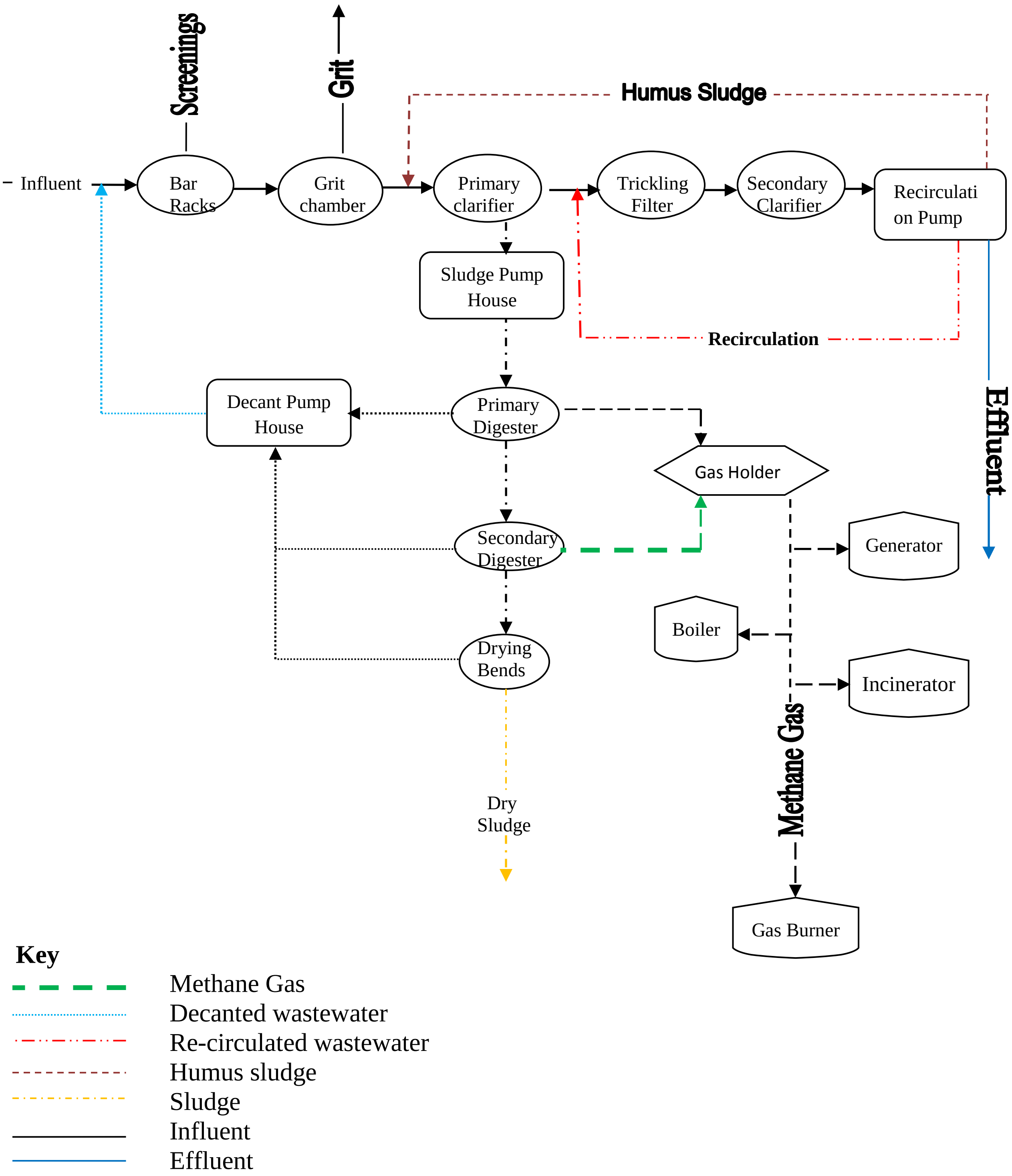


Figure 2.5: Flow chart showing the wastewater treatment process at KSTW

2.6.1 The inlet works

Sewage entering the inlet works passes through a relatively widely spaced raked screen, then a fine raked screen through a constant velocity grit channel. Screening is undertaken to remove floating materials, rags and solids which would cause blockage of pipes and damage the plant. During heavy rains the influent capacity exceeds the plant's optimal treatment capacity. During this period excess incoming wastewater is channeled to Ruai Treatment Works while some find their way directly into the river untreated. Figure 2.6 shows the inlet point at Kariobangi Treatment Works.

Figure 2.6: The Kariobangi Treatment Works Inlet

2.6.2 The Clarifier

Water from the inlet is then directed to the primary clarifier from where sludge is removed and pumped to the sludge digestion tanks. The relatively clear water free from heavy sludge presence is then transferred to the secondary clarifier for further screening. In this case the secondary clarifier was dysfunctional and therefore the water was moved to the filter. A clarifier at work is shown in Figure 2.7.

Figure 2.7: Kariobangi Treatment Works Clarifier

2.6.3 Sludge Digestion Tanks

The sludge leaving the clarifier is directed to the sludge digestion tanks located approximately 50 metres away from the clarifier. Formally, biogas would be produced from these digestion tanks. But currently the tanks experience leakages as well as unfavorable conditions to produce biogas. The biogas was to provide energy sufficient to run the plant. The sludge from the tanks is therefore, dried and sold to farmers especially those doing commercial tree plantations. Figure 2.8 shows the sludge digestion tanks.

Figure 2.8: Sludge Digestion Tanks at Kariobangi Treatment Works

2.6.4 The Filters

The plant consists of both circular and rectangular filters. The filters as show in Figure 2.9 were gravel filled. Water is passed on top of these filters then allowed to flow downwards via gravity as filtration takes place.

Figure 2.9: One of the filters at Kariobangi Treatment Works

2.6.5 The Outlet

Once water has been filtered it passes to the outlet where it is then discharged into Nairobi River. The outlet area needed some renovation as the security metals have been eaten away through corrosion. These made them to pose high health risk as chances of one falling into the deep trenches were high. Figure 2.10 shows the outlet.

Figure 2.10: The Kariobangi Treatment Works outlet

2.6.6 Activities within the Plant

Wastewater from the treatment plant is used for agricultural purposes. There was small scale farming of kales within the treatment plant as shown in Figures 2.11 and 2.12. The study found out that raw sewage water was being used to water these vegetables. Figure 2.13 shows kale farm around a decommissioned clarifier with some water inside it a clear indication that the water could be used to irrigate the Kales. It was apparent that serious health problems await the consumers and the community around the plant as well as the larger population of Nairobi as these harvests often find their way into various retail markets within the city.

Figure 2.11: A farm containing Kales

Figure 2.12: Land preparation for kale planting

There were also people who would collect some useful wastes such as pieces of metals carried along by the wastewater. This activity seemed very vital to the people around as there was ready market emanating from the numerous cottage industries within the vicinity of the plant.

As mentioned earlier, there were many cottage industries ranging from welders of simple household items to machines such as the weighing scale. There were also paint making industries.

Figure 2.13: Cowpea farm around a decommissioned clarifier

2.6.7 State of the Plant

Several facilities within the plant were not operational. Figure 2.14 and Figure 2.15 show pictures of unused clarifiers, some with stagnant wastewater while others were empty and no longer used. Several filters were also abandoned or got damaged and have never been repaired. The sludge digesting tanks were not spared either. They were characterized by leakages making biogas production impossible. The filters both rectangular and circular ones were not in use any more. Some of the circular filters were being used as sludge drying beds.

Figure 2.14: Decommissioned clarifier with water **Figure 2.15: Decommissioned clarifiers**

CHAPTER THREE

METHODOLOGY

3.1 EQUIPMENT

The lists of equipment used were as shown in Table 3.1.

Table 3.1: List of Equipment

S.NO	Equipment	Model	Manufacturer
1	AAS	AA-7000	SHIMADZU Ltd
2	Autoclave	2074/2079	Prestige Medical Ltd
3	BOD Incubators WTW Oxitop Box	D-82362	WTW Ltd
4	Electronic Balance	ER-180	Japan Ltd
5	Hanna pH meter	13314	HANNA Ltd
6	Hot plate Stirrer	LMS-1003	Labtech Ltd
7	Nephlometer Turbidimeter	2100P	HACH Ltd
8	Paqualab Photometer	EL-420-550	ELE Ltd
9	Water baths	854chwatach	Memmert Ltd

3.2 CHEMICALS/REAGENTS

The lists of some of the chemical used were as shown in Table 3.2.

Table 3.2: List of some chemicals used

S.NO	Chemical	Concentration	Manufacturer
1	Manganese sulfate	2.15 M	Riedel
2	Starch Indicator	1 g	ACME chemicals Ltd
3	Sodium thiosulfate	0.025 M	Muby chemicals Ltd
4	Potassium dichromate	0.025 N	Vishnu chemicals Ltd
5	Ferrous ammonium sulfate	0.125 M	Choice organochem Ltd
6	Potassium dichromate	0.01389 M	E.T Monks Ltd
7	Ferroin indicator solution		Sigma-Aldrich Ltd
8	Manganese sulfate	2.15 M	Bushveld Ltd
9	Sodium hydroxide pallets	2 g	Labo Kemie PVT Ltd
10	Sodium azide	10 g	Sigma Ltd
11	Sodium iodide	10 g	Okmar chemicals Ltd
12	Silver sulphate	5.5 g	Alpha chemika Ltd
13	Sulfuric acid		Sigma Ltd
14	Nitric acid		Kobian Kenya Ltd

3.3 SAMPLING

Wastewater sampling was done for a period of four months starting from February 2015 to May 2015. Grab water samples were collected at the Inlet, within the plant (Primary Clarifier) and at the Outlet of the treatment plant using a sampler. Three-litre plastic bottles were used to carry the samples. Glass containers were used to carry samples for total coliform determination. At each sampling point, the wastewater samples were taken in quadruplicate that gave rise to a total of 12 samples per each sampling session and 48 for the entire study period. During the research period, sampling was done at 10.00 am. Figure 3.1 shows the sampling points within the plant.

Figure 3.1: Distribution of the sampling points within KSTW

3.4 PROCEDURE

3.4.1 Physico-Chemical Parameters

Temperature

150 ml of the sample was placed in a 200 ml beaker and the probe electrode dipped in. The readings were then taken directly from the meter and recordings made. The measurements were taken in triplicate on the site.

pH

The pH meter was first calibrated with standard pH buffers of pH 4, pH 7 and pH 9. 150 ml of the sample was placed in a 200 ml beaker and the pH meter electrode dipped in. The readings were then taken directly from the meter and recordings made. The measurements were taken in triplicate on the site.

Color

A 50 ml Nessler tube (color viewing tube) was filled to the mark with sample water and a stopper inserted excluding the air bubbles. This tube was then inserted in the top right opening of the comperator. A second tube was filled with distilled water which served as the standard and was inserted in the top left opening of the comparator. The comparator was then held up to the light source and the color disc rotated until the two liquids appeared identical. The readings were taken from the discs and tabulated.

Conductivity

150 ml of the sample was placed in a 200 ml beaker and the conductivity meter electrode dipped in. The reading was then taken directly from the meter and recordings made. The measurements were taken in triplicate on site.

Turbidity

20 NTU, 100 NTU and 500 NTU standards wer used to calibrate the Turbidimeter. 17 ml of the sample was measured into a tube then inserted in the tube holder in the turbidimeter. The readings were taken for each sample.

Settleable Solids

An Imhoff cone was filled to the 1litre mark with the sample. The sample was left to settle for 45 minutes. The sample around the side of the cone was gently agitated with a rod then allowed to settle for a further 15 minutes. The volume of settleable solids in the cone was recorded in milliliters per litre.

Total Dissolved Solids (TDS) dried at 180°C

An evaporating dish was heated to 180 ± 2 °C for 1 hour in an oven and stored in an oven. The dish was weighed before it was used. 100 ml of a sample was measured and filtered through the glass-fibre filter paper under slight suction to remove suspended solids. 5 ml of distilled water was used to rinse the residue three times. The filtrate was then transferred into a previously weighed evaporating dish and then heated on a hotplate. The residue was then dried at 105 °C for two hours in a drying oven, cooled in a desiccator for about 30 minutes and the dish weighed until a constant weight was obtained.

Total Suspended Solids (TSS)

100 ml of a well mixed sample was measured and filtered through a pre-weighed glass-fibre filter paper under suction. The residue was then washed three times with 5 ml distilled water allowing it to drain free from water after each wash. The paper was then removed, placed in a watch glass and dried in an oven at 105 °C for one hour. After an hour, the sample was cooled in a desiccator for 30 minutes after which the paper and the solids weighed until a constant weight obtained. The analysis was done in triplicate.

Dissolved Oxygen

Manganese sulfate (2.15M)

480 g of $MnSO_4.4H_2O$ was dissolved in 100 ml of distilled water in a beaker, filtered into a 1-litre volumetric flask then diluted to volume using distilled water.

Alkali-iodide-azide

500 g NaOH and 135 g NaI were added to 1-litre volumetric flask and distilled water added to the mark. This solution was then transferred to a 1.5 litre beaker. 10 g of sodium azide (NaN_3) dissolved in 40 ml of distilled water was then added.

Starch Indicator

100 ml of distilled water was heated to boiling point. A paste of 1 g potato starch was then prepared in 2 ml of distilled water and the boiled water added. This was then cooled and stored at 5 °C.

Standard sodium thiosulfate solution (Stock 0.1M)

24.82 g $NaS_2O_3.5H_2O$ was dissolved in distilled water and made up to 1000 ml in a volumetric flask. This was then preserved by adding 5 ml of chloroform to maintain the concentration at 0.1M. Standard 0.025 M (0.025 N) of the solution was then made by diluting 250 ml of stock to 1000 ml in a volumetric flask.

Potassium dichromate (0.025N)

1.225g $K_2Cr_2O_7$ was dissolved in distilled water then made up to 1000 ml in a volumetric flask.

