UNIVERSITY OF NAIROBI

DEPARTMENT OF CIVIL ENGINEERING

EVALUATION OF THE PERFORMANCE OF AN ONSITE WASTEWATER TREATMENT PLANT

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ABSTRACT

In areas where there are no sewerage systems, wastewater requires to be treated onsite. This study evaluated the performance of onsite wastewater treatment plants located at Maasai Mall at Rongai, Kajiado County, and at Kabete Flats in the Lower Kabete area of Nairobi. The two onsite wastewater treatment systems worked on the principle of aerobic digestion through aeration. This OWTS has one flow equalization chamber, one sludge-holding chamber, two aeration chambers, two settlement tank, stand-by pump system, chlorinator housing and a storage chamber. The OWTS treats approximately 4,000 litres per day in the Maasai Mall system and 2,700 litres per day in the Kabete system. These systems were designed by the *JET Inc.*®, and sized, installed and maintained by *CESP Kenya*. Samples were collected from the inlet and outlet, and analyzed for the major water quality parameters pH, COD, BOD_5, TSS and TDS to evaluate the efficiency of the OWTS. The OWTS at Maasai Mall reduced initial concentrations of BOD_5, COD, TSS, TDS of 674, 1088, 200 and 1410 mg/L respectively to approximately 19, 56, 60 and 810 mg/L respectively. Percentage removal of BOD_5, COD, TSS and TDS of up to 95.6, 94.9, 70.0 and 42.6% respectively was achieved. Similar removals were observed for the Kabete OWTS. The ratio of$BOD_5$to COD in the samples tested was in the range 0.4 to 0.7 for untreated effluent and 0.1 to 0.2 for the final treated effluent. This is typical of domestic/municipal sewage wastes where the BOD_5 to COD ratio is between 0.3 to 0.8 and 0.1 to 0.3 for untreated and treated effluent, respectively. The effluent was within standards for treated wastewater re-use in flushing of toilets and gardening.

DEDICATION

To my parents, Mr. and Mrs. Kara, for giving so selflessly and withholding nothing from me that I required to pursue my education and to my sister, Njeri, for the encouragement and support.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EPA - Environmental Protection Agency

WHO - World Health Organization

BOD - Biochemical Oxygen Demand

COD - Chemical Oxygen Demand

DO - Dissolved Oxygen

TSS - Total Suspended Solids

TDS - Total Dissolved Solids

CESP - Collaboration Engineering Solutions and Products

OWTS - Onsite Wastewater Treatment System

ETP - Effluent Treatment Plant

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Kenya is a developing country whose population is growing rapidly resulting in urbanization and associated pollution. A lot of wastewater is generated from industries and households; however, there is inadequate infrastructure for its management. Poorly treated wastewater with high levels of pollutants caused by poor design, operation or treatment systems creates major environmental problems when discharged to the surface land or water bodies. On the other hand, Kenya is classified as a water-scarce country with only 650 m^3/year per capita of renewable fresh water which could drop to about 350 m^3/year by the year 2020. This means that Kenya is suffering from a water crisis and is threatened by more of it during the next years. (Ngigi and Macharia, 2006).

Effective treatment methods of wastewater can be a great contributor in mitigating the low availability of potable water in the country. This treated wastewater however requires meeting some set out quality standards to be considered suitable for re-use, for which in Kenya, the National Environmental Management Authority (NEMA) has provided these guidelines, in line with World Health Organization (WHO) standards. This has led to the need for cost-effective technologies to be adopted for wastewater treatment, management and re-use.

Where there are no sewerage systems, onsite wastewater systems are designed to treat and dispose of effluent on the same property that produces the wastewater. These systems offer sustainable technology to deal with sewage management for the extraordinary real estate, commercial and industrial development that has grown in Kenya over the past years with inadequate centralized sewer lines as well as provide alternative wastewater treated for secondary uses such as irrigation, landscaping thus save fresh water for potable use as a means of addressing water scarcity in the country.

Untreated (raw) wastewater is characterized by high levels of organic matter, nutrients, numerous pathogenic microorganisms and toxic compounds making it a significant source of non-point source pollution. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Sewage is treated so as to reduce undesirable characteristics, usually, it is BOD and suspended solids concentrated to the degree necessary to ensure it does not pollute or contaminate to unacceptable degree, any water resource into which it is discharged or so that it can be re-used, like in flushing of toilets or irrigation.

Increasing awareness on the limited water resource currently available has yielded recognition of the concept of water reuse, rather than disposal, over recent years. In many parts of the world, acceptance of this concept has been accelerated by development of new wastewater treatment processes and technologies that can yield high effluents at economically feasible levels.

Recognition of the impacts of onsite treatment systems on ground water and surface water quality (e.g. nitrate and bacteria contamination, nutrient inputs to surface waters) has increased interest in optimizing the systems' performance. Public health and environmental protection officials now acknowledge that onsite treatment systems are not just temporary installations that will be replaced eventually by centralized sewage treatment services, but permanent approaches to treating wastewater for release and reuse in the environment. Onsite systems are recognized as viable, low-cost, long-term, decentralized approaches to wastewater treatment if they are planned, designed, installed, operated, and maintained properly (USEPA, 1997).

Finding economically, affordable, alternative wastewater treatment plants and technologies is a need in the treatment of wastewater. This study seeks to contribute in the search and awareness of the efficiency of commercial wastewater treatment plants for water management and re-use.

1.2.PROBLEM STATEMENT

Onsite wastewater treatment is a sanitation option where there is no sewer or where there is need to recycle water. Onsite wastewater treatment systems treat wastewater from homes or businesses and return treated wastewater back into the receiving environment. Most onsite wastewater treatment systems involve two stages of treatment; the first stage in a tank or treatment system, and the second when the effluent is dispersed on to land or the garden and further breaks down. The first stage may be carried out in a septic tank or in a more advanced system such as an aerated wastewater treatment system or advanced sewage treatment system. These systems are much more advanced than septic tanks and treat effluent to a level that allows it to be used on the garden or even recycled for toilet flushing and vehicle washing.

Site limitations and more stringent performance requirements have led to significant improvements in the design of wastewater treatment systems and how they are managed. The onsite wastewater treatment system (OWTS) industry has developed many new treatment technologies that can achieve high performance levels on sites with size, soil, ground water, and landscape limitations that might preclude installing conventional systems. New technologies and improvements to existing technologies are based on defining the performance requirements of the system, characterizing wastewater flow and pollutant loads, evaluating site conditions, defining performance and design boundaries, and selecting a system design that addresses these factors.

