

**EFFICIENCY OF MUNICIPAL WASTE WATER TREATMENT PLANTS IN
KENYA:**

A CASE STUDY OF MOMBASA KIPEVU TREATMENT WORKS

BY

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Science in Chemistry of the University of Nairobi*

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DECLARATION

**THIS THESIS IS MY ORIGINAL WORK AND HAS NEVER BEEN PRESENTED FOR
A DEGREE IN ANY OTHER UNIVERSITY**

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DEDICATION

*THIS THESIS IS DEDICATED TO MY DEAR HUSBAND PAUL WAMBUA,
DAUGHTERS PHIONA MAWILI, BAKHITTAH MAWILI & MITCHELLE MAWILI,
SONS ANDREW WAMBUA & THE LATE FIDEL KASIMA AND MY PARENTS MR &
MRS PETER MAKOKHA AND SAMUEL WAMBUA.*

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ABSTRACT

This research study undertakes to establish the efficiency of Kipevu wastewater treatment works which is located in Mombasa County by analyzing the influent, effluent and storm water that runs adjacent to the treatment works. Sampling was done from August 2011 to February 2012. A total of thirty six samples were analyzed. The parameters studied included pH, Biological Oxygen Demand after five days (BOD₅), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), oil and grease, total phosphorus, nitrates, heavy metals; chromium VI, cadmium (Cd), zinc (Zn) and Lead (Pb). Conformity to National Environmental Management Authority (NEMA) standards for wastewater and industrial effluents was determined.

Results obtained were as follows: Influent and effluent pH values were 7.0 - 7.2 and 6.8 - 6.9 respectively. pH values for the storm water drain was 7.2 - 6.8. Percentage reduction efficiency of pH ranged between 4.23 and 1.43 percent. TSS concentrations for influent and effluent were 150 - 1200 mg/L and 21.8 - 1200 mg/L respectively. TSS percentage reduction efficiency ranged between 0 and 95.69. Concentrations of the storm water obtained were 24.6 - 500 mg/L. TDS concentration for the influent and effluent were 1000 - 1400 mg/L and 587 - 1117 mg/L respectively. TDS reduction efficiency ranged between 58.07 and 5.0 percent. TDS concentration in the storm water drain ranged between 670 mg/L and 2670 mg/L. The influent and effluent concentrations of BOD₅ were 200 - 1200 mg/L and 85 - 260 mg/L respectively. Percentage reduction efficiency for BOD ranged between 35 and 83.33 %. Concentration of the storm water drain ranged between 50 and 300 mg/L. COD influent and effluent concentrations were 150 - 1800 mg/L and 80 - 520 mg/L respectively. Percentage reduction efficiency of COD varied between 98.89 and 5 %. Concentrations in the storm water drain were 80 - 640 mg/L. Influent and effluent concentrations for oil and grease were 79 - 331 mg/L and 39 - 117 mg/L respectively. Percentage oil and grease reduction efficiency was 12.50 - 66.67 %. Concentrations in the storm water drain ranged between 50 mg/L and nil. Influent and effluent concentrations were 7.93 - 13.46 mg/L and 11.19 - 3.59 mg/L respectively. Percentage reduction efficiency was 8.3 - 39.91 %. The storm water drain concentrations were 0.56 - 3.42 mg/L. Nitrates concentrations for the influent and effluent were 2.40 - 11.0 mg/L and 2.1 - 5.26 mg/L respectively. Percentage reduction efficiency ranged from 12.50 - 85.45. Concentrations of the storm water drain varied between 1.70 - 38 mg/L.

During the period of study, Cr^{6+} and Cd^{2+} were not detected in the influent as their concentrations were below the detection limit of 0.02 mg/L. In December 2011, Pb^{2+} and Zn^{2+} had effluent concentration of 0.18 mg/L and 0.07 mg/L with reduction efficiency of 30.77 % and 97.71 % respectively. In January 2012, Pb^{2+} and Zn^{2+} had concentrations of 0.11 mg/L and 0.05 mg/L respectively with percentage reduction efficiency of 90.9 and 98.48 respectively.

Pollution load for phosphorus and nitrates were 965 and 413.76 mg/s respectively. Heavy metals zinc and lead loaded 3.48 and 8.42 mg/s respectively into the Indian Ocean waters. BOD_5 and COD had high pollution load of 2.27×10^4 and 3.34×10^4 mg/s respectively. The pollution loading of TSS and TDS into the ocean were 4.42×10^4 and 1.20×10^5 mg/s respectively. Oil and grease had a pollution load of 1.08×10^4 mg/s.

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LIST OF ACRONYMS

BOD₅	Biological Oxygen Demand after 5 days
COD	Chemical Oxygen Demand
CWSB	Coast Water Services Board
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
EMCA	Environmental Management and Co-ordination Act
EMF	Electromotive Force
EPZ	Export Processing Zones
FAO	Food and Agriculture Organization
FAS	Ferrous Ammonium Sulfate
KTDA	Kenya Tea Development Agency
NEMA	National Environmental Management Authority
Ni-Cd	Nickel- Cadmium cells
NIST	Natural Institute of Science and Technology
NPK	Nitrogen, Phosphorus and Potassium fertilizer
NSFC	National Small Flows Clearinghouse
NWCPC	National Water Conservation and Pipeline Corporation
PARP-1	Poly (ADP-Ribose) Polymerase 1
pH	Basicity Measure
RNA	Ribonucleic acid
ROS	Reactive Oxygen Species
SS	Suspended Solids
TDS	Total Dissolved Solids
TS	Total Solids
TSS	Total Suspended solids
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WRMA	Water Resources Management Authority
WSP	Wastewater Stabilization Ponds
XPA	Xeroderma Pigmentosum, Complementation Group A

CHAPTER ONE: INTRODUCTION

1.1. General Introduction

Urban population and industrial development in Kenya has grown rapidly with the water resources fast becoming one of its most important treasures. Water is essential for human consumption, sanitation, and it supports life and most industrial processes. Safe water supply and effective sanitation has always resulted to improved life expectancy. Water remains a vital means of transport in many parts of the world and its significance in recreation cannot be underestimated. Water is vastly used in agriculture for food production and this is by far the most important global application and is particularly of paramount importance in the developing countries. In developing countries, considerable part of this finite natural resource is polluted by sewage and industrial wastes which include a wide range of synthetic chemicals.

Water scarcity in many parts of Kenya is a limiting factor against development activities. Hence, there is need for water saving and water enhancement strategies. The current water availability is estimated at 650 m³ per year per capita and could drop to about 350 m³ per year per capita by the year 2020. With dropping per capita freshwater availability, there is increasing dominance of wastewater in the water balance and this makes wastewater a very important source of irrigation for urban agriculture (Kaluli *et al*, 2011).

Wastewater is water that has been used for various purposes around the community. Unless properly treated, wastewater can harm public health and the environment. Most communities generate wastewater from both residential and non-residential sources. In Kenya, sewage is generated by residential, institutional, commercial and industrial establishments and includes liquid household wastes from toilets, bathrooms, kitchens, and sinks. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets. The menace of water borne diseases and epidemic threatens the well-being of population, and has resulted in numerous deaths in the recent past. Feachem *et al* (1983) suggested that the provision of clean water supplies is necessary in order to reduce the level of infections in the short term but in the long term it is vital that the environment be protected from faecal pollution.

Most domestic and industrial uses of water lead to deterioration in its value and subsequent generation of wastewater. This needs to be collected and sufficiently treated prior to eventual disposal to the receiving environment. In many cities and towns though, treated wastewater serves as an important alternative to the water resources for a variety of applications. According to Gray (2004), the fundamental reasons for treating wastewater include: preventing pollution of the natural resources and thereby protecting the environment, and protecting public health by safeguarding water supplies and therefore preventing the spread of water-borne diseases such as cholera, typhoid, ascariasis, skin sepsis, ulcers, malaria and schistosomiasis. The selection and design of treatment works are based on factors that include the characteristic of wastewater to be treated, the quality that must be maintained in the environment where the wastewater is to be discharged or from the reuse of the wastewater, and the applicable environmental standard or discharge requirements that must be met (Omoto, 2006; Wakelin *et al*, 2008).

1.2. Location of Mombasa County

Mombasa district lies between latitude $3^{\circ} 80'$ and $4^{\circ}10'$ South and longitudes $39^{\circ} 60'$ and $39^{\circ} 80'$ East. It covers an area of 295 km^2 of which 15 km^2 is an island, 215 km^2 mainland and 65 km^2 Indian Ocean waters. The Coral Island is situated along the shoreline of the Indian Ocean separated from the mainland by two creeks namely Tudor Creek and Kilindini Harbor which is Kenya's only seaport as shown in figures 1.1 and 1.2. It is connected to the mainland to the north by the Nyali Bridge, to the south by the Likoni Ferry and to the west by the Makupa Causeway, alongside which runs the Kenya-Uganda Railway.



Figure 1.1: Map of Mombasa

Figure 1.2: Map of Kenya

Maps adapted from Map data 2013 © Google

1.3. Geography and Climate

Being a coastal town, Mombasa is characterized by a flat topography. It has a warm, tropical wet and dry climate. The amount of rainfall depends essentially on season. The rainy months are April, May, October and November as depicted in figure 1.3. On average, the temperatures are always high as depicted in figure 1.4. The warmest month is March and the coolest is July. May is the wettest month while February is the driest month.

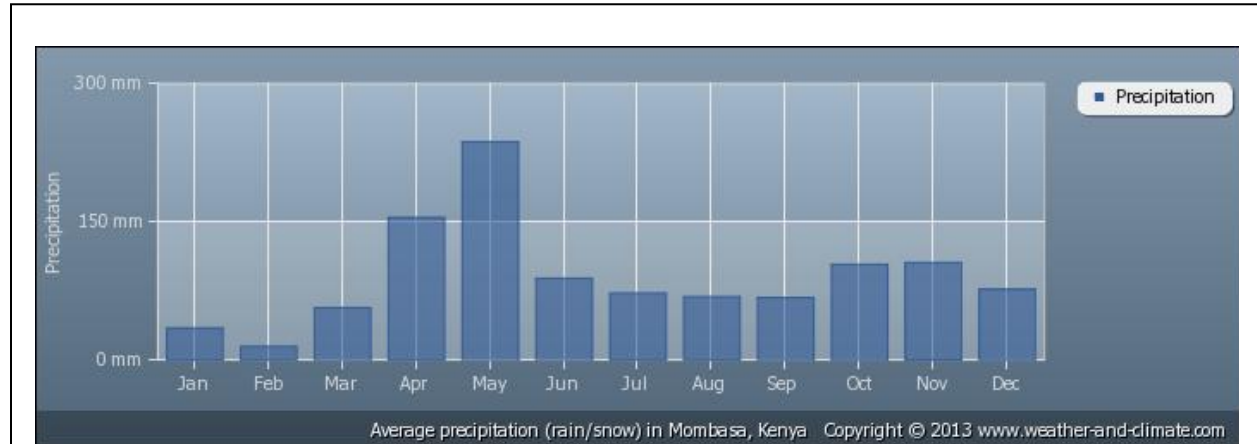


Figure 1.3: Average precipitation in Mombasa

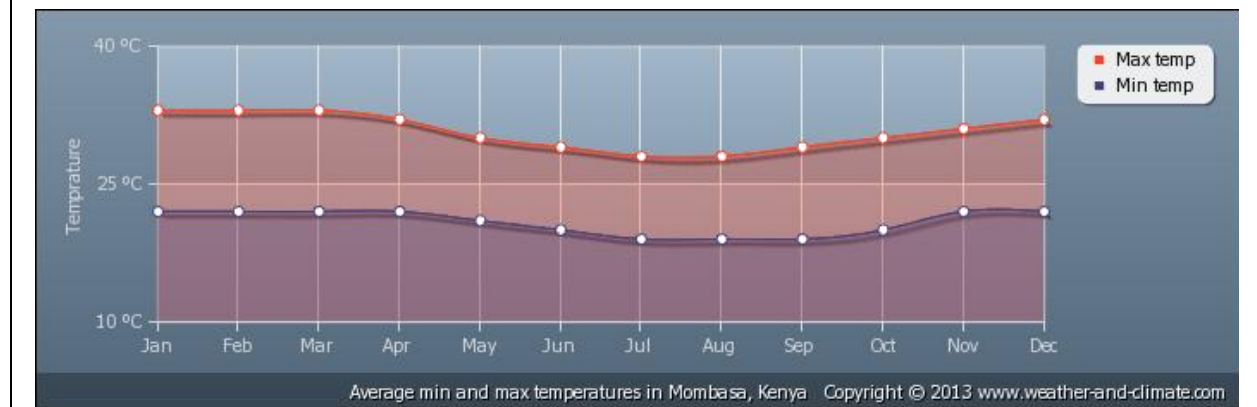


Figure 1.4: Average minimum and maximum temperatures in Mombasa

1.4. Sewerage Systems in Mombasa

Coast Water Services Board (CWSB), which is the regulator of water and sewerage companies in the region reported in 2012 that households in Mombasa generate about 337 000 m³ of wastewater per day but the town faces a major challenge in its disposal. Mombasa has two sewerage treatment plants at Kizingo and Kipevu, but it's only the latter that is fully functional after undergoing rehabilitation at a cost of Kenya shillings 297 million in the year 2012.

Less than 300,000 of Mombasa's three million plus residents have access to sewerage services, according to the Coast Water Services Board's (CWSB) report for 2012. The only functional sewage treatment plant at Kipevu serves residents of Changamwe, Port Reitz, Magongo and Jomvu. There have been complaints and public outcry about the sewage disposal crisis in Mombasa. The treatment plant at Kizingo ceased working several years ago while a pump station at Old Town and four others in the area are non-functional. This occurred as CWSB received numerous complaints from hoteliers on non-availability of waste disposal system.

Mombasa Water and Sewerage Company has the mandate to manage the sewerage system within Mombasa City on behalf of Coast Water Services Board (CWSB) which was established under an Act of Parliament, Water Act 2002. The management mandate includes both the sewer system and the treatment works. Tudor and Kizingo treatment works and their sewer systems serve the Island while west mainland area is connected to Kipevu treatment works. Tudor and Kizingo are currently non-functional while Kipevu is estimated to perform at less than 30% of its installed capacity therefore leading to the disposal of raw and partially treated sewage into the sea at Port Tudor, Ziwani and Kilindini Harbor. The rest of the municipality manages its waste water through privately constructed septic tanks, soakage pits, and pit latrines which have a potential to pollute water sources (Nzuki, 2008).

A major challenge to the management of land use patterns in Mombasa is the lack of a master plan to guide development activities and dictate land use. Development and land use have largely been uncontrolled leading to the proliferation of slums and informal settlements. The current unplanned development status has placed a strain on Mombasa Ministry of Water and Irrigation (MOWI), available solid and waste water management strategies including the sewer system and treatment works. Cases have been reported of housing estates, industrial establishments and hotels which empty their sewer into storm water drains. Some establishments discharge raw sewage directly into the sea. There are also cases where untreated industrial effluent is discharged into the public sewer system.

Currently the sewer systems serve less than 15% of the potential clients, while 80% of the population is covered by "onsite" individual or estate waste water management programmes which do not discharge into a public sewer system. The programmes include use of pit latrines, septic tanks, and soakage pits. The rest of the population, (5%) has no proper sanitation

arrangement. The sewer network and services are predominant on both the island and west mainland while other areas including city council estates, national housing schemes, and individual estates fall under sewage services managed by the respective estate authorities (Okuku *et al*, 2011).

1.5. Demographic Characteristics and Land Tenure

The population of Mombasa City has been on the rise mainly due to high fertility rate and rural urban migration, according to population and housing census of 2009. The Kenyan coastal population distribution is mainly affected by rainfall distribution, altitude, agro-ecological zones and administrative policy through which a number of settlement schemes have been created. The coastal population in Kenya is culturally heterogeneous. The largest indigenous ethnic groups are the Mijikenda and Swahili people. The major religions practiced are Islam and Christianity. Over the centuries, there have been many immigrants and traders who settled in Mombasa, particularly from Iran, the Middle East, Somalia, and the Indian sub-continent, who came mainly as traders and skilled craftsmen.

1.6. Population Growth Rate

Mombasa City has a population growth pattern which mirrors that of other major coastal towns. A high population growth rate averaging at 3.6 % between 1989 and 1999 and 3.5% between 1999 and 2009 was recorded for the municipality. The general population density has been estimated at 4,084 persons per square kilometer, according to the 2009 population and housing census. According to the 2009 Kenya Population and Housing Census which was conducted in 2009 and released in 2011, the total population of Coast Province now referred to as Mombasa County was given as 3.3 million of which 1.7 million were women and 1.6 million men. The population below the age of fifteen was given as 42.3 percent.

The main factors that have attributed to the population growth include among others; Increase in fertility rate, improved health services and rural-urban migration which has been triggered by employment opportunities in the tourism and the transport sectors. The rapid growth of population in the County has over-stretched the use of available resources and services such as water, sewerage and transport. On many occasions the effluent discharged into the environment (ocean) does not conform to NEMA standards (Okuku *et al*, 2011).

1.7. Institutional and Legislative Framework

The evolution of environmental policy and a legal framework in Kenya over the last 20 years reflects a commitment on the part of the government to ensure sustainability of natural resources by mitigating the impacts of socio-economic development. Following on the Brundtland Commission report entitled *Our Common Future*, and use of environmental management models from developed countries, helped in the crafting of the Environmental Management and Co-ordination Act (EMCA) by Kenyan parliament in 1999. It builds on the following principles namely: Sustainability of the environment and natural resources, precautionary approach to mitigate environmentally deleterious impacts of socio-economic activities, integration of environmental considerations into development planning and management, promotion of public participation in environmental decision making and enforcement, and providing a legal and institutional framework for the application of the foregoing principles. The legislation also saw the establishment of National Environment Management Authority (NEMA), whose core functions include ensuring that the key players (Industrialists, government enterprises and establishments, entrepreneurs, private developers, and individuals) comply with the laid down provisions of the Environmental Management Coordination Act, EMCA 1999. Therefore all key players are duty bound to conduct proper treatment of wastewater in line with the environmental management requirements in the protection of human health.

A major national challenge today is how to maintain sustainable development without degrading the natural environment on which people are dependent on. It is now accepted that development projects must be economically viable, socially acceptable and environmentally sound. Among the major environmental problems being experienced in many parts of Kenya today include: land degradation, loss of biodiversity, environmental pollution, and water resource degradation. This situation is aggravated by lack of awareness and inadequate information amongst the public on the consequences of their interaction with the environment. In addition, there is limited involvement of the local communities and key stakeholders in participatory planning and development as well as management of environment and natural resources (Nzuki, 2008).

Environmental integrity is an important component of sustainable development. Sustainable development may be generally defined as development that meets today's needs without compromising the ability of the environment to meet the needs of the future generations. Tebbut [1998] stated that the ways in which sustainable development can be achieved are set out in

twenty- seven clauses which cover the special needs of developing countries. These include among others: the diminution of unsustainable patterns of production and consumption, the importance of public participation, the value of environmental impact analysis and the need for effective environmental legislation and adoption of the precautionary principle in matters affecting the quality of the environment.

Agenda 21 was agreed on at Rio de Janeiro in 1992 Earth Summit by United Nations as an action plan for the next century, that took into account the various needs of the developed and developing countries. It provides for high-level political commitments to realistic, achievable goals for integrating environmental concerns into a broad range of activities in industry, agriculture, energy, fisheries, land use, water resource management, and waste (solid waste and sewage) management and treatment. In addition, commitment to regular reporting by individual countries of their progress towards the agreed “objectives” was emphasized.

For both the treatment works and sewer sites, the major environmental concerns in the existence and management of sewage treatment works and sewer systems relates to contamination of the Kilindini harbor creek through nutrient loading which is likely to encourage eutrophication and blooms of algae stimulated by too much nutrition from sewage and industrial wastes. Algal blooms cause bad tastes and odor as a result of organic decomposition and green coloration of water. The effects could cause serious damage to aquatic life in Indian Ocean. Negative impact on fisheries and other marine bio-diversity productivity through creation of oxygen sags and a potential for bio-accumulation through food chains (persistent toxicity) can occur leading to cases of contaminated seafood and micro-biological contamination of water (Vijay *et al*, 2010). Pathogenic microbes, bacteria, viruses, and protozoa flourish under the prevailing anaerobic conditions which could contaminate the water leading to outbreaks of waterborne diseases such as cholera, typhoid, bacterial and amoebic dysentery, enteritis, polio, infectious hepatitis and schistosomiasis. Prolonged eutrophication eventually leads to the extinction of the water-buoy or great reduction in its capacity (Wakelin *et al*, 2008). This results to fouling of the sea, reduced aesthetic value, increased turbidity (which reduces light penetration) and reduction in the dissolved oxygen (DO) levels of water leading to anoxic conditions (Nzuki, 2008).

In recognizing the importance of natural resources and environment in general, the Kenya Government has put in place a wide range of policy, institutional and legislative measures to

address the underlying causes of environmental degradation occasioned by the discharge of raw and untreated effluent into water bodies.

1.8. Description of the Treatment Works

Kipevu sewerage treatment works and sewer system is located within a range of 5-10 km to the west of Mombasa Island. The treatment plant is located within the south-east corner of west mainland abutting the northern boundary of the Kilindini Port. Access to the site is gained via the port access road which joins Magongo road, some 2 km north of the Makupa Causeway. The site is bounded by a railway track to the north and west and by road to the south and east. The southern boundary is 300 m long, the eastern boundary 350 m long while the north and west boundary is formed by a railway line which is a 550 m long curve. The existing southern boundary of the site is 30 to 40 m north of the Kenya Ports Authority (KPA) fence. This is featured in figure 1.5.

The facility is supported by four pumping stations located at Mikindani, Miritini, Chaani and Portreitz. Together they serve four main areas including Mikindani, Changamwe, Miritini and Portreitz. The west mainland is the major industrial location in Mombasa. The sewer systems service effluent from both residential and industrial establishments. Social amenities served include residential houses, hospitals, schools and religious institutions (Nzuki, 2008).