Analysis

300 ml glass stoppered bottle was filled to the brim with sample water. 2.0 ml of manganese sulfate was immediately added to the bottle by inserting a calibrated pipette just below the surface of the sample water. The pipette was released slowly so that no bubbles were introduced via the pipette. 2 ml of alkali-azide was then added in the same manner and the bottle stoppered with care ensuring that no air was introduced. The sample was mixed by inverting several times. 2 ml of concentrated sulfuric acid was added via a pipette held just above the surface of the sample. The bottle was carefully stoppered and inverted several times till the floc dissolved. In a glass flask, 201 ml of the sample was titrated with sodium thiosulfate to a pale straw color. This was done by slowly dropping the titrant from a calibrated pipette while continually swirling the sample water. 2 ml of starch solution was added and a blue color formed. This was continuously titrated until the sample turned clear. The concentration of the dissolved oxygen in the sample

was equivalent to the number of milliliters of titrant used. 1 ml of sodium thiosulfate added is equivalent to 1 mg/l dissolved oxygen.

Chemical oxygen demand (COD)

Standard ferrous ammonium sulfate (0.125M)

49 g of $Fe(NH_4)_2(SO4)_2.6H_2O$ was dissolved in 100 ml distilled water in a 1000 ml volumetric flask. 10 ml of concentrated sulphuric acid was added, cooled and topped up to the mark with distilled water to give 0.125 M solution.

Potassium dichromate (0.01389M)

4.08 g of $K_2Cr_2O_2$ previously dried at 103 °C for two hours was dissolved in 100 ml of distilled water then topped up to 1000 ml mark in a volumetric flask to give 0.01389 M solution.

Sulphuric acid reagent

5.5 g of Ag_2SO_4 was added to 500 ml conc. sulfuric acid and allowed to stand for two days till it dissolved completely.

Ferroin indicator solution

This was prepared by dissolving 1.485 g of 1, 10-phenanthroline monohydrate and 695 mg $FeSO_4.7H_2O$ in distilled water and diluted to 1000 ml in a volumetric flask.

Analysis

2.5 ml of the sample was measured and put into digestion tubes. 1.5 ml of digestion solution (potassium dichromate) was then added followed by 3.5 ml of acid reagent. The tube was cupped tightly and inverted severally for thorough mixing. The mixture was then digested using a thermo reactor preheated at 150°C for 2 hours. The digested mixture was allowed to cool transferred into 100 ml conical flask. Two drops of ferroin indicator were added, the mixture titrated using ferrous ammonium sulphate and the results tabulated.

Five Day Biological Oxygen Demand (BOD_5)

45.7 ml of I sample, 97 ml of the C sample and 164 ml of the O sample were each put in a different BOD bottle. A breather was fixed and a pellet of sodium hydroxide added from the breather. The automatic reader stopper was then fixed and the bottles incubated in the Oxitop box for a period of five days. The readings for each day were taken and tabulated.

3.4.2 Chemical Parameters

Nitrate

Nitratest Tube was filled with a sample up to 20 ml mark. One level spoonful of nitratest powder and one nitratest tablets were then added. The cap was replaced and the tube shaken for one minute. The tube was allowed to stand for about one minute then gently inverted three times to aid mixing. The screw cap was then removed and the clear solution decanted into a test tube and filled to the 10 ml mark. One Nitricol tablet was added, crushed and mixed till it dissolved. The mixture was allowed to stand for 10 minutes till colour developed. The tubes were then inserted into a photometer from which the readings were then taken.

Total Phosphorus

The Tubetest heater was turned on, control set to 105 ˚C and allowed to heat up to 105 °C. The caps of the Tubetests Total Phosphorus/12 were removed and 2.0 ml of the three sets of the samples were added using a pipette. Two digest ox tablets were added to each tube, crushed and then mixed until it dissolved. The cap was tightly replaced and the tubes inverted gently until mixed. The the contents of the tubes were then digested for one hour then removed, the tubes placed in the test tube rack and allowed to cool. The cap was carefully removed from the cooled tubes and 2.0 ml of PhosNeut Solution added using a pipette. One PhosNo. 1 tablet was then added, crushed then mixed to dissolve. One Phos No.2 tablet was then added crushed then mixed to dissolve. The tubes were gently inverted several times until complete mixing was achieved. The tubes were then allowed to stand for 10 minutes so as to allow color development. The readings were taken at a wavelength of 640 nm on a Photometer.

3.4.3 Heavy Metals

100 ml of a well-mixed acid preserved sample was transferred into a 250 ml conical flask. 5 ml of conc. HNO_3 and added a magnetic stirrer. This was then brought to a slow boil and evaporated on a hot plate to 15 ml before precipitation occurred. This was heated while adding concentrated HNO_3 as was necessary until digestion was complete. This was showed by a light-colored, clear solution. The walls of the flask was washed down with distilled water then filtered. The filtrate was then transferred to a 100 ml volumetric flask with two 5 ml portions of water and the rinsings added to the volumetric flask. This was then cooled, diluted to the mark and thoroughly mixed. 20 ml of each sample was then aspirated into the AAS to determine the concentrations.

3.4.4 Oil and grease

100 ml of the sample was put into a 250 ml separating funnel. Three drops of sulphuric acid was added to bring the pH to 2 so as to prevent oxidation. 50 ml of n-hexane at 50 °C was then added and the mixture shaken so that any oil or grease present in the aqueous phase could move to the organic solvent phase. After thoroughly mixing, the lower layer was drained off and the upper organic layer was collected into a conical flask filled with anhydrous sodium sulphate to remove water. The contents of the conical flask were then filtered into a pre-weighed 250 ml round bottomed flask. The organic layer was then evaporated using hot water bath leaving the oil & grease. The flask was then weighed for the determination of oil & grease

3.4.5 Bacteriological parameter

Total Coliforms

14g of nutrient agar was weighed, dissolved in 500 ml of distilled water. This was then heated using hot plate for complete dissolution. The solution was then put into autoclave for 15 minutes for sterilization. 0.1, 0.5 and 1.0 ml of the I, C and O samples diluted 1000 times respectively were put into Petri dishes. 15 ml of the culture media were added. The samples were then cultured in an incubator for 24 hours and the results tabulated.

3.5 POLLUTION LOAD

Pollution load was calculated as shown in equation 3.1.

$$\text{Pollution load} = \text{Concentration of the pollutant (mg/l)} \times \text{Volume of water (flow) l/s}$$

Equation 3.1: Computation of Pollution load

3.6 PERCENTAGE REDUCTION EFFICIENCY

Efficiency of pollutant removal is very significant in wastewater treatment. The efficiency ratings are usually used to set goals as well as to maintain effective performance of the treatment plant. Percentage Reduction Efficiency for each parameter was computed as shown in equation 3.2.

$$reduction\ efficiency = \frac{Influent\ concentrat\,ion - Effluent\ concentrat\,ion}{Influent\ concentrat\,ion} \times 100$$

Equation 3.2: Computation of Reduction Efficiency

3.7 COMPLIANCE INDEX

Compliance index is a statistical tool that shows at a glance the effectiveness of a treatment works. Compliance index value of <1 implies compliance to the set standards while a value >1 implies non-compliance. This means that the effluent discharged into the environment have concentrations of given parameters higher than the ones set by the environmental protection bodies. Compliance Index for each parameter was therefore computed as shown in equation 3.3.

$$Compliance\ \ Index = \frac{Effluent\ concentrat\,ion}{Maximum\ allowable\ value}$$

Equation 3.3: Calculation of Compliance Index

3.8 AREA SERVED BY THE PLANT

The areas served by the plant were CBD, Kariobangi North and South, Jericho, Buru Buru, Huruma, Mathare, Uhuru and Eastleigh as shown in Figure 3.2 The experimental results obtained from this study were compared with data obtained from the treatment plant for the period ranging from February – May 2010. This was to enable identification of any changes in the efficiency of the plant over a period of five years. The levels of individual parameters analyzed also contributed into deducing possible effects of the growth of Nairobi city on the efficiency of the plant. Questionnaire used is as shown in **appendix 15.** Questionnaires were used to establish the areas within the city served by Kariobangi Sewerage Treatment Works and to assess the overall effects of the development activities in these areas on the performance of the plant. The questionnaires were given to the technical staff with different work experience within the plant.

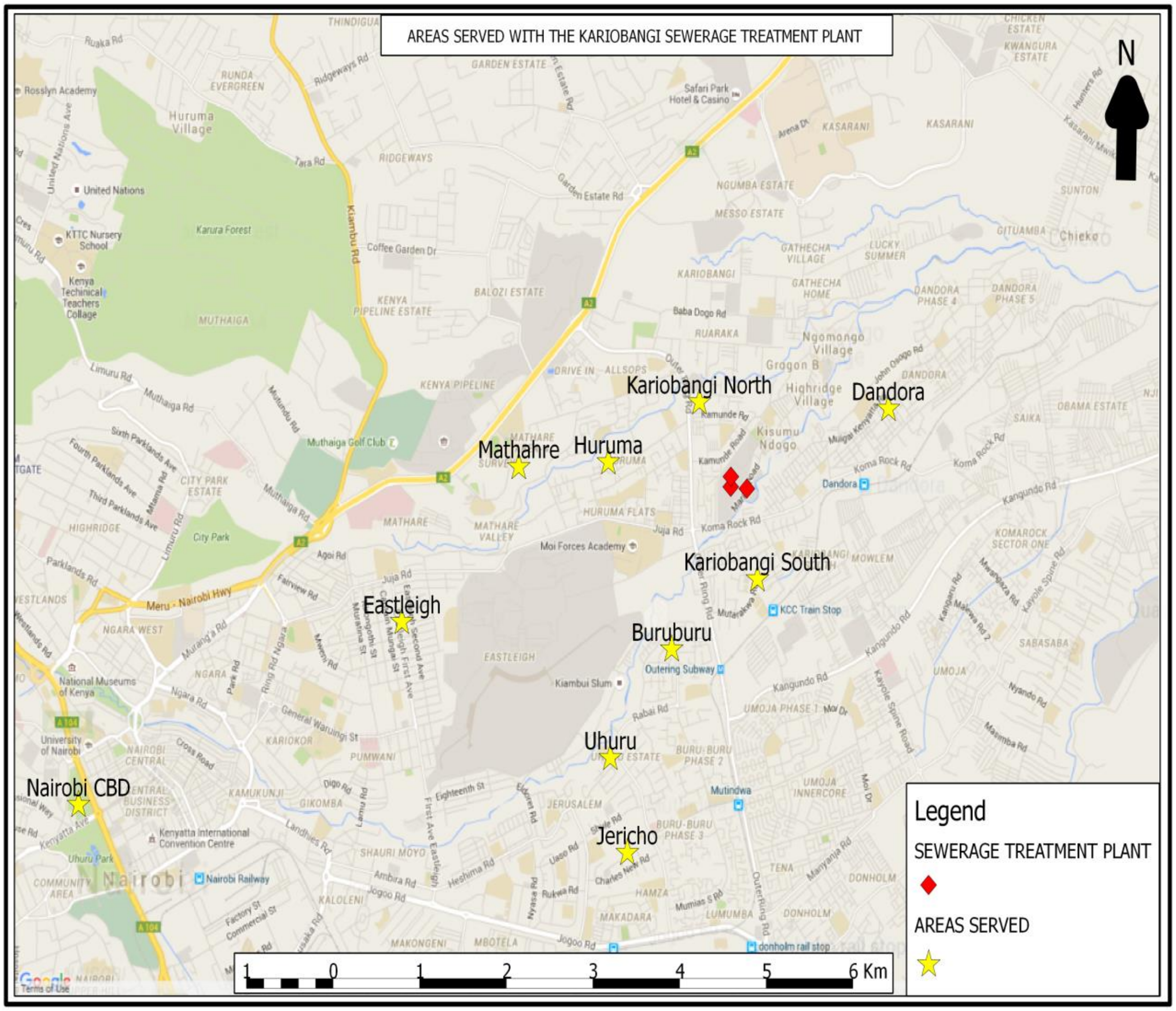


Figure 3.2: Areas served by Kariobangi Sewerage Treatment Works

CHAPTER FOUR

RESULTS AND DISCUSSION

I, C and the O were the sampling points.

4.1 RESULTS FOR THE SEWAGE COMPONENTS

4.1.1 Physico-Chemical Parameters

Temperature

The temperature of the samples was measured on site in which influent and effluent temperature values were found to range from 22.2 to 27.1 °C and 22.0 to 27.3 °C respectively as shown in Table 4.1. The influent temperature for the month of February was 27.1 °C which was higher than the subsequent three months; March, April and May which had 23.5, 2.4 and 22.2 °C respectively. This could be due to the fact that the ambient temperature during the month of February was higher (28 °C) compared to the other months.

Table 4.1: Results for temperature analysis for the period of ranging from February to May

Month	Influent (°C)	Effluent (°C)	Primary Clarifier (°C)	Standard for discharge into public sewer (°C)	Standards for discharge into the environment (°C)
February	27.1 ±0.2	27.3 ±0.3	27.8 ±0.4	20-30	Ambient Temp ±3
March	23.5 ±0.3	22.5 ±0.6	24.0 ±0.6		
April	23.4 ±0.1	23.5 ±0.4	23.3 ±0.2		
May	22.2 ±0.4	22.0 ±0.2	21.9 ±0.5		

pH

Analyses of the pH were done on site. The findings were recorded as shown in Table 4.2. February recorded relatively lower pH value of 6.2 for influent as compared to the other three months. This could have been due to the heavy downpour which characterized these months particularly the last two months. The rains most likely might have contributed to increase in the pH through dilution. The pH values for the primary clarifier and effluent were also within the NEMA provided standards

There was increase in pH of the effluent from February to May compared to the corresponding influent values for the same months this could have been due to gradual increase in the dilution of wastewater as a result of the rains which also increased from February to May.