While wastewater can be treated for discharge into natural water courses, scarcity and pollution of fresh water which is a threat to development and life sustainability makes it prudent to consider the reuse of the treated waste water. Potable water that is treated to drinking water standards is commonly used for irrigation of lawns and other general cleaning purposes; activities that could utilize water of much lower quality. Reuse of treated wastewater would save available potable water for drinking and uses that require high quality water standards and contribute to alleviating problems of water scarcity. Wastewater which has undergone treatment can be recycled and be used for the purposes mentioned above. However, there is limited data on the efficiency of onsite wastewater treatment systems. Therefore, there is need for research and data collection on the performance of these systems to determine treatment efficiency.

1.3.OBJECTIVES

The aim of this study was to establish the efficiency of the *JET Inc.* ® onsite wastewater treatment systems at Maasai Mall in Rongai in Kajiado County and at Kabete Flats in the Lower Kabete area of Nairobi for the improvement of water quality characteristics for disposal and re-use

The specific objectives were to:

1. Evaluate the water quality parameters (BOD_5, COD, DO, pH, TDS, TSS levels) of wastewater discharged from the Maasai Mall and Kabete Flats.

2. Evaluate the effluent wastewater quality for the onsite wastewater treatment plant.

3. Establish the efficiency of the treatment process in terms of system performance.

4. Determine the appropriateness of the effluent for re-use.

1.4.SCOPE AND LIMITATIONS OF THE STUDY

This study focusses on institutional wastewater effluent. Tests will be carried out on wastewater sampled from the Maasai Mall wastewater treatment plant, a commercial shopping mall in Rongai, and Kabete Flats, residential apartments at Lower Kabete. The research will focus on the performance of an advanced wastewater treatment system manufactured by *JET Inc.* ®

The research project will be cover influent and effluent water quality parameters. These parameters will be tested at the University of Nairobi, Public Health Engineering Laboratory.

CHAPTER TWO

2. LITERATURE REVIEW

2.1.WASTEWATER CHARACTERISTICS

The effective treatment and management of any wastewater system requires a reasonably, accurate knowledge of its characteristics. The many substances found in wastewater are used by system designers and operators to evaluate wastewater because they affect public health and the environment and consequently, the design, cost and effectiveness of treatment. These characteristics vary from location to location, depending on population and the activity of the generating establishment (residential, municipal, commercial, industrial and agricultural). Wastewater typically has physical, biological and chemical characteristics.

Physical characteristics of wastewater include odour, gray color, turbidity and a solid content of almost 0.1%. Biologically, wastewater contains various microorganisms. Protista (bacteria, fungi, protozoa, algae), plants and animals. Toxic compounds are generated by the Protista and found in wastewater. Chemically, wastewater is composed is both inorganic and organic compounds as well as various gases. Inorganic compounds include heavy metals, nitrogen, sulphur, phosphorus, chlorides etc. Organic compounds may constitute carbohydrates, proteins, fats, greases, oils, pesticides, phenols etc. Wastewater contains a higher portion of dissolved solids than suspended, about 85% - 90% of the total inorganic component is dissolved and about 55%-60% of the total organic component is dissolved. Gases dissolved in wastewater are hydrogen sulphide, methane, ammonia, oxygen, carbon (IV) oxide and nitrogen (Bansode, 2002).

2.2.OTHER IMPORTANT WASTEWATER CHARACTERISTICS

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: 1) biological processes are temperature dependent 2) chemical reactions and reaction rates and aquatic life are temperature sensitive. The best temperature for wastewater treatment range from 25 – 35˚C

The measure of acidity or alkalinity of a solution, known as pH affects the treatment of wastewater. It needs to remain between 6 and 9 to protect beneficial organisms.

Table 2.1: Typical Raw Municipal Sewage Characteristics

Component	Units	Concentration Range	Typical Concentration
Solids, total (TS)	mgL^{-1}	390 – 1230	720
Dissolved, total (TDS)	mgL^{-1}	270 – 860	500
Total Suspended Solids (TSS)	mgL^{-1}	155 – 330	250
Settleable Solids	mgL^{-1}	5 – 20	10
5-day Biochemical Oxygen Demand BOD_5	mgL^{-1}	155 – 286	250
COD	mgL^{-1}	250 – 800	430
pH	s.u.[a]	6 – 9	6.5
Total Coliform Bacteria	CFU/100mL[b]	10^8 - 10^{10}	10^9
Facel Coliform Bacteria	CFU/100mL	10^6 - 10^8	10^7
Total Nitrogen	mgL^{-1}	26 – 75	60
Total Phosphorus	mgL^{-1}	6 – 12	10

a = standard units
b = Colony-Forming Units per 100 milliliters

2.3.CONVENTIONAL METHOD OF WASTEWATER TREATMENT

As mentioned earlier, the main purpose of wastewater treatment is to remove the contaminants from water so that the treated water can meet the acceptable quality standards. Available wastewater treatment process can be broadly classified as physical, chemical, or biological. These processes, which consist of a series of unit operations, are applied in different sequences and combinations, depending on the prevailing situations of influent concentration condition and composition and specifications of the effluent. Physical processes include screening, sedimentation, flotation and filtration. They are based on the exploitation of the physical properties of the contaminants. Chemical processes utilize the chemical properties of the added reagents as well as the impurities. They include precipitation, disinfection and coagulation. Biological processes utilize biochemical reactions e.g. activated sludge process (Rao, 1991).

Wastewater treatment processes are grouped according to the water quality they are expected to produce, that is, primary treatment, secondary treatment and tertiary wastewater treatment.