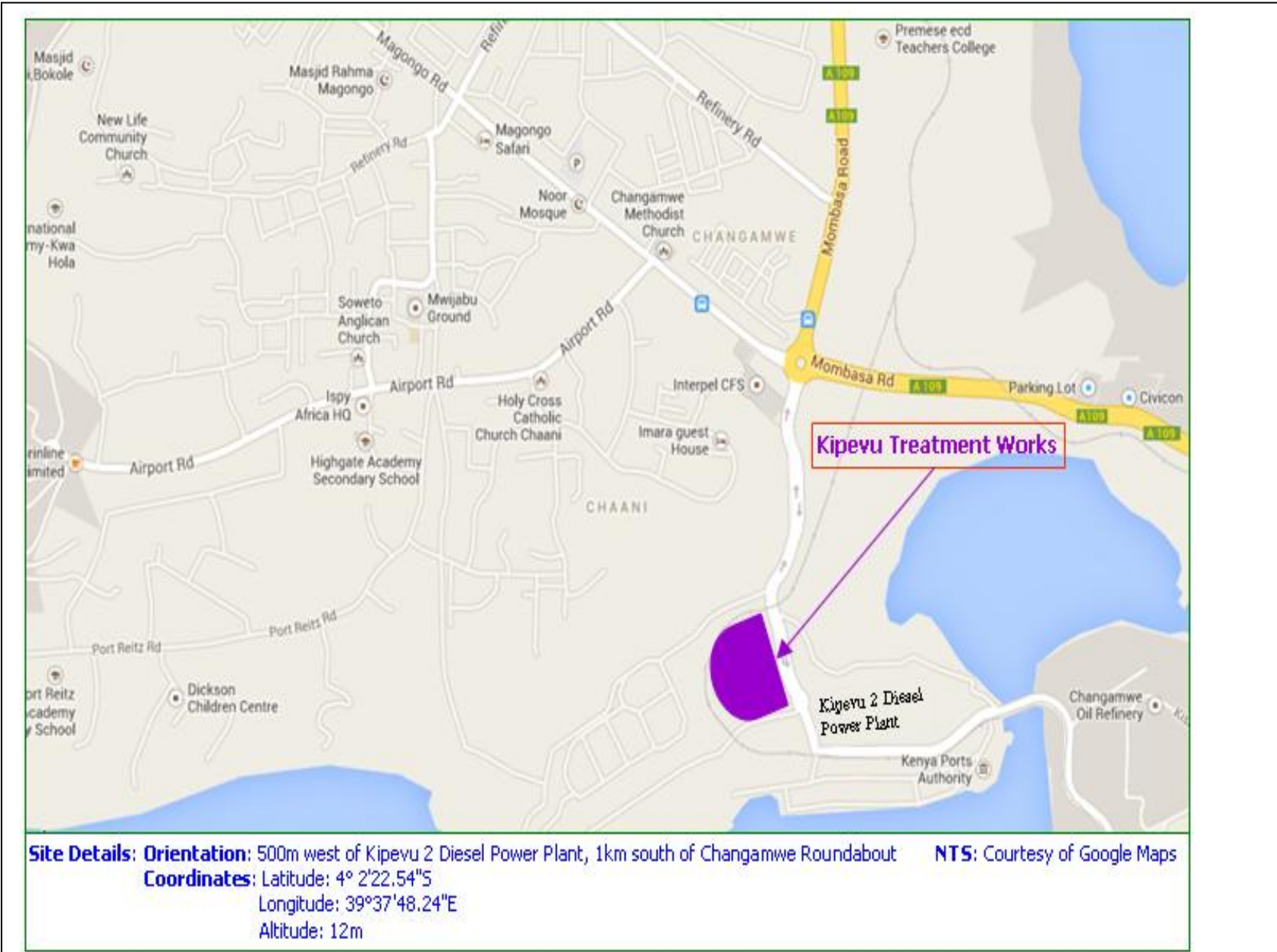


Figure 1.5: Spatial location of Kipevu Treatment Works

Scale. 1cm: 20 km

1.9. Wastewater Treatment

Wastewater treatment plant is a combination of different treatment processes or units designed to produce an effluent of specific quality from wastewater (influent) of known composition and flow rate. In industrialized countries, treatment plants have undergone phased expansion and upgrading to meet ever increasing stricter effluent standards. Primary treatment plants were extended with secondary step while secondary plants are now being completed with tertiary and advanced treatment phases. In most cases, these methods incorporate physical, chemical, and biological processes in the same operation (Omoto, 2006). Application of chitinous products in wastewater treatment has received considerable attention in recent years (Gregorio and Pierre-Marrie, 2008).

Water availability is mainly a function of rainfall. About every five years, Kenya experiences rainfall shortages lasting for one to three years. The country experienced droughts resulting in both human and ecological impact in 1928, 1933-1934, 1942 – 1944, 1952 – 1955, 1960, 1965, 1971-1975, 1984-1985, and 1998-2000. Kenya's Ministry of Water and Irrigation goal to avail water in sufficient quantity and quality by 2010 has not been achieved. There is need to identify innovative ways of bridging the existing water supply gap and meet Kenya's industrial, domestic and agricultural water needs. One such method is wastewater reuse (Kaluli *et al*, 2011).

1.9.1. Primary Treatment

Primary treatment comprises of physical processes involving mechanical screening, grit removal, and sedimentation which is aimed at removal of oil and fatty acids, settleable, suspended and floating solids such as paper bags and related plastics simultaneously. A bit of biochemical oxygen demand (BOD) and nutrients (N and P) are also removed. In primary and secondary treatment, sludge is produced at a volume less than 0.5% of the wastewater flow.

1.9.2. Secondary Treatment

Secondary treatment mainly converts biodegradable organic matter (thereby reducing BOD) and organic nitrogen to carbon dioxide, water, and nitrates by means of aerobic and/ or anaerobic microbial processes. Typical examples of secondary treatment processes include waste stabilization ponds, activated sludge, aquaculture, rotating bio-discs, trickling filters and constructed wetlands.

1.9.3. Tertiary Treatment

Basically, tertiary treatment is aimed at controlling eutrophication in sensitive surface waters and some reuse schemes. It is designed to remove nutrients, total nitrogen (comprising organic nitrogen and sometimes ammonia nitrogen) and total phosphorus (comprising of particulate and soluble phosphorus) from secondary effluent. Additional suspended solids (SS) removal and BOD reduction is achieved by tertiary processes.

1.9.4. Advanced Treatment

Advanced wastewater treatment refers to use of additional processes beyond those used conventionally to prepare wastewater for direct reuse for industrial, agricultural and municipal purposes. The processes target specific contaminants. Some of the state of the art techniques employed includes reverse osmosis, electro dialysis, selective ion exchange, hyper- filtration, chemical treatment and detoxification.

1.10. Problem Statement

Wastewater and industrial effluents in Mombasa Town eventually find its way into Indian Ocean. Today the waters of Indian Ocean are heavily polluted by solid, liquid and organic wastes. The negative impact associated with polluted water have raised great concern from the public, tourists, and scientific community regarding the toxicological effects of the ocean waters to the riparian communities as well as the aquatic organisms whose natural habitats are getting considerably degraded.

Kipevu Treatment Works which serves the west mainland is the only functional treatment plant in Mombasa and thus this study focuses on the effectiveness of the facility in treating the wastewater before discharging into the Indian Ocean.

1.11. Justification

Kipevu wastewater treatment works is the only functional wastewater treatment plant that serves Mombasa City. It is therefore important to establish its efficiency in removal of pollutants from the wastewater generated within west mainland area before it is discharged into the Indian Ocean.

1.12. Objectives

1.12.1. General Objective

The main objective of this research is to evaluate the effectiveness of Kipevu Wastewater Treatment Works in Mombasa City, Mombasa County.

1.12.2. Specific Objectives were to:

- i. Determine influent wastewater analysis of pH, oil and grease, BOD₅, COD, TSS, TDS, nitrates, total phosphorus, heavy metals (chromium VI, cadmium, lead and zinc).
- ii. Analyze the effluent for pH, oil and grease, BOD₅, COD, TSS, TDS, nitrates, total phosphorus, heavy metals (chromium VI, cadmium, lead and zinc).
- iii. Evaluate the efficiency of the treatment works based on influent and effluent data of pH, oil and grease, BOD₅, COD, TSS, TDS, nitrates, total phosphorus, heavy metals (chromium VI: cadmium: lead and zinc).
- iv. Evaluate the pollution loading of phosphorus, nitrates, zinc, lead, TDS, TSS, BOD₅, COD and oil and grease from Kipevu treatment works into the Indian Ocean.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

Wastewater produced in large cities consists of domestic and industrial effluents besides urban run-offs, and are commonly referred to as *municipal wastewater*. Municipal wastewater usually comprises of effluents such as strong spent liquor and/ or weak wastewater from the service industry as well as a variety of cottage industries and domestic discharge. Although there is considerable similarity in the basic composition of sewage (a complex mixture of natural inorganic and organic materials with a small proportion of synthetic substances) the precise volume and characteristics will not only vary from one country to another because of variation in the climatic conditions and social customs, but also within individual countries due to supply water characteristics, water availability, population size and the presence of industrial wastes (Gray,2004).

Raw sewage has been physically characterized as a rather turbid liquid with small quantities of floatable and visible particles of organic materials that are settleable. The colour is normally grey to yellow- brown according to the time of the day interspaced with spectacular colour changes normally of the dyes present. Much darker or even black colour is as a result of oxygen depletion during transit in the sewer line. Domestic wastewater has a musty smell which turns pungent or offensive if the wastewater becomes anaerobic. Strong odors of raw sewage such as rotten egg, flesh or cabbage, ammoniacal, faecal, medicinal, acidic or fishy may be due to biochemical degradation of pollutants such as nitrogenous compounds, hydrogen sulfide, ammonia, skatole, diamines, mercaptans or sulfur dioxide.

Sewage is the wastewater released by residences, businesses and industries in a community. It is 99.94 percent water, with only 0-0.6 percent of the wastewater containing dissolved and suspended solid material. The cloudiness of sewage is caused by suspended particles which in untreated sewage ranges from 100 to 350 mg/l. A measure of the strength of the wastewater is biochemical oxygen demand (BOD₅). Untreated sewage has a BOD₅ ranging from 100 to 300mg/l. Pathogens or disease causing organisms are present in sewage. *Coliform* bacteria are used as an indicator of disease causing organisms. In addition sewage also contains nutrients (such as ammonia and phosphorus), minerals, metal cations and anions. Ammonia can range

from 12 to 50mg/l while phosphorus can range from 6 to 20 mg/l in untreated sewage [Gray, 2004].

Sewage treatment is a multi-stage process to renovate wastewater. The goal is to reduce or remove organic matter, solids, nutrients, disease-causing micro-organisms and other pollutants from wastewater (Naidoo and Olaniran, 2013). Each receiving body of water has limits to the amount of pollutants it can receive without degradation. Therefore each sewage treatment plant must hold a permit listing the allowable levels of BOD₅, suspended solids, *coliform* bacteria, and other pollutants. In Kenya, discharge permits are issued by Water Resources Management Authority (WRMA) and National Environmental Management Authority (NEMA).

When polluting organic matter is discharged into a watercourse, lake, or sea, a natural purifying action, involving biochemical oxidation occurs. Biochemical oxidation is brought about by micro-organisms which utilize the polluting substances as sources of carbon, while consuming atmospheric oxygen dissolved in the water for respiration. The rate of purification depends on many conditions, including temperature and the nature of the organic matter. The Royal Commission on Sewage Disposal proposed that the weight of dissolved oxygen required by a definite volume of liquid for the process of biochemical oxidation during 5 days at 18.33°C be taken as a measure of the quality of the liquid.

Wastewater is mostly water by weight. Other materials make up only a small portion of wastewater, but can be present in large enough quantities to endanger public health and the environment. Practically anything that can be flushed down a toilet, drain, or sewer can be found in wastewater. Even household sewage contains many potential pollutants. The wastewater components that most wastewater facilities are designed to remove are suspended solids, biodegradable organics, and pathogenic organisms (Burks and Minnis, 1994).

2.2. Typical Sewage Components and their Environmental Significance

2.2.1. Inorganics

Inorganic minerals and metal ions such as sodium, potassium, calcium, magnesium, cadmium, copper, lead, nickel, and zinc are common in wastewater from both residential and non-residential sources. They can originate from a variety of sources in the community including

industrial and commercial sources, storm water, inflow infiltration from cracked pipes and leaky manhole covers. Most inorganic substances are relatively stable and cannot be broken down easily by organisms in wastewater (Awuah and Abrokwa, 2008).

Large amounts of many inorganic substances can contaminate soil and water. Some are toxic to animals and humans and may accumulate in the environment. For this reason, extra treatment steps are often required to remove inorganic materials from industrial wastewater sources. The processes target specific contaminants. Some of the state of the art techniques employed includes reverse osmosis, electro dialysis, selective ion exchange, hyper- filtration, chemical treatment and detoxification. Heavy metals, for example, which are discharged with many types of industrial wastewaters, are difficult to remove by conventional treatment methods. Inorganic ions in solution contribute to the *conductivity* of the wastewater. Backwash from water softeners contains high calcium chloride concentrations which increases the conductivity (Burks and Minnis, 1994).

2.2.2. Organic Matter (Oxygen- Demanding Wastes)

Organic materials are found everywhere in the environment. They are composed of the carbon-based chemicals that are the building blocks of most living things. Organic materials in wastewater originate from plants, animals, or synthetic organic compounds, and enter wastewater as human wastes, paper products, detergents, cosmetics, foods, and agricultural products. Industrial and commercial sources are also a major contributor of organic matter. Organic compounds contain carbon, hydrogen, oxygen, nitrogen, and other non metallic elements. Many organics are proteins, carbohydrates, or fats and are biodegradable. However, even biodegradable materials can cause pollution. Too much organic matter in wastewater can be devastating to receiving waters (Burks and Minnis, 1994).

Large amounts of biodegradable materials are dangerous to lakes, streams, and oceans because organisms use dissolved oxygen in the water to break down the wastes. This can reduce or deplete the supply of oxygen in the water needed by aquatic life, resulting in fish kills, odors, and overall degradation of water quality (Naidoo and Olaniran, 2013). The amount of oxygen organisms need to break down wastes in wastewater is referred to as the biochemical oxygen demand (BOD) and is one of the measurements used to assess overall wastewater strength.

Some organic compounds are more stable than others and cannot be quickly broken down by organisms, posing an additional challenge for treatment. This is true of many synthetic organic compounds developed for agriculture and industry. In addition, certain synthetic organics are highly toxic. Insecticides and herbicides are toxic to humans, fish, and aquatic plants and often are disposed of improperly in drains or carried in storm water. In receiving waters, they kill or contaminate fish, making them unfit to eat. They also can damage processes in treatment plants. Benzene and toluene are two toxic organic compounds found in some solvents, pesticides, and other products. New synthetic organic compounds are being developed all the time, which can complicate treatment efforts. Oxygen-demanding wastes may upset the oxygen balance of surface water because their breakdown uses up oxygen. The optimum dissolved oxygen (DO) in natural water is 4-6 mg/l and this is essential for supporting aquatic life (Omoto, 2006).

2.2.2.1. Biological Oxygen Demand (BOD₅)

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. BOD is the number of milligrams of oxygen required to carry out the oxidation of organic carbon in one litre of water (Spiro and Stigliani, 2003). The BOD test measures the biodegradable fraction of the wastewater by monitoring the assimilation of organic material by aerobic micro organisms over a set period of time under strictly controlled conditions. Biodegradable waste is usually composed of organic wastes, including leaves, grass clippings and manure (Gray, 2004). The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during five days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water. BOD can be used as a gauge of the effectiveness of wastewater treatment plants. BOD is similar in function to chemical oxygen demand (COD), in that both measure the amount of organic compounds in water. However, COD is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biologically active organic matter.

BOD may be measured directly in a few samples such as river waters, but in general a dilution procedure is required. The dilution method of measuring BOD is based upon the fundamental concept that the rate of biochemical degradation of organic matter is directly proportional to the amount of un-oxidized material existing at that particular time. This means that, the rate at which

oxygen is used in dilutions of the waste is in direct ratio to the presence of waste in the dilution, provided that all other factors are equal. The method consists of filling with sample to overflowing, an airtight bottle of the specified size and incubating it at the specified temperature (usually $20^{\circ}\text{C} \pm 1$) for five days. Dissolved oxygen (DO) is measured initially and after incubation, and the BOD is computed from the difference between initial and final DO. Because the initial DO is determined shortly after the dilution is made, all oxygen uptake occurring after this measurement is included in the BOD measurement (Potter and Everitt, 1959; Mancy and Jagle, 1966).

It is necessary to have at present a population of micro organisms capable of oxidizing the biodegradable organic matter in the sample. Domestic wastewater, un-chlorinated or otherwise un-disinfected effluents from biological waste treatment plants, and surface waters receiving wastewater discharges contain satisfactory microbial populations. Samples which do not contain sufficient microbial population e.g., untreated industrial wastes, disinfected wastes and high temperature wastes or wastes with extreme pH values, are first seeded by adding a population of micro-organisms (Lenore *et al*, 1999).

The solubility of oxygen (O_2) in water is only 9mg/L at 20° and gets increasingly less at higher temperatures. The oxygen supply can be replenished by contact with air, as in rapidly flowing streams but 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 used up (Thomas and William, 2003). BOD removal in anaerobic ponds is realized through sedimentation of settleable solids and subsequent anaerobic digestion in the resulting sludge layer. Temperature above 15°C favors the process of BOD removal as showed that biogas (around 70% methane and 30% carbon dioxide) production increased sevenfold for every 5°C rise in temperature. The biochemical reaction that occurs in anaerobic ponds has been likened to those that take place in anaerobic digesters. Anaerobic digestion serves to reduce odor and bulkiness of sludge to an inert material without obnoxious odor. The process involves two successive processes referred to as acidogenesis and methanogenesis (Warren and Mark, 2005).

Acidogenesis refers to the breaking down of large organic compounds and converting them to organic acids along with gaseous by-products of carbon dioxide, methane and trace amounts of

hydrogen sulfide. This step is performed by various facultative bacteria operating anaerobically. The facultative bacteria continue to use oxygen bound on nitrate and sulfate breaking down the organic matter to organic acids and alcohol that produce least energy. If the process were to stop there, the accumulated acids would lower the pH and would inhibit further decomposition by “pickling” the remaining raw sludge. For digestion to occur, second stage gasification helps convert organic acids to methane (CH₄) and carbon dioxide (CO₂). Acid-splitting methane-forming bacteria perform this last step called methanogenesis (Mark, 2012).

Acid-splitting methane-forming bacteria are strict anaerobes and quite vulnerable to environmental conditions of temperature, pH and anaerobiosis. The methane bacteria have a lower growth rate than acid formers, and are very specific in food supply requirements. 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 stability of the digestion process depends on the proper balance of the two biological stages. 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 - 7.4 respectively) may lead to build up of organic acids as the supply of organic acids exceeds the assimilative capacity of the methane-forming bacteria. The 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. The exact cause of digester problems is often mysterious (Mark, 2012). A study on anaerobic pond treatment of tapioca starch waste suggested that overloading most likely impaired methanogenesis leading to reduction in BOD (Stone, 1981).

2.2.2.2. Chemical Oxygen Demand (COD)

In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers) or wastewater, making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L) also referred to as ppm (parts per million), which indicates the mass of oxygen consumed per liter of solution (Clair *et al*, 2003).

COD is often measured as a rapid indicator of organic pollutants in water. It is normally measured in both municipal and industrial wastewater treatment plants and gives an indication of the efficiency of the treatment process. COD is measured on both influent and effluent water. The efficiency of the treatment process is normally expressed as COD removal, measured as a percentage of the organic matter purified during the cycle. COD measures oxygen demand by chemical (as distinct from biological) means, using potassium dichromate as the oxidizing agent. Oxidation takes two hours and the method is thus much quicker than a 5-day BOD assessment. Since the BOD: COD ratio is fairly constant for a given effluent; COD is used more frequently for routine monitoring of an effluent once this ratio has been determined (Lenore *et al*, 1999). The ratio of BOD: COD provides a useful guide to the proportion of organic materials present in wastewater that is biodegradable. The ratio varies from 1:1.25 to 1:2.50 depending on the water being analyzed. The ratio increases with each stage of biochemical treatment as biodegradable matter is consumed but non-biodegradable organic remains and is oxidized in the COD test (Gray, 2004). The relationship remains fairly constant for specific wastes, although the correlation is much poorer when the COD values are $< 100\text{mg O}_2/\text{l}$.

2.2.3. Pathogenic Micro-organisms

Sewage is known to contain a diverse range of organisms, which originate not only from faeces but also from soil and water. These pathogens often originate from people and animals that are infected with or are carriers of a disease. For example, water and blackwater from typical homes contain enough pathogens to pose a risk to public health. Other likely sources in communities include hospitals, schools, farms, and food processing plants.

Pathogenic micro-organisms such as viruses, bacteria, fungi, rotifers, protozoa, and worms which occurs 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. Therefore disinfection is the prime step in water pollution control (Tebbut, 1998). Outbreaks of these diseases can occur as a result of drinking water from wells polluted by wastewater, eating contaminated fish, or being involved in recreational activities in polluted waters. Some illnesses can be spread by animals and insects that come in contact with wastewater. Even municipal drinking water sources are not completely immune to health risks from wastewater pathogens. Drinking water treatment efforts can become over-whelmed when

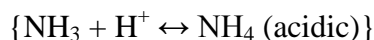
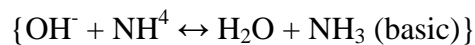
water resources are heavily polluted by wastewater. For this reason, wastewater treatment is as important to public health as drinking water treatment (NSFC, 1996).

2.2.4. Nutrients

Wastewater often contains large amounts of nitrogen and phosphorus in the form of nitrate and phosphate, respectively which promote plant growth. Organisms only require small amounts of nutrients. In biological treatment there is an excess of available nutrients in treated wastewater. In severe cases, excess nitrogen and phosphorous can result in *eutrophication*, the nutrient enrichment of water bodies causing excessive growth of aquatic plants (algae, cyanobacteria, rooted aquatic vegetation, duckweed). The dissolved oxygen in the water body becomes depleted when the aquatic plants die, fall to the bottom, and are decomposed by aerobic bacteria. The oxygen depletion can reduce the populations of indigenous fish and other oxygen-consuming organisms. Nutrients from wastewater have also been linked to ocean red tides that poison fish and cause illness in humans.

2.2.4.1. Nitrogen

Nitrogen forms that are important in wastewater include organic nitrogen, nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and nitrogen gas (N_2). All of these forms are biochemically interconvertible. Organic nitrogen is nitrogen bound to carbon which is the principal nitrogen constituent in feces. Organic nitrogen also includes urea (H_2NCONH_2) which is the principal component in urine. Organic nitrogen is not readily available to plants and needs bacterial conversion to nitrate before it is available for plants. Nitrite is not usually observed in water sources because it is readily converted to nitrate by bacterial processes. However, it is extremely toxic to most fish and other aquatic species (Wolfgang *et al*, 2002). Also, nitrites are oxidized by chlorine and can, therefore, increase the chlorine dosage requirements and the cost of disinfection. Ammonia exists in water as either the ammonium ion (NH_4^+) or ammonia gas (NH_3), depending on the pH of the water.