Table 4.2: Results for pH analysis for the period ranging from February to May

Month	**Influent pH**	**Effluent pH**	**Primary Clarifier pH**	**Limits for discharge into public sewer**	**Limits for discharge into the environment**
February	6.2 ±0.04	6.7 ±0.02	6.3 ±0.07	6-9	6.5-8.5
March	6.8 ±0.02	7.0 ±0.04	6.6 ±0.09		
April	6.8 ±0.01	7.2 ±0.03	6.8 ±0.06		
May	7.0 ±0.04	7.1 ± 0.03	7.2 ±0.02		

Color

The color value for influent for April was 40 H.U and was higher than the rest of the months. This could have been because April marked the onset of the heavy rains which could have been washing down most of the organic waste to the sewer lines. The values for the effluent were also within the standards as shown in Table 4.3. The fact that the values obtained were within the maximum allowable limits meant that the plant effectively handled turbidity of the influent.

Table 4.3: Results for color analysis for the period ranging from February to May

Month	**Influent (H.U)**	**Effluent (H. U)**	**Percentage Reduction Efficiency**	**Primary Clarifier**	**Compliance index**	**Remarks**
February	30 ±0	5 ±0	83.3	10 ±0	0.333	Compliant
March	30 ±0	7.5 ±0	75.0	10 ±0	0.5	Compliant
April	40 ±0	7.5 ±0	81.3	17.5 ±0	0.5	Compliant
May	30 ±0	5.0 ±0	83.3	10 ±0	0.333	Compliant

The reduction efficiency was in the range of 75.0-83.3 % as shown in Figure 4.3. There was general improvement in the color of the influent as it moved through the clarifier to the outlet. February and May recorded the highest percentage reduction efficiencies of 83.3 % each as shown in Figure 4.1. March had the lowest reduction efficiency of 75.0 %.

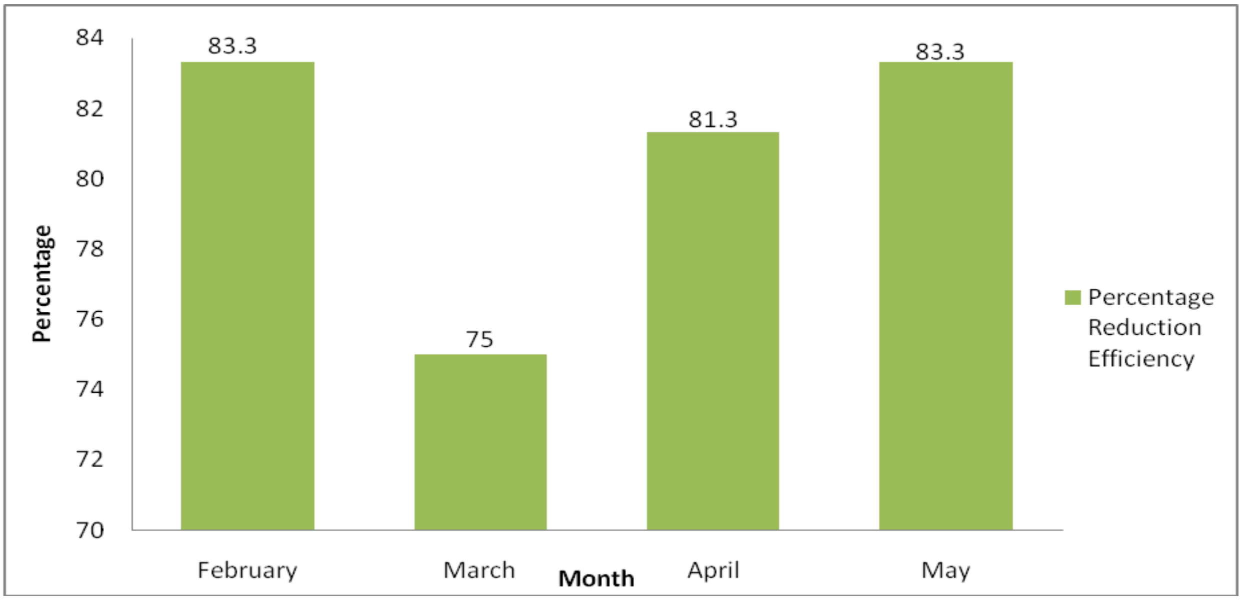


Figure 4.1: Percentage reduction efficiency for color for the period of February to May

Conductivity

Conductivity values obtained showed great variations over the period. Comparing the influent and the effluent values for each month, there is significant reduction in conductivity between the influent and the effluent except for February in which the conductivity reduced with a very small margin and March in which there was increase in the effluent conductivity values as shown in Table 4.4. This observed decrease could be due to decrease in total dissolved solids responsible for conductance. However, the relatively higher effluent value for the month of March could be associated to possible accumulation of the dissolved substances and increase in metal ions in the wastewater as rains begun towards the end of March. The conductivity values for influent, clarifier and effluent for the first two months of February and March as shown in Table 4.4 were higher compared to the last two months of April and May. These variations could be attributed to the seasonal change particularly heavy down pour which characterized the months of April and May resulting to possible dilution of the wastewater.

Table 4.4: Results for conductivity analysis for the period ranging from February to May

Month	Influent (mS/m)	Effluent (mS/m)	Primary Clarifier (mS/m)
February	6.32 ±0.01	6.30 ±0.02	7.06 ±0.02
March	5.43 ±0.03	6.34 ±0.04	6.23 ±0.03
April	1.13 ±0.01	0.80 ±0.03	0.86 ±0.04
May	1.10 ±0.04	0.5 ±0.01	0.74 ±0.01

Turbidity

The turbidity values for the influent for all the months were higher compared to the clarifier and effluent values as shown in Table 4.5. However, the wastewater was more turbid in the month of April than any other month recording 665.5 NTU for the influent. This could be due to the heavy rains that begun in the month of April and so were the large amount of solid wastes that were being transported along with the wastewater.

Table 4.5: Results for turbidity analysis for the period ranging from February to May

Month	Influent (NTU)	Effluent (NTU)	Percentage Reduction Efficiency	Primary Clarifier (NTU)
February	413 ±6	23 ±2	94.4	44 ±2
March	446 ±5	62.4 ±0.2	86.0	123.5 ±4.2
April5	665.5 ±6.6	12.85 ±0.1	98.1	57.05 ±0.9
May	498 ±7	11.7 ±0.3	97.7	39 ±1

In general, there was significant reduction of turbidity values from the influent to effluent implying effective operation of the treatment plant in handling turbidity. The percentage reduction efficiency was as shown in Figure 4.2 and ranged between 86.0-98.1 %.

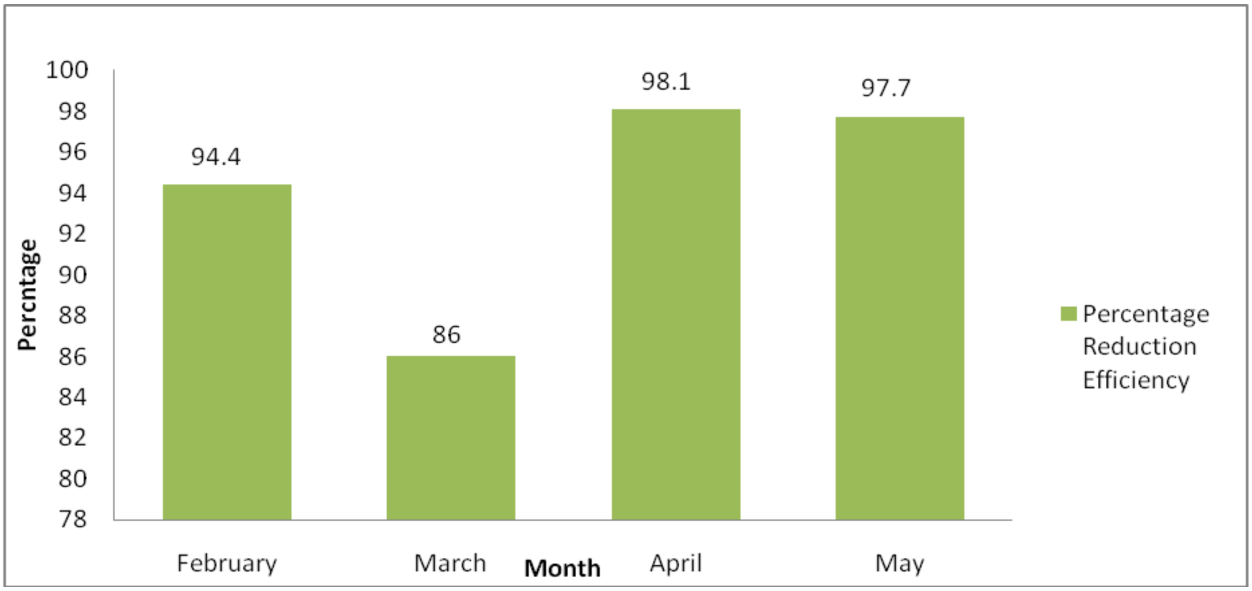


Figure 4.2: Percentage reduction efficiency for turbidity for the period of February to May

Settleable Solids

The month of May recorded the highest value of 15.7 ml/l of the settleable solids for the influent compared to all other months. There was gradual increase in the values of the settleable solids obtained for the influent from February to May as shown in Table 4.6. This could be attributed to the heavy downpour which washed into the sewer lines large amount of solid particles. The clarifier values were relatively lower compared to the effluent values. This could have been due to little retention time of wastewater in the clarifier.

Table 4.6: Results for settleable solids analysis for the period ranging from February to May

Month	Influent (ml/l)	Effluent (ml/l)	Percentage Reduction Efficiency	Primary Clarifier (ml/l)
February	6. 5±0.1	0.25 ±0.02	96.2	0.5 ±0.1
March	7.5 ±0.2	1.9 ±0.2	74.7	0.2 ±0.1
April	12.5±0.4	1.8 ±0.3	85.6	0.6 ±0.1
May	15.7±0.2	1.4 ±0.1	91.1	0.9 ±0.2

Percentage reduction efficiency was generally high for all the months ranging from 96.2-74.7 % as shown in Figure 4.3. This implied removal of a reasonable amount of settleable solids during the treatment process.

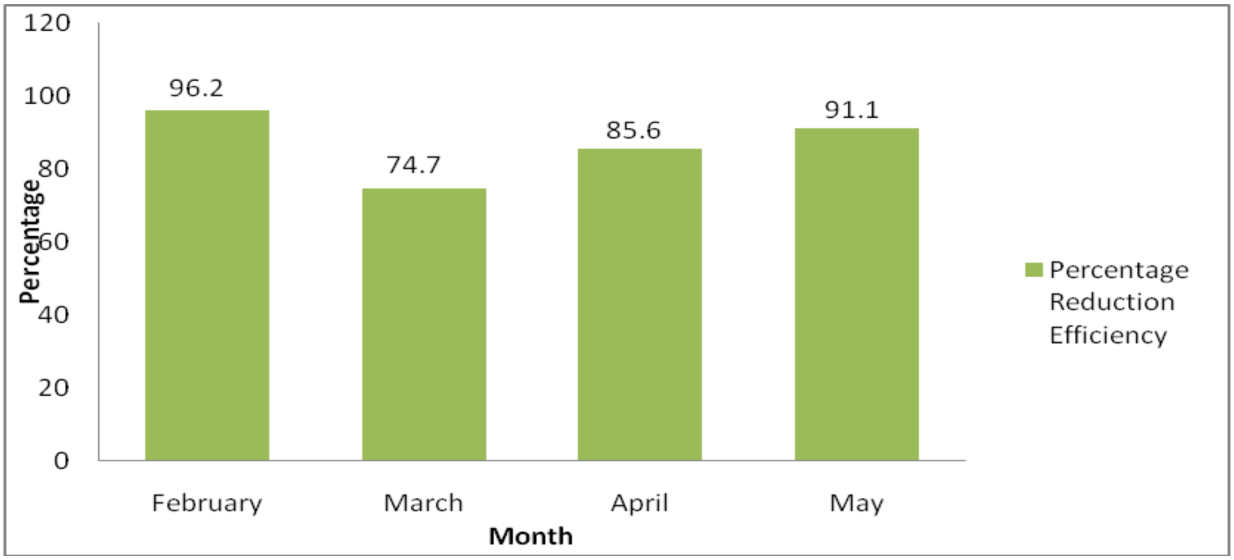


Figure 4.3: Percentage reduction efficiency for SS for the period of February to May

Total Dissolved Solids

The month of March recorded the highest value of 33660 mg/l while May recorded the lowest influent value of 680 mg/l as shown in Table 4.7. The first two months recorded the highest values of 26,122 mg/l and 33 666 mg/l respectively compared to the months of April and May which recorded 700 mg/l and 680 mg/l respectively. The months of April and May recorded low values which could have been due to dilution of the wastewater as a result of the rains.

Table 4.7: Results for TDS analysis for the period ranging from February to May

Month	Influent (mg/l)	Effluent (mg/l)	Percentage Reduction Efficiency	Primary Clarifier (ml/l)	Compliance index	Remarks
February	26122 ±123	26040 ±130	0.03	29180 ±100	21.7	Not compliant
March	33660 ±200	39300 ±150	-16.8	38626 ±142	32.8	Not compliant
April	700±30	500 ±20	28.6	530 ±15	0.42	Compliant
May	680±20	310 ±5	54.4	460 ±10	0.26	Compliant

The percentage reduction efficiency was in the range of -0.03-16.8 % as shown in Figure 4.4. The negative percentage reduction efficiency value means that the effluent value was higher than the influent value. The concentration of the effluent for the month of March was 38, 626 mg/l while the corresponding influent concentration 33, 6660 mg/l as shown in Table 4.7 These variations could be attributed to accumulation of TDS in the plant within the month of March. There was also minimal reduction of TDS in the month of February.