A schematic layout of a conventional wastewater treatment plant is presented in Figure 2.1

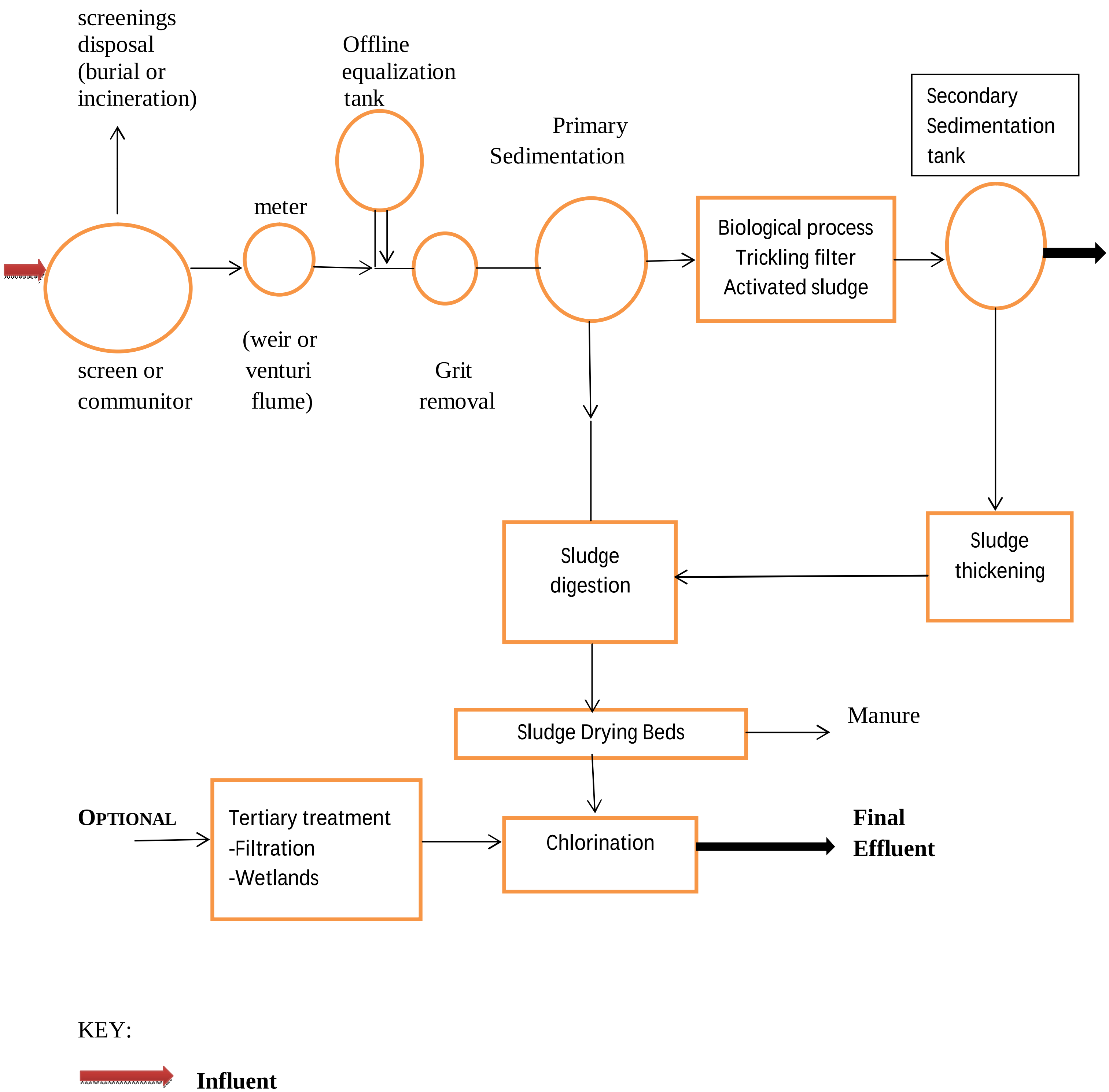

Figure 2.1: Typical Flow sheet of a Conventional Treatment Plant

2.3.1. PRIMARY TREATMENT

Primary treatment removes identifiable suspended solids and floating matter.

Screening: This process involves removal of large objects such as stones or sticks that could otherwise block tanks inlets and plug lines

Grit removal: The velocity of the sewage is slowed to allow sand, grit, broken glass and stones to settle. These are then removed because they may cause damage to equipment.

Comminutors: They are sometimes adopted to supplement coarse screening and serve to reduce the size of large particles so that they will be removed in the form of sludge in subsequent treatment processes.

Sedimentation tanks or clarifiers: They are round or rectangular basins, typically 3 to 5 m deep, with hydraulic retention time between 2 and 3 hours. Settleable solids (primary sludge) settle out and are pumped to sludge processing units. Scum is swept across the tank surface by water jets or mechanical means from which it is also pumped to sludge processing units.

2.3.2. SECONDARY TREATMENT

This is also known as biological treatment. Oxygen supplied to the bacteria is consumed under controlled conditions so that most of the BOD is removed in the treatment plant rather than in the watercourse. Non-settleable solids are converted to settle-able solids.

Activated sludge process: The essential features of the process include aeration, followed by solid-liquid separation and sludge recycle system. A bacterium converting activated sludge is continually recirculated back to the aeration basin to increase the rate of organic decomposition allowing the solids to settle.

Trickling filters: Conventional trickling filters normally consist of a rock bed, 1 to 3 meters in depth, with enough openings between rocks to allow air to circulate easily. The influent is sprinkled over the bed packing which is coated with a biological slime. Oxygen and the dissolved organic matter diffuse into the film to be metabolized by the microorganisms in the slime layer. As the microorganisms utilize the organic matter, the thickness of the slime film increases to a point where it cannot be supported on the solid media anymore. It therefore detaches itself from the surface. This process is known as sloughing. A settling tank following the trickling filter removes the detached bacterial film and some suspended matter.

Lagoon: Lagoons rely mainly on interaction of sunlight, algae, microorganisms and oxygen.

2.3.3. TERTIARY TREATMENT

Tertiary treatment serves to remove (1) suspended solids (2) BOD (3) plant nutrients (4) dissolved solids and (5) toxic substances. The process includes chemical and physical treatments. Chemical treatments involve hydrolysis, ozonation, precipitation, coagulation and flocculation. Physical processes consist of electro-dialysis, reverse osmosis, carbon adsorption and centrifugation. (Rao, 1991)

Industrial wastewater may contain traces of heavy metals, organic chemicals and other contaminants. The effluent from a typical secondary treatment plant still contains 20 - 40mg/l BOD and 20 - 40mg/l suspended solids, which may be objectionable in some streams. High concentrations of BOD can cause damage to aquatic life by reducing the dissolved oxygen content.

2.4.ONSITE WASTEWATER TREATMENT SYSTEMS (OWTS)

2.4.1. SEPTIC TANK

The most common and traditional onsite wastewater treatment system is a septic tank and a soil adsorption field that allows treated effluent to infiltrate into the soil. The septic tank allows particulate matter to settle to the bottom of the tank so that large solids do not plug the drain field, digests organic matter and stores liquids through a period of detention. An effluent screen placed in the outlet of the septic tank is used to filter suspended solids out of the effluent. Final treatment and dispersal of the wastewater takes place in the soil adsorption filed.