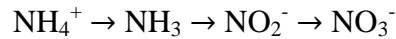
Scheme 2.1: pH dependence of ammonia

At pH levels above 9.3, ammonia gas is the predominant form, and at pH levels below 9.3, the ammonium ion is the predominant form. Ammonia is usually present in surface water and is due to the chemical transformation of urea and anaerobic processes. Ammonium binds to soil which is negatively charged.

Nitrate is the most oxidized species of nitrogen. It is readily available to plants and is considered the limiting nutrient (the nutrient that keeps the biotic system in balance) for primary productivity in salt waters, an important consideration in the design of onsite systems along coastal areas. Because nitrate in solution, is a negative ion, it will not bind to soil which is also negatively charged. Therefore, nitrate passes through soil to groundwater which is why regulatory agencies may require onsite systems to provide nitrogen reduction in the effluent. Nitrate is also the species of nitrogen for which a limit has been set for drinking water (10 mg/L) due to blue baby syndrome. It is the most abundant fixed nitrogen source in the ocean and varies in concentration depending on habitat. In most cases of excess nitrate concentrations in aquatic systems, the primary source is surface runoff from agricultural or fertilized lawns and cropland that have received excess nitrate fertilizer, wastewater treatment plants, failing on-site septic systems, runoff from animal manure storage areas, and industrial discharges that contain corrosion inhibitors. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and dead zones which can become toxic to warm-blooded animals at higher concentrations (10 mg/L) (APHA, 1998). The natural level of ammonia or nitrate in surface water is typically low (less than 1 mg/L). In the effluent of wastewater treatment plants, it can go up to 30 mg/L.

Algal blooms may cause other changes to ecosystem function, favouring some groups of organisms over others. As a consequence, as nitrate forms a component of total dissolved solids, they are widely used as an indicator of water quality. Eutrophication leads to high nitrate concentrations, which are observed in lakes, rivers, estuaries, and coastal habitats. Offshore surface water contains low nitrate concentrations because of algal uptake, therefore accumulation of nitrate occurs below the photic zone. The average oceanic nitrate concentration is 30 micro molar. In freshwater or estuarine systems close to land, nitrate can reach high levels that can potentially cause the death of fish. While nitrate is much less toxic than ammonia, levels over 30 ppm of nitrate can inhibit growth, impair the immune system and cause stress in some aquatic

species. Nitrate (NO_3^-) results from a process known as oxidation or nitrification, which is the stepwise addition of oxygen atoms to a nitrogen atom (Wolfgang *et al*, 2002) (Scheme 2.1).



Scheme 2.2: Oxidation of ammonium ion

This nitrate ion is a powerful oxidizer used by bacteria as a substitute for oxygen in anoxic environments. It is taken up by phytoplankton, algae, or plants and reduced to help build nucleotides.

In the absence of oxygen, decomposition of organic matter in water containing nitrates increases the conversion of nitrates to ammonia and free nitrogen; consequently, the nitrates are depleted. This implies that nitrates are rarely, if ever, found in putrid sewage. However, Lijklema *et al* (1988), specifies that sewage composition may be fundamentally altered if industrial discharge is allowed into the municipal sewerage system. In waste stabilization ponds/ systems the nitrogen cycle is at work with the probable exception of nitrification and denitrification. In anaerobic ponds organic nitrogen is hydrolyzed to ammonia and ammonia concentrations are 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).

2.2.4.2. Phosphorus

Phosphorus also exists in wastewater in many forms and includes soluble orthophosphate ion (PO_4^{3-}), organically-bound phosphate, and other phosphorus- oxygen compounds. Inorganic phosphates are present in the non-ionic form in organic molecules such as DNA, RNA and nucleotides. Most of the organically-bound phosphate in wastewater is from excreta and food residue. Some cleaning agents still contain phosphate, although the practice of adding phosphate to cleaning agents has been vastly reduced since the 1980s. Phosphorus is usually the limiting nutrient in freshwater surface waters and is the principal cause of eutrophication in surface water bodies. However, phosphate rapidly combines with other naturally-occurring chemicals, such as limestone, to form calcium phosphate. If a subsurface effluent distribution system is close to a sensitive water body, limestone added to the soil absorption system can stop the phosphate from migrating to the water body (Burks and Minnis, 1994).

Due to precipitation reactions occurring simultaneously with high pH (alkaline) conditions in the lagoon, approximately 50% of phosphorus removal can be expected. Organic phosphate is precipitated as algal biomass and phosphorus associated with non-biodegradable fraction of the algal cells remains immobilized in the sediments. Thus one way of increasing phosphorus removal in waste stabilization ponds (WSP) is to increase the facultative ponds numerically.

Phosphorus of all living tissue, vegetable and animal in process of disruption, is finally oxidized to phosphates. Algae and phytoplankton for their growth besides silica utilize phosphates which eventually lead to eutrophication of lakes and rivers (Dates, 1994).

Primary phosphorus (inorganic) is precipitated as an insoluble hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$, at pH level above 9.5. The mechanism of phosphorus removal most likely takes place in maturation ponds (Mara *et al.*, 1992). However, anaerobic treatment retains more nutrients (NPK) in the effluent implying that it has higher potential for use in irrigation (Omoto, 2006).

Polyphosphates and organophosphorus compounds are converted to molybdate-reactive orthophosphate using potassium peroxodisulfate. Orthophosphate ions are reacted with an acid solution containing molybdate and antimony ions to form an antimony phosphomolybdate complex. The complex is reduced with ascorbic acid to form a strongly coloured blue molybdenum complex. The absorbance of this complex is measured to determine the concentration of orthophosphate present. Ammonium molybdate and potassium antimonyl tartrate react in acid medium with orthophosphate to form a heteropoly acid - phosphomolybdic acid - that is reduced to intensely colored molybdenum blue by ascorbic acid (McHale and McChesney, 2007).

2.2.5. Solids

Settleable solids come from domestic wastes and storm run-off which create sludge deposits leading to siltation of the water reservoirs and frequent blockages of treatment works. Heavy metals and other micro-pollutants tend to accumulate in the sludge because they often adsorb onto suspended particles. Suspended solids in water bodies may block sunlight required for photosynthesis by the bottom vegetation. Silts and coal may cause asphyxiation by injuring the gills of fish (Omoto, 2006).

2.2.5.1. Total Solids (TS)

Total solids refer to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. Total solids (also referred to as total residue) is the term used for material left in a container after evaporation and drying of a water sample. Total Solids includes both total suspended solids, the portion of total solids retained by a filter and total dissolved solids, the portion that passes through a filter (APHA, 1998).

Total solids can be measured by evaporating a water sample in a weighed dish, and then drying the residue in an oven at 103 to 105° C. The increase in weight of the dish represents the total solids. Instead of total solids, laboratories often measure total suspended solids and/or total dissolved solids.

2.2.5.2. Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life. High TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down. Reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from the water. Low dissolved oxygen can lead to fish kills. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (because warmer waters can hold less dissolved oxygen), and can harm aquatic life in many other ways (Paul and Bjourn, 1998).

The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. When suspended solids settle to the bottom of a water body, they can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae. Settling sediments can fill in spaces between rocks which could have been used by aquatic organisms for homes. High TSS in a water body can often mean higher concentrations of

bacteria, nutrients, pesticides, and metal ions in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water. In the water, the pollutants may be released from the sediment or travel farther downstream (Hem, 1985). High TSS can cause problems for industrial and treatment plant use, because the solids may clog or scour pipes and machinery.

To measure TSS, the water sample is filtered through a pre-weighed filter. The residue retained on the filter is dried in an oven at 103 to 105° C until the weight of the filter no longer changes. The increase in weight of the filter represents the total suspended solids. TSS can also be measured by analyzing for total solids and subtracting total dissolved solids. The type of filter holder, the pore size, porosity, area and thickness of the filter, the physical nature and the particle size influence the separation of suspended solids from dissolved solids, and amount of material deposited on the filter. The unit for TSS is given as milligrams of sample per liter (mg/L) (APHA, 1998).

The maximum allowable limit for discharge into the environment and public sewer systems are given by NEMA as 30 mg/L and 250 mg/L respectively. This is to ensure protection from sewer blockages and extra load on sludge disposal system.

2.2.5.3. Total Dissolved Solid (TDS)

Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micrometers). TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells (Mitchell and Stapp, 1992). However, if TDS concentrations are too high or too low, the growth of many aquatic lives can be limited, and death may occur. Similar to TSS, high concentrations of TDS may also reduce water clarity and contribute to a decrease in photosynthesis.

To measure TDS, the water sample is filtered, and then the filtrate is evaporated in a pre-weighed dish and dried in an oven at 180° C, until the weight of the dish no longer changes. The increase in weight of the dish represents the total dissolved solids, and is reported in milligrams per liter

(mg/l) (APHA, 1998). NEMA has given maximum allowable limit for discharge into the environment and public sewer for TDS as 1200 mg/L and 2000 mg/L respectively.

2.2.5.4. Fixed Solids

Fixed solids refer to the residue of total, suspended, or dissolved solids after heating to dryness at a specified temperature.

2.2.5.5. Volatile Solids

The weight loss on ignition is called volatile solids. Determinations of fixed and volatile solids do not distinguish precisely between inorganic and organic matter because both organic and inorganic losses (due to decomposition or volatilization of some mineral salts) occur.

The temperature at which the residue is dried has an important bearing on results, since weight losses due to volatilization of organic matter, water of crystallization and gases from heat-induced chemical decomposition as well as weight gains due to oxidation depend on temperature and time of heating. Some samples may be stronger desiccants than those used in desiccators and may take on water. When residues are dried at $180\pm 2^\circ\text{C}$, some water of crystallization may remain, especially if sulfates are present and organic matter may be lost by volatilization, but not completely destroyed. Loss of carbon dioxide (CO_2) results from conversion of bicarbonate to carbonate and carbonate may be decomposed partially to oxides or basic salts. Some chloride and nitrate salts may also be lost. However, presence of oil or grease may lead to difficulty of drying to constant weight in a reasonable time (Omoto, 2006).

2.2.6. Oil and Grease

Oil and grease is the term given to the combination of fats, oils, waxes, and other related constituents found in wastewater. Fatty organic materials from animals, vegetables, and petroleum are not quickly broken down by bacteria and can cause pollution in receiving environments. When large amounts of oils and greases are discharged to receiving waters from community systems, they increase BOD levels, and they may float to the surface and harden, causing aesthetically displeasing conditions. They also can trap trash, plants, and other materials causing foul odors and attracting flies and mosquitoes and other disease vectors. Their decomposition also uses up oxygen and sometimes their presence in water provide good habitat asphyxiation of fish and generation of obnoxious gases as a result of anaerobic processes. In some cases, too much oil and grease causes septic conditions in ponds and lakes by preventing

oxygen from the atmosphere from reaching the water. It can also interfere with the light transmission through water surface. Gaseous exchange at the surface of the water is also affected. Oil and grease normally cause blockages in sewer lines thereby resulting in overflows and pollution of the environment (USEPA, 1983).

If the wastewater is warm and greasy, the grease cannot quickly separate from the water, so the grease flows through the septic tank and into the soil where it solidifies upon cooling. The grease can clog the gravel and soil pores ruining the drainage system. Excessive grease also adds to the septic tank and treatment plant scum layer, requiring more frequent tank pumping. Both possibilities can result in significant costs to homeowners and are the reasons why grease traps are mandatory for restaurants and food service facilities. Petroleum-based waste oils used for motors and industry are considered hazardous waste and should be collected and disposed of separately from wastewater.

2.3. Other Important Wastewater Characteristics

In addition to the many substances found in wastewater, there are other characteristics that system designers and operators use to evaluate wastewater. For example, color, odor, and turbidity of wastewater give clues about the amount and type of pollutants present and treatment necessary. The following are some other important wastewater characteristics that can affect public health and the environment, as well as the design, cost, and effectiveness of treatment.

2.3.1. Temperatures

The temperature of wastewater is usually higher than that of the water supply because of the addition of warm water from domestic use. Wastewater temperature is important for two reasons: (a) biological processes are temperature dependent and (b) chemical reactions, reaction rates and aquatic life are all temperature sensitive. In general, biological treatment activity accelerates in warm temperatures and slows in cool temperatures but extreme hot or cold can stop treatment processes altogether. For example, aerobic digestion and nitrification stop when temperature rise to 50°C; and when temperature falls below 2°C virtually all biological activity becomes dormant. Therefore, some systems are less effective during cold weather and some may not be appropriate for very cold climates. The best temperatures for wastewater treatment range from 25°C to 35°C. The rate of reaction increases with rise in temperature in anaerobic ponds. The optimum

temperature for methane forming bacteria is above 20°C and methane production rate doubles for every 5°C rise in temperature in the atmospheric range. Incidentally, bacteria are classified according to their optimum temperature range for growth. Mesophilic bacteria grow in a temperature range of 10-40°C and thermophilic bacteria have a range of 45-75°C (Droste, 1997).

Wastewater temperature also affects receiving waters. Hot water, for example, which is a byproduct of many manufacturing processes, can be a pollutant. When discharged in large quantities, it can raise the temperature of receiving streams locally and disrupt the natural balance of aquatic life.

2.3.2. pH

The acidity or alkalinity of wastewater affects both treatment and the environment. The pH is actually the measure of the inverse concentration of hydrogen ions and is a logarithmic scale. As pH values decrease, it indicates increasing acidity, while a high pH indicates alkalinity. The pH of wastewater needs to remain between 6 and 9 to protect beneficial organisms. Acids, cleaning agents, and other substances that alter pH can inactivate treatment processes when they enter wastewater.

Optimum pH for methanogenesis is between 6 and 8. pH of 6 is probably the lowest limit for anaerobic ponds. According to Lettinga *et al* (1993), acidogenic population is more tolerant to pH variation and as a result, acidogenic fermentation is more likely to predominate over methanogenic fermentation leading to souring of the reactor contents. Thus, the system must contain adequate buffer capacity to neutralize the production of volatile acids and carbon dioxide which dissolves at the operating 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).

2.3.3. Gases

Certain gases in wastewater can cause odors, affect treatment, or are potentially dangerous. Methane gas, for example, is a byproduct of anaerobic biological treatment (found in septic tanks) and is highly combustible. Special precautions need to be taken near septic tanks,

manholes, treatment plants, and other areas where wastewater gases can collect. Hydrogen sulfide and ammonia gases can be toxic and pose asphyxiation hazards. Ammonia as a dissolved gas in wastewater also is dangerous to fish. Both gases emit odors, which can be a serious nuisance. Unless effectively contained or minimized by design and location, wastewater odors can affect the mental well-being and quality of life of residents. In some cases, odors can even lower property values and affect the local economy (Rachana *et al*, 1991).

2.3.4. Flow

Whether a system serves a single home or an entire community, it must be able to handle fluctuations in the quantity and quality of wastewater it receives to ensure proper treatment is provided at all times. Systems that are inadequately designed or hydraulically overloaded may fail to provide treatment and allow the release of pollutants to the environment. To design systems that are both safe and cost-effective as possible, engineers must estimate the average and maximum (peak) amount of flows generated by various sources.

Because extreme fluctuations in flow can occur during different times of the day and on different days of the week, estimates are based on observations of the minimum and maximum amounts of water used on an hourly, daily, weekly, and seasonal basis. The possibility of instantaneous peak flow events that result from several or all water-using appliances or fixtures being used at once should be taken into account (Michael, 1990).

2.3.5. Heavy Metals

The effects of metals in water and wastewater range from beneficial through troublesome to dangerously toxic. Some metal ions are essential while others may adversely affect water consumers, wastewater treatment systems, and receiving waters. Some metal ions may be either beneficial or toxic, depending on concentration (APHA, 1998). Heavy metals and chloro-organics affect the rate of anaerobic digestion 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.

Changes in the redox potential can have important consequences for sentimental pollution, especially with respect to metal ions such as cadmium, lead and nickel. The solubility of heavy metals is highest in oxidizing and in acidic environments. At neutral to alkaline pH in oxidizing

environments these metallic ions adsorb onto the surface of insoluble iron (III) hydroxide ($\text{Fe}(\text{OH})_3$) and manganese (IV) oxide (MnO_2) particles especially when phosphate is present to act as a bridging ion. When the redox potential shifts to only slightly oxidizing or reducing conditions due to microbial action, and the pH shifts towards the acidic range, iron (III) hydroxide ($\text{Fe}(\text{OH})_3$) and manganese (IV) oxide (MnO_2) in soils and sediments (and sludges) are reduced and solubilized. The adsorbed metal ions likewise become solubilized and move into ground water (or into the water column) when there is iron (III) hydroxide ($\text{Fe}(\text{OH})_3$) and manganese (IV) oxide (MnO_2) in the sediment. However, if sulfate is reduced microbially to HS^- , 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).

2.3.5.1. Flame Atomic Absorption Spectrophotometry (AAS)

Atomic absorption spectroscopy (AAS) is a spectroanalytical procedure for the quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state. In analytical chemistry the technique is used for determining the concentration of a particular element (the analyte) in a sample to be analyzed. AAS can be used to determine over 70 different elements in solution or directly in solid samples employed in pharmacology, biophysics and toxicology research.

The technique makes use of absorption spectrometry to assess the concentration of an analyte in a sample. It requires standards with known analyte content to establish the relation between the measured absorbance and the analyte concentration and relies therefore on the Beer-Lambert Law. The electrons of the atoms in the atomizer can be promoted to higher orbitals (excited state) for a short period of time (nanoseconds) by absorbing a defined quantity of energy (radiation of a given wavelength). This amount of energy (wavelength) is specific to a particular electron transition in a particular element. Each wavelength corresponds to only one element, and the width of an absorption line is only of the order of a few picometers (pm), which gives the technique its elemental selectivity. The radiation flux without a sample and with a sample in the atomizer is measured using a detector, and the ratio between the two values (the absorbance) is converted to analyte concentration or mass using the Beer-Lambert Law (Skoog, 2007; L'vov, 2005).

In flame atomic absorption spectrometry, a sample is aspirated into a flame and atomized. A light beam is directed through the flame, into a monochromator, and onto a detector that measures the amount of light absorbed by the atomized element in the flame. For some metal, atomic absorption exhibits superior sensitivity over flame emission. Because each metal has got its own characteristic absorption wavelength, a source lamp composed of the elements is used. This marks the method relatively free from spectral or radiation interference. Most atomic absorption instruments also are equipped for operation in an emission mode, which may provide better linearity for some elements (Lenore *et al*, 1999).

Interferences to AAS may occur. These include among others chemical interference. Many metals can be determined by direct aspiration of sample into an air-acetylene flame. The most troublesome type of interference is termed “chemical” and results from the lack of absorption by atoms bound in molecular combination in the flame. This can occur when the flame is not hot enough to dissociate the molecules or when the dissociated atom is oxidized immediately to a compound that will not dissociate further at the flame temperature. Molecular absorption and light scattering caused by solid particles in the flame can cause erroneously high absorption values resulting in positive errors. When such phenomena occur, background correction is used to obtain accurate values. Three types of background correction can be used. These include continuum-source background correction, Zeeman background correction and Smith-Hieftje background correction.

Continuum-source background corrector utilizes either a hydrogen filled hollow cathode lamp with metal cathode or a deuterium arc lamp. When both line sources are placed in the same optical path and are time-shared, the broadband background from the elemental signal is subtracted electronically, and the resultant signal will be background-compensated (Welz *et al*, 2006).

Zeeman background correction is based on the principle that a magnetic field splits the spectrum into two linearly polarized light beams parallel and perpendicular to the magnetic field. One is called the pi component and other sigma component. These two line beams have exactly the same wavelength and differ only in the plane of polarisation. Zeeman background correction

provides accurate background correction at much higher absorption levels than is possible with continuum sources background correction system.

Smith-Hieftje background correction is based on the principle that absorbance measured for a specific element is reduced as the hollow cathode lamp is increased while absorption of non-specific absorption substance remains identical at all current levels. When this method is applied, the absorption at a high current mode is subtracted from the absorption at a low-current mode. Under these conditions, any absorbance due to non-specific background is subtracted out and corrected for (Skoog, 2007).

2.3.5.2. Digestion of Metals

To reduce interference by organic matter and to convert metal associated with particulate to a form (usually the free metal) that can be determined by inductively coupled plasma spectroscopy or atomic absorption spectroscopy, digestion techniques are used. Least rigorous digestion method is required to provide complete and consistent recovery compatible with the analytical method and the metal being analyzed. There are two types of digestion namely open digestion and closed system digestion. Open digestion includes; nitric acid digestion, nitric acid-hydrochloric acid digestion, nitric acid-sulphuric acid digestion, nitric acid-perchloric acid digestion, nitric acid-perchloric acid-hydrofluoric acid digestion and dry ashing. Closed system digestion involves microwave-assisted digestion (Öztürk *et al*, 2009).

Nitric acid will digest most samples adequately. Nitrate is an acceptable matrix for both flame and electro-thermal atomic absorption. Some samples may require addition of perchloric, hydrochloric, or sulphuric acid for complete digestion. Metal recovery for each digestion and analytical procedures used are first confirmed. As a general rule, nitric acid alone is adequate for clean samples or easily oxidised materials; nitric acid-hydrochloric acid digestion or nitric acid-sulphuric acid digestion is adequate for readily oxidisable organic matter; nitric acid-perchloric acid digestion or nitric acid-perchloric acid-hydrofluoric acid digestion is necessary for difficult-to-oxidize organic matter or minerals. Dry ash formation is helpful if large amounts of organic matter are present (APHA, 1998).

2.3.5.2.1. Chromium

a) Occurrence

Chromium metal and ferrochromium alloy are commercially produced from chromite by silicothermic or aluminothermic reactions, or by roasting and leaching processes (Kotaś, and Stasicka, 2000). Chromium metal has proven of high value due to its high corrosion resistance and hardness. A major development was the discovery that steel could be made highly resistant to corrosion and discoloration by adding metallic chromium to form stainless steel (Zhao *et al*, 2001). This application, along with chrome plating (electroplating with chromium) currently comprises 85 percent of the commercial use for the element, with applications for chromium compounds forming the remainder. Chromium salts are used extensively in industrial processes. Main uses are in alloys such as stainless steel, in chrome plating and in metal ceramics (Dennis and Such, 1993). Chromium plating was once widely used to give steel a polished silvery mirror coating. Chromium is used in metallurgy to impart corrosion resistance and a shiny finish, as dyes and paints. Chromium oxides are used as a green color in glassmaking and as a glaze in ceramics. Green chromium oxide is extremely light and as such is used in cladding coatings. It is also the main ingredient in IR reflecting paints, used by the armed forces, to paint vehicles, to give them the same IR reflectance as green leaves. It is also used as a catalyst in dyeing and in the tanning of leather, and to make molds for the firing of bricks (Sreeram and Ramasami, 2003).