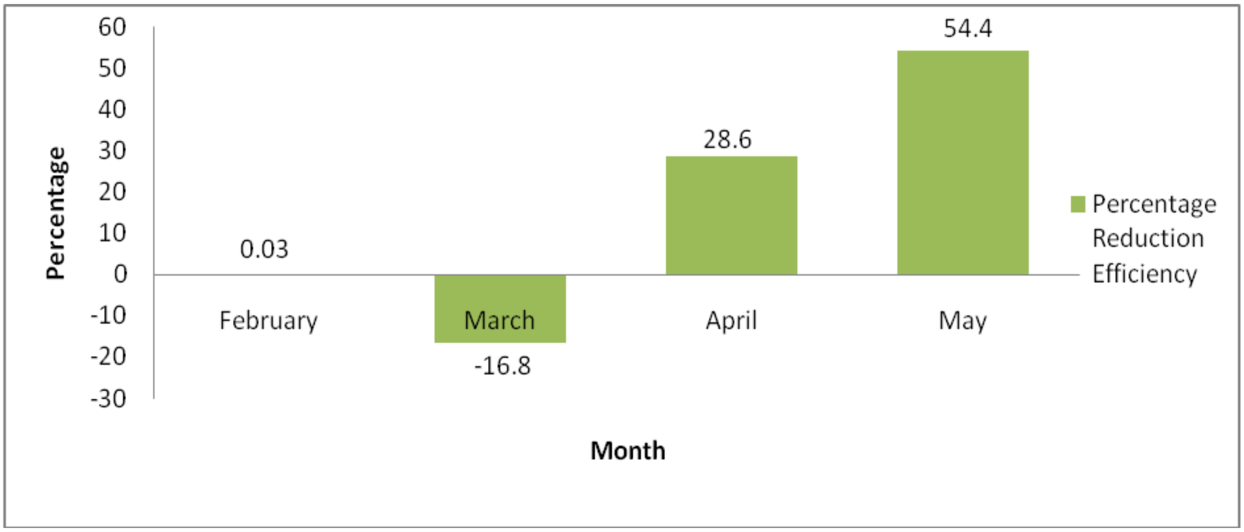


Figure 4.4: Percentage reduction efficiency for TDS for the period of February to May

Total Suspended Solids

February recorded a TSS value of 9189 mg/l while March recorded 3690 mg/l for the influent. May recorded TSS value of 2800 mg/l as shown in Table 4.8. However, there was general decrease in the values of TSS recorded from February to May; the drier period had effluent values of 8818 mg/l and 60 mg/l respectively. These were lower compared to the wet period of April-May which had 1470 mg/l and 40 mg/l respectively**.** This could be due to dilution of the wastewater by storm waters resulting into decrease in the TSS.

Table 4.8: Results for TSS analysis for the period ranging from February to May

Month	**Influent (mg/l)**	**Effluent (mg/l)**	**Percentage Reduction Efficiency**	**Primary Clarifier (mg/l)**	**Compliance index**	**Remarks**
February	9189 ±40	8818 ±31	4.0	8993 ±34	293.3	Not compliant
March	3690 ±20	60 ±3	9.8	52 ±3	2.0	Not compliant
April	2980 ±11	1470 ±10	50.7	2230 ±15	49	Not compliant
May	2800 ±12	40 ±2	98.6	560 ±7	1.3	Not compliant

There was a systematic increase in the percentage reduction efficiency for TSS from February to May as shown in Figure 4.5 which could be due to dilution of some of the TSS.

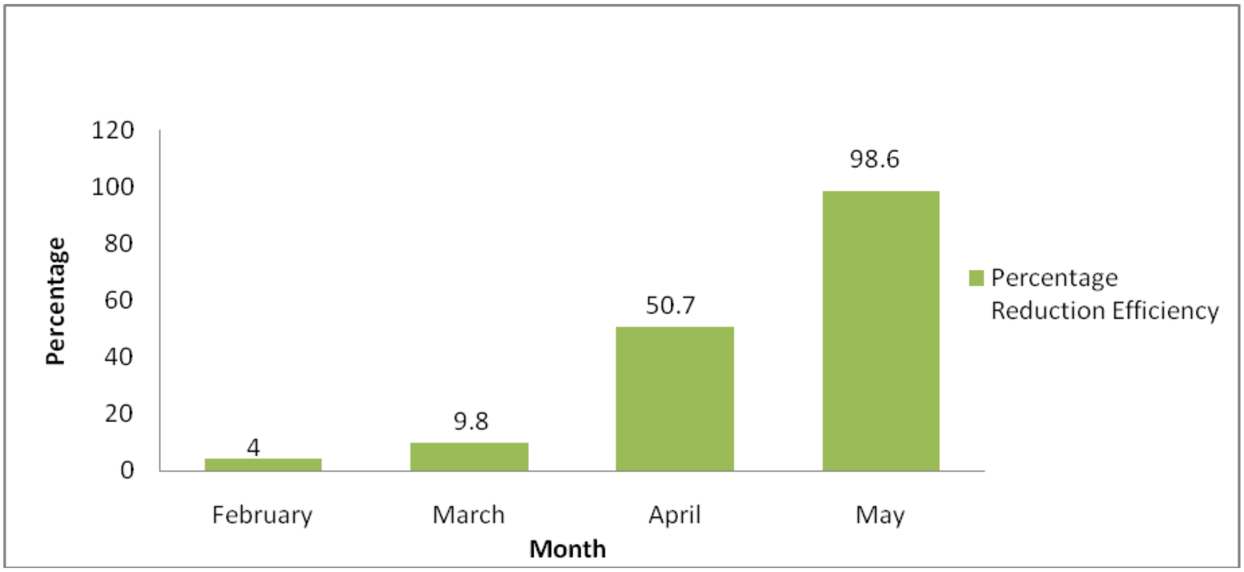


Figure 4.5: Percentage reduction efficiency for TSS for the period of February to May

Dissolved Oxygen

DO for the Influent values increased gradually within the period. May had DO value of 5.8 mg/l O_2 for the influent shown in Table 4.9. This implied that the influent quality improved with time and this could be attributed to the steady flow of influent resulting to aeration of the wastewater. The effluent values were higher than the influent values. This meant improved water quality of the water leaving the plant. The clarifier values were relatively higher than the influent values except for March.

Table 4.9: Results for DO analysis for the period ranging from February to May

Month	Influent mg/l O_2	Effluent mg/l O_2	Primary Clarifier mg/l O_2
February	5.5 ±0.1	5.7 ±0.1	5.8 ±0.1
March	5.2 ±0.1	5.8 ±0.1	4.8 ±0.1
April 2015	5.6 ±0.1	6.1 ±0.1	5.9 ±0.1
May 2015	5.8 ±0.1	6.7 ±0.1	5.8 ±0.1

Chemical Oxygen Demand (COD)

March recorded COD value of 4000 mg/l for the influent while May recorded 600 mg/l. The values of the clarifier were higher compared to the effluent values particularly in the months of March and May with COD values of 420 mg/l and 180 mg/l respectively.

Table 4.10: Results for COD analysis for the period ranging from February to May

Month	Influent mg/l	Effluent mg/l	Percentage Reduction Efficiency	Primary Clarifier mg/l	Compliance Index	Remarks
February	1200±20	212±1	82.3	296 ±3	4.2	Not compliant
March	4000±10	280±2	93.0	420±5	5.6	Not compliant
April	1080±15	315±3	70.8	305±2	6.3	Not compliant
May	600±5	170±1	71.7	180±1	3.4	Not compliant

The percentage reduction efficiency for COD was quite high for all the months ranging from 93-70.8% as illustrated in Figure 4.6. However, none of these translated into effluent compliance to set discharge standards.

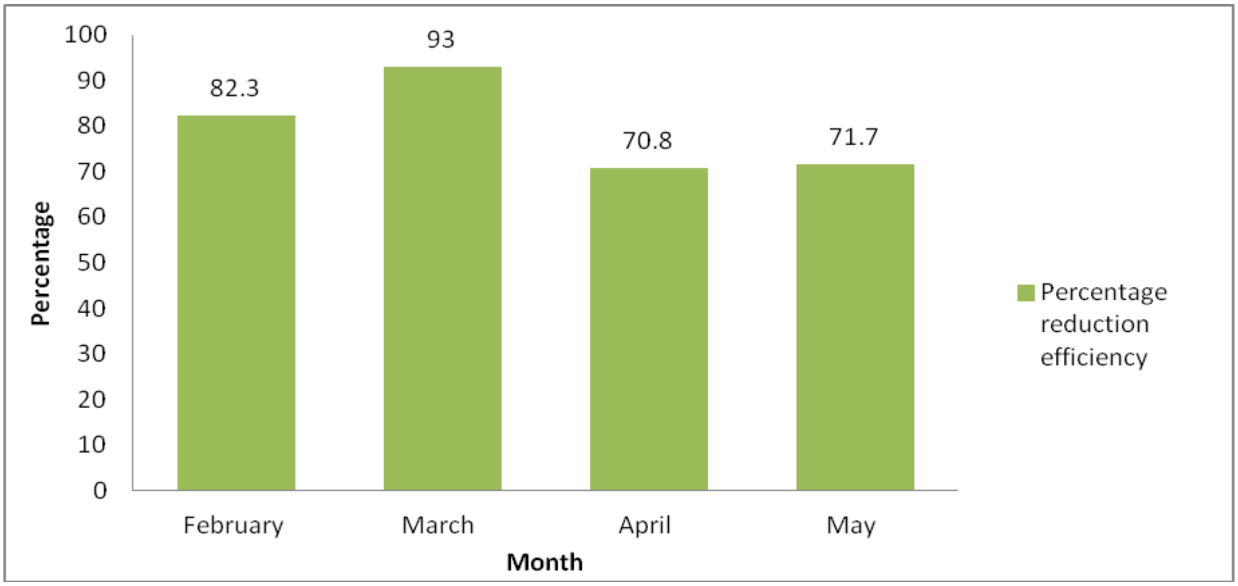


Figure 4.6: Percentage reduction efficiency for COD for the period of February to May

Biochemical Oxygen Demand for five days (BOD_5)

The influent BOD_5 values obtained for the month of February and March were higher than the recommended discharge value to the public sewers. The effluent values for all the months were also higher than the recommended value of 30 mg/l. This could be because of the inability of the plant to have effective BOD reduction. February recorded the highest values of 650 mg/l while May recorded the lowest value of 310 mg/l for the influent. April and May influent values were within the acceptable value. The clarifier values were lower than the influent values. The percentage reduction efficiency was in the range of 56.9- 64.5 % as shown in Figure 4.7.

Table 4.11: Results for BOD_5 analysis for the period ranging from February to May

Month	Influent (mg/l)	Effluent (mg/l)	Percentage Reduction Efficiency	Primary Clarifier (mg/l)	Compliance Index	Remarks
February	650±5	280±2	56.9	360±1	9.3	Not compliant
March	550±10	210±3	61.8	290±2	7.0	Not compliant
April	380±2	150±5	60.5	190±5	5.0	Not compliant
May	310±1	110 ±2	64.5	150±2	3.7	Not compliant

The percentage reduction efficiency in the BOD concentration from influent to effluent was as shown in Figure 4.7 with May recording the highest reduction efficiency of 64.5 %.

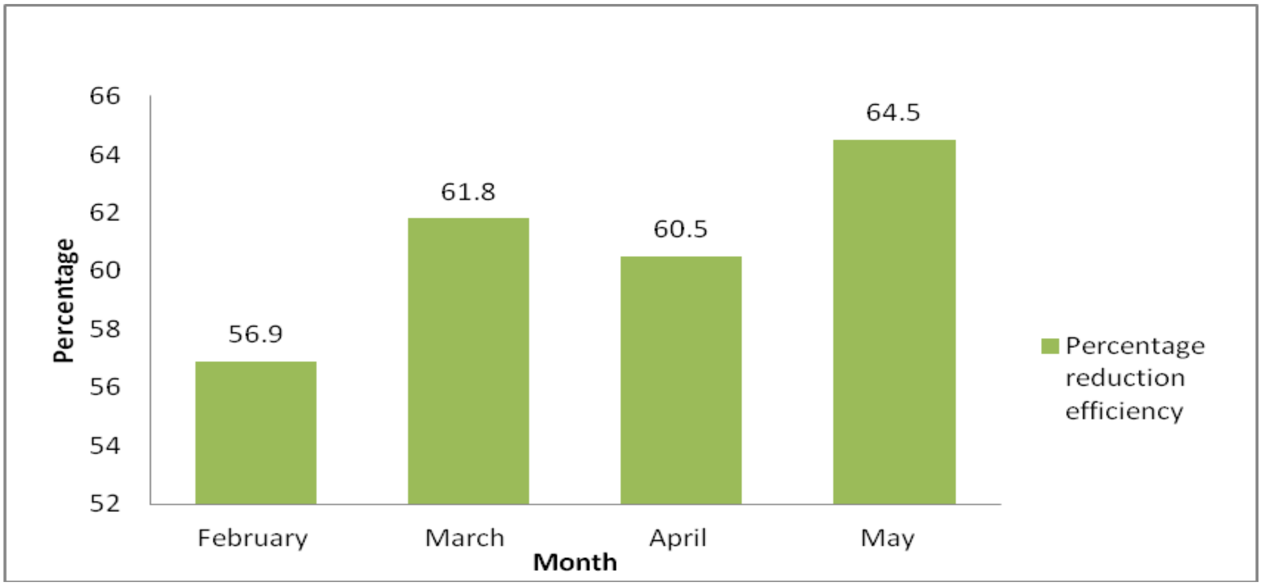


Figure 4.7: Percentage reduction efficiency for BOD_5 for the period of February to May

4.1.2 Chemical Parameters

Nitrates

The nitrate values obtained for the influent over the period was much lower as shown in Table 4.12 than the allowable limits of 20 mg/l. This could be due to low discharge of nitrogen containing substances such as fertilizers into the sewer lines as a result of low level of agricultural activities along the sewer lines. There was gradual increase in the influent values with May recording the highest value of 1.437 mg/ l. This could have been due to increased nitrate washings into the sewer lines to the plant.