Advanced OWTS use pumps and advanced treatment like aerobic and bio-filter units. Factors like location, space, laws and regulations and quantity of wastewater being treated determine the type of OWTS used. These systems use technologies that require greater frequency of operation and maintenance.

Some of these treatment units are described below.

2.4.2. AEROBIC TREATMENT UNITS

It is a mechanical OWTS that provides secondary wastewater treatment where solids settle in a compartment and are partially digested by microorganisms. A motor pumps air into the chamber and mixes the liquid facilitating diffusion of air and supporting aerobic digestion that further degrades the wastewater. The treated effluent is discharged through a soil absorption field.

Advantages: TSS and BOD are reduced and this improves the efficiency and life of the absorption field.

2.4.3. FIXED-ACTIVATED SLUDGE TREATMENT

Fixed-Activated Sludge Treatment – similar to aerobic treatment units that fit inside septic tanks. The wastewater cycles between the two and this recycling action causes microorganisms to convert ammonia and nitrates into nitrogen gas.

Advantage: The effluent is recycled making this system more efficient in removal of ammonia and nitrates.

2.4.4. RECIRCULATING SAND FILTER

Effluent from the septic tank is pressurized and sprayed on a packed bed filter of sand or other granular material. Micro-organisms breakdown organic matter and convert ammonia into nitrate as the effluent filters through the sand. When the effluent reaches the under drain, a portion of the water enters the soil absorption field and the rest re-circulates through the septic tank, where the nitrates are converted into nitrogen gas.

Advantages: Efficient at reducing biochemical oxygen demand, total suspended solids, and ammonia and nitrate levels in a relatively small area.

2.4.5. TRICKLING FILTER

Microorganisms typically grow on a specially designed synthetic material, such as a plastic polymer, instead of being carried with the liquid, as in a typical septic system.

Advantage: Can handle surges of flow to the system without losing the microbial community responsible for effluent treatment therefore extremely effective at reducing BOD.

The main disadvantages of these advanced systems are that they require electricity and moving parts, frequent inspection and maintenance and high equipment replacement costs

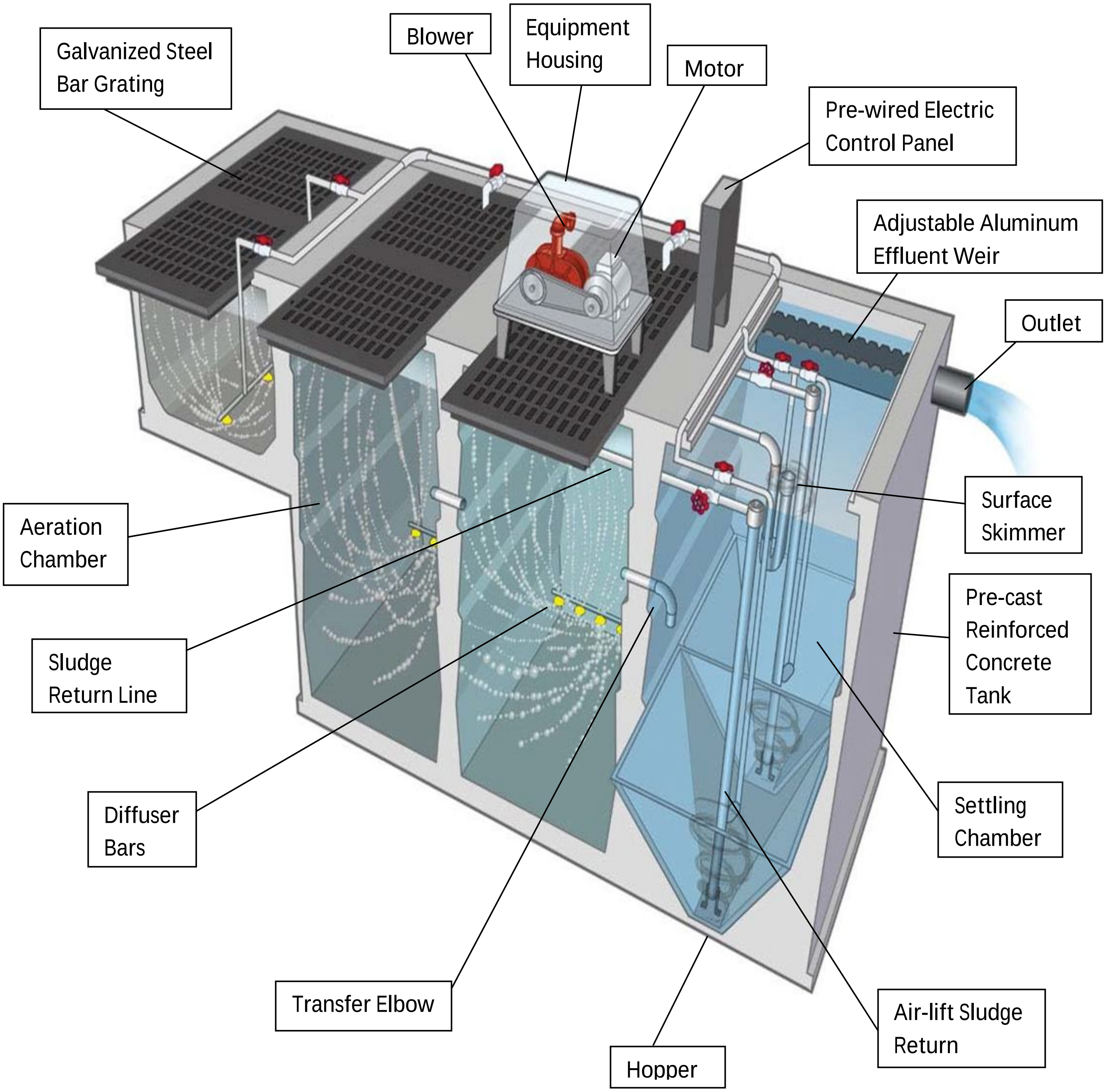

Figure 2.2: Cut-away of a Typical *JET Inc.*® Commercial Wastewater Treatment Plant

2.5.THE TREATMENT PROCESS

The *JET Inc.*® Wastewater Treatment Plants employ the biological process of 'extended aeration' or aerobic digestion.