Chromium (III) compounds are used in making synthetic rubies. Such a synthetic ruby crystal was the basis for the first laser produced in 1960, which relied on stimulated emission of light from the chromium atoms in such a crystal. Because of their toxicity, chromium (VI) salts are used for the preservation of wood from decay, wood attacking insects, including termites, and marine borers. The formulations contain chromium based on the oxide CrO_3 between 35.3 and 65.5 percent. Chromium (III) salts, especially chrome alum and chromium (III) sulfate, are used in the tanning of leather. The chromium (III) stabilizes the leather by cross linking the collagen fibers. Chromium tanned leather can contain between 4 and 5 percent of chromium, which is tightly bound to the proteins (Sreeram and Ramasami, 2003). The high heat resistivity and high melting point makes chromite and chromium (III) oxide a material for high temperature refractory applications, like blast furnaces, cement kilns, molds for the firing of bricks and as foundry sands for the casting of metals. In these applications, the refractory materials are made from mixtures of chromite and magnesite. Several chromium compounds are used as catalysts

for processing hydrocarbons. Chromium (IV) oxide (CrO_2) is a magnetic compound. Its ideal shape anisotropy imparts high coercivity and remnant magnetization therefore making it a compound superior to the $\gamma\text{-Fe}_2\text{O}_3$. Chromium (IV) oxide is used to manufacture magnetic tape used in high-performance audio tape and standard audio cassettes (Mallinson, 1993). Chromates can prevent corrosion of steel under wet conditions, and therefore chromates are added to drilling muds.

Chromium (III) oxide is a metal polish known as green rouge. Chromic acid is a powerful oxidizing agent and was a useful compound for cleaning laboratory glassware of any trace of organic compounds. The use of dichromate cleaning solutions is now phased out due to the high toxicity and environmental concerns. Modern cleaning solutions are highly effective and chromium free. Potassium dichromate is a chemical reagent, used as a titrating agent. It is also used as a mordant for dyes in fabric.

The main human activities that increase chromium (VI) concentrations are chemical, leather and textile manufacturing and electro plating. These applications will mainly increase concentrations of chromium in water. Through coal combustion, chromium will also end up in air. Through waste disposal chromium will end up in soils and may enter a water supply through the discharge of wastes. Chromate compounds are frequently added to cooling water for corrosion control. Chromium may exist in water supplies in both the hexavalent and the trivalent states although the trivalent form rarely occurs in potable water. In larger amounts and in different forms, chromium can be toxic and carcinogenic. The most prominent example of toxic chromium is hexavalent chromium (Cr VI). Abandoned chromium production sites often require environmental cleanup.

b) Effects of Chromium on health

Chromium (VI) is a danger to human health, mainly for people who work in the steel and textile industry. People who smoke tobacco also have a higher chance of exposure to chromium. Chromium (VI) is known to cause various health effects. When it is a compound in leather products, it can cause allergic reactions, such as skin rash. After breathing it, chromium (VI) can cause nose irritations and nosebleeds. Other health problems that are caused by chromium (VI) are: Skin rashes, upset stomachs, ulcers, respiratory problems, weakened immune systems,

kidney and liver damage, alteration of genetic material, lung cancer, ulcerations, dermatitis, irritation, edema and death (Doisy *et al*, 1976).

Chromium (VI) is mainly toxic to organisms. It can alter genetic materials and cause cancer. Chromium is not known to accumulate in the bodies of fish, but high concentrations of chromium, due to the disposal of metal products in surface waters, can damage their gills (Mertz, 1993).

2.3.5.2.2. Lead

a) Occurrence

Lead is a serious cumulative body poison. Natural water seldom contains more than 5µg/L although much higher values have been reported. Lead in a water supply may come from industrial, mine and smelter discharges or from the dissolution of old lead plumbing. Tap waters that are soft, acid and not suitably treated may contain lead resulting from an attack on lead service pipes or solder pipes joints

Lead is a soft metal that has known many applications over the years. It has been used widely since 5000 BC for application in metal products, cables, pipelines, paints and pesticides. Alloys of lead include pewter and solder. Tin – lead alloys are widely used in the electronic industry. Tetraethyl lead (PbEt₄) is still used in some grades of petrol (gasoline) but is being phased out on environmental grounds (Needleman, 2000). Lead is a major constituent of the lead-acid battery used extensively in car batteries. It is used as a coloring element in ceramic glazes and as projectiles. It is the traditional base metal for organ pipes, and it is used as electrodes in the process of electrolysis. One of its major uses are in the glass of computer and television screens, where it shields the viewer from radiation. Other uses are in sheeting, cables, solders, lead crystal glassware, ammunitions and bearings, and as weight in sport equipment (Yi and Wong, 2006).

b) Health Effects of Lead

Lead is one out of four metals that have the most damaging effects on human health. It can enter the human body through uptake of food (65percent), water (20percent) and air (15percent). Foods such as fruit, vegetables, meats, grains and seafood may contain significant amounts of lead. Cigarette smoke also contains small amounts of lead. It can enter (drinking) water through corrosion of pipes. This is more likely to happen when the water is slightly acidic. Lead can be harmful to people of all ages. Recent scientific studies show that negative health

effects are occurring at lower levels of exposure to lead than previously thought. Low-level exposure may have subtle effects on the intellectual development and behaviour of infants and children (Bellinger, 2008; Pichery *et al*, 2011). Lead can cause several unwanted effects, such as: Disruption of the biosynthesis of haemoglobin and anaemia, a rise in blood pressure, kidney damage, miscarriages and subtle abortions, disruption of nervous systems, brain damage, declined fertility of men through sperm damage, diminished learning abilities of children (Philip *et al*, 2002), behavioral disruptions of children such as aggression, impulsive behavior and hyperactivity (Pichery *et al*, 2011). Lead can enter a foetus through the placenta of the mother thereby causing serious damage to the nervous system and the brains of unborn children (Tong *et al*, 2000).

c) Environmental effects of Lead

Not only leaded gasoline causes lead concentrations in the environment to rise. Other human activities, such as fuel combustion, industrial processes and solid waste combustion, also contribute. Lead can end up in water and soils through corrosion of leaded pipelines in a water transporting system and through corrosion of leaded paints.

It accumulates in the bodies of water and soil organisms. These will experience health effects from lead poisoning. Health effects on shellfish can take place even when only very small concentrations of lead are present. Body functions of phytoplankton can be disturbed when lead interferes. Phytoplankton is an important source of oxygen production in seas and many larger sea-animals eat it. Soil functions are disturbed by lead intervention, especially near highways and farmlands, where extreme concentrations may be present. Soil organisms suffer from lead poisoning, too. Lead is a particularly dangerous chemical as it can accumulate in individual organisms via food chains.

2.3.5.2.3. Zinc

a) Occurrence

Zinc is the fourth most common metal in use, trailing only iron, aluminium, and copper in annual production. Zinc is an essential and beneficial element in human growth. Zinc can be toxic when exposures exceed physiological needs. Zinc is necessary for various metabolic processes like embryonic development, cellular differentiation and cell proliferation. It provides the substrates for expression of the genetic potential of the individual (Prasad, 2008). Deficiencies of zinc have

marked effects on weight gain in animals. Zinc is found in insulin and enzymes such as superoxide dismutase. Eyesight, taste, smell and memory are also connected with zinc and a deficiency in zinc can cause malfunctions of these organs and functions (Hambidge and Krebs, 2007). In males, zinc is important for the production of semen. Deficiencies in zinc in males can lead to reduced sperm count and sex drive.

Concentrations above 5 mg/l can cause a bitter astringent taste and opalescence in alkaline water. Zinc most commonly enters the domestic water supply from deterioration of galvanized iron sheets and dezincification of brass. In such cases zinc and cadmium also may be present because they are impurities of the zinc used in galvanizing. Zinc in water may also result from industrial waste pollution. People are exposed to zinc primarily from flesh foods which include meat, poultry, fish and other sea food. Fruits and vegetables contain relatively low zinc concentrations. In high concentrations, zinc has adverse effects both on fresh and marine waters. Some of the adverse effects on marine organisms include: acute effects on mysids, fish, amphipods, decapods, polychaetes and mollusks (Heath, 1995).

Zinc is used to galvanize metals such as steel to prevent their corrosion. It is also used in alloys such as brass, which has wide applications because of its strength and corrosion resistance. Zinc is used in die castings, especially by the automobile industry. Rolled zinc is used as part of the containers of batteries. Zinc oxide is used as a white pigment in watercolors and paints, and as an activator in the rubber industry. As an over-the-counter ointment, it is applied as a thin coating on the exposed skin of the face and nose to prevent dehydration and thereby protect against sunburn in the summer and windburn in the winter. Applied thinly to a baby's diaper area (perineum) with each diaper change, it protects against rash. As determined in the age-related eye disease study, it's part of an effective treatment for age-related macular degeneration in some cases. Zinc chloride is used as a deodorant and as a wood preservative. Zinc sulfide is used in luminescent pigments, for making the hands of clocks and other items that glow in the dark. Zinc methyl ($Zn(CH_3)_2$) is used in a number of organic syntheses. Zinc stearate is a lubricative plastic additive while lotions made of calamine, a mixture of zinc carbonates and silicates, is used to treat skin rash.

Zinc compounds are included in most proprietary over-the-counter daily vitamin and mineral preparations. Along with some other metals, it is believed by some to possess anti-oxidant properties, which protect against premature aging of the skin and muscles of the body. Zinc gluconate glycine is taken in lozenge form as a remedy for the common cold (Eby, 2004; Hemilä, 2011).

2.3.5.2.4. Cadmium

a) Occurrence

Cadmium is a lustrous, silver- white, ductile, very malleable metal. Its surface has a bluish tinge and the metal is soft enough to be cut with a knife, but it tarnishes in air. It is soluble in acids but not in alkalis. It is similar in many respects to zinc but it forms more complex compounds. Cadmium is found in the industries as an inevitable by-product of zinc, palladium and copper extraction. After being applied it enters the environment mainly through the ground, because it is found in manures and pesticides.

b) Applications

About three-fourths of cadmium is used in nickel- cadmium (Ni-Cd) batteries and most of the remaining one-fourth is mainly used for pigments, coating and plating and as stabilizers for plastics. It has also been particularly used to electroplate steel. Cadmium electroplating, consuming six percent of the global production, can be found in the aircraft industry due to the ability to resist corrosion when applied to steel components. This coating is passivated by the usage of chromate salts. Cadmium is used as a barrier to control nuclear fission due to its ability to absorb neutrons. The pressurized water reactor uses an alloy consisting of 80 percent silver, 15 percent indium, and five percent cadmium (Audi *et al*, 2003). Cadmium oxide is used in black and white television phosphors and in the blue and green phosphors for color television picture tubes. Cadmium sulfide (CdS) is used as a photoconductive surface coating for photocopier drums.

In paint pigments, cadmium forms various salts, with cadmium sulfide (CdS) being the most common. This sulfide is used as a yellow pigment. Cadmium selenide can be used as red pigment, commonly called cadmium red (Gunter and Gerhard, 2005). In PVC, cadmium was used as heat, light, and weathering stabilizers. Currently, cadmium stabilizers have been completely replaced with barium-zinc, calcium-zinc and organo-tin stabilizers. Cadmium is used

in many kinds of solder and bearing alloys, due to a low coefficient of friction and fatigue resistance. It is also found in some of the lowest-melting alloys, such as wood's metal (Morrow, 2010).

Helium–cadmium lasers are a common source of blue-ultraviolet laser light. They operate at either 325 or 422 nm and are used in fluorescence microscopes and various laboratory experiments. Cadmium selenide quantum dots emit bright luminescence under UV excitation (He-Cd laser). The color of this luminescence can be green, yellow or red depending on the particle size (Nambiar, 2006). Colloidal solutions of those particles are used for imaging of biological tissues and solutions with a fluorescence microscope. Cadmium is a component of some compound semiconductors, such as cadmium sulfide, cadmium selenide, and cadmium telluride, which can be used for light detection or solar cells (Miller and Mullin, 1991). In molecular biology, cadmium is used to block voltage-dependent calcium channels from fluxing calcium ions, as well as in hypoxia research to stimulate proteasome-dependent degradation.

c) Effects of Cadmium on Human Health

Humans normally absorb cadmium into the body either by ingestion or inhalation. Human uptake of cadmium takes place mainly through food. Foodstuffs that are rich in cadmium can greatly increase the cadmium concentration in human bodies. These include liver, mushroom, shellfish, mussels, cocoa powder and dried seaweed. In aquatic ecosystems cadmium can bio accumulate in mussels, oysters, shrimps, lobsters and fish. Cadmium can also be transported over great distances when it is absorbed by sludge. Cadmium rich sludge can pollute surface waters as well as soils. Some of health effects caused by cadmium include kidney failure, lung damage, diarrhoea, stomach pains, severe vomiting, bone fracture, reproductive failure and possibly infertility, damage to the central nervous system, damage to the immune system, psychological disorders and possibly DNA damage or cancer development (Jarup, 2003).

Cadmium is an established human and animal carcinogen. Most evidence is available for elevated risk for lung cancer after occupational exposure. However, associations between cadmium exposure and tumors at other locations including kidney, breast, and prostate may be relevant as well. Furthermore, enhanced cancer risk may not be restricted to comparatively high occupational exposure, but may also occur via environmental exposure, for example in areas in close proximity to zinc smelters. Interference with proteins involved in the cellular response to

DNA damage, the deregulation of cell growth as well as resistance to apoptosis appears to be involved in cadmium-induced carcinogenicity. Within this context, cadmium has been shown to disturb nucleotide excision repair, base excision repair, and mismatch repair. Particularly sensitive targets appear to be proteins with zinc-binding structures, present in DNA repair proteins such as XPA, PARP-1 as well as in the tumor suppressor protein. Further potential mechanisms relate to the interference with cellular redox regulation, either by enhanced generation of ROS or by reaction with thiol groups involved in the regulation of signaling pathways. Particularly the combination of these multiple mechanisms may give rise to a high degree of genomic instability evident in cadmium-adapted cells, relevant not only for tumor initiation, but also for later steps in tumor development (Maret and Jean, 2013).

2.4. Typical Constituents of a Sewage System

Typical sewage is composed of organics, pathogens, phosphates, oils/ greases, heavy metals and salts. Table 2.1 gives a summary of the typical constituents of a city sewage system.

Table 2.1: Summary of the Typical Constituents of sewage from a city sewage system

Constituent	Potential Sources	Effect in Water
Oxygen demanding substances	Mostly organic materials particularly human feces.	Consume dissolved oxygen.
Refractory organics	Industrial wastes and household products.	Toxic to aquatic life.
Pathogenic micro-organisms (viruses, bacteria, protozoa)	Human wastes.	Cause diseases like cholera and typhoid. Major deterrent to sewage recycle through water systems.
Phosphates	Detergents	Algal nutrients
Grease and Oil	Cooking oil, food processing, industrial waste.	Aesthetics, harmful to aquatic life.
Salts	Human wastes, water softeners, industrial wastes.	Increase water salinity.
Heavy metals	Industrial wastes, chemical laboratories.	Toxicity to aquatic life ending up in food chain.
Chelating agents	Some detergents, industrial wastes.	Heavy metals ion solubilization and transport.
Solids	All sources.	Aesthetics, harmful to aquatic life.

Source: Adapted from Bhatia (2002)

2.5. National Environmental Management Authority (NEMA) Standards

A number of the characteristics of sewage effluent are likely to cause problems with regards to treatment in a convectional water works. The high contents of non-biodegradable organics, total solids, ammonia and nitrate nitrogen are likely to be troublesome. Also the very high levels of bacteriological (and viral) impurity would be such as to cause concerns to water treatment authorities.

Third and fifth schedules of EMCA, 2006, give Standards for effluent discharge into the environment and public sewers respectively. This is depicted in Tables 2.2 and 2.3.

Table 2.2: Effluent Standards for 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
pH (Hydrogen ion activity, marine)	5.0-9.0
Oil and Grease	Nil
Chemical Oxygen Demand (COD, mg/l)	50
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 Act (Water Quality) Regulations, 2006.

Table 2.3: Standards for Effluent Discharge into Public Sewers

Parameter	Maximum levels permissible	Reason
Total suspended solids (mg/l)	250	Protection from sewer blockages and extra load on sludge disposal system.
Total dissolved solids (mg/l)	2000	
Temperature (°C)	20-35	High temperature promotes corrosion and increases solubility of other pollutants.
pH	6-9	Protection of sewer and sewage works fabrication from corrosion.
Oil and Grease (mg/l).	10	Prevention of fouling of working equipment and safety of men.
Biological Oxygen Demand (BOD ₅ days at 20°C, mg/l)	500	Local authorities would be concerned with large load on small sewage works and balancing of flows may be required in order to avoid overloading treatment units.
Zinc (mg/L)	5.0	Prevention of treatment inhibition. The soluble metal is more toxic and should be prohibited from sewer systems.
Chromium VI (mg/L)	0.05	
Cadmium (mg/L)	0.5	
Lead (mg/L)	1.0	

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

A sewer code, user free, and separate contracts between an industry and city can provide adequate control and sound financial planning while they accommodate industry by joint treatment. Pretreatment at the industrial site is recommended for high strength wastes. Therefore, consideration should be given to modification in industrial processes, segregation of wastes, flow equalization and waste strength reduction. Furthermore, process changes, equipment modification, by-product recovery and implant wastewater re-use can optimize production by cutting down on costs for both water supply and wastewater treatment.

Current industrial plant design provide for segregation of separate waste streams for individual pre-treatment, controlled mixing, or separate disposal. The latter applies to both uncontaminated cooling water that can be discharged directly to surface watercourses. Toxic wastes that cannot be adequately processed by the municipal plant must be processed or disposed off by the industry. Manufacturing plant may be required to equalize wastewater by holding them in a basin for stabilization prior to their discharge to the sewer. Unequalized flows may have dramatic

fluctuations in quality that could upset the efficiency of a biological treatment system (Omoto, 2006).

2.6. Wastewater Reuse

Wastewater has been used in a number of countries across the world. These include United Kingdom (UK), United States of America (U.S.A), Australia, Israel, India, Japan, China, Kingdom of Jordan, Kuwait, and Tunisia, among others. In general, the major reuses of wastewater include aquaculture, agriculture, irrigation, habitat restoration, industrial reuse, and ground water recharge. In Tokyo Japan, filtered and disinfected wastewater effluent is used for toilet flushing in a high-rise development area and for industrial processes. In Denver USA, a demonstration plant has been constructed to convert secondary effluent to water of portable quality. The feasibility study of wastewater reuse in space technology is under consideration in USA (Tebbut, 1998). Some hotels in Kenyan south coast undertake onsite wastewater treatment after which the filtered and disinfected wastewater effluent is used for toilet flushing, landscaping, and for cleaning the compound.

In water scarce parts of the world, effluent quality standards for reuse have been recommended by World Health Organization (WHO) and United States Environmental Protection Agency (USEPA). The potential health risks inherent in the use of sewage effluent must always be guarded against in any reuse situation. Sensible controls on application can reduce hazards from reclaimed sewage effluents to acceptable levels. Food and Agriculture Organization of the United Nations (FAO), Technical Report suggests that properly planned use of municipal wastewater alleviates surface water pollution problems and not only conserves valuable water resources but also takes advantage of the nutrients contained in sewage to grow crops. The availability of this surplus water near population centers will increase the choice of crops which farmers can grow since the nitrogen and phosphorus content of sewage might reduce or eliminate the requirements for commercial fertilizers (Asano *et al*, 1985; Asano and Tchobanoglous, 1987).

It is advantageous to consider effluent reuse at the same time as wastewater collection, treatment, and disposal so that sewerage system design can be optimized in terms of effluent transport and treatment methods. The cost of transmission of effluent from inappropriately sited sewage treatment plants to distant agricultural land is normally prohibitive. Sewage treatment techniques

for effluent reuse may not always be appropriate for agricultural use. There are risks involved in the use of wastewater for restricted and unrestricted crop irrigation. A risk of rotavirus infection is eminent due to the presence of *Escherichia coli* bacteria in the wastewater and sludge (Mara *et al*, 1992).

2.7. Kipevu Sewer Systems and Treatment Works

2.7.1. Sewer Systems and Treatment Works Installation

The sewerage system of Kipevu/ Mainland West is comprised of sewer reticulation network which is the primary conduit for the sewer system linking to households (residential estates), industries, and other establishments to the main sewer network; Five (5) trunk sewers which anchor the services of the reticulation system serving as a convergent and onward transportation of sewage to the treatment plant. The trunk sewers include Miritini, Mikindani, Chaani, Portreitz, and the old Kalahari; Four (4) pump stations ensure effluent flow to the treatment works in areas with no substantial gravity. The four pump stations are located at Miritini, Mikindani, Jomvu, and Portreitz. The sewage treatment works also comprise of the inlet works, the aeration tanks, settlement tanks, sludge thickening tanks and the sludge drying beds. There are other auxiliary installations including the plant operation room, administrative buildings and residential quarters which are found both at the pump stations and the sewer treatment plant.

2.7.2. Inlet Works

Sewage arriving at the inlet works passes through a coarse hand- raked screen, then a fine raked screen and a constant velocity grit channel. Screening is undertaken to remove floating materials, rags and solids which would cause blockages of pipes and damage to mechanical plant. This is as shown in Figure 2.1.



The screening facility consists of a coarse screen (12 mm bars, 100 mm spaces) through which all of the flow passes and three fine screens (12 mm bars, 25 mm spaces) of which a maximum of two are utilized at any one time. A further fine screen is fitted at the emergency overflow weir to ensure all flows which pass down the emergency overflow receive coarse and fine screening. All the screens are of the hand raked type and set at an angle of 45 degrees.

The inlet works are designed so as to receive a flow rate of three times the average daily flow rate and flow rates higher than this threshold are passed to the storm water channel via an overflow weir. The inlet works are designed such that two of the three channels can carry the peak hydraulic flow. The 50 percent standby capacity allows for one channel to be unused at all times thereby allowing cleaning and degritting to take place.