Table 4.12: Results for nitrates analysis for the period of February to May

Month	**Influent) (mg/l NO_3)**	**Effluent (mg/l NO_3)**	**Percentage Reduction Efficiency**	**Primary Clarifier (mg/l NO_3)**
February	0.770±0.08	0.902±0.001	-17.1	0.924±0.002
March	0.158±0.002	0.132±0.001	16.5	0.167±0.003
April	1.178±0.001	1.001± 0.002	15.0	1.178±0.002
May	1.437±0.003	0.912±0.003	36.5	1.100±0.01

The percentage reduction efficiency for the month of February was very low as shown in Figure 4.8. This meant that the concentration of nitrates in the effluent was higher than the concentration of the same in the influent. This could be due to accumulation of nitrates at the clarifier.

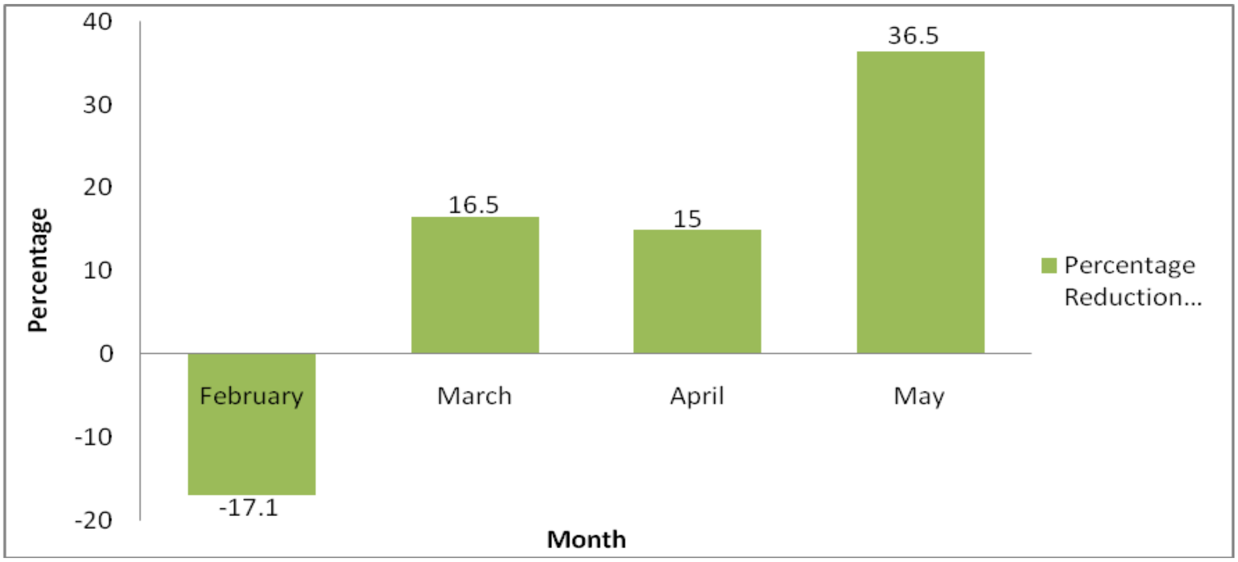


Figure 4.8: Percentage reduction efficiency for nitrates for the period of February to May

Phosphate

The phosphate values obtained for the influent over the period were much higher as indicated in Table 4.13 than the allowable limits of 30 mg/l PO_4. This could be due to high discharge of phosphate containing substances such as detergents into the sewer lines. There was gradual increase in the influent values with May recording 200 mg/ l PO_4.

Table 4.13: Results for phosphate analysis for the period ranging from February to May

Month	**Influent (mg/l PO_4)**	**Effluent (mg/l PO_4)**	**Percentage Reduction Efficiency**	**Primary Clarifier (mg/l PO_4)**
February	76±1	86±2	-13.2	86±2
March	142.5±1.0	92.5±0.1	35.1	82.5±0.5
April	159±2	123±1	22.6	143±1
May	200±3	127±3	36.5	179±1

The percentage reduction efficiency for phosphates are as shown in Figure 4.9. The negative percentage reduction efficiency for the month of February was negative. This means that the effluent concentration was higher than the influent concentration for the same month.

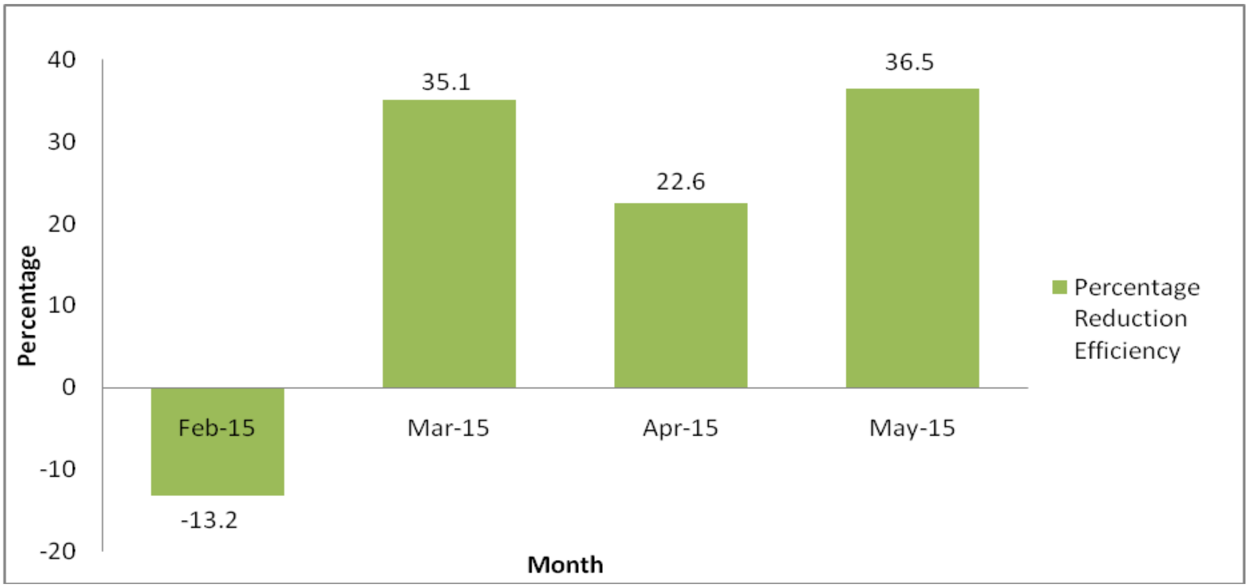


Figure 4.9: Percentage reduction efficiency for phosphorus for the period of February to May

4.1.3 Heavy Metals

Cadmium

There was gradual decrease in the influent values ranging from 0.5055 to 0.7230 mg/l. The cadmium levels for the clarifier and the effluent were higher than the influent values except for April effluent value which was lower. The effluent levels were way above the recommended discharge level into the environment which is 0.01 mg/l. February recorded 1.4465 mg/l while May had 0.8500 mg/l as shown in Table 4.14a. This great difference between the influent and the effluent values could be attributed to possible accumulation of cadmium in the clarifier and wastewater pathways within the treatment plant. This is because Cadmium being a heavy metal is attached to the sludge material and other solids.

Table 4.14a: Results for cadmium analysis for the period ranging from February to May

Month	**Influent conc. (mg/l)**	**Effluent conc. (mg/l)**	**Percentage Reduction Efficiency**	**Primary Clarifier (mg/l)**	**Compliance Index**
February	0.7320±0.001	1.4465±0.0001	-	1.4465±0.0101	144.65
March	0.6735±0.0001	1.3010±0.002	-	1.0570±0.0001	130.1
April	0.6015±0.0002	0.4935±0.0001	18.0	0.7715±0.0012	49.35
May	0.5055±0.0010	0.8500±0.01	-	0.9605±0.0001	85

Lead

The lead concentrations in the influent and the effluent and the clarifier were below 0.39 mg/l for the entire study period as indicated in Table 4.14b. This could be due to restrictions on lead usage in petroleum fuels resulting into low or no concentrations in the environment. Availability of lead alternatives such as lead alloys containing less percentage of led must have also contributed to the reduction lead in the environment.

Table 4.14b: Results for Lead analysis for the period ranging from February to May

Month	**Influent (mg/l)**	**Effluent. (mg/l)**	**Primary Clarifier (mg/l)**
February	< 0.39	< 0.39	< 0.39
March	< 0.39	< 0.39	< 0.39
April	< 0.39	< 0.39	< 0.39
May	< 0.39	< 0.39	< 0.39

..

Total Chromium

February recorded the highest influent value of 58.565 mg/l. May recorded the least amount of 4.625 mg/l as shown in Table 4.14c. There was general decrease in the concentrations of chromium for the influent. Despite the elevated influent levels, the effluent levels were below the detection limit of 0.32 mg/l except for the month of March which registered a concentration of 10.16 mg/l. The chromium concentrations for the clarifier were equally higher with April recording the highest value of 47.16 mg/l. The high clarifier concentrations could be due to accumulation of chromium in the clarifier. Chromium being a heavy metal possibly got attached on the sludge surfaces.

Table 4.14c: Results for chromium analysis for the period ranging from February to May

MONTH	**Influent (mg/l))**	**Effluent Cr conc. (mg/l)**	**Percentage Reduction**	**Primary Clarifier conc. (mg/l)**	**Compliance Index**
February	58.565±0.211	< 0.32	-	35.125 ±0.001	-
March	51.605±0.121	10.16 ±0.11	80.3	41.080 ±0.201	5.1
April	4.625±0.001	< 0.32	-	47.160 ±0.130	-
May	43.755±0.044	< 0.32	-	3.715 ±0.113	-

Zinc

March recorded the highest value of 4.2335 mg/l. The effluent values were generally higher than the recommended maximum allowable limit of 0.5 mg/l except for the month of May which recorded a concentration of 0.1025 mg/l as shown in table 4.14d. This could be attributed to zinc usage in the cottage industries within the vicinity of the treatment plant.

Table 4.14d: Results for zinc analysis for the period ranging from February to May

Month	**Influent (mg/l)**	**Effluent (mg/l)**	**Percentage Reduction Efficiency**	**Primary Clarifier (mg/l)**	**Compliance Index**	**Remarks**
February	2.883±0.001	1.422±0.003	50.7	0.606±0.231	1.1	Not compliant
March	4.2335±0.001	1.9355±0.012	54.3	2,1835±0.001	3.9	Not Compliant
April	1.3815±0.101	1.0160±0.010	26.5	1.0855±0.301	2.0	Not compliant
May	0.8790±0.220	0.1025±0.001	88.3	1.2835±0.001	0.2	Compliant

The percentage reduction efficiency for the four months of study was generally high as shown in Figure 4.10 except for the month of April which recorded 26.5 %.

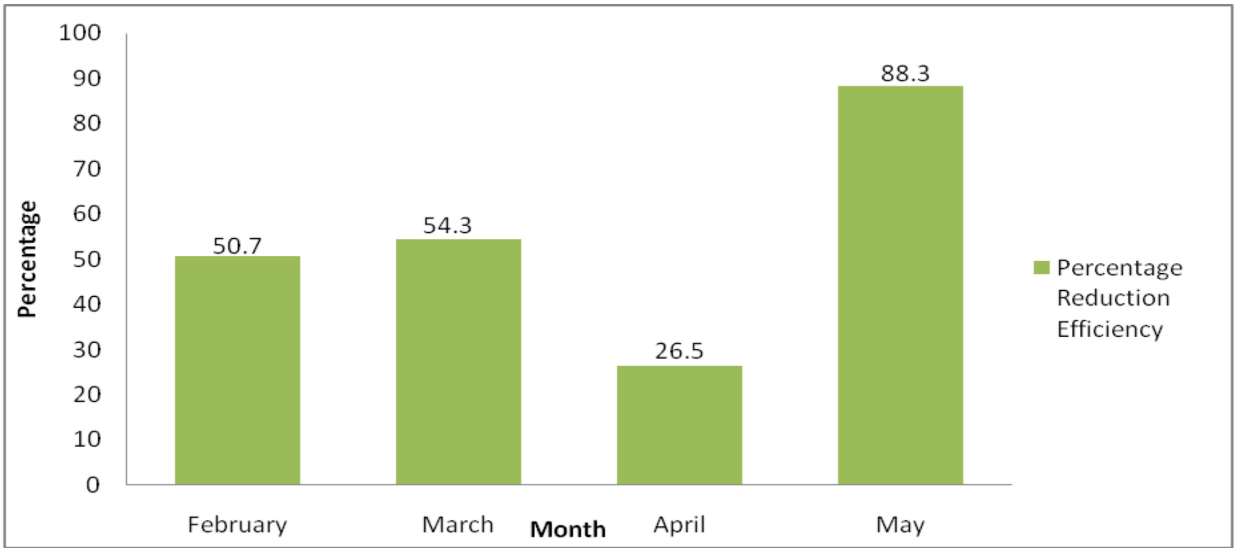


Figure 4.10: Percentage reduction efficiency for zinc for the period of February to May

4.1.4 Oil and grease

The influent values of oil and grease obtained over the period were lower than the recommended value of 10 mg/l. Generally, the effluent values were lower compared to the influent as shown in Table 4.15. Clarifier values ranged from 1.125 to 1.179 mg/l compared to influent values which ranged from1.012 to 1.901 mg/l.

Table 4.15: Results for Oil & grease analysis for the period ranging from February to May

Month	**Influent (mg/l)**	**Effluent (mg/l)**	**Percentage Reduction Efficiency**	**Primary Clarifier (mg/l)**
February	1.079±0.011	0.923± 0.001	14.4	1.179±0.002
March	1.012±0.001	0.075±0.001	92.6	1.178±0.012
April	1.587±.0.012	1.000±0.100	37.0	1.125±0.001
May	1.901±0.003	1.032±0.002	45.7	1.349±0.002

The percentage reduction efficiency was in the range of 92.6- 14.4 % as shown in Figure 4.11. March recorded percentage reduction efficiency of 92.6 % as shown Figure 4.14. The month of March marked the onset of heavy rains and oil & grease being less dense than water must have been carried away with the large influent volumes.