In this process incoming wastewater enters an aeration tank where the contents are thoroughly mixed and aerated by large volumes of air which are pumped into the tank under pressure. As the air bubbles to the surface, it transfers oxygen to the tank liquids. Aerobic bacteria present in the activated sludge in the tank use this oxygen to convert the wastewater to inoffensive, clear, odorless liquids and gases. The bacteria actually destroy the wastewater by using oxygen. After the treated liquid leaves the aeration tank, it is held in a settling tank, which is completely still. Here any partially treated particles settle to the tank bottom and are returned to the aeration tank for further treatment. This settling produces a clear, highly treated liquid which is ready for final discharge.

2.5.1. EXTENDED AERATION PLANTS

Basically, extended aeration plants can be divided into four main elements.

These elements are:

1. Pre-Treatment
2. Aeration
3. Settling
4. Optional Equipment

2.5.1.1.PRE-TREATMENT

In this first stage, a pre-treatment device is used to physically breakdown the wastewater and trap untreatable material such as plastic or metal before it can enter the plant.

The three basic types of pre-treatment devices are bar screens, comminutors and trash traps.

In the pre-treatment tank or trash trap the untreatable material is settled out and organic solids are pre-treated and broken down both physically and bio-chemically before being passed on to the aeration tank.

Figure 2.3: Influent point with Trash trap and Bar Screen

2.5.1.2.AERATION

In the aeration tank, aerobic digestion takes place. Here the pre-treated incoming wastewater is mixed and aerated by air diffusers, located in the bottom of the tank. These diffusers inject ample air to meet the oxygen demand of the aerobic digestion process as well as mix the entire tank contents.

2.5.1.3.SETTLING

The next step in the process takes place in the settling compartment where there is no circulation so any remaining solids can settle to the tank bottom and be returned to the aeration chamber by the sludge return.

Figure 2.4: Aeration Chamber, Settling Chamber and Equipment Housing (Blower and Motor)

2.5.1.4.OPTIONAL EQUIPMENT

Surface skimmers: They are used to remove any floating particles or material from the surface of the final settling tank. After it is removed, the material is returned to the aeration chamber for further treatment. They are a helpful maintenance tools because they eliminate the need for manually cleaning the settling tank surface.

Stand-by equipment: Duplicate mechanical components for stand-by operation are sometimes required. The plants are designed so that these duplicate mechanical components alternate operation, allowing no single set of components to sit idle for long. This special alternation keeps the stand-by equipment in as fine a running order as the other set of components.

Figure 2.5: Duplex Electronic Pump Controllers at Maasai Mall ETP

Sludge-holding tank: Sometimes excess activated sludge is produced. In this case a sludge-holding tank can be installed. Sludge is pumped into the holding tank through auxiliary piping which is connected to the plant's sludge-return pump. The sludge is held here until it is hauled away or returned to the plant for final treatment. Holding tanks can equipped with diffusers which aerate the tanks. Aerating a sludge-holding tank provides some treatment and eliminates the possibility of odour.

Figure 2.6: Air-lift Sludge Return

Disinfection System: A hypo-chlorination system can be designed and installed to add liquid chlorine to treatment plant effluent. Chlorine can also be added as a gas. It comes in cylinders which also feed into a contact chamber.

Advantages:

1. Effective for most microorganisms
2. Can oxidize iron and manganese making them easier to remove
3. Keeps a residual in distribution system
4. Technology is well understood
5. Relatively easy to use in hypochlorite form

Disadvantages:

1. Generates toxic disinfection by-products
2. Not effective against certain protozoa
3. Can cause taste and odour problems

2.6.ORGANIC COMPOUNDS IN WASTEWATER

Many of the contaminants in wastewater are highly stabilized organic compounds that are not destroyed by biological or chemical treatment of wastes. The organic contaminants are not appreciably removed by steps of coagulation, chlorination and filtration employed in water purification plants. Some organic pollutants are more absorbable than others. Organic solvents are absorbable due to their low solubility in water. Higher molecular weight compounds are also effectively absorbed. Compounds such as alcohols are poorly absorbed. (Stenzel, 1995).

2.6.1. BOD

The most widely used and parameter of organic pollution applied to both wastewater and surface water is the 5-day BOD (BOD_5). This determination involves the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. BOD test results are now used to (1) determine the approximate quantity of oxygen that will be required to biologically stabilize the organic matter present (2) determine the size of waste-treatment facilities (3) measure the efficiency of some treatment processes and (4) determine compliance with wastewater discharge permits (Metcalf and Eddy, 2004).

Biochemical Oxygen Demand (BOD) is one of the most important and useful parameters that indicates the organic strength of a wastewater. It not only indicates the strength of wastewater but also that of the treated effluent. It is essentially a measure of the biological and chemical component of the waste in terms of the dissolved oxygen needed by the natural aerobic biological system in the wastewater to break down the waste under defined conditions.

2.6.2. COD

COD test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in an acid solution. During digestion, the chemically oxidizable organic material reduces a stoichiometrically equivalent amount of dichromate; the remaining dichromate is titrated with a standard ferrous ammonium sulphate solution. The amount of potassium dichromate reduced gives a measure of the amount of oxidizable organic material.

The measure of COD offers a quick estimate of carbonaceous material compared to conventional BOD measurements

The COD test does not distinguish between organic materials that are biodegradable and those that are not, and, hence, gives a measure of the total oxidizable organic material in the sample representing the wastewater (Rao, 1991). As a result COD values should be greater than BOD values and may be much greater when significant amounts of biologically resistant organic matter is present.

2.7.SOLID MATTER IN WASTEWATER

This is a measurement of the concentration of particulate solids that can dissolve or suspend in wastewater, that is, total dissolved solids (TDS), total suspended solids (TSS), total volatile solids (TVS) and total fixed solids (TFS).