2.7.3. Grit Removal Strategy

From the fine screen the flow passes forward for grit removal which is carried out to prevent clogging of pipes, channels and tanks and abrasive wear on plant machinery. Constant velocity grit channels are used to reduce the velocity of flow of sewage such that particles of a certain minimum size and density settle to the bottom of the channel while the smaller less dense organic material is carried forward (Fig. 2.2). This strategy excludes the requirement for maintenance other than general cleaning.



Figure 2. 2: Three constant velocity grit channels.

Three constant velocity grit removal channels have been provided on a two duty one standby basis (at peak hydraulic flow). The standby channel will be degrittied and cleaned while the other two channels are in use. Degritting is done manually by lifting the oavits thereby removing the buckets of grit from the invert of the channel to the slab at coping levels.

The channels are of near-parabolic cross-section (straight lines used in practice) with the depth of flow, and hence velocity, controlled by the downstream flow control flumes.

2.7.4. Flow Measurement

Accurate continuous flow measurements are important for the efficient management of the treatment works. Currently this is not being implemented ostensibly due to lack of equipment. The initial plan design of the facility proposed that the flow measurements be automatically recorded and transmitted to an operation room and, in addition, permanent records are kept to facilitate continuous monitoring of performance against the variations of flow that will occur. Generally, flow measurement is achieved by measurement of the depth of flow upstream of the flume.

2.7.5. Emergency Overflow

A weir is situated immediately downstream of the coarse screen thereby providing an emergency overflow facility. The weir is set at a level which allows the peak hydraulic flow to pass through the inlet works. Flows in excess of this pass over the weir and to the storm water channel via an emergency overflow pipeline. The weir also serves as emergency overflow for the total flow should the screen become severely blocked.

2.7.6. Flow to Full Treatment Flumes

From the inlet works the sewage passes through the “flow- to- full treatment” flume which provides a facility to split the flow between that passing forward to the aeration tanks and that to be discharged to the sea outfall pipeline. The unit consists of standing wave flume, approach channel and a weir penstock. The weir penstock can be manually adjusted and its range is such that it can allow all of the incoming flow to pass forward for treatment or a selected amount depending on the number of the aeration tanks in operation.

A penstock is provided in the inlet chamber which when opened will allow all flows to pass to the by-pass pipeline. This facility can be utilized should it be necessary to prevent flows with detrimental effect on the treatment process from entering the aeration tanks.

2.7.7. Biological Treatment and Final Settlement

Biological treatment of sewage from the flow to full treatment flume reaches aeration tanks through four weirs contained in a distribution chamber. The weirs are of equal length each with the necessary fittings to allow a hand stop to be installed. The hand stop cuts off the flow to any

of the aeration tanks should this be necessary for maintenance purposes. The aeration tanks operate in conjunction with the final settlement tanks to provide the biological treatment of the sewage to remove the polluting organic matter.

Within the aeration tanks (Fig 2.3), living micro-organisms utilize the complex organic compounds which form the polluting elements of the sewage, to produce micro-organisms which are eventually settled out in the settlement tanks. The process requires dissolved oxygen, which is provided by the aerators and sufficient time to allow the micro-organisms to complete their task, which is provided by the retention time in the aeration tanks.

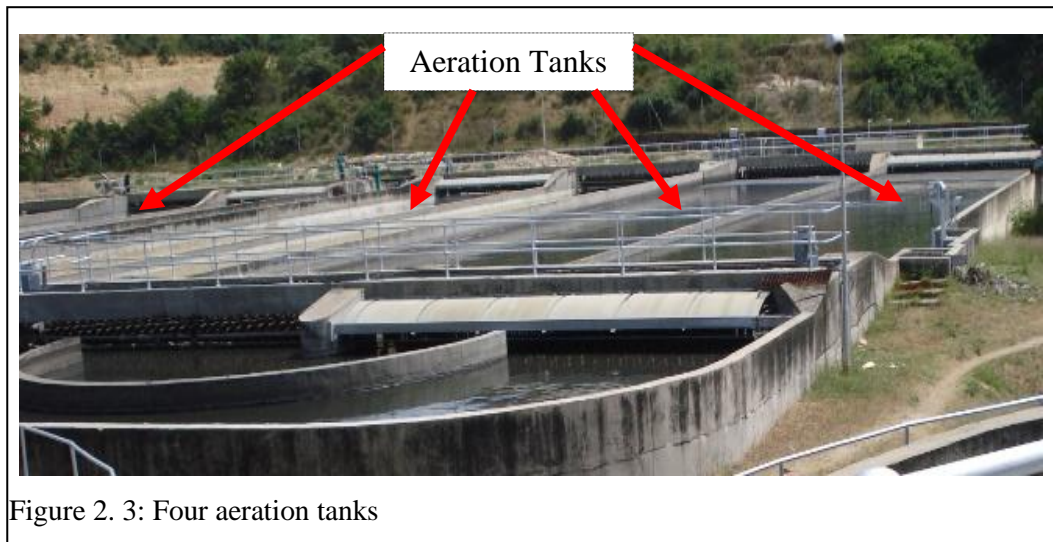


Figure 2. 3: Four aeration tanks

The mixed liquor in the aeration tank then passes to the settlement tanks where it is separated into settled sludge and final effluent. The quantity of micro-organisms in the aeration tanks is maintained by returning proportion of the sludge which is removed from the settlement tanks.

2.7.8. Final Settlement Tanks

Flow from the aeration tanks passes to the final settlement tank (Fig 2.4) via a distribution chamber. The settlement tanks are circular, radial flow tanks. Sewage enters the tank from the distribution chamber to a central vertical pipe and leaves the tank over the peripheral weir. Sludge settling onto the floor of the tank is moved to the hopper at the centre by scrapers attached to a motorized bridge spanning between the perimeter wall and a central support. The bridge rotates continuously and is fitted with scum blades operating at water level which will move surface scum into a trough for removal via the sludge draw-off chamber.



Figure 2. 4: Final settlement tanks

Surface scum is prevented from flowing over the peripheral weir by scum plates fixed adjacent to the weir. Sludge is removed from the central hopper of each tank by hydrostatic head and will discharge into the sludge draw-off chamber adjacent to the tanks. Sludge draw-off from each tank is manually controlled by raising or lowering an adjustable bell mouth in the draw-off chamber. The draw-off chamber is fitted with a low-level sludge draw-off facility which allows the tank to be fully emptied via the works wash-out system. Sludge from the tanks flow by gravity to the pump of the return sludge pumping station.

2.7.9. Return Activated Sludge and Surplus Sludge Pumping Station

Sludge is drawn off from the final settlement tanks under hydrostatic pressure and flows to the pumping station under gravity. The purpose of the pumping station is two- fold. First, to return sludge to the inlet of the aeration tanks where it mixes with the incoming sewage so that the quantity of suspended solids in the aeration tank can be maintained. Second, it serves to pump sludge which is in excess of requirement to the sludge thickening tanks prior to drying on the sludge drying beds. The pumping station comprises a wet well housing submersible sewage pumps and a valve chamber where the interconnecting pipe-work and valves are located.

2.7.10. Sludge Thickening Tanks

Sludge is delivered to the sludge thickening tanks (Fig 2.5) by the surplus sludge pumps, and enters the inlet chamber of the high level distribution chamber via the vertical leg of the surplus sludge pumping main. From the inlet chamber the flow pass over a weir penstock into a second

chamber prior to entering the delivery pipe to each tank. Two circular sludge thickening tanks are installed at the treatment works. Sludge enters the tank from the distribution chamber to a central vertical pipe through an overhead pipeline. The flow to the tanks is semi-continuous as the operation of the surplus sludge pumps is intermittent (on a time clock).



Figure 2. 5: Sludge thickening tanks.

There is a fixed bridge and a rotating central shaft which carries a picket fence type stirring mechanism. The stirring mechanism is fitted with vertical tines fixed to a low, level beam which passes between stationary vertical tines fixed to the underside of the bridge. The effect of the slow moving stirrer is to gently agitate the sludge, thus promoting flocculation of particles, and release water trapped within the sludge blanket which is being formed.

Sludge gathers in the blanket near the bottom of the tank and supernatant liquors pass over the peripheral weir and flow to the works washout pumping station where they are returned to the inlet of the aeration tanks. Sludge from the tanks flows by gravity or via the thickening sludge pumping station to the drying beds.

2.7.11. Sludge Drying Beds and On-site Sludge Storage

The sludge drying beds (Fig 2.6) are twenty one (21) in number and are charged from the sludge thickening tanks either by gravity or via the thickened sludge pumping station. The sludge drying beds have been constructed to maximize operation advantage as they are simple constructions with little or no need for mechanical equipment. The principal disadvantages are the relatively large area of land used and reduced dewatering efficiency in wet weather. However in Mombasa evaporation rates remain high and with correct operation any rain water collecting on the surface of the drying sludge can quickly be drained away using adjustable weirs. The beds have a

provision for decanting of rain water. The drying time recorded for the beds is less than 15 days. Since the beds are designed for manual removal of sludge, wide wheeled wheelbarrows are provided for transport of sludge by wheel loader or dumper from the beds.



Figure 2.6: Twenty one sludge drying beds

2.7.12. Works Wash-out System

The wash-out system comprises of a series of gravity sewers and manholes, a pumping station and a pumping main. The gravity lines collect various liquors and wash waters from the treatment works units and convey them to the pumping station from where they are delivered, via the pumping main, to the inlet end of the aeration tanks. The wash-out system can also be utilized to empty the inlet works channels, the final settlement tanks and the sludge thickening tanks.

Supernatant liquors from the sludge thickening and under grain liquors from the beds flow continuously to the wash-out system. Draining of a screen/ constant velocity grit channel prior to cleaning and degritting (after placing of hand-stops) is achieved by the opening of the appropriate sludge plug at the inlet works. Sewage remaining in the channel and waste waters used to clean the channel and screening areas flow to the wash-out system.

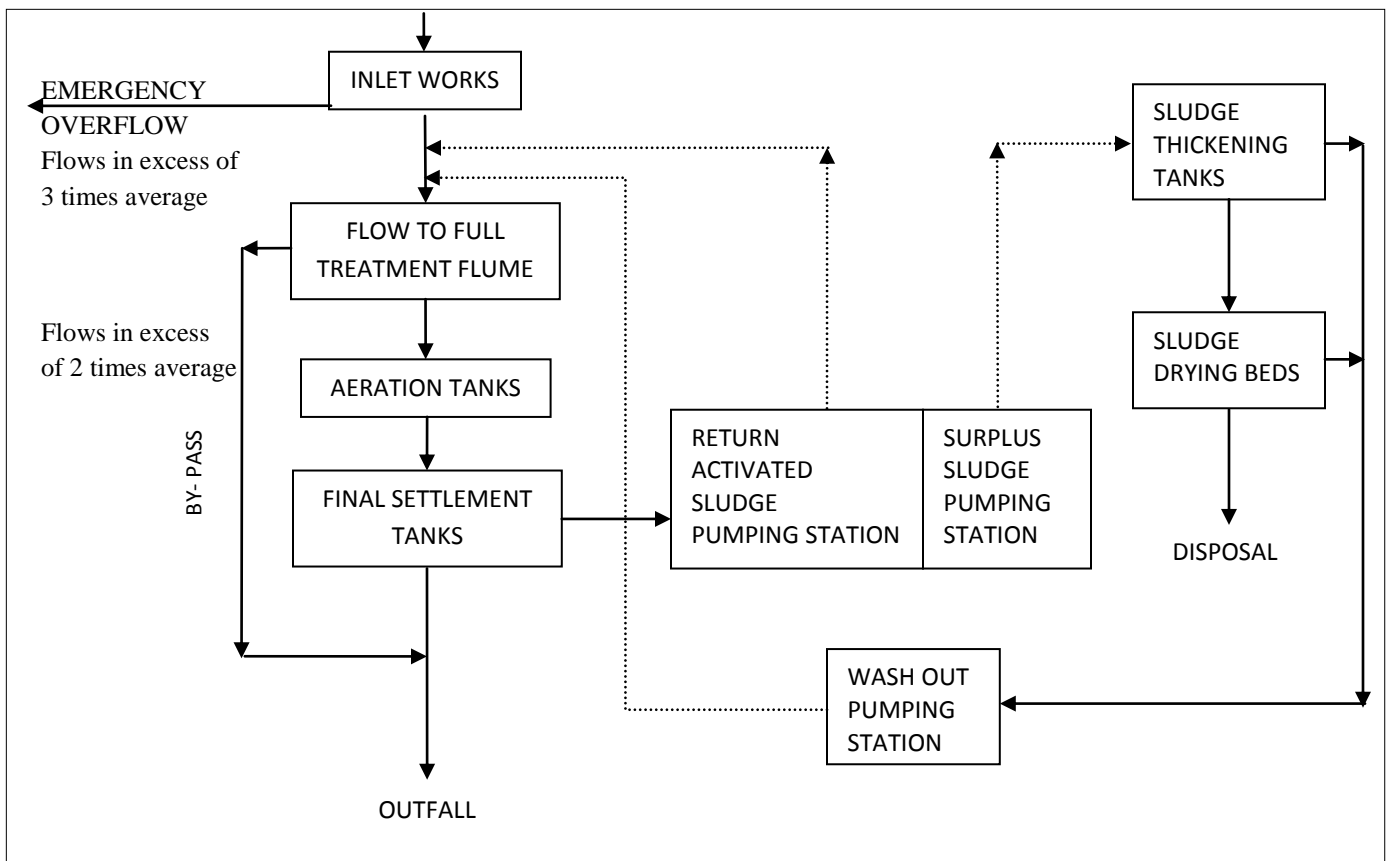
The final settlement tanks and the whole sludge thickening tanks may be completely emptied by opening a low level sluice valve in the appropriate sludge chamber.

2.7.13. Works Wash-water System

The wash water system comprises of a pumping station, pressurized distribution main and a number of hydrants. The wash water system provides high pressure, pumped, recycled water for all general washing duties. The system serves all areas of the works where the necessity to wash down chambers, tanks, walkways and other equipments exist and hydrants are installed at these locations.

2.7.14. Work By-pass and Sea Outfall

The ultimate disposal of the effluent from Kipevu Treatment Works is at the Kilindini Harbor. The outfall provides not only the shortest route for the disposal into the sea but is also a discharge point acceptable to KPA, being in a small bay adjacent to the harbor not used for mooring, between Berth No. 14 and the container terminal. Schematic flow of the wastewater from the inlet works to the outfall (Kilindini Harbour) is as shown in Scheme 2.3.



Scheme 2.3: Schematic flow of Kipevu Treatment Works

CHAPTER THREE: MATERIALS AND METHODS

3.1. Introduction

3.1.1. Sample Collection

Grab water samples were collected in one liter polyethylene bottles which had been previously cleaned and rinsed with dilute acid and preserved as suggested by APHA (1998). In most cases immediate analysis of samples was not performed after sample collection (i.e. within the same day) and appropriate storage conditions (at or below 4 °C) was employed for a period that did not exceed three days.

The sample points included: Inlet works, discharge point (output) and the storm water drain that is adjacent to the treatment works. Analysis of the effluent at the pre-treatment stage (inlet works) was necessary to provide benchmarking during effluent quality analysis at the outflow of the treatment plant. Sampling was done for six months and commenced in the month of August 2011 and continued once every other month until February 2012. The analysis of the wastewater samples was done at Government Chemist, Mombasa and SGS analytical laboratory also in Mombasa.

3.1.2. Reagents

All reagents used for analyses were of analytical grade of minimum assay 98 percent of the active ingredient. The reagents included: acetylene standard commercial grade, ammonium molybdate, anhydrous sodium sulphate, ascorbic acid, conc. sulphuric acid, ferrous sulphate heptahydrate, conc. hydrochloric acid, ferrous sulphate, 1,10- phenanthroline indicator, manganous sulphate, nitrate buffer (ISAB), nitrate standard, conc. nitric acid, orthophosphoric acid, petroleum ether (40-60°C), potassium antimonyl tartrate, 0.125N potassium dichromate, silver sulphate, sodium azide solution, sodium hydroxide, sodium thiosulphate, soluble starch, standard buffers (pH 4,7 and 9) and stock phosphate solution. The reagents were supplied by Kobian (K) Limited.

3.1.3. Instrumentation

The instruments used in the analyses included the following: Hot Plate, nitrate electrode (Model Cat. No. 970701), atomic absorption spectrometer (AAS-Model: VARIAN AA240F S), colorimetric equipment (*Spectrophotometer*, with infrared phototube for use at 880 nm,

providing a light path of 2.5 cm or longer), pH meter (SHANGAI REX, Model pH S-2C) consisting of a potentiometer, a glass electrode, a reference electrode, and a temperature-compensating device.

3.2. Procedure for pH Determination

The pH meter was first calibrated with standard pH buffers of pH 4, pH 7 and pH 9 which were obtained commercially. 50 mL of the sample was placed in a 100mL beaker and the pH meter electrode dipped. Readings were taken directly from the pH meter and recorded. The pH measurements of the effluents were taken in triplicate at room temperature.

3.3. Procedure for the determination of Total Suspended Solids (TSS)

100mL of a well mixed sample was measured and filtered through the glass-fibre filter paper under slight suction and the residue washed three times with 5mL distilled water allowing it to drain free from water after each wash. The paper was then removed, placed on a watch glass and dried in an oven at 105°C for 1 hour, cooled in a desiccator and paper weighed plus solids until constant weight was achieved upon cooling to room temperature. Analysis was done in triplicate and the average weight obtained.

3.4. Procedure for the determination of Total Dissolved Solids (TDS)

100mL of a well mixed sample was measured and filtered through the glass-fibre filter paper under slight suction to remove suspended solids. This was transferred into a previously weighed evaporating dish and evaporated on a hot plate. The residue was then dried at 105°C for 2 hours in a drying oven, cooled in a desiccator and dish weighed until a constant weight was obtained.

3.5. Biochemical Oxygen Demand (BOD₅) determination

3.5.1. Preparation of reagents

3.5.1.1. Manganous sulfate solution

240 g of manganous sulphate ($\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$) was added to a 500 mL volumetric flask and 100 mL distilled water added to dissolve it. This was then made to volume.

3.5.1.2. Alkali iodide-azide

This was prepared by dissolving 200 g NaOH and 54 g NaI in a 500 mL volumetric flask and diluted to 1 Litre. 10 g of NaN_3 was dissolved in 16 mL distilled water and added. The resulting mixture was allowed to cool. The solution was left to stand overnight and then decanted into 100 mL plastic bottles.

3.5.1.3. Sodium thiosulphate solution (0.0125 M)

This was prepared by dissolving 3.1 g of sodium thiosulphate pentahydrate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) in distilled water. 1.5 mL of 6 M NaOH solution was added and the mixture diluted to 1000 mL. The solution was standardized with standard potassium bi-iodate solution.

3.5.1.4. Standard potassium bi-iodate solution (0.00105 M) and Standardization

This was prepared by dissolving 406.2 mg of $\text{KH}(\text{IO}_3)_2$ in distilled water and diluted to 1000 mL. Approximately 1 g of KI was dissolved in 50 mL distilled water in an Erlenmeyer flask. 0.5 mL 6N H_2SO_4 and 10 mL standard bi-iodate solution was added. This was diluted to 100 mL and liberated iodine titrated with thiosulphate titrant adding starch towards the end of titration.

3.5.2. Procedure

1 mL sample was diluted to 200 mL and transferred into 250 mL bottles for incubation. To this, 1 mL MnSO_4 solution was added followed by 1 mL alkali-iodide-azide reagent. The incubation bottles were stoppered carefully to exclude air bubbles and the solution mixed by inverting the bottle a few times. After the precipitation settled, 1 mL conc. Sulphuric acid was added; the bottle restoppered and mixed thoroughly by inverting several times until dissolution was complete. The sample was then incubated for five days. Titration was then done with 0.0125 M $\text{NaS}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ to a pale yellow colour. A few drops of starch solution was added and titration continued to first disappearance of blue colour.

Blank determination was done using the same procedure and 1 mL of distilled water used instead of the sample. The dissolved oxygen of the diluted sample was determined before and after incubation for five days at 20°C. The difference gave the BOD of the sample, taking into account the dilution factor.

3.6. Chemical Oxygen Demand (C.O.D)

3.6.1. Principle of the Method

The sample was boiled under reflux for two hours with potassium dichromate and silver sulphate catalyst in conc. sulphuric acid. Part of the dichromate was reduced by the organic matter present in the sample and the excess was determined by titration with iron (II) sulphate using 1, 10-phenanthroline indicator.

The COD was expressed as milligrams of oxygen absorbed from standard dichromate per litre of the sample.

3.6.2. Preparation of Reagents

3.6.2.1. Standard Ferrous ammonium sulphate (0.125 M)

This was prepared by dissolving 49 g of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ in 100 mL distilled water in a 1000 mL volumetric flask. 10 mL conc. sulphuric acid was added, cooled and diluted to 1000 mL.

3.6.2.2. 0.01389 M Potassium dichromate

This was prepared by dissolving 4.08 g of $\text{K}_2\text{Cr}_2\text{O}_7$ previously dried at 103°C for 2 hours in distilled water and diluted to 1000 mL.

3.6.2.3. Sulphuric acid reagent

This was prepared by adding 5.5g of Ag_2SO_4 into 500 mL conc. H_2SO_4 and allowed to stand for two days to dissolve.

3.6.2.4. Ferroin indicator solution

This was prepared by dissolving 1.485g of 1, 10-phenanthroline monohydrate and 695 mg $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ in distilled water and diluted to 1000 mL.

3.6.3. Procedure

5 mL of a well mixed effluent sample was transferred into a round-bottomed flask. 1 mL of sulphuric acid reagent was added followed by 5 mL of 0.01389 M potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) solution and mixed thoroughly. A reflux condenser was attached and the remaining sulphuric acid reagent (14 mL) added. This was mixed well and refluxed for two hours after which it was cooled and 45mL of distilled water added. The condenser was disconnected. This was then transferred into a beaker and two drops of 1, 10 phenanthroline indicator were then

added and residual dichromate titrated with 0.125M ferrous ammonium sulphate. A blank test was also done using the same procedure but in this case 5mL of deionised water was used instead of the effluent sample.

3.7. Determination of Oil and Grease

3.7.1. Principle of the Method

This method is for determination of n-hexane extractable material (oil and grease) and n-hexane extractable material that is not adsorbed by silica gel (non-polar material) in industrial and domestic aqueous wastes. Acidified sample is extracted for oils and “grease” (fats, waxes, e.t.c) using light petroleum spirit and the organic extract expressed as mg/L of the sample.