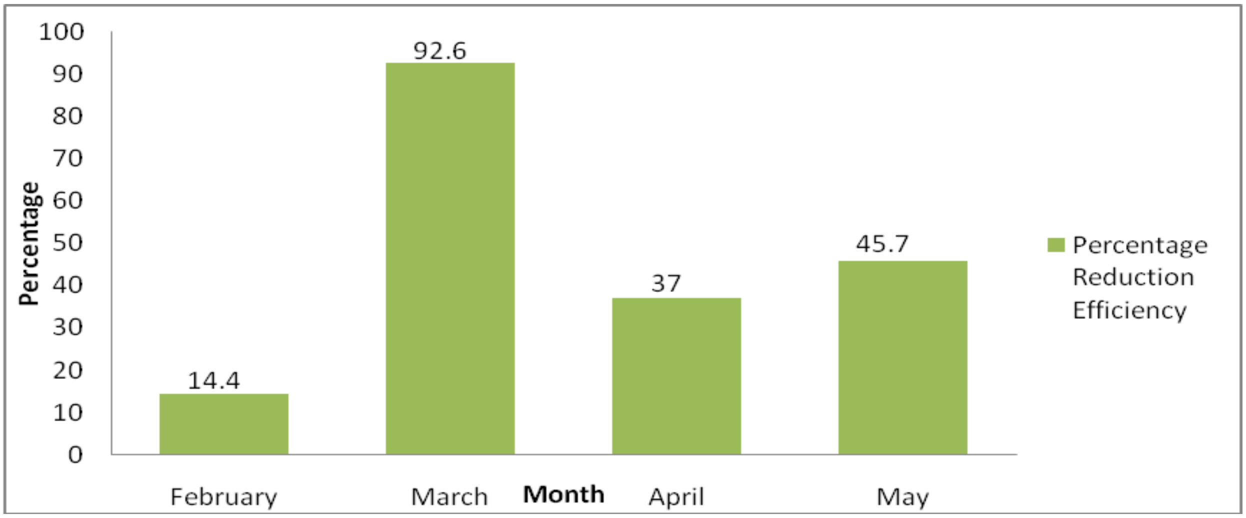


Figure 4.11: Percentage reduction efficiency for oil & grease for the period of February to May

4.1.5 Total Coliform-Bacteriological

General decrease in the values of total coliform was observed from March to May. March recorded 590000 counts/100 ml while May recorded 253000 counts/100 ml total coliform for influent. The values of total coliform for the clarifier were relatively lower than the values for the influent. The effluent values were also lower compared with the respective influent values except for March which had effluent value higher than the corresponding influent value. However, March recorded the highest values for total coliforms both for the influent and the effluent.

Table 4.16: Results for Total Coliform analysis for the period ranging from February to May

Month	Influent	Effluent	Percentage Reduction Efficiency	Primary Clarifier	Compliance Index	Remarks
February	483000±1000	160000±50	66.9	180000±50	5333.3	Not compliant
March	590000±200	783000±1000	-32.7	561000±400	26100	Not compliant
April	352000±100	243000±120	31.0	267000±300	8100	Not compliant
May	253000±150	189000±90	25.3	223000±100	6300	Not

						compliant

The percentage reduction efficiency for March was -32.7 % as shown in Figure 4.12. This meant that the amount of total coliforms in the effluent was higher than the amount in the influent. This could be due to accumulations of the total coliforms within the plant particularly the clarifiers as a result of low rate of sludge removal.

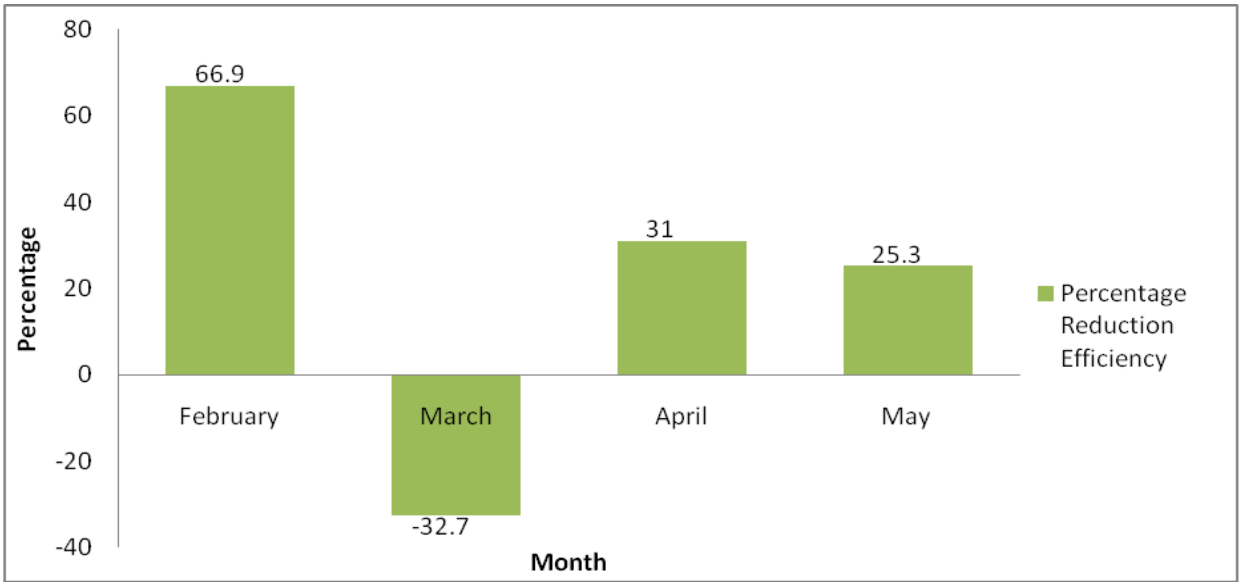


Figure 4.12: Percentage reduction efficiency for total coliforms for the period of February to May

4.2 POLLUTION LOADING

Pollution loading refers to stress placed upon an ecosystem through pollution by either physical or chemical means or both. Pollution loading provides exhaustive information about the level of impact of the pollutants on the environment. It is a function of pollutants' concentration and water flow. Pollution loading can be calculated for a number of parameters. For this study pollution load was computed for settleable solids, TSS, TDS, BOD, COD, nitrates, phosphorus, Oil & grease, cadmium, chromium, zinc and total coliforms.

Table 4.17: Pollution loading for some individual parameters

Parameter	**Average concentration (mg/l) for the Effluent**	**Average Outflow volume (l/s)**	**Pollution loading (mg/s)**
Settleabe solids	1275	109.3	139,357.5
TSS	2597		283852.1
TDS	16537.5		1,807,548.75
BOD	187.5		20, 493.76
COD	323		35,303.9
Nitrates	0.737		80.55
Total phosphorus	107.1 mg/		11,706.03
Oil and grease	0.7574		82.78
Cadmium	0.2046		22.36
Chromium	1.0227		111.78
Zinc	1.119		122.31
Total coliform	343750 counts/100ml		375,718,750 counts/s

4.3 DEVELOPMENT ACTIVITIES IN THE AREAS SERVED BY THE PLANT

The plant was mean to exclusively treat domestic waste. However, with the mushrooming cottage industries such as metal works, paint making among others in the areas served by the plant, industrial wastes as well have found their to the treatment plant. This coupled with infrastructural developments in these areas have immensely contributed to the amount of waste that reaches the plant for treatment. As a result, high levels of settleable solids, TDS were obtained. Replacement of the informal settlements by modern day skyscrapers as shown in Figure 4.14 and Figure 4.16 for both residential and commercial uses have also increased the number of persons using such facilities hence more pressure on the treatment plant. The plant had an inbuilt methanation unit which was meant to serve as energy source for the plant hence reduction in cost of operation. This was no longer the case as heavy metals from the cottage industries affect the methanation process.

Source: Google Earth Pro.

Figure 4.13: A section of Mathare Valley before Upgrade

Source Google Earth Pro

Figure 4.14: A Section of Mathere Valley after the upgrade

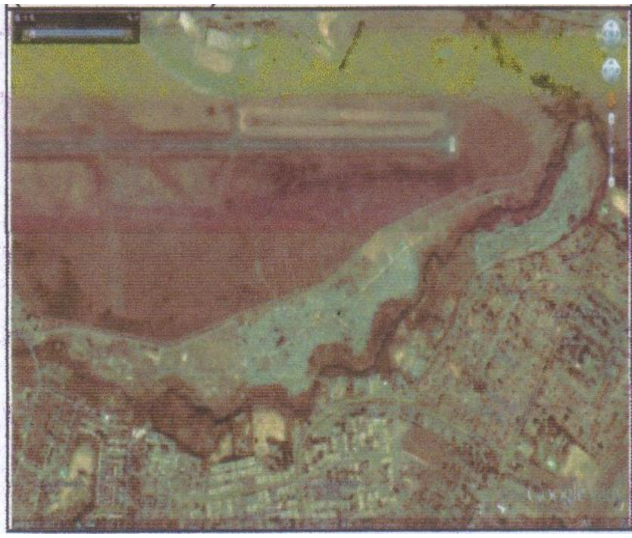
Figure 4.15 shows a section of Huruma before the replacement of the shanties with the tall residential buildings shown in Figure 4.16.

Source: Google Earth Pro

Source: Google Earth Pro

Figure 4.15: A Section of Huruma before upgrade **Figure 4.16: A Section of Huruma after upgrade**

Figure 4.17 shows the sparsely populated Eastleigh South to Uhuru estate area along Nairobi River in the year 2003. By the year 2012 population of the placed increased forcing more settlements of people along the banks of Nairobi River as shown in Figure 4.18



Source: Google Earth Pro

Figure 4.17: Eastleigh South to Uhuru estate (Nairobi River) in 2003

Source: Google Earth Pro

Figure 4.18: Eastleigh South to Uhuru estate (Nairobi River) in 2013

Comparison of the results obtained from this study and the results obtained five years ago at the plant it was noted that over the last five years, the efficiency of KSTW has deteriorated in its fundamental objective of ensuring that the quality of wastes in the effluent is minimized to the acceptable limits. The effluent levels of settleable solids and TDS had tremendously increased from 103.4 and 452.45 mg/l in 2010 (**Appendix 17**) to 1275 and 16537.5 mg/l respectively in 2015 (**Table 4.17**) giving percentage increase of 1133.1 and 3555.1 respectively as shown in Table 4.18. This implied reduction in the capacity of the plant to effectively minimize these pollutants before being discharged in to the environment. The high levels of settleable solids could also be attributed to the increased housing and infrastructural development activities within the plant’s catchment area in the last few years as shown in Figure 4.14 and Figure 4.16. The debris and loose soils from the construction sites found their way to the treatment plant. Increased farming activities which involves tilling of land near sewer lines could have also contributed to the increased levels of both the TDS and settleable solids in the final effluent. The

COD and BOD_5 values in 2015 were 187.5 and 323 mg/l compared 146.8 and 288. 5 mg/l obtained in 2010. This implied increased amounts of organic material in the wastewater emanating from the area served by the treatment plant. There were no significant differences in the temperature and pH values over the five-year period. It was also noted that the concentration of nitrate obtained in this study was o.737 mg/l compared to 2.6725 mg/l obtained five years ago. It was also noteworthy that the following parameters were not being analyzed at the plant: Color, turbidity, conductivity, TSS, Dissolved oxygen, phosphates, oil and grease, chromium, zinc, lead, cadmium and total coliforms.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

TSS, TDS except Feb and March, BOD, COD, Oil and grease and total coliforms had effluent values higher than the NEMA guidelines.

Temperature, color, Ph, TDS; Feb and March, Cr, Zn had effluent values within the NEMA provisions of maximum allowable limits.

Nitrates, phosphates, dissolved oxygen, conductivity and turbidity had no maximum allowable limit values provided by NEMA.

The concentration of Lead was < 0.39 mg/l for the entire study period.

Color, turbidity, settleable solids, TSS; April and May, TDS; May, BOD except March, COD, oil and grease; March, Zn except April and total coliforms; February had greater percentage reduction efficiency ranging from 75 -83.3 %, 86- 98.1%, 74.7 - 96.2 %, 50.7 -98.6 %, 54 %, 56.9-64.5 %, 70.8- 93.0 %, 92.6 %, 50.7- 88.3% and 66.9 % respectively. However, despite the high percentage reduction efficiency, the effluent values for TSS, TDS except Feb and March, BOD, COD, Oil and grease and total coliforms were still higher than the maximum allowable limits.

The concentrations for COD and BOD were significantly affected by the change in season. There were higher concentrations in dry season that is February-March compared to the wet season lasting between April and May. This was due to dilution of the wastewater by the storm waters. On the other hand, the levels of settleable solids were high during the wet season compared to the dry season. This was due to increased surface run-off.

The pollution loads that resulted from the parameters; TSS, TDS, BOD_5, COD, nitrates, phosphorus, Oil and grease, Cd, Cr, Zn and Total coliforms were 283,852 mg/s, 1,807,548.75, 20,493.76 mg/s, 35, 303.9 mg/s, 54.65 mg/s, 11,706.03, 82.78, 22.36, 111.78, 122.31 mg/l and 375,718, 750 counts/s respectively.

Five years ago, the KSTW was more efficient than it is today in handling the BOD, COD, settleable solids, and TDS even though the levels were still higher than the recommended levels.

Color, turbidity, conductivity, TSS, Dissolved oxygen, phosphates, oil and grease, chromium, zinc, lead, cadmium and total coliforms were not being analyzed at the plant.

The plant has an installed capacity of 32, 000 m^3/day while currently operates at 8, 000 m^3/day

Population growth and infrastructural development particularly housing have led to increase in the amount of waste directed to the plant for treatment. The debris from these construction sites might be responsible for clogging of the plant rendering it inefficient in handling solids among other pollutants.