TDS is measured as the mass of residue remaining when a measured volume of filtered water is evaporated. The mass of dried solids remaining on the filter is called total suspended solids

(TSS). Settleable solids are measured as the visible volume accumulated at the bottom of an Imhoff cone after water has settled for on

2.8.DISSOLVED OXYGEN (DO) IN WASTEWATER

A DO test measures the concentration of oxygen dissolved in a water or wastewater sample. The concentration of DO in a sample is significantly influenced by:

1. Temperature – as water temperature increases DO decreases (Table 2.2)
2. Salinity – as water salinity increases DO decreases
3. Atmospheric pressure – as pressure increases DO also increases because water holds less oxygen as altitude increases

Table 2.2: Effect of Temperature on Oxygen Saturation on 1 Atmospheric Pressure (Sea Level)

Temperature (ºC)	Concentration (mg/L) of DO at Saturation
0	14.6
5	13.1
10	11.3
15	10.1
20	9.1
25	8.2

Adapted from Metcalf and Eddy 2003

2.9.HYDROGEN-ION CONCENTRATION IN WASTEWATER

pH approximates the concentration of hydrogen ions in a solution. In the laboratory pH is measured by electrometric pH measurement which is the determination of the activity of the hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode

CHAPTER THREE

3. RESEARCH METHODOLGY

3.1.SOURCES OF WASTEWATER

Wastewater used in the study was sampled from two sites; namely

1. The Maasai Mall in Rongai
2. Kabete Flats in Lower Kabete

These sites served as suitable locations to obtain influent and effluent samples because they are a commercial and residential area respectively that have a similar OWTS installed and maintained for approximately a year.

The source of the wastewater influences the characteristics of the waste stream. In general, the source can be categorized as residential, municipal, commercial, industrial or agricultural.

Laboratory tests were set up to determine the water quality improvement characteristics of the treated wastewater by assessing and monitoring some physio-chemical characteristics of the wastewater at the inlet and the outlet of the treatment plant.

The physio-chemical parameters investigated include BOD, COD, pH, dissolved oxygen, total suspended solids and total dissolved solids

3.2.MATERIALS AND METHODS

The samples were tapped at the inflow and outflow points. Collection of the influent and effluent was carried out in the morning hours both at the same time so as to accurately determine the efficiency of treatment and allow for time for transportation and testing. Care was taken not to collect deleterious materials, which would otherwise alter the results. The period between sampling and detailed analysis was maintained below 12 hours to maintain physio-chemical properties as similar as possible to OWTS sites; in so doing, preservation procedures were not necessary. Except the BOD_5 test which was conducted on the different dilutions 5 days after incubation as is the procedure.

The wastewater analysis was carried out at the University of Nairobi, Public Health Engineering laboratory.

3.3.WATER QUALITY ANALYSIS

The influent and effluent wastewater characteristics were each determined through a series of standard tests. The parameters of concern determined through standard tests included;

1. BOD
2. COD
3. pH
4. Dissolved Oxygen (DO)
5. Total Suspended Solids (TSS)
6. Total Dissolved Solids (TDS)

3.3.1. BOD

Determination of BOD involves the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. If sufficient oxygen is available, the aerobic biological decomposition of an organic waste will continue until all of the waste is consumed. Standard methods will be used to determine BOD.

BOD bottles of a capacity of 280ml each were filled with a specific volume of wastewater samples and dilution water added to result in the dilutions 1:10, 1:25, 1:50, 1:100 and a dilution water blank sample (dilution water without any sample). Dual sets of each dilution ratio including the dilution water blank were prepared.

The stoppers of each bottle were then replaced carefully so as not to trap any bubbles. This was followed by removing the stopper and 2 ml of each of manganoussulphate and Alkali oxide iodide were added with the tip of the pipette below the water surface. The stopper was then carefully replaced and the contents mixed.

The contents were then remixed after the precipitate had settled down. After the precipitates settled down again 2 ml of sulphuric acid was added with pipette's tip below the water level. This was followed by replacing the stopper and mixing all the contents till all the precipitate had dissolved.

203 ml was measured from the bottle and transferred to an Erlenmeyer flask. This was titrated against standard sodium thio-sulphate solution until the colour changed to pale yellow. 1 ml of starch indicator solution was then added and titration continued until the blue colour disappeared. The volume of titrate used was recorded as the D_1 value. This was done for one set of each dilution.

The remaining set of bottles was incubated at 20ºC for 5 days in the incubation cabinet. The dissolved oxygen concentration in each bottle (D_2) at the end of the incubation was determined in the same procedure outlined above.

The BOD value was then computed as shown:

$$5 - \text{day}, 20^{\circ}\text{C BOD} = \frac{D_1 - D_2}{P} \ (\text{mg/L})$$

Where;

D_1 = DO of diluted sample immediately after preparation, mg/L

D_2 = DO of diluted sample after 5days incubation at 20˚C

P = decimal volumetric fraction of sample used.

3.3.2. COD

This test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically by a strong chemical oxidant.

Open reflux method was used to measure the COD in both the influent and effluent. The test is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The test is usually used for monitoring and control of wastewater processes and results are obtained within a relatively short time (3 hours).

The following reagents were added to a 250 ml Erlenmeyer flask: 0.4 g solid mercuric sulphate, 5 ml (influent) and 10 ml (effluent) of sample diluted to 20 ml with distilled water, 10 ml of 0.25 N potassium dichromate and a few glass beads.

The above step was then repeated with 20 ml of distilled water used in place of the sample to act as a blank. Both the sample and blank flasks were then fitted to a condenser system with care being taken to make sure that the ground glass joint was snug. This was followed by starting the flow of cooling water through the condenser and then adding very slowly 30 ml of silver sulphate concentrated sulphuric acid solution to both flasks while swirling them to mix the contents.

After the addition of the acid, the heaters were switched on and the reagents left to reflux for about 2 hours before switching off the heaters. The condensers were then flushed with distilled water and disconnected from the flasks carefully after they had cooled. The flasks were removed from the heater and their contents diluted to about 150 ml with distilled water each. This was followed by the addition of 2 – 3 drops of ferroin indicator to the flasks and their contents titrated with standard ferrous ammonium sulphate of 0.01N strength. The titration was stopped once the colour of the contents changed from blue-green to reddish-brown. The amount of titrant used for both sample and blank was then noted down.

The value of COD was calculated as follows:

$$\text{COD} = \frac{(\text{a} - \text{b}) \times \text{N} \times 8000}{\text{ml of sample}} \quad (\text{mg}/L)$$

Where;

a = ml of titrant used for the blank sample

s = ml of titrant for the original sample

N = normality of the sample

3.3.3. HYDROGEN ION CONCENTRATION (pH)

A pH Meter was used. The pH meter electrodes were carefully raised out of their container and rinsed with distilled water. Drops of water were wiped from the electrodes. Approximately 75 ml of sample was placed in a 100ml beaker and the electrodes were immersed in the beaker containing the sample. The selector switch was turned to 'pH'. The pH was read directly from meter. The electrodes were raised, rinsed with distilled water and replaced in a beaker of distilled water.