3.7.2. Procedure

100 mL of a well mixed effluent sample was transferred into a 500 mL separating funnel. Three drops of concentrated sulphuric acid was added to adjust the pH to 5. 50 mL of petroleum ether (40-60°C) was then added and the mixture shaken in order to extract the organic layer. The aqueous layer was drained into a clean 500 mL beaker and the organic extract into another 500 mL beaker. The aqueous layer was transferred back to the separating funnel and serially extracted three times with 50 mL petroleum ether. The organic extracts were combined and dried with 100 g anhydrous sodium sulphate. The dry organic extract was decanted into a clean 500 mL beaker and filtered through a 90mm Whatman No.30 filter paper. The filter paper was washed with 20 mL petroleum ether (40-60°C) after which the organic extract was evaporated on a rotary evaporator, dried, cooled and weighed.

3.8. Phosphorus determination (Ascorbic Acid Method)

3.8.1. Principle

The total phosphorus concentration was determined spectrometrically according to standardized method ISO 6878. Phosphorus analyses embody two general procedural steps: (a) conversion of the phosphorus to dissolved orthophosphate, and (b) colorimetric determination of dissolved orthophosphate.

3.8.2. Preparation of Reagents

3.8.2.1. Sulfuric acid (H₂SO₄), 2.5 M

70 mL conc. sulphuric was diluted to 500 mL with distilled water in a 500 mL volumetric flask.

3.8.2.2. Potassium antimonyl tartrate solution

1.3715 g K(SbO)C₄H₄O₆·¹/₂H₂O was dissolved in 400 mL distilled water in a 500 mL volumetric flask and diluted to volume. This was stored in a glass-stoppered bottle.

3.8.2.3. Ammonium molybdate solution

20 g (NH₄)₆Mo₇O₂₄·4H₂O was dissolved in 100 mL distilled water in a 500 mL volumetric flask and diluted to volume. This was stored in a glass-stoppered bottle.

3.8.2.4. Ascorbic acid solution, 0.1 M

1.76 g ascorbic acid was dissolved in 10 mL distilled water in a 100 mL volumetric flask and diluted to volume.

3.8.2.5. Combined reagent

The above reagents were mixed in the following proportions for 100 mL of the combined reagent: 50 mL 2.5 M H₂SO₄, 5 mL potassium antimonyl tartrate solution, 15 mL ammonium molybdate solution, and 30 mL ascorbic acid solution. After addition of each reagent the solution was mixed thoroughly. The reagent was stable for 4 hours.

3.8.2.6. Stock phosphate solution:

50 mL of 1000 ppm stock phosphate solution which was commercially obtained was diluted to 1 liter with distilled water.

3.8.3. Procedure

10 mL of the effluent sample was transferred into a clean, dry 125 mL Erlenmeyer flask. 0.05 mL (one drop) phenolphthalein indicator was added followed by 8.0 mL of the combined reagent and mixed thoroughly. After 20 min, absorbance of each effluent sample was measured at 880 nm, using reagent blank as the reference solution.

For the blank determination, 10 mL of distilled water was used instead of the effluent sample and the procedure was repeated.

3.9. Nitrogen (Nitrate)

3.9.1. Principle:

Nitrate electrode method (APHA 4500 NO₃⁻ D) was used for nitrates concentration between 0.14 to 1400 mg NO₃⁻-N/l.

A nitrate electrode consists of a probe with a sensor that measures nitrate activity in the water; this activity affects the electric potential of a solution in the probe. This change is then transmitted to the meter, which converts the electrical signal that is read in milligrams per litre (mg/L).

3.9.2. Procedure

The meter was optimized using 25mL of the nitrate standard was commercially obtained and 0.5mL buffer (ISAB). 25mL of the effluent sample and 0.5mL of the nitrate buffer (ISAB) was then transferred into a 100mL beaker and the electrode inserted. Direct readings in mg/L were made from the meter and recorded.

3.10. Heavy Metals

3.10.1. Principle

In flame atomic absorption spectrometry, a sample is aspirated into the flame and atomized. A light beam is directed through the flame, into a monochromator, and onto a detector that measures the amount of light absorbed by the atomized element in the flame. Because each metal has got its own characteristic absorption wavelength a source lamp composed of the elements is used, this makes the method relatively free from spectral or radiation interference.

3.10.2. Procedure

3.10.2.1. Sample digestion

The effluent samples were openly digested using nitric acid digestion method as follows: 150 mL of a well-mixed, acid-preserved effluent sample was transferred to a 250 mL beaker. 5 mL conc. nitric acid and a few boiling chips were added. The mixture was brought to a slow boil and evaporated on a hot plate to the lowest volume possible (about 110 to 120 mL). While heating conc. nitric acid was added as necessary until digestion was complete as shown by a light-coloured, clear solution. Care was taken not to dry the sample during digestion. The walls of the beaker were washed down with 10 mL distilled water and then filtered. Filtrate was transferred

to a 250 mL volumetric flask with two 5 mL portions of water. Rinsings were added to the volumetric flask. Cooling was done and diluted to mark. 100 mL of this solution was used for the required metal determinations.

3.10.2.2. Instrument Calibration

Operating conditions: The following analytical conditions for atomic absorption analysis are based on cathode lamp for single element. The type of instrument used was AA-240 FS. A hollow cathode lamp was installed for the desired metal (Cadmium, Chromium, Lead and Zinc) in the instrument and the wavelength dial roughly set according to Table 3.1.

Table 3.1: Wavelength instrument detection level sensitivity and optimum concentration range for elements

Element	Wavelength (nm)	Flame Gases	Instrument Detection Level mg/L	Sensitivity	Optimum Conc. range mg/L
Cd	228.8	A-Ac	0.002	0.025	0.05-2
Cr	357.6	A-Ac	0.2	0.1	0.2-10
Pb	283.3	A-Ac	0.05	0.5	1-20
Zn	213.9	A-Ac	0.005	0.02	0.05-2

Table adapted from the guide manual for water and wastewater analysis (Prakash, 2014).

A- Air; Ac- Acetylene

3.10.2.3. Standard solution:

Standard solutions of known metal concentrations were prepared from stock standard solutions of 1000 ppm obtained from several commercial sources. The standard solutions prepared by dilution of the stock standard solutions were used for calibration of the instrument (AAS) and calibration curves prepared. The concentrations used are as shown on table 3.2.

Table 3.2: Metal calibration standards

Element to be tested	Calibration standard
Cd	0.005, 0.01, 0.02
Cr	0.005, 0.01, 0.02
Pb	0.1, 0.2, 0.3
Zn	0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35

3.10.2.4. Analysis of Sample

1.0 mL of the digested sample was loaded to the AAS. Concentrations in mg/L of the elements were read directly from the instrument readout. The standard calibration data for Cd, Zn, Pb and Cr are given in the appendices 7, 8, 9 and 10 respectively.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Introduction

The presentation of the results of the effluent analysis considered samples collected in six months starting from the month of August 2011 to February 2012. The sampling points included inlet works (influent), outlet works (effluent) and the nearby storm water drain which had evidence of both industrial and domestic effluent.

4.2. Reduction Efficiency

Efficiency ratings can be used to set goals, maintain efficient performance, and even break those goals. There are several different types of efficiencies that play a role in water and wastewater treatment. One of the most important in the wastewater field is the efficiency of removal, which involves the removal of a pollutant.

The reduction efficiency of the treatment plant for each parameter was calculated as follows:

$$\text{Reduction efficiency } (E_r) = \frac{\text{Initial Amount} - \text{Reduced Amount}}{\text{Initial Amount}} \times 100\%$$

4.3. Parameter pH

The pH of the samples analyzed was read directly from the instrument read out as depicted in Tables 4.1. The readings were compared to the standards given by NEMA in the third and fifth schedules of EMCA regulations. The efficiency of Kipevu treatment works was also determined as summarized in Table 4.1.

Table 4.1: Analysis of pH during the period of data collection

MONTH	INFLUENT pH	REMARKS (6.0-9.0) Public Sewer	EFFLUENT pH	REMARKS (6.5-8.5) To Environment	STORM WATER pH
August 2011	7.2	Within	6.9	Within	7.1
October 2011	7.0	Within	6.8	Within	7.2
November 2011	7.0	Within	6.8	Within	7.0
December 2011	7.1	Within	6.8	Within	7.0
January 2012	7.0	Within	6.9	Within	6.8
February 2012	7.2	Within	6.9	Within	7.2

The pH values obtained for inlet (influent) and outlet (effluent) at the Kipevu treatment works was compared with the values that is given by NEMA in the EMCA Regulations of 2006. According to the third schedule of EMCA regulations, the effluent that is discharged into the environment (in this case Indian Ocean) should be between 6.5 and 8.5 while that discharged into public sewers should be between 6 and 9.

The values obtained from the analyses both at the inlet and outlet indicate adherence to these standards. Therefore the treatment works was very effective in pH regulations. This is more so because the wastewater that was discharged into public sewer and finally reached Kipevu treatment works was within maximum permissible levels. The pH of the storm water drain almost resembled that of the effluent.

4.4. Total Suspended Solids (TSS)

The increase in weight of the paper expressed as milligrammes of suspended solids per given volume of sample times one thousand will give the concentration of suspended solids in mg of sample per litre.

$$\text{Suspended Solids (mg/L)} = \frac{(A-B) \times 1000}{\text{Sample Volume in ml}} \dots \dots \dots (A. 1)$$

Where:

- Sample volume = 100mL
- A = weight of dried residue + paper (mg),
- B = weight of paper (mg),
- (A-B) = mass of suspended solids (mg)

The results obtained for the inlet (influent), outlet (effluent) and storm water drain is as given in Table 4.2. The results so obtained were compared to the standards given by NEMA in the third and fifth schedules of EMCA regulations.

Table 4.2: Analysis of TSS during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (250 mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (30 mg/L) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	1.2×10 ³	Higher	1.2×10 ³	Higher	0	500
October '11	460	Higher	350	Higher	23.91	170
November '11	424	Higher	164	Higher	61.32	277
December '11	506	Higher	21.8	Lower	95.69	24.6
January '12	150	Lower	40	Higher	73.33	35
February '12	600	Higher	50	Higher	91.67	30

During the entire period of data collection the NEMA recommended standard for effluent discharge into the environment was only attained in the month of December 2011 and was recorded as 21.8 mg/L. This could have been due to break down of equipment (screens, macerators and poor grit removal) in the primary treatment units.

Maximum levels permissible by NEMA for TSS is given as 250 mg/L for effluent discharge into public sewer. All values were higher during the study period (424-1200 mg/L) except in the month of January 2012 (150 mg/L). Higher values could have resulted due to overloading of the treatment works.

Reduction efficiency of TSS for the treatment plant was at its best in December 2011 (95.69%) and at its worst in August 2011 (0%). This was likely due to the presence of algae in the aeration and settlement tanks. Algae if present, normally constitutes part of the total suspended solids in the final effluent. Higher levels of total suspended solids would result to sewer blockages and extra load on sludge disposal system. However, after renovation of the treatment plant in September 2011, reduction of TSS improved significantly to 61% in November 2011, 95.69% in December 2011 and 91.67% in February 2012. However, in the month of January 2012 there was a slight decrease in the reduction efficiency which was recorded as 73.33%. This is represented in Figure 4.1.

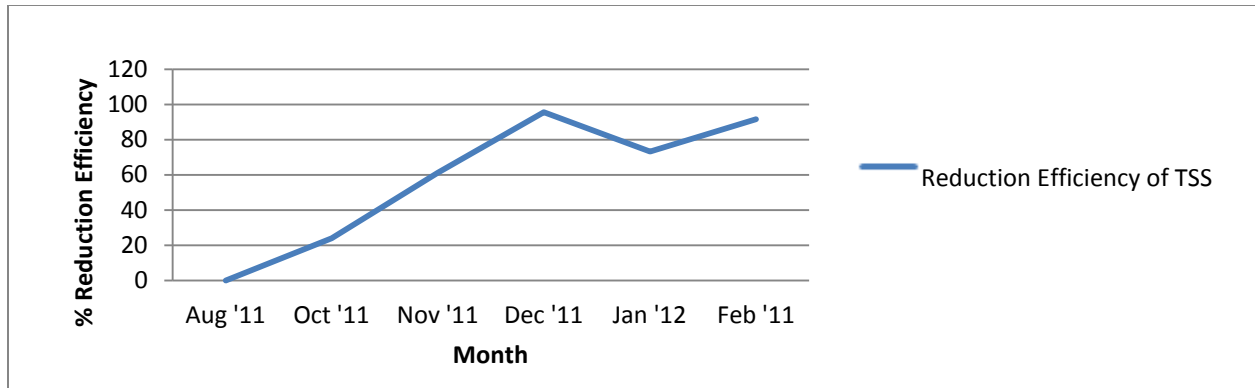


Figure 4.1: Reduction efficiency of TSS

4.5. Total Dissolved Solids

This is the amount of solute (mg) dissolved in water per given volume times one thousand.

$$\text{Total Dissolved solid (mg/L)} = \frac{(A-B) \times 1000}{\text{Sample Volume (mL)}} \dots \dots \dots \text{B.1}$$

Where:

Sample volume = 100mL

A = weight of dried residue + dish (mg), and

B = weight of dish (mg)

A-B = weight of residue

The results obtained are tabulated in Table 4.3. Comparison was made to the standards given by NEMA in the third and fifth schedules of EMCA regulations. The reduction efficiency of TDS for Kipevu treatment works was also determined as summarized in Figure 4.2.

Table 4.3: Results for TDS during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (2000mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (1200mg/L) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	400	Lower	380	Lower	5	670
October '11	1000	Lower	700	Lower	30.0	1900
November '11	1400	Lower	1200	Lower	14.29	2000
December '11	1146	Lower	1117	Lower	2.53	670
January '12	1250	Lower	1000	Lower	20	2500
February '12	1400	Lower	587	Lower	58.07	2670

During the entire data collection period, the NEMA recommended value for effluent discharge into the environment (1200 mg/L) was attained. The concentration ranged from 380-1200 mg/L. It was also noted that the recommended standard for effluent discharge into public sewer (2000 mg/L) was adhered to during the entire study period. Values for this ranged from 400-1400 mg/L. In the storm water drain, the concentration of TDS was high which is a clear indication of discharge of sewage into the storm water drain.

Reduction efficiency of TDS was generally low during the entire period. The treatment plant efficiency was at its best in the month of February 2012 with efficiency of 58.07% and at its worst in the month of December 2011 with an efficiency of 2.53% as shown in Figure 4.2.

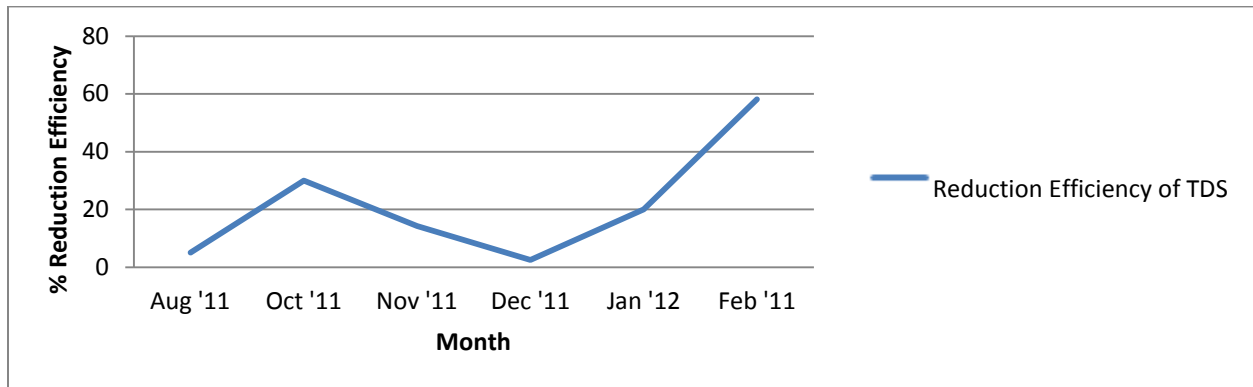


Figure 4.2: Reduction efficiency of TDS

4.6. Biological Oxygen Demand

The values for BOD₅ was calculated as follows:

$$BOD_5 \text{ (mg/L)} = [(S_1 - S_2) - (B_1 - B_2)] \times \text{dilution factor} \dots \dots \dots C. 1$$

- Where
- S₁: Volume of 0.0125N sodium thiosulphate used on day 1
 - S₂: Volume of 0.0125N sodium thiosulphate used after five days of incubation
 - B₁: Volume of 0.0125N sodium thiosulphate used on blank on day 1
 - B₂: Volume of 0.0125N sodium thiosulphate used after five days of incubation
- Dilution factor = 200

The results obtained were recorded in Table 4.4. The results were compared to the standards given by NEMA in EMCA regulations of 2006.

Table 4.4: Results of BOD during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (500 mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (30 mg/L) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	1200	Higher	200	Higher	83.33	50
October '11	360	Lower	85	Higher	76.39	90
November '11	380	Lower	95	Higher	75.0	65
December '11	350	Lower	200	Higher	42.86	50
January '12	200	Lower	100	Higher	50.0	300
February '12	400	Lower	260	Higher	35.0	80

The Kipevu Treatment Works did not even once during the study period attain the NEMA recommended value for effluent discharge into the environment (30 mg/L). Values ranged from 85-260 mg/L. Maximum levels permissible by NEMA for BOD is 500 mg/L for effluent discharge into public sewer which was adhered to during the study period (200-400 mg/L) except in the month of August 2011 which was recorded at 1200 mg/L.

During the entire period of data collection and study, there was production of foam in the aeration tanks, sedimentation tanks and sludge thickening tanks. Foam formation is as a result of overfeeding and accumulation of toxic industrial waste, such as heavy metals which may also inhibit the digestion process (reaction) (Mark, 2003). This could have been the reason why BOD₅ concentrations were generally higher in the effluent than the standard given by NEMA (30 mg/L). Higher levels of BOD would result to overloading of treatment units.

During the period of study, it was noted that there was no control on the portion of sludge that was returned to the aeration tanks to keep the population of micro-organisms in the aerators constant. The retention time in the aeration tanks was also not constant. These factors contributed to fluctuations in the BOD₅ concentrations within the treatment works.

In the storm water drain however, BOD loadings were also higher which was a clear indication that some facilities discharge sewer into storm water drain.

Reduction efficiency of Kipevu Treatment Works for BOD was at its best in August 2011 (83.33%). Surprisingly, this was the month with the highest concentration in the influent at 1200

mg/L. The efficiency was at its worst in February 2012 (35%). Generally the reduction efficiency for BOD declined progressively during the entire period of data collection as depicted in Figure 4.3.

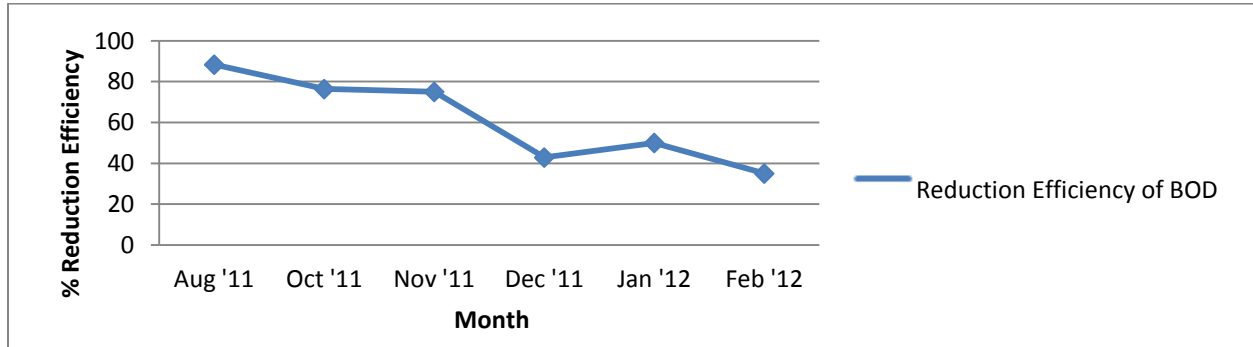


Figure 4.3: Reduction efficiency of BOD₅

4.7. Chemical Oxygen Demand (COD)

COD for Kipevu Treatment Works was computed as follows:

$$C.O.D \text{ (mg/L)} = \frac{[Blank \text{ titre} - Sample \text{ titre}]}{Vol \text{ of sample taken (5ml)}} \times M \times 8000 \dots \dots \dots D. 1$$

Where M = Molarity of K₂Cr₂O₇, (0.125 M).

The results obtained were recorded in Table 4.5. The results were compared to NEMA standards for COD in influent and effluent.

Table 4.5: Results for COD during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (1000mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (50mg/L) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	400	Lower	380	Higher	5.0	80
October '11	1800	Higher	520	Higher	98.89	640
November '11	220	Lower	100	Higher	54.55	80
December '11	150	Lower	80	Higher	46.67	80
January '12	300	Lower	120	Higher	60.0	80
February '12	250	Lower	180	Higher	28.0	80

During the entire period of data collection the NEMA recommended value for effluent discharge into the environment (50 mg/L) was not attained. All values were higher (80-520 mg/L). Maximum levels permissible by NEMA for COD is 1000mg/L for effluent discharge into public sewer which was adhered to during the study period (150-400 mg/L) except for the month of October 2011 when the concentration was 1800 mg/L.

Reduction efficiency for COD was highest in the month of October 2011 at 98.89% and was worst in the month of August 2011 at 5%. After the renovation of the treatment works in September 2011, the efficiency increased in October 2011 to 98.89% but again declined progressively until December 2011. In January 2012 there was a slight improvement in the efficiency as shown in Figure 4.4.