5.2 RECOMMENDATIONS

From the study, the following suggestions were put forward:

1. There is need to have an overhaul of the plant to its original design capacity of 32,000 m^3/day as most of its components are dysfunctional.
2. Since only one clarifier out of six was operational and none of the nine filters was working, the remaining clarifiers and the filters should be rehabilitated. The digestion tanks should be repaired to facilitate methanation. This would enable energy production making the plant to be self-sustaining in its energy requirements.
3. The outlet should be fitted with flow rate meter to measure the outlet volumes.
4. Discharge into public sewers should be strictly monitored to ensure that the phosphate levels are within the allowable limits.

5. Mechanisms should be put in place to ensure reduction in effluent concentrations for BOD, COD, Oil and grease and Cadmium.
6. Color, turbidity, conductivity, TSS, Dissolved oxygen, phosphates, oil and grease, chromium, zinc, lead, cadmium and total coliforms analyses should be initiated at the plant to ensure that the concentrations in the effluents are controlled.
7. . The debris from construction sites should be well disposed to prevent being washed away into the sewer lines during rainy seasons

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APPENDICES

Appendix 1: Analysis of wastewater parameters for the month of February 2015

PARAMETER	FEBRUARY				
	INFLUENT CONC.	CLARIFIER CONC.	EFFLUENT CONC.	MAXIMUM ALLOWABE LIMIT TO THE ENVIRONMENT (NEMA)	COMMENTS
pH	6.2	6.3	6.7	6.5-8.5	Compliant
Temperature (°C)	27.1	27.8	27.3	+3 Based on ambient temperature	Compliant
Color (H.U)	30	10	5	15	Compliant
Turbidity (NTU)	413	44	23	No guideline value	
Conductivity (mS)	6.3	7.1	6.3	No guideline value	
Settleable Solids (ml/L)	6.5	0.5	0.3	No guideline value	
Total Supended Solids	9189	8993	8818	30	Non-

(mg/L)					compliant
Total Dissolved Solids (mg/L)	26122	29180	2604	1200	Non-compliant
Dissolved Oxygen (mg/LO$_2$)	5.5	5.7	5.8	No guideline value	
Chemical Oxygen Demand (mg/L)	1200	96	112	50	Non-compliant
Biochemical Oxygen Demand (mg/L)	650	60	100	30	Non-compliant
Phosphorus (mg/LPO$_4$)	76	86	86	No guideline value	
Nitrates (mg/LNO$_2$)	0.77	0.924	0.902	No guideline value	
Oil and grease (ml/L)	1.0787	1.1790	0.9230	Nil	Non-compliant
Cadmium (ppm)	0.1446	0.2893	0.2893	0.01	Non-compliant
Zinc (ppm)	0.5766	0.1212	0.2844	0.5	Compliant
Chromium (ppm)	1.1713	0.7025	ND	2.0	Compliant
Lead (ppm)	ND	ND	ND	0.01	Compliant
Total Coliform (counts/100ml)	483000	180000	160000	30/100	Non-compliant

Appendix 2: Analysis of wastewater parameters for the month of March 2015

PARAMETER	MARCH				
	INFLUENT CONC.	CLARIFIER CONC.	EFFLUENT CONC.	MAXIMUM ALLOWABE LIMIT TO THE ENVIRONMENT (NEMA)	COMMENTS
pH	6.8	6.6	7.0	6.5-8.5	Compliant
Temperature (°C)	23.5	24.0	22.5	+3 Based on ambient temperature	Compliant
Color (H.U)	30	10	5	15	Compliant
Turbidity (NTU)	446	123.5	62.4	No guideline value	
Conductivity (mS)	5.43	7.06	6.30	No guideline value	
Settleable Solids (ml/L)	7.5	0.2	1.9	No guideline value	
Total Supended Solids (mg/l)	3690	52	60	30	Non compliant
Total Dissolved	33660	38626	39300	1200	Non compliant

Solids (mg/l)					
Dissolved Oxygen (mg/l O_2)	5.2	5.8	4.8	No guideline value	
Chemical Oxygen Demand (mg/l)	4000	120	80	50	Non compliant
Biochemical Oxygen Demand (mg/l)	550	290	210	30	Non compliant
Phosphorus (mg/lPO_4)	142.5	82.5	92.5	No guideline value	
Nitrates (mg/lNO_2)	0.158	0.167	0.132	No guideline value	
Oil and grease (ml/l)	1.012	1.1780	0.0745	Nil	Non compliant
Cadmium (ppm)	0.1347	0.2114	0.2602	0.01	Non compliant
Zinc (ppm)	0.8467	0.4364	0.3871	0.5	Compliant
Chromium (ppm)	1.0321	0.8216	0.2032	2.0	Non compliant
Lead (pp	ND	ND	ND	0.01	Compliant
Total Coliform (counts/100ml)	590000	561000	783000	30/100	Non compliant

Appendix 3: Analysis of wastewater parameters for the month of April 2015

PARAMETER	APRIL				
	INFLUENT CONC.	CLARIFIER CONC.	EFFLUENT CONC.	MAXIMUM ALLOWABE LIMIT TO THE ENVIRONMENT (NEMA)	COMMENTS
pH	6.8	6.8	7.2	6.5-8.5	Compliant
Temperature (°C)	23.4	23.3	23.5	+3 Based on ambient temperature	Compliant
Color (H.U)	40	17.5	7.5	15	Compliant
Turbidity (NTU)	665.5	57.05	12.85	No guideline value	
Conductivity (mS)	1.13	0.86	0.80	No guideline value	
Settleable Solids (ml/L)	12.5	0.6	1.8	No guideline value	
Total Supended Solids (mg/L)	2980	2230	1470	30	Non compliant
Total Dissolved Solids	700	530	500	1200	Compliant

(mg/L)					
Dissolved Oxygen (mg/LO$_2$)	5.6	5.9	6.1	No guideline value	
Chemical Oxygen Demand (mg/L)	1080	105	115	50	Non compliant
Biochemical Oxygen Demand (mg/L)	380	130	110	30	Non compliant
Phosphorus (mg/LPO$^{3-}{}_4$)	159	143	123	No guideline value	
Nitrates (mg/LNO$^-{}_3$)	1.178	1.178	1.001	No guideline value	
Oil and grease	1.587	1.1246	1.0002	Nil	Non compliant
Cadmium (ppm)	0.1203	0.1543	0.0987	0.01	Non compliant
Zinc (ppm)	0.2763	0.2171	0.2032	0.5	Non compliant
Chromium (ppm)	0.0925	0.9432	ND	2.0	Compliant
Lead (ppm)	ND	ND	ND	0.01	Compliant
Total Coliform (counts/100ml)	352000	267000	243000	30/100	Non compliant

Appendix 4: Analysis of wastewater parameters for the month of May 2015

PARAMETER	MAY				
	INFLUENT CONC.	CLARIFIER CONC.	EFFLUENT CONC.	MAXIMUM ALLOWABE LIMIT TO THE ENVIRONMENT (NEMA)	COMMENTS
pH	7.0	7.2	7.1	6.5-8.5	Compliant
Temperature (°C)	22.2	21.9	22.0	+3 Based on ambient temperature	Compliant
Color (H.U)	30	10	5.0	15	Compliant
Turbidity (NTU)	498	39	11.7	No guideline value	
Conductivity (mS)	1.10	0.74	0.5	No guideline value	
Settleable Solids (ml/L)	15.7	0.9	1.4	No guideline value	
Total Supended Solids (mg/L)	2800	560	40	30	Non compliant
Total Dissolved Solids (mg/L)	680	460	310	1200	Compliant
Dissolved Oxygen (mg/LO$_2$)	5.8	5.8	6.7	No guideline value	
Chemical Oxygen	600	80	70	50	Non compliant

Demand (mg/L)					
Biochemical Oxygen Demand (mg/L)	310	90	60	30	Non compliant
Phosphorus (mg/LPO$^{3-}{}_4$)	200	179	127	No guideline value	
Nitrates(mg/LNO$^-{}_3$)	1.437	1.100	0.912	No guideline value	
Oil and grease	1.901	1.349	1.032	Nil	Non compliant
Cadmium (ppm)	0.1011	0.1921	0.1700	0.01	Non compliant
Zinc (ppm)	0.1758	0.2567	0.0205	0.5	Non compliant
Chromium (ppm)	0.8751	0.0743	ND	2.0	Non compliant
Lead (ppm)	ND	ND	ND	0.01	Non compliant
Total Coliform (counts/100ml)	253000	223000	189000	30/100	Non compliant

Appendix 5: Flow data for the month of February 2015

Details	Unit	1st Week	2nd Week	3rd Week	4th Week	Total	Daily Average
Inflows	M^3	71736	71736	71736	71736	286944	10248

Appendix 6: Flow data for the month of March 2015

Details	Unit	1st Week	2nd Week	3rd Week	4th Week	Total	Daily Average
Inflows	M^3	10248	10248	10248	10248	358680	12810

Appendix 7: Flow data for the month of April 2015

Details	Unit	1st Week	2nd Week	3rd Week	4th Week	Total	Daily Average
Inflows	M^3	71736	71736	71736	16097	231305	8260.8

Appendix 8: Flow data for the month of May 2015

Details	Unit	1st Week	2nd Week	3rd Week	4th Week	Total	Daily Average
Inflows	M^3	47010	22284	14042	97378	180714	6454.1

Appendix 9: Total Phosphorus/12 Calibration Chart (transmittance-display photometer only)

	Total Phosphorus			**mg/l**						**640nm**
%T	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
90	0.00	0.00	0.05	0.10	0.15	0.19	0.22	0.25	0.28	0.32
80	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72
70	0.76	0.80	0.84	0.88	0.92	0.96	1.00	1.05	1.10	1.15
60	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65
50	1.70	1.76	1.82	1.88	1.94	2.00	2.06	2.12	2.18	2.24
40	2.20	2.36	2.44	2.52	2.60	2.68	2.76	2.84	2.92	3.00
30	3.08	3.16	3.24	3.32	3.40	3.50	3.60	3.70	3.80	3.90
20	4.00	4.15	4.30	4.45	4.60	4.75	4.90	5.10	5.30	5.50
10	5.70	5.90	6.15	6.40	6.70	7.00	7.30	7.60	8.20	9.00
0	10.0	11.0	12.0	-	-	-	-	-	-	-

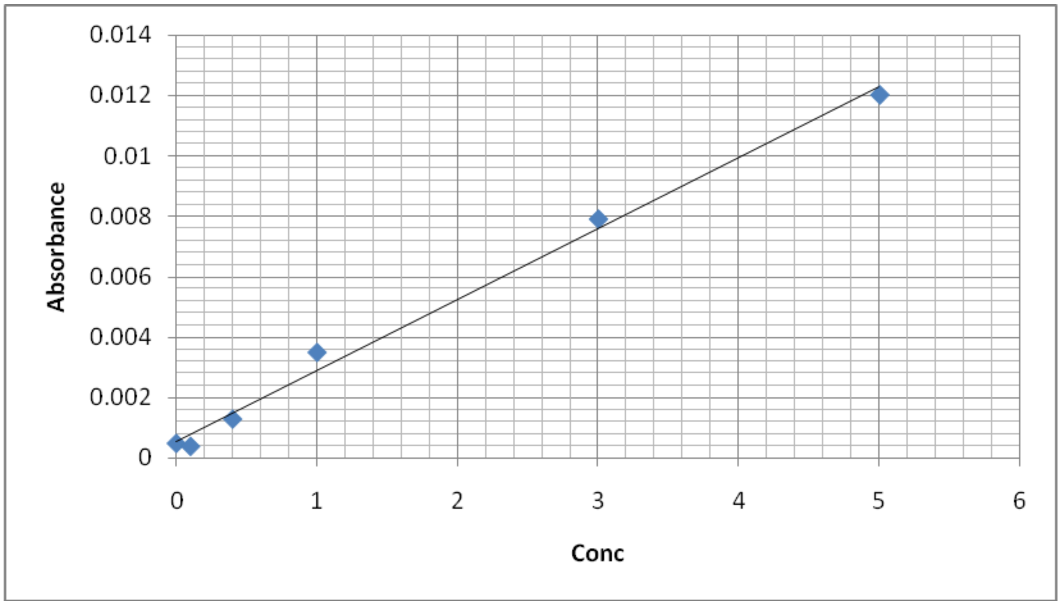
Appendix 10: Nitrate -Nitrogen or Nitrate Calibration Chart (transmittance-display photometer only)

	NITRATE NITROGEN mg/l N 410nm									
%T	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
90	-	-	0.0	0.0	0.0	0.1	0.3	0.5	0.6	0.7
80	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.8	2.0	2.1
70	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.4	3.5
60	3.7	3.8	4.0	4.2	4.3	4.5	4.7	4.9	5.1	5.3
50	5.5	5.7	5.9	6.1	6.3	6.5	6.8	7.0	7.2	7.5
40	7.7	8.0	8.3	8.6	8.9	9.3	9.6	10.0	10.3	10.6
30	11.0	11.3	11.6	12.0	12.3	12.7	13.1	13.5	14.0	14.5
20	15.0	15.4	15.8	16.3	16.8	17.4	18.0	18.5	19.1	19.7
10	20.4	21.1	21.8	22.6	23.5	24.4	25.3	26.8	28.3	29.8
0	31.6	33.9	-	-	-	-	-	-	-	-