3.3.4. DISSOLVED OXYGEN (DO)

A Dissolved Oxygen Probe was used to measure the concentration of dissolved oxygen in the samples. The tip of the probe was dipped into each sample and kept in there for a few minutes until the concentration data stabilized. The probe was rinsed with distilled water and gently blotted dry after each reading.

3.3.5. TOTAL SUSPENDED SOLIDS (TSS)

Total suspended solids refer to matter that remains as residue after evaporation and drying at 103°C and 105°C. Tests for various forms of solids do not determine specific chemical substances but rather classes of material which have similar physical properties and response to ignition.

Moisture-free, dry piece of filter paper was weighed on a digital balance. It was then wet with distilled water.

The Gooch crucible was mounted onto a suction pump, the wet filter paper inserted into it to act as a filter and 50ml (influent) or 100ml (effluent) of the sample transferred quickly by means of a 100ml volumetric cylinder and shaken vigorously using strong suction. The filter paper was then removed and dried in the oven overnight at 103ºC to 105ºC thereafter weighed.

The total suspended solids were computed as follows:

$$TSS = \frac{W \times 10^6}{V} \; (mg/L)$$

Where;

W = residue obtained (g)

V = volume of sample taken for filtration (mL)

3.3.6. TOTAL DISSLOVED SOLIDS (TDS)

100ml of each sample was measured using a volumetric cylinder and transferred to a dry evaporating dish. The combined weight was measured using an analytical balance and recorded.

The contents of in the dish were evaporated in a water-bath and the final reading of the dish and residue were weighed on the analytical balance.

The total dissolved solids were computed as follows:

$$TDS = \frac{W \times 10^6}{V} \text{ (mg/L)}$$

Where;

W = of residue obtained (g)

V = volume of sample taken for filtration (mL)

All experimental procedures were obtained from the Standard Method for the Examination of Water and Wastewater

3.4.TREATMENT EFFICIENCY

In order to design onsite wastewater treatment systems, we must consider the nature of the wastewater because the effluent quality depends upon the influent characteristics. The treatment capacity and treatment efficiency of systems are calculated based upon the influent concentrations and the effluent requirements as shown;

$$Efficiency\ (\%) = \frac{C_{in} - C_{out}}{C_{in}} \times 100$$

Where;

C_{in} = Influent concentration (typically mg/L)

C_{out} = Effluent concentration (typically mg/L)

Efficiency is expressed as a percentage (%)

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. INTRODUCTION

This study investigated the efficiency of a commercial wastewater treatment plant by. Wastewater from Maasai Mall and Kabete Flats OWTSs were tested and analyzed.

BOD_5, COD, DO, TSS, TDS and pH tests were conducted on both the influent and treated effluent and the data collected was analyzed by co-relational analysis. This chapter presents the results of the analysis in the sub- sections below.

4.2. COMMERCIAL WASTEWATER

The following results were obtained for the experiments run on the commercial wastewater from the Maasai Mall:

Table 4.1: Results of Analysis for Inlet and Outlet Parameters (Maasai Mall)

	Wastewater Quality Parameters					
Samples	**BOD (mg/L)**	**COD (mg/L)**	**TSS (mg/L)**	**TDS (mg/L)**	**DO (mg/L)**	**pH**
INFLUENT (Inlet)	550 - 798	1088	200	1410	1.12	7.69
EFFLUENT (Outlet)	3 - 35	56	60	810	4.46	7.45

The performance of the ETP in terms of average graph, that is, the average reading of the wastewater characteristics is shown in the graph below:

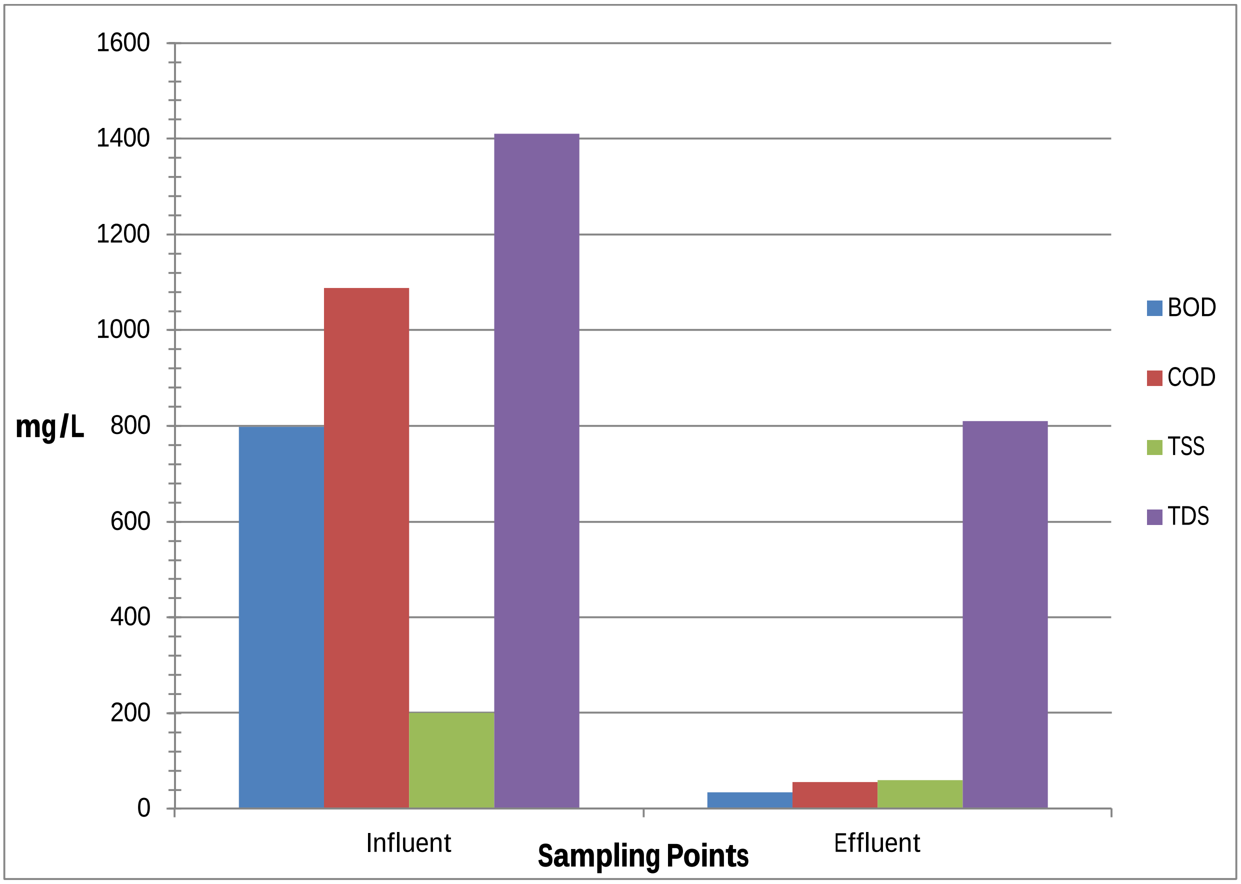

Figure 4.1: Average of different parameters in the ETP (Maasai Mall)