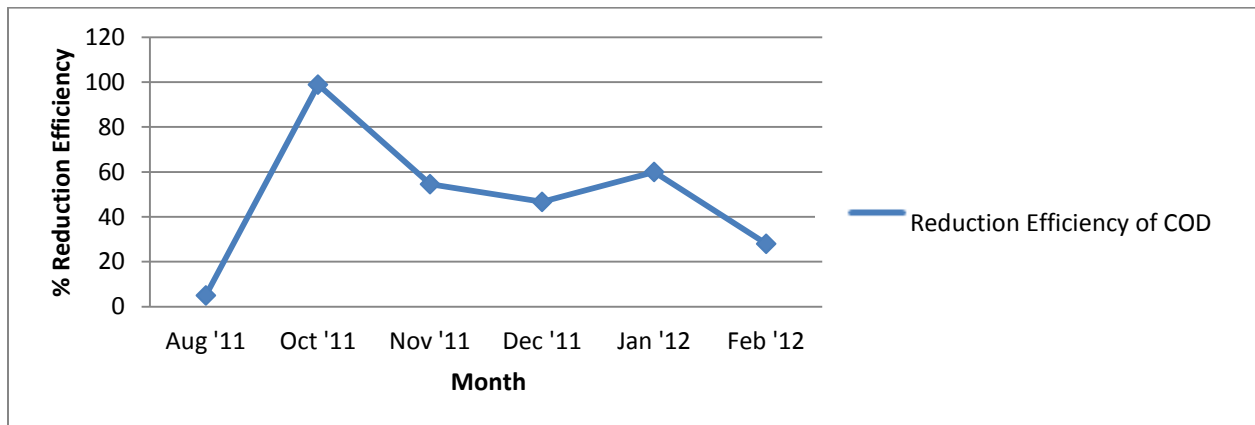


Figure 4.4: Reduction efficiency of COD

4.8. Oil and Grease

The results for oil and grease for the samples collected were computed as the increase in weight of the beaker expressed as milligrammes of organic extract per given volume of sample times one thousand.

$$\text{Organic extract (mg/L)} = \frac{(A-B) \times 1000}{\text{Sample Volume in ml}} \dots \dots \dots (E. 1)$$

Where:

A = weight of dried residue + beaker (mg), and

B = weight of beaker (mg).

The results so obtained are recorded in Table 4.6. The values obtained were compared to the standards given by NEMA and the reduction efficiency of the treatment works computed.

Table 4.6: Results of Oil and Grease during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (10mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (Nil) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	331	Higher	117	Higher	64.65	Nil
October '11	79	Higher	39	Higher	50.63	24
November '11	112	Higher	85	Higher	24.11	Nil
December '11	141	Higher	76	Higher	46.10	8
January '12	80	Higher	70	Higher	12.50	50
February '12	180	Higher	60	Higher	66.67	20

Generally, oil and grease concentration at the Kipevu Treatment Works was above the value given by NEMA for effluent discharged into the environment (0 mg/L). The concentration of the influent (79-331 mg/L) was also above the NEMA standard of 10mg/L. This could be due to pollution from several industries around Kipevu that deal with petroleum products. Among these are Changamwe Oil Refineries and other petroleum filling stations that are all connected to the Kipevu Treatment Works and Sewer System. These are clear indications that the discharged wastewaters by these facilities are not properly cleaned and the effluent discharged into the public sewer surpass the maximum levels permissible by NEMA. Higher levels of oil and grease may have resulted in to fouling of working equipment.

The storm water drain had high concentrations of oil and grease. This confirmed that wastewaters were discharged into the storm water drain. However, in August 2011 and November 2011, there was no oil and grease that was discharged into the storm water drain.

Kipevu Treatment Works was most efficient in reduction of oil and grease in February 2012 at a value of 66.67% and at its worst in Jan 2012 at a value of 12.50% as shown in Figure 4.5.

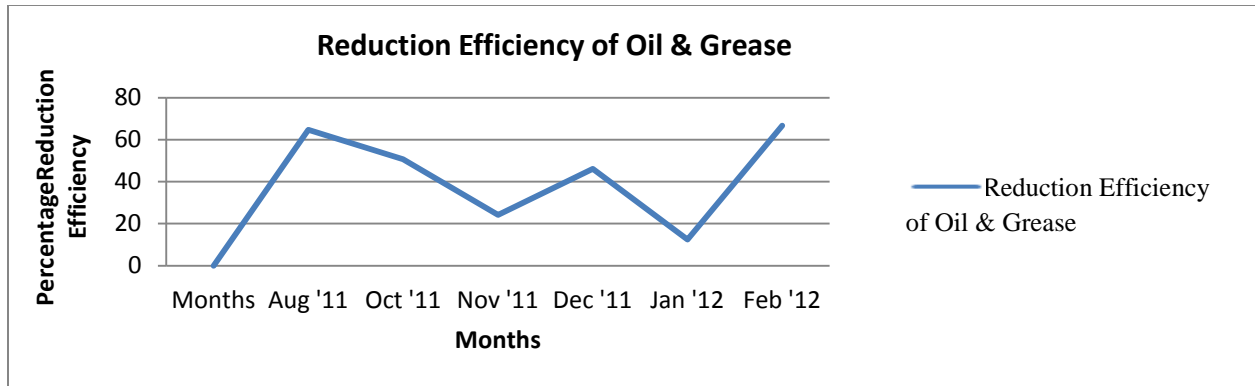


Figure 4.5: Reduction efficiency of Oil and Grease

4.9. Total Phosphorus

Total phosphorus was computed as follows:

$$\text{Phosphorus (mg/L)} = \frac{\text{mg P (in approximately 18.05 mL Final volume)} \times 1000}{\text{mL sample}} \dots \dots \dots \text{F. 1}$$

The results obtained are given in Table 4.7. Comparison of the results with NEMA standards for effluents was done. Efficiency of the treatment works in reduction of total phosphorus was calculated and also given in table 4.7.

Table 4.7: Results of total phosphorus during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (30 mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	13.46	Lower	11.19	16.86	0.56
October '11	9.12	Lower	8.36	8.33	2.23
November '11	10.31	Lower	3.59	65.18	2.38
December '11	7.93	Lower	4.98	37.20	3.37
January '12	8.52	Lower	5.12	39.91	3.42

Concentration of the influent was lower than the NEMA standard of 30 mg/L during the entire period of study (7.93-13.46 mg/L). The reduction efficiency of phosphorus for Kipevu treatment works was at its best in November 2011 (65.18%) and at its worst in October 2011 (8.33%) as shown in Figure 4.6. The concentration of the storm water drain varied between 0.56 mg/L in August 2011 and 3.42 mg/L in January 2012. Generally, the concentrations of the storm water drain increased progressively during the study period. The reduction efficiency of the treatment

works increased substantially in November after rehabilitation of the treatment works and decreased progressively in December 2011 and January 2012.

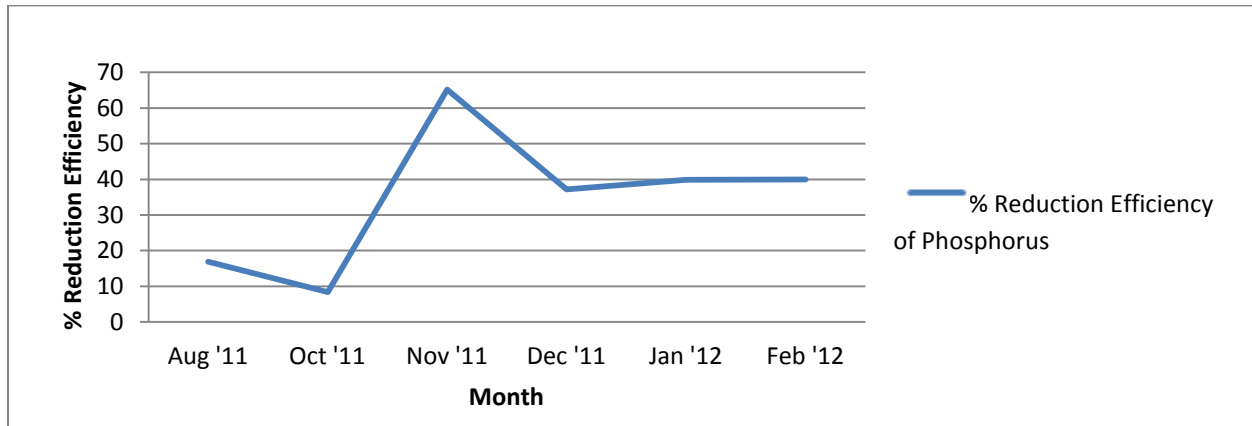


Figure 4.6: Reduction efficiency of total phosphorus

4.10. Nitrates

Concentrations of nitrates in the samples analyzed were read directly from the instrument (nitrates meter) readout and were recorded in Table 4.8. These were compared to standards given by NEMA.

Table 4.8: Results of Nitrates during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (20mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	2.40	Lower	2.10	12.50	1.70
October '11	4.40	Lower	2.50	43.18	2.90
November '11	10.60	Lower	5.26	50.38	4.66
December '11	6.30	Lower	2.80	55.56	38
January '12	11.00	Lower	1.60	85.45	35

The reduction efficiency of nitrates for the entire period of data collection was progressive with the highest efficiency in January 2012 (85.45%) and worst in August 2011 (12.50%) as shown in Figure 4.7. During the entire data collection period, the influent concentrations (2.4-11 mg/L) were lower than the NEMA recommended value of 20 mg/L for effluent discharged into public sewers. The concentration of effluent discharged into the environment was 1.6-5.26 mg/L. However, NEMA does not have the maximum allowable concentration.

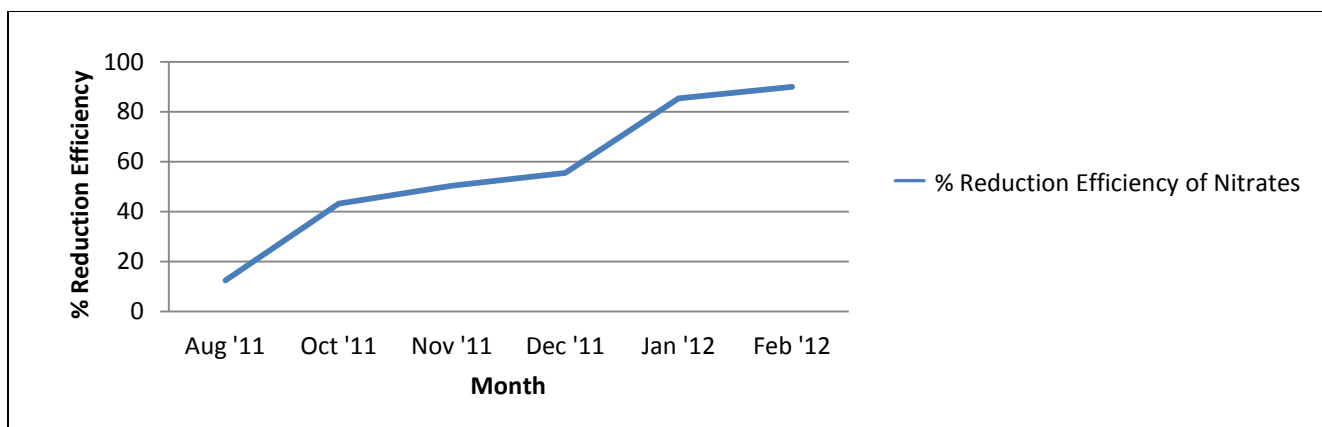


Figure 4.7: Reduction efficiency of nitrates

4.11. Heavy Metals

Concentrations in mg/L of the heavy metals (chromium (IV), cadmium, lead and zinc) were read directly from the instrument (AAS) readout and recorded in Table 4.9. The results were compared to standards given by NEMA for wastewater discharged into public sewers and to the environment (ocean).

Table 4.9: Results of Cr VI during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (0.05mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (0.05 mg/L) To Environment	CONC IN STORM WATER (mg/L)
August '11	N.D	Lower	N.D	Lower	N.D
October '11	N.D	Lower	N.D	Lower	N.D
November '11	N.D	Lower	N.D	Lower	N.D
December '11	N.D	Lower	N.D	Lower	N.D
January '12	N.D	Lower	N.D	Lower	N.D

ND = Not Detected. Detection limit for Cr IV was 0.02 mg/L

During the period of study, Chromium VI was not detected in the influent as its concentration was below the detection limit (0.02 mg/L). Concentration of chromium VI in storm water was also below detectable limit of 0.02 mg/L. This is a clear indication that there was no chromium VI pollution during the period of data analysis.

Data for Cd²⁺ during the study period is as shown on Table 4.10.

Table 4.10: Results of Cd during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (0.5mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (0.01) To Environment	CONC IN STORM WATER (mg/L)
August '11	N.D	Lower	N.D	Lower	N.D
October '11	N.D	Lower	N.D	Lower	N.D
November '11	N.D	Lower	N.D	Lower	N.D
December '11	N.D	Lower	N.D	Lower	N.D
January '12	N.D	Lower	N.D	Lower	N.D

ND = Not Detected. Detection limit for Cd was 0.02 mg/L

During the period of study, cadmium ions were not detected in the influent as their concentrations were below the detection limit (0.02 mg/L). The concentration in the storm water was also below detection limits of the AAS. Zn²⁺ results are depicted on Table 4.11.

Table 4.11: Results of Zn during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (5.0 mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (0.5) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	0.09	Lower	N.D	Lower	UD	0.09
October '11	N.D	Lower	N.D	Lower	UD	N.D
November '11	0.03	Lower	N.D	Lower	UD	0.03
December '11	3.06	Lower	0.07	Lower	97.71	0.09
January '12	3.28	Lower	0.05	Lower	98.48	0.09

ND = Not Detected. Detection limit for Zn was 0.02 mg/L: U.D = Undefined

Storm water values were below NEMA standard for discharge into the environment (nil to 0.09 mg/L). Zinc concentration in the influent varied between 0.09 and 3.28 mg/L. In October 2011, zinc concentration was below the detectable limit of 0.02 mg/L. These values were lower than the standard given by NEMA (5.0 mg/L) for effluent discharged in public sewers. The concentration in the effluent discharged into the Indian Ocean varied between 0.05 in January 2012 and 0.07 mg/L in December 2011. During the entire period, the effluent concentrations were below NEMA standard (0.5 mg/L) for effluent discharged into the environment. In August,

October and November 2011, zinc concentration was below detectable limits. Percentage reduction efficiency of 97.71 and 98.48 respectively was attained in the months of December 2011 and January 2012. The data for lead is shown in Table 4.12.

Table 4.12: Results of Pb during the period of data collection

MONTH	CONC IN INFLUENT (mg/L)	REMARKS (1.0 mg/L) Public Sewer	CONC IN EFFLUENT (mg/L)	REMARKS (0.01) To Environment	% REDUCTION EFFICIENCY	CONC IN STORM WATER (mg/L)
August '11	N.D	Lower	N.D	Not known	UD	N.D
October '11	N.D	Lower	N.D	Not known	UD	N.D
November '11	N.D	Lower	N.D	Not known	UD	N.D
December '11	0.26	Lower	0.18	Higher	30.77	0.35
January '12	0.44	Lower	0.05	Higher	90.9	0.30

ND = Not Detected. Detection limit for Pb²⁺ was 0.02 mg/L: UD = Undefined

In August, October and November 2011, the influent concentration of lead was below detectable limit of 0.02 mg/L. In December 2011 and January 2012, lead concentration was 0.26 and 0.44 mg/L respectively which were lower than the NEMA standard (1.0 mg/L) for effluent discharged into public sewers. Concentration of the effluent discharged into the ocean varied between 0.05 mg/L in January 2012 and 0.18 mg/L in December 2011. These were higher than NEMA standard (0.01 mg/L). Storm water concentration varied between 0.35 in December 2011 and 0.30 mg/L in January 2012. Percentage reduction for Pb²⁺ in December 2011 and January 2012 were 30.77 and 90.9 respectively. The reduction efficiency of the metal Lead and Zinc is as shown in Figure 4.8.

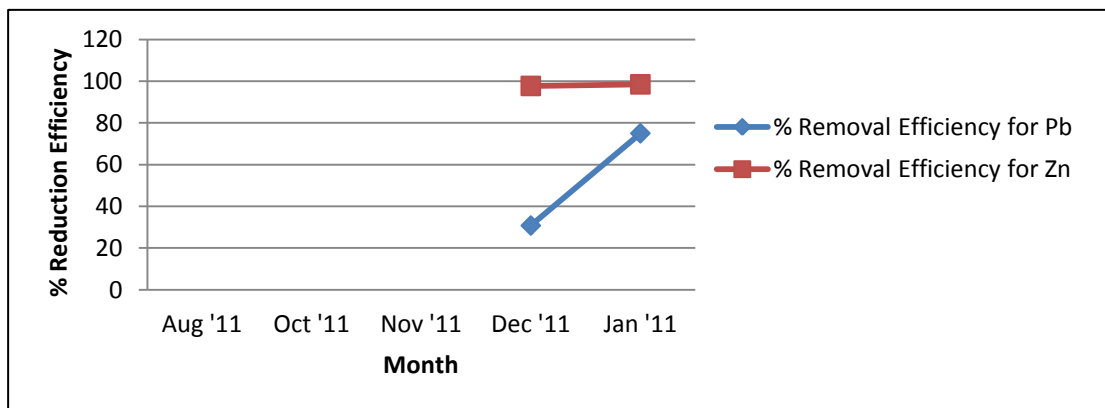


Figure 4.8: Reduction efficiency of heavy metals (Cr VI, Cd, Pd and Zn)

4.12. Pollution Load

Pollution load is defined as stress placed upon an ecosystem through pollution by physical or chemical means. This is done by man-made or natural means. Pollutant load provide much more comparative information for assessing the level of impact. They are a function of pollutant concentrations and water flow. Pollutant loads can be calculated for nutrients, TSS, and fecal coliform bacteria. In this case, pollution load was calculated for total phosphorus, nitrates, zinc, lead, BOD₅, COD, TSS, TDS, oil and grease.

Pollution load was computed as follows:

$$\text{Pollution Load} = \text{conc. (mg/L)} \times \text{volume of water (Lit/sec)}$$

4.12.1. Volumes of Wastewater into and out of the Treatment Plant

Table 4.13 stipulates the volumes of wastewater into and out of the Kipevu Treatment Works for selective dates during the period of data collection. This covered ten days.

$$\begin{aligned} \text{Total Outlet Volume} &= \sum \text{Outlet volumes during the period of data collection} \\ &= 125437.24 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Average Daily Volume} &= \frac{\sum(\text{Outlet volumes for 10 days})}{\text{No of days (10)}} \\ &= \frac{125437.24 \text{ m}^3}{10 \text{ days}} \\ &= 12543.72 \text{ m}^3 / \text{day} \end{aligned}$$

$$\text{Av. volume of wastewater into the ocean} = 12543.72 \text{ m}^3 / \text{day}$$

Table 4.13: Volumes as recorded at the Kipevu Treatment Works

DATE	m ³ /hr	8 A.M (m ³)	2 P.M (m ³)	AVERAGE VOL (m ³ /hr)	VOL PER DAY (m ³ /day)
2/8/11	Inlet	303.8	442.8	373.3	8959.2
	Outlet	432.4	432.4	432.4	10377.6
15/8/11	Inlet	217.1	260.2	238.65	5727.6
	Outlet	432.4	432.4	432.4	10377.6
8/10/11	Inlet	381.5	458.8	420.15	10083.6
	Outlet	545.4	545.2	545.3	13087.2
17/10/11	Inlet	285.6	297.7	291.65	6999.6
	Outlet	545.4	545.0	545.2	13084.84
5/11/11	Inlet	285.6	265.4	275.5	6612
	Outlet	545.4	544.3	544.85	13076.4
17/11/11	Inlet	241.6	226.3	233.95	5614.8
	Outlet	545.3	544.9	545.1	13082.4
2/12/11	Inlet	194.2	226.3	210.25	5046
	Outlet	545.3	544.9	545.1	13082.4
24/12/11	Inlet	207.0	209.9	208.45	5002.8
	Outlet	545.9	545.9	545.9	13101.6
2/1/12	Inlet	216.3	No	216.3	5191.2
	Outlet	545.2	Power	545.2	13084.8
31/1/12	Inlet	261.9		261.9	6285.6
	Outlet	545.1		545.1	13082.4

4.12.2. Calculation of Pollution Load

4.12.2.1. Phosphorus

Total concentration of P (outlet) = \sum (Outlet concentration for P in the study period)

$$= (11.19 + 8.36 + 3.59 + 4.98 + 5.12) = 33.24 \text{ mg/L}$$

Average concentration (outlet) = $\frac{\sum(\text{Outlet concentration for P in the study period})}{5}$

$$= (33.24 \text{ mg/L}) / 5 = 6.648 \text{ mg/L}$$

$$\begin{aligned}
\text{Pollution Load} &= \text{conc. (mg/L)} \times \text{volume of water (Lit/sec)} \\
&= 6.648 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\
&= 965 \text{ mg/s}
\end{aligned}$$

4.12.2.2. Nitrates

$$\begin{aligned}
\text{Total conc. of NO}_3^- \text{ (outlet)} &= \sum(\text{Outlet concentration for NO}_3^- \text{ in the study period}) \\
&= (2.10 + 2.50 + 5.26 + 2.80 + 1.60) = 14.26 \text{ mg/L}
\end{aligned}$$

$$\begin{aligned}
\text{Average concentration (outlet)} &= \frac{\sum(\text{Outlet concentration for NO}_3^- \text{ in the study period})}{5} \\
&= \frac{14.26}{5} = 2.85 \text{ mg/L}
\end{aligned}$$

$$\begin{aligned}
\text{Pollution Load} &= \text{conc. (mg/L)} \times \text{volume of water (Lit/sec)} \\
&= 2.85 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\
&= 413.76 \text{ mg/s}
\end{aligned}$$

4.12.2.2.1. Implication of Pollution Load for Phosphorus and Nitrates

Excess nitrogen and phosphorous can result in *eutrophication*, the nutrient enrichment of water bodies causing excessive growth of aquatic plants (algae, cyanobacteria, rooted aquatic vegetation, duckweed). The dissolved oxygen in the water body becomes depleted when the aquatic plants die, fall to the bottom, and are decomposed by aerobic bacteria. The oxygen depletion can reduce the populations of indigenous fish and other oxygen-consuming organisms. Nutrients from wastewater have also been linked to ocean red tides that poison fish and cause illness in humans.

4.12.2.3. Zinc

$$\text{Total Zinc outlet concentration} = (0.07 + 0.05) = 0.12 \text{ mg/L}$$

$$\text{Average Zinc concentration} = \frac{0.12}{5} = 0.024$$

$$\text{Pollution Load} = 0.024 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} = 3.48 \text{ mg/s}$$

4.12.2.4. Lead

$$\text{Total Lead outlet concentration} = (0.18 + 0.11) = 0.29 \text{ mg/L}$$

$$\text{Average Lead concentration} = \frac{0.29 \text{ mg/L}}{5} = 0.058 \text{ mg/L}$$

$$\begin{aligned} \text{Pollution Load} &= 0.058 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\ &= 8.42 \text{ mg/s} \end{aligned}$$

4.12.2.4.1. Implication of Pollution Load for Zinc and Lead

In high concentrations, zinc has adverse effects both on fresh and marine waters which include: acute effects on mysids, fish, amphipods, decapods, polychaetes and mollusks. In high concentration, some fish can accumulate zinc in their bodies. When zinc enters the bodies of these fish it is able to bio magnify up the food chain.