To convert mg/l N to mg/l NO_3 multiply result by 4.4

Appendix11: Calibration Curve for Chromium

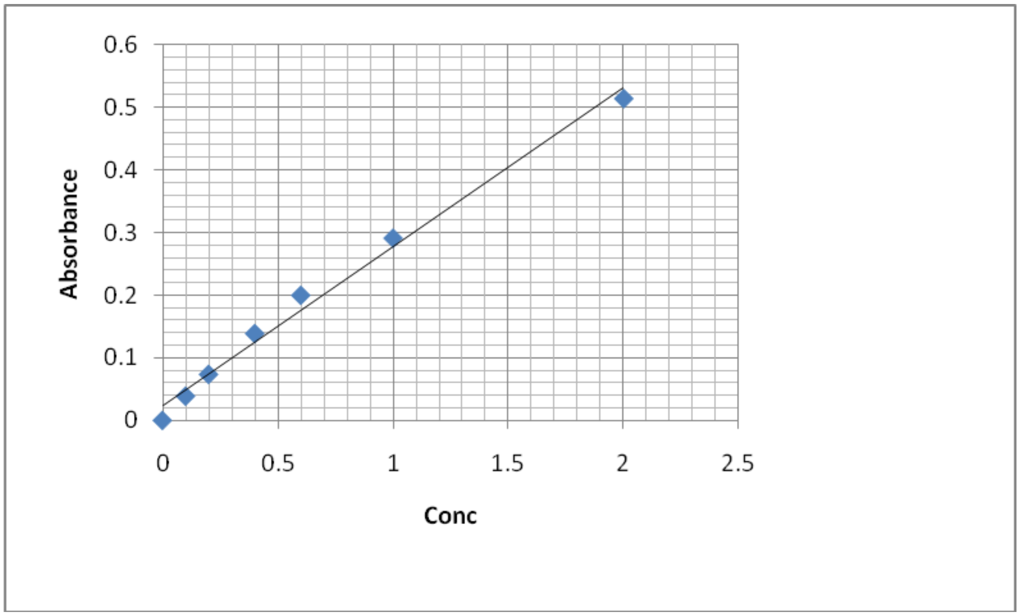
Std conc	Abs	
0	0.0005	
0.1	0.0004	
0.4	0.0013	
1	0.0035	
3	0.0079	
5	0.012	
Sample	Abs	Conc
C_1	0.0033	1.1713
C_2	0.0022	0.7025
C_3	0.0001	-0.1925



Appendix12: Calibration Curve for Zinc

Std conc	Abs
0	0.0003
0.1	0.0391
0.2	0.0738
0.4	0.1389
0.6	0.2
1	0.2912
2	0.5141

Sample	Abs	Conc
c1	0.1705	0.5766
c2	0.0967	0.2844
c3	0.0555	0.1212



Appendix 13: Pollution loading computation

The average daily outflow during the research period was

$$= \left(\frac{10{,}248 + 12{,}810 + 8{,}260.8 + 6{,}454.1}{4} \right) m^3 / day$$

$$= 9{,}443.2\ m^3 / day$$

$$= \left(\frac{9{,}444.2\ m^3 + 1000\ l}{1\ m^3} \right) / day$$

$$= 9{,}443{,}200\ l / day$$

$$= (\frac{9{,}443{,}200}{24 \times 60 \times 60})\ l / s$$

$$= 109.3\ l / s$$

12.1: Settleable solids

Average concentration of settleable solids

$$= \left(\frac{monthly\ \ concentrat\,ions}{number\ \ of\ \ months} \right) mg\,/\,l$$

$$= \left(\frac{250 + 1900 + 1800 + 1400}{4} \right) mg\,/\,l$$

$$= 1275\ mg\,/\,l$$

Pollution load = Concentration of the pollutants (mg/l) × Volume of water (l/s)

$$= 1{,}2765\ mg\,/\,l \times 109.3\,l\,/\,s$$

$$= 139{,}357\ mg\,/\,s$$

12.2: Total Suspended Solids

Average concentration of TSS

$$= \left(\frac{monthly\ \ concentrat\,ions}{number\ \ of\ \ months} \right) mg\,/\,l$$

$$= \left(\frac{8818 + 60 + 1470 + 40}{4} \right) mg\,/\,l$$

$$= 2597\,mg\,/\,l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 2597\,mg\,/\,l \times 109.3\,l\,/\,s$$

$$= 283{,}852.1\,mg\,/\,s$$

12.3: Total Dissolved Solids

Average concentration of TDS

$$= \left(\frac{monthly\ \ concentrat\,ions}{number\ \ of\ \ months} \right) mg/l$$

$$= \left(\frac{26{,}040 + 39{,}300 + 500 + 310}{4} \right) mg/l$$

$$= 16{,}537.5\ mg/l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 16{,}537\ .5\ mg/l \times 109.3 l/s$$

$$= 1{,}807{,}548.8\ mg/s$$

12.4: Biochemical Oxygen Demand

Average concentration of BOD_5

$$= \left(\frac{monthly\ \ concentrat\,ions}{number\ \ of\ \ months} \right) mg/l$$

$$= \left(\frac{100 + 210 + 110 + 60}{4} \right) mg/l$$

$$= 120\ mg/l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 120\ mg/l \times 109.3\ l/s$$

$$= 13{,}116\ mg/s$$

12.5: Chemical Oxygen Demand

Average concentration of COD

$$= \left(\frac{monthly\ \ concentrat\,ions}{number\ \ of\ \ months} \right) mg\,/\,l$$

$$= \left(\frac{112 + 80 + 115 + 70}{4} \right) mg\,/\,l$$

$$= 94.3\ mg\,/\,l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 94.3\ mg\,/\,l \times 109.3\, l\,/\,s$$

$$= 10{,}306.99\ mg\,/\,s$$

12.6: Nitrates

Average concentration of Nitrates

$$= \left(\frac{monthly\ \ concentrat\,ions}{number\ \ of\ \ months} \right) mg\,/\,l$$

$$= \left(\frac{0.902 + 0.132 + 1.001 + 0.912}{4} \right) mg\,/\,l$$

$$= 0.737\ \ mg\,/\,l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 0.737\ \ mg\,/\,l \times 109.3\, l\,/\,s$$

$$= 80.55\ mg\,/\,s$$

12.7: Total phosphorus

Average concentration of Phosphorus

$$= \left(\frac{monthly\ concentrat\,ions}{number\ \ of\ \ months} \right) mg / l$$

$$= \left(\frac{86 + 92.5 + 123 + 127}{4} \right) mg / l$$

$$= 107.1\, mg / l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 107.1\, mg / l \times 109.3\, l / s$$

$$= 11{,}706.03\, mg / s$$

12.8: Oil and grease

Average concentration of Oil and grease

$$= \left(\frac{monthly\ concentrat\,ions}{number\ \ of\ \ months} \right) mg / l$$

$$= \left(\frac{0.9230 + 0.0745 + 1.0002 + 1.0320}{4} \right) mg / l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 0.7574\ mg / l \times 109.3\, l / s$$

$$= 82.78\, mg / s$$

12.9: Cadmium

Average concentration of Cadmium

$$= \left(\frac{monthly\ concentrat\,ions}{number\ \ of\ \ months} \right) mg / l$$

$$= \left(\frac{0.2893 + 0.2602 + 0.0987 + 0.1700}{4} \right) mg / l$$

$$= 0.2046 \ mg / l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 0.2046 \ mg / l \times 109.3 \ l / s$$

$$= 22.36 \ mg / s$$

12.10 Chromium

Average concentration of Chromium

$$= \left(\frac{monthly \ concentrat\, ions}{number \ of \ months} \right) mg / l$$

$$= \left(\frac{1.4465 + 1.3010 + 1.4935 + 0.8500}{4} \right) mg / l$$

$$= 1.0227 \ mg / l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 1.0227 mg / l \times 109.3 \ l / s$$

$$= 111.78 \ mg / s$$

12.11: Zinc

Average concentration of Zinc

$$= \left(\frac{monthly \ concentrat\, ions}{number \ of \ months} \right) mg / l$$

$$= \left(\frac{1.4220 + 1.9355 + 0.0160 + 0.1025}{4} \right) mg / l$$

$$= 1.1190 \ mg / l$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 1.1190 \ mg / l \times 109.3 \, l / s$$

$$= 122.31 \, mg / s$$

12.12: Total Coliforms

Average concentration of Total coliforms

$$= \left(\frac{monthly \ concentrat\,ions}{number \ of \ months} \right) mg / l$$

$$= \left(\frac{160{,}000 + 783{,}000 + 243{,}000 + 189{,}000}{4} \right) mg / l$$

$$= 343{,}750 \ counts / 100 \ ml$$

Pollution load = Concentration of the pollutant (mg/l) × Volume of water (l/s)

$$= 343{,}750 \ counts / 100 \ ml \times 109.3 \, l / s$$

$$= 375{,}718{,}750 \ counts / 100 \ ml$$

Appendix 14: Sample Preservation Methods

Determination	**Container**	**Minimum Sample Size, ml.**	**Preservation**	**Maximum Storage Recommended/ Regulatory.**
BOD	P, G	1000	Refrigerate	6h/48h
COD	P,G	100	Analyse as soon as possible, or add H_2SO_4 to pH<2; Refrigerate.	7d/28d
Color	P,G	500	Refrigerate	48h/48h
Temperature	P,G	—	Analyse immediately.	Stat/Stat.
Hydrogen ion (pH)	P,G	—	Analyse immediately.	Stat/Stat.
Oil and Grease	G. Wide- mouth calibrated.	1000	Add H_2SO_4 to pH<2, refrigerate.	28d/ 28d
Settleable solids, TSS, TDS	P,G	—	Refrigerate	7d/2-7d
Metals general	P(A), G(A)	—	For dissolved metals filter immediately, add HNO_3 to pH<2.	6 months/6 months
Chromium VI	P(A), G(A)	300	Refrigerate.	24h/24h
Nitrate	P,G	100	Analyse as soon as possible, Refrigerate.	48h/48h (28d for chlorinated samples).
Phosphate	G(A)	100	For dissolved phosphate	48h

			filter immediately.	

Source: Environmental Protection Agency, (1984).

Warm chilled samples and store at 20 ± 3ºC before analysis

P = Plastic

P(A) = Plastic (polyethylene or equivalent) rinsed with 1+1 HNO_3.

G = Glass

G(A) = Glass rinsed with 1+1 HNO_3.

Refrigerate = Storage at 4°C in the dark.

Stat = No storage allowed; Analyse immediately.

Appendix 15: The Questionnaire

AREA SERVED BY KARIOBANGI TREATMENT PLANT AND THE EFFECTS OF DEVELOPMENT ACTIVITIES THEIRIN ON THE EFFICIENCY OF THE PLANT

QUESTIONNAIRE

Gender

Male ☐ Female ☐

KEY:

1. For how long have you been working at Kariobangi Sewerage Treatment Works?

   20 YEARS ☐ 10 YEARS ☐ LESS THAN 5 YEARS ☐

2. Which are the areas served by KSTW

3. How has population growth in within these areas affected the operations of the plant with reference to;

   i. Quantity of the influent

   ☐ ☐ ☐

INCREASED DECREASED SAME

ii. Quality of the Influent

IMPROVED ☐ WORSE ☐ SAME ☐

iii. Quantity of the Effluent

IMPROVED ☐ DECREASED ☐ SAME ☐

iv. Quality of the Effluent

IMPROVED ☐ WORSE ☐ SAME ☐

4. How has the industries around the plant and other catchment areas affected the operations of the plant?

i. Quantity of the influent

INCREASED ☐ DECREASED ☐ SAME ☐

ii. Quality of the Influent

IMPROVED ☐ WORSE ☐ SAME ☐

iii. Quantity of the Effluent

IMPROVED ☐ DECREASED ☐ SAME ☐

iv. Quality of the Effluent

IMPROVED ☐ WORSE ☐ SAME ☐

5. How has urban farming within these areas affected the operations of the plant with reference to;

i. Quantity of the influent

☐ ☐ ☐

INCREASED DECREASED SAME

ii. Quality of the Influent

IMPROVED ☐ WORSE ☐ SAME ☐

iii. Quantity of the Effluent

IMPROVED ☐ DECREASED ☐ SAME ☐

iv. Quality of the Effluent

IMPROVED ☐ WORSE ☐ SAME ☐

6. How has Housing and infrastructural development within these areas affected the operations of the plant with reference to

i. Quantity of the influent

INCREASED ☐ DECREASED ☐ SAME ☐

ii. Quality of the Influent

IMPROVED ☐ WORSE ☐ SAME ☐

iii. Quantity of the Effluent

IMPROVED ☐ DECREASED ☐ SAME ☐

iv. Quality of the Effluent

IMPROVED ☐ WORSE ☐ SAME ☐

Appendix 16: Results for period of February-May 2010

	Feb		March		April		May	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
BOD	429.1	230.5	391.25	152.8	290	90	385	112.5
COD	989.4	334.9	990.6	309.9	928.8	225.7	818.2	284.5
PV	67.1	61.2	78.4	31.1	66.6	24.7	66.3	25.5
TS	1115.7	27.1	1110.7	587.8	958.8	489.5	982.5	531.2
DS	656.6	509.4	668.2	491.5	580.9	392.3	591.3	416.6
pH	7.36	7.54	7.40	7.59	7.74	7.97	7.44	7.55
SS	458.8	102.1	416.1	96.9	380.8	100.1	391.1	114.5
Chlorides	66.5	61.0	67.3	57..3	62.3	55.5	60	54
Nitrites	0.44	1.17	0.41	0.4	1.22	0.30	0.57	0.25
Nitrates	2.5	1.94	2.5	2.5	4.2	3.75	2.5	2.5
TEMP	23.5	23.6	23.7	23.4	23.6	23.3	22.9	22.8

Appendix 17: Average effluent concentrations for the period of Feb-May 2010

Parameter	**Average concentration (mg/l) except for pH and Temp**
BOD	146.45
COD	288.75
PV	35.625
TS	408.9
DS	452.45
pH	7.6625
SS	103.4
Chlorides	56.95
Nitrites	0.53
Nitrates	2.6725
Temperature (°C)	23.275

Appendix 18: Average daily inflow over the period of February-May 2010

Month	**February**	**March**	**April**	**May**
Average inflow M^3/Day	11681.5	12197.7	12815.6	13620
Design Capacity M^3/Day	32000	32000	32000	32000
%Utilization capacity	36.5	38.12	40	42.5