In high concentrations, lead accumulates in the bodies of water organisms. These will experience health effects from lead poisoning. Health effects on shellfish can take place even when only very small concentrations of lead are present. Body functions of phytoplankton, an important source of oxygen production in seas and many larger sea-animals eat it; can be disturbed when lead interferes. Lead is a particularly dangerous chemical as it can accumulate in individual organisms via food chains.

4.12.2.5. BOD₅

$$\begin{aligned} \text{Total BOD}_5 \text{ outlet concentration} &= (200 + 85 + 95 + 200 + 100 + 260) \\ &= 940 \text{ mg/L} \end{aligned}$$

$$\text{Average BOD}_5 \text{ concentration} = \frac{940 \text{ mg/L}}{6} = 156.67 \text{ mg/L}$$

$$\begin{aligned} \text{Pollution Load} &= 156.67 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\ &= 2.27 \times 10^4 \text{ mg/s} \end{aligned}$$

4.12.2.6. COD

$$\begin{aligned} \text{Total COD outlet concentration} &= (380 + 520 + 100 + 80 + 120 + 180) \text{ mg/L} \\ &= 1380 \text{ mg/L} \end{aligned}$$

$$\text{Average COD concentration} = \frac{1380}{6} = 230 \text{ mg/L}$$

$$\begin{aligned} \text{Pollution Load} &= 230 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\ &= 3.34 \times 10^4 \text{ mg/s} \end{aligned}$$

4.12.2.6.1. Implication of Pollution Load for BOD₅ and COD

Too much oxygen- demanding wastes (BOD₅ and COD) in wastewater can be devastating to receiving waters. These may upset the oxygen balance of surface water because their breakdown uses up dissolved oxygen. This can reduce or deplete the supply of oxygen in the water needed by aquatic life, resulting in fish kills, odors, and overall degradation of water quality.

4.12.2.7. TDS

$$\begin{aligned}\text{Total TDS outlet concentration} &= (380 + 700 + 1200 + 1117 + 1000 + 587) \text{ mg/L} \\ &= 4984 \text{ mg/L}\end{aligned}$$

$$\text{Average TDS concentration} = \frac{4984 \text{ mg/L}}{6} = 830.67 \text{ mg/L}$$

$$\begin{aligned}\text{Pollution Load} &= 830.67 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\ &= 1.20 \times 10^5 \text{ mg/s}\end{aligned}$$

4.12.2.8. TSS

$$\begin{aligned}\text{Total TSS outlet concentration} &= (1200 + 350 + 164 + 21.8 + 40 + 50) \\ &= 1825.8 \text{ mg/L}\end{aligned}$$

$$\text{Average TSS concentration} = \frac{1825.8 \text{ mg/L}}{6} = 304.3 \text{ mg/L}$$

$$\begin{aligned}\text{Pollution Load} &= 304.3 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\ &= 4.42 \times 10^4 \text{ mg/s}\end{aligned}$$

4.12.2.8.1. Implication of Pollution Load for TDS and TSS

High concentrations of TSS and TDS may reduce water clarity and contribute to a decrease in photosynthesis. Reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from the water. Low dissolved oxygen can lead to fish kills. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even, and can harm aquatic life in many other ways. The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. Changes in TDS concentrations can be

harmful because the density of the water determines the flow of water into and out of an organism's cells. However, if TDS concentrations are too high or too low, the growth of many aquatic lives can be limited, and death may occur.

4.12.2.9. Oil and Grease

$$\begin{aligned} \text{Total outlet concentration} &= (117 + 39 + 85 + 76 + 70 + 60) \\ &= 447 \text{ mg/L} \end{aligned}$$

$$\text{Average concentration} = \frac{447 \text{ mg/L}}{6} = 74.5 \text{ mg/L}$$

$$\begin{aligned} \text{Pollution Load} &= 74.5 \text{ mg/L} \times \frac{12543.72 \times 10^3 \text{ M}^3 \cdot \text{L}}{1 \times \text{M}^3 \times (24 \times 3600) \text{ sec}} \\ &= 1.08 \times 10^4 \text{ mg/s} \end{aligned}$$

4.12.2.9.1. Implication of Pollution Load for Oil and Grease

When high concentrations of oil and grease are discharged to receiving waters, they increase BOD levels, and they may float to the surface and harden, causing aesthetically unpleasing conditions. They also can trap trash, plants, and other materials causing foul odors and attracting flies and mosquitoes and other disease vectors. Their decomposition also uses up oxygen and sometimes their presence in water provide good habitat asphyxiation of fish and generation of obnoxious gases as a result of anaerobic processes. In some cases, too much oil and grease causes septic conditions by preventing oxygen from the atmosphere from reaching the water. It can also interfere with the light transmission through water surface. Gaseous exchange at the surface of the water is also affected.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Influent and effluent pH during study period were within the NEMA stipulated value for discharge into the environment (Indian Ocean) and public sewers.

TSS values for the influent for the entire study period were higher than NEMA value of 250mg/L for discharge into public sewer except in January 2012 (150 mg/L). Effluent values for discharge into the environment were all higher than NEMA value of 30mg/L except in December 2011 (21.8 mg/L).

TDS values during the entire study period were lower than NEMA standard of 2000 mg/L for effluent discharged into public sewers. Effluent values were all lower than NEMA standard of 1200 mg/L for discharge into the environment.

Oil and grease values for influent and effluent were higher than NEMA values for both discharges into environment (0 mg/L) and public sewers (10 mg/L).

BOD₅ values for influent were lower than NEMA stipulated value of 500 mg/L for discharge into public sewers except for August 2011 (1200 mg/L). All effluent values were higher than the NEMA standard of 30mg/L for discharge into the environment.

COD values conformed to NEMA standard for public sewer discharge (1000 mg/L) except in October 2011. Effluent values were all higher than NEMA standard of 50 mg/L for discharge into the environment.

Influent concentration of total phosphorus and nitrates were within the NEMA stipulated values of 30 and 20 mg/L respectively for discharge into public sewers. Discharge concentrations of phosphorus into environment ranged from 3.59 to 11.19 mg/L while for nitrates ranged from 1.6-5.26 mg/L. However, NEMA has no standards for phosphorus and nitrates for discharge into the environment.

Chromium and cadmium were not detected during the study period. Zinc was detected in influent in August 2011 (0.09 mg/L), November 2011 (0.03 mg/L), December 2011 (3.06 mg/L) and January 2012 (3.28 mg/L). Influent zinc values were lower than NEMA standard value for

discharge into public sewer (5.0 mg/L). In the effluent, Zinc was detected in December 2011 with a concentration of 0.07 mg/L and January 2012 at a concentration of 0.05 mg/L. Effluent values were all below the NEMA standard for discharge into the environment which is given as 0.5 mg/L.

Lead was detected in influent in December 2011 at a concentration of 0.26 mg/L and January 2012 at a concentration of 0.44 mg/L. In the other months lead was not be detected. Generally, influent lead values were all below NEMA standard for discharge into public sewer (1.0 mg/L). In the effluent, lead was detected in December 2011 at a concentration of 0.18 mg/L and January 2012 at a concentration of 0.05mg/L. Effluent values during the study period were higher than NEMA standards for discharge into the environment given as 0.01 mg/L.

Ideally, the storm water drain is supposed to serve the purposes of draining rain water, surface run-offs or pre-treated waste waters. However the results of the parameters at a section of the storm water drain situated adjacent to the Kipevu Treatment Works are a clear indication of discharge of untreated industrial and domestic wastes into the storm water drain.

Pollution load was calculated for phosphorus, nitrates, heavy metals (zinc and lead), BOD₅, COD, TDS, TSS, oil and grease during the period of data collection. Phosphorus and nitrates had a pollution load of 965 and 413.76 mg/s. Heavy metals zinc and lead loaded 3.48 and 8.42 mg/s into the Indian Ocean. BOD₅ and COD had high pollution load of 2.27×10^4 and 3.34×10^4 mg/s respectively. The pollution loading of TSS and TDS into the ocean was calculated as 4.42×10^4 and 1.20×10^5 mg/s respectively. Oil and grease had a pollution load of 1.08×10^4 mg/s. These values are high and continued pollution could lead to eutrophication of the coastal waters.

5.2. Recommendations

From the study of the Kipevu wastewater treatment plant, the following were recommended:

1. Maintenance of the drainage channels.

The staff should be deployed to constantly remove grit, floating materials, rags and solids retained in the inlet works during the preliminary treatment of the wastewater which would likely cause blockages and clogging of pipes, abrasive wear and damage to mechanical plant.

2. Monitoring of the influent and effluent should be done regularly to provide room for improvement.

3. The volumes of the inlet and outlet wastewater should be recorded accurately and pollution loads of each parameter calculated and recorded each day.

4. Wide wheeled wheelbarrows and tractors should be availed to remove sludge from the sludge drying beds. This is to reduce accumulation of sludge at the treatment plant.

5. Reduction of oil and grease content by finding root cause of pollution. The industries that are served by Kipevu treatment works and sewer systems should clean and filter their wastewaters before discharging into public sewer system.

6. BOD₅ of effluent to be reduced to the NEMA stipulated standard of 30mg/L (discharge into environment) and below by setting control on the portion of sludge that is returned to the aeration tanks to keep the population of micro-organisms in the aerators constant. The retention time in the aeration tanks ought to be constant.

7. COD of effluent to be reduced to the NEMA stipulated standard of 50mg/L and below.

8. Reduction of TSS of the effluent to below 30mg/L as stipulated by NEMA by reducing the algae present in the biological section of the treatment works. This can be done by ensuring the aerators and settlement tanks operate to the optimum.

9. Lead concentration need to be reduced in effluent to below 0.01 mg/L. This can be done by use of chemicals to cause precipitation of the dissolved metals, solids or other materials from the waste water. Other tertiary processes can be incorporated.

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APPENDICES

APPENDIX 1: Results of the analysis done in the month of August (2011).

APPENDIX 2: Results of the analysis done in the month of October (2011).

APPENDIX 3: Results of the analysis done in the month of November (2011).

APPENDIX 4: Results of the analysis done in the month of December (2011).

APPENDIX 5: Results of the analysis done in the month of January (2012).

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APPENDIX 7: Cadmium calibration curve

APPENDIX 8: Zinc calibration curve

APPENDIX 9: Lead calibration curve

APPENDIX 10: Chromium calibration curve

Appendix 1: Results of the analysis done on the wastewater in the month of August (2011).

PARAMETER	AUGUST				
	CONC. IN INFLUENT	CONC. IN EFFLUENT	CONC IN STORM WATER	TOLERANCE LIMITS (NEMA) ENVIRONMENT (mg/L)	REMARKS
Hydrogen ions (pH)	7.2	6.9	7.1	6.5-8.5	Within the range
Biological Oxygen Demand (5 days at 20°C, mg/L)	1200	200	50	30 max	Off the range
Chemical Oxygen Demand (mg/L)	400	380	80	50 max	Off the range
Total Suspended Solids Dried at 105°C (mg/L)	1.2×10 ³	1.2 ×10 ³	0.5×10 ³	30 max	Off the range
Total Dissolved Solids Dried at 180°C (mg/L)	1200	1050	670	1200 max	Within the range
Oil and Grease (g/L)	331 mg/L	117 mg/L	Nil	Nil	Off the range
Total Phosphorus (mg/L)	13.46 mg/L	11.19 mg/L	0.56	2 Guideline value	
Total Nitrogen (mg/L)	2.40	2.10	1.70	2 Guideline value	
Chromium VI (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.05	Within the range
Cadmium(mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Lead (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Zinc (mg/L)	0.09	N.D (DL=0.02)	0.09	0.5	Within the range

Appendix 2: Results of the analysis done on the wastewater in the month of October (2011).

PARAMETER	OCTOBER				
	CONC. IN INFLUENT	CONC. IN EFFLUENT	CONC. IN STORM WATER	TOLERANCE LIMITS (NEMA) ENVIRONMENT (mg/L)	REMARKS
Hydrogen ions (pH)	7.0	6.8	7.2	6.5-8.5	Within the range
Biological Oxygen Demand (5 days at 20°C, mg/L)	360	85	90	30 max	Off the range
Chemical Oxygen Demand (mg/L)	1800	520	640	50 max	Off the range
Total Suspended Solids Dried at 105°C (mg/L)	460	350	170	30 max	Off the range
Total Dissolved Solids Dried at 180°C (mg/L)	1000	700	1900	1200 max	Outlet works within the range. Storm water off the range.
Oil and Grease	79	39	24	Nil	Off the range
Total Phosphorus (mg/L)	9.12	8.36	2.23	2 Guideline value	
Total Nitrogen (mg/L)	4.40	2.50	2.90	2 Guideline value	
Chromium VI (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.05	Within the range
Cadmium(mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Lead (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Zinc (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.5	Within the range

Appendix 3: Results of the analysis done on the wastewater in the month of November (2011).

PARAMETER	NOVEMBER				
	CONC. IN INFLUENT	CONC. IN EFFLUENT	CONC. IN STORM WATER	TOLERANCE LIMITS (NEMA) ENVIRONMENT (mg/L)	REMARKS
Hydrogen ions (pH)	7.0	6.8	7.0	6.5-8.5	Within the range
Biological Oxygen Demand (5 days at 20°C, mg/L)	380	95	65	30 max	Off the range
Chemical Oxygen Demand (mg/L)	220	100	80	50 max	Off the range
Total Suspended Solids Dried at 105°C (mg/L)	424	164	277	30 max	Off the range
Total Dissolved Solids Dried at 180°C (mg/L)	1400	1200	2000	1200 max	Off the range
Oil and Grease	112	85	Nil	Nil	Off the range
Total Phosphorus (mg/L)	10.31	3.59	2.38	2 Guideline value	
Total Nitrogen (mg/L)	10.60	5.26	4.66	2 Guideline value	
Chromium VI , as Cr(mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.05	Within the range
Cadmium(mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Lead (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Zinc (mg/L)	0.03	N.D (DL=0.02)	0.03	0.5	Within the range

Appendix 4: Results of the analysis done on the wastewater in the month of December (2011).

PARAMETER	DECEMBER				
	CONC. IN INFLUENT	CONC. IN EFFLUENT	CONC. IN STORM WATER	TOLERANCE LIMITS (NEMA) ENVIRONMENT (mg/L)	REMARKS
Hydrogen ions (pH)	7.1	6.8	7.0	6.5-8.5	Within the range
Biological Oxygen Demand (5 days at 20°C, mg/L)	350	200	50	30 max	Off the range
Chemical Oxygen Demand (mg/L)	150	80	80	50 max	Off the range
Total Suspended Solids Dried at 105°C (mg/L)	506	21.8	24.6	30 max	Within the range
Total Dissolved Solids Dried at 180°C (mg/L)	1146	1117	670	1200 max	Off the range
Oil and Grease	141	76	8	Nil	Off the range
Total Phosphorus (mg/L)	7.93	4.98	3.37	2 Guideline value	
Total Nitrogen (mg/L)	6.30	2.8`0	38	2 Guideline value	
Chromium VI (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.05	Within the limit
Cadmium(mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the limit
Lead (mg/L)	0.26	0.18	0.35	0.01	Off the limit
Zinc (mg/L)	3.06	0.07	0.09	0.5	Within the limit

Appendix 5: Results of the analysis done on the wastewater in the month of January (2012).

PARAMETER	JANUARY				
	CONC. IN INFLUENT	CONC. IN EFFLUENT	CONC. IN STORM WATER	TOLERANCE LIMITS (NEMA) ENVIRONMENT (mg/L)	REMARKS
Hydrogen ions (pH)	7.2	6.9	6.8	6.5-8.5	Within the range
Biological Oxygen Demand (5 days at 20°C, mg/L)	200	100	300	30 max	Off the range
Chemical Oxygen Demand (mg/L)	300	120	80	50 max	Off the range
Total Suspended Solids Dried at 105°C (mg/L)	150	40	35	30 max	Off the range
Total Dissolved Solids Dried at 180°C (mg/L)	1250	1000	2500	1200 max	Within the range
Oil and Grease	80	70	50	Nil	Off the range
Total Phosphorus (mg/L)	8.52	5.12	3.42	2 Guideline value	
Total Nitrogen (mg/L)	11	1.60	35	2 Guideline value	
Chromium VI (mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.05	Within the range
Cadmium(mg/L)	N.D (DL=0.02)	N.D (DL=0.02)	N.D (DL=0.02)	0.01	Within the range
Lead (mg/L)	0.44	0.11	0.30	0.01	Off the range
Zinc (mg/L)	3.28	0.05	0.09	0.5	Within the range

Appendix 6: Results of the analysis done in the month of February (2012).

PARAMETER	FEBRUARY			
	CONC. IN INFLUENT	CONC. IN EFFLUENT	CONC. IN STORM WATER	TOLERANCE LIMITS (NEMA) ENVIRONMENT
Hydrogen ions (pH)	7.0	6.9	7.2	6.5-8.5
Biological Oxygen Demand (5 days at 20°C, mg/L)	400	260	80	30 max
Chemical Oxygen Demand (mg/L)	250	180	80	50 max
Total Suspended Solids Dried at 105°C (mg/L)	600	50	30	30 max
Total Dissolved Solids Dried at 180°C (mg/L)	1400	587	2670	1200 max
Oil and Grease	180	60	20	Nil

Appendix 7: Calibration Standard for Cd

SpectrAA Report.

10:29 21/02/2014

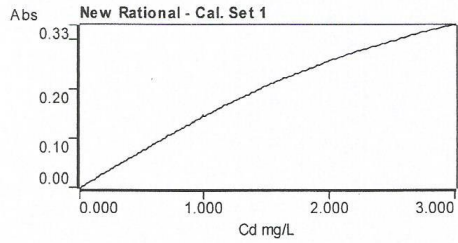
Page 1 of 1

Analyst SM
 Date Started 11:22 06/01/2012
 Worksheet cd 06012012
 Comment
 Methods Cd
 Computer name KENRB025
 Serial Number:

Nominal Weight = 1.0000 Nominal Volume = 1.0000

Method: Cd (Flame)

Sample ID	Conc mg/L	%Prec	Mean Abs	Weight	Volume
CAL ZERO	0.000	0.0	-0.0015	1.0000	1.0000
	Readings				
	-0.0015	06/01/2012	11:26:22		
STANDARD 1	1.000	0.5	0.1432	1.0000	1.0000
	Readings				
	0.1432	06/01/2012	11:27:32		
STANDARD 2	2.000	0.5	0.2542	1.0000	1.0000
	Readings				
	0.2542	06/01/2012	11:27:40		
STANDARD 3	3.000	0.5	0.3287	1.0000	1.0000
	Readings				
	0.3287	06/01/2012	11:27:48		



Appendix 8: Calibration Standard for Zn

SpectrAA Report.

10:22 21/02/2014

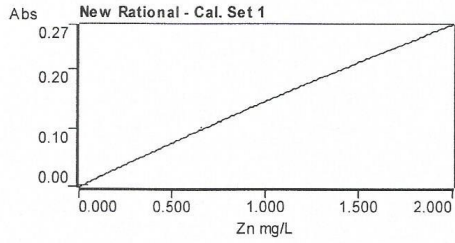
Page 1 of 2

Analyst VA
 Date Started 14:21 01/03/2012
 Worksheet cr in waters
 Comment
 Methods Cr,Pb,Zn
 Computer name KENRB025
 Serial Number:

Nominal Weight = 1.0000 Nominal Volume = 1.0000

Method: Zn (Flame)

Sample ID	Conc mg/L	%Prec	Mean Abs	Weight	Volume
CAL ZERO	0.000	14.9	0.0009	1.0000	1.0000
	Readings				
	0.0009	01/03/2012	14:39:24		
STANDARD 1	0.667	0.5	0.0985	1.0000	1.0000
	Readings				
	0.0985	01/03/2012	14:40:08		
STANDARD 2	1.333	0.4	0.1851	1.0000	1.0000
	Readings				
	0.1851	01/03/2012	14:40:30		
STANDARD 3	2.000	0.3	0.2750	1.0000	1.0000
	Readings				
	0.2750	01/03/2012	14:40:52		



Appendix 9: Calibration Standard for Pb

SpectrAA Report.

10:22 21/02/2014

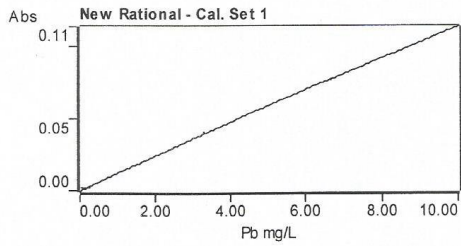
Page 1 of 2

Analyst VA
 Date Started 14:21 01/03/2012
 Worksheet cr in waters
 Comment
 Methods Cr,Pb,Zn
 Computer name KENRB025
 Serial Number:

Nominal Weight = 1.0000 Nominal Volume = 1.0000

Method: Pb (Flame)

Sample ID	Conc mg/L	%Prec	Mean Abs	Weight	Volume
CAL ZERO	0.00	7.3	0.0023	1.0000	1.0000
	Readings				
	0.0023	01/03/2012	14:39:16		
STANDARD 1	3.33	0.5	0.0403	1.0000	1.0000
	Readings				
	0.0403	01/03/2012	14:40:02		
STANDARD 2	6.67	0.5	0.0761	1.0000	1.0000
	Readings				
	0.0761	01/03/2012	14:40:26		
STANDARD 3	10.00	0.4	0.1144	1.0000	1.0000
	Readings				
	0.1144	01/03/2012	14:40:48		



Appendix 10: Calibration Standard for Cr

SpectrAA Report.

10:21 21/02/2014

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Analyst VA
 Date Started 14:21 01/03/2012
 Worksheet cr in waters
 Comment
 Methods Cr,Pb,Zn
 Computer name KENRB025
 Serial Number:

Nominal Weight = 1.0000 Nominal Volume = 1.0000

Method: Cr (Flame)

Sample ID	Conc mg/L	%Prec	Mean Abs	Weight	Volume
CAL ZERO	0.000	18.0	0.0005	1.0000	1.0000
	Readings				
	0.0005	01/03/2012	14:39:04		
STANDARD 1	5.000	0.5	0.1025	1.0000	1.0000
	Readings				
	0.1025	01/03/2012	14:39:54		
STANDARD 2	10.000	0.5	0.1963	1.0000	1.0000
	Readings				
	0.1963	01/03/2012	14:40:18		
STANDARD 3	15.000	0.5	0.2950	1.0000	1.0000
	Readings				
	0.2950	01/03/2012	14:40:40		