A significant reduction in the final concentrations of the effluent samples was observed. Initial concentrations of BOD, COD, TDS of 674, 1088 and 1410 mg/L were reduced to approximately 19, 56 and 810 mg/L respectively, after treatment. The effluent BOD value of 19 mg/L is well below the WHO treated wastewater re-use standards of 30 mg/L is environmentally acceptable for gardening purposes, that is, irrigation of non-food crops.

The final COD value was found to be slightly above the WHO recommended standard limits of 50 mg/l for the discharged of wastewater into surface water and the effluent would require further treatment if surface water disposal is intended. However, the COD value is below the WHO recommended standard limit of 1000 mg/l for discharge of wastewater into public sewers.

The initial TSS level was 200.0 mg/l. The value of TSS in the wastewater might be attributed to various materials of solid waste from the sewage influent. A drop in the TSS value was observed from analysis. The TSS value decreased to 60 mg/l representing a TSS removal efficiency of 70.0%, which is higher than WHO standard value of 30 mg/l. The final TDS effluent value of 810 mg/L was below NEMA standards of 1200 mg/L for effluent discharge into the environment

The final pH of the effluent was found to be basic, dropping from an initial pH of 7.69 to 7.45. The mean pH level was observed to be 7.57 which is within the WHO tolerance limits of 6.0-9.0 for the discharged of wastewater to natural water or public sewers.

4.2.1. REMOVAL EFFICIENCY

Table 4.2: Removal Efficiency (Maasai Mall)

Wastewater Characterization (mg/L)	Removal Efficiencies (%)
BOD	95.61
COD	94.85
TSS	70.00
TDS	42.55

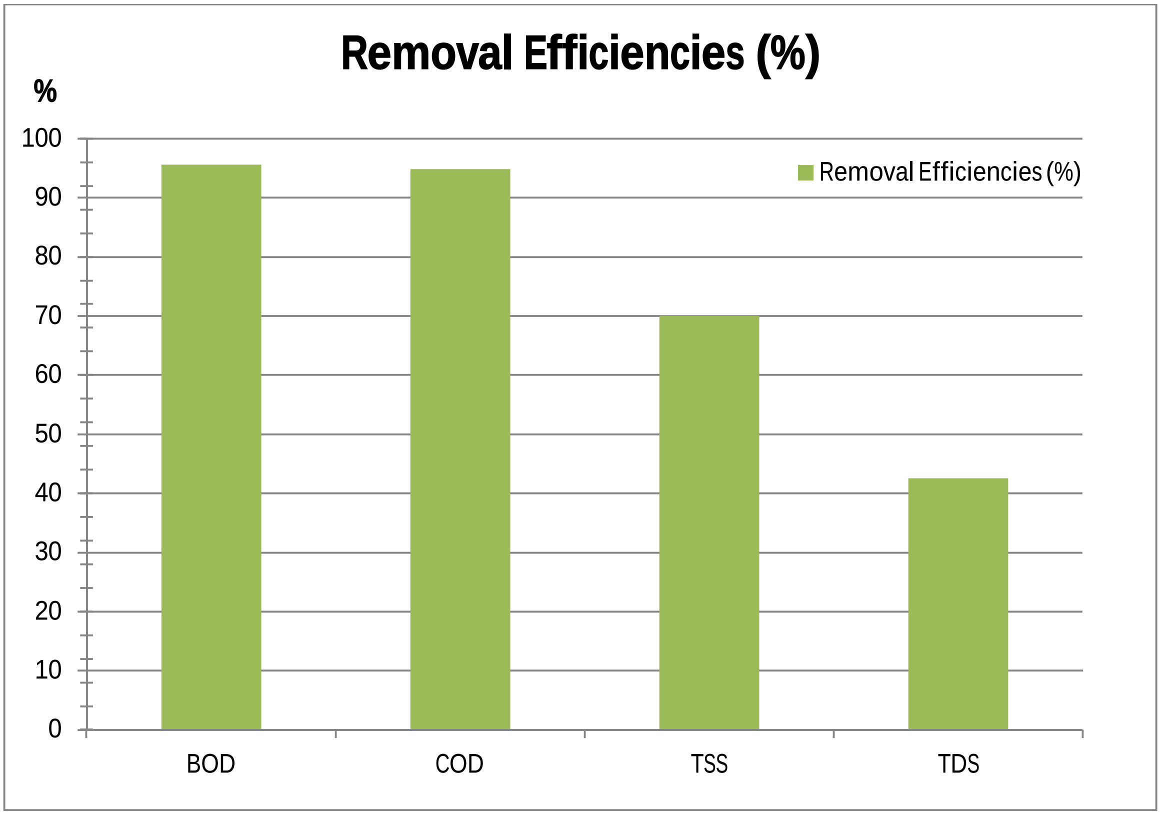

Figure 4.2: Graphical Representation of Removal Efficiencies (Maasai Mall)

Percentage removal of up to 95.6% of BOD, 94.9% COD, 70.0% TSS and 42.6% TDS was recorded for each. From the results it could be concluded that the OWTS showed great efficiency in terms of treatment. This effluent is suitable for recycling and re-use in flushing of toilets.

4.3.RESIDENTIAL WASTEWATER

The following results were obtained for the experiments run on the residential wastewater from the Lower Kabete Flats:

Table 4.3: Results of Analysis for Inlet and Outlet Parameters (Kabete Flats)

	Wastewater Quality Parameters					
Samples	**BOD (mg/L)**	**COD (mg/L)**	**TSS (mg/L)**	**TDS (mg/L)**	**DO (mg/L)**	**pH**
INFLUENT (Inlet)	280 - 320	864	350	1090	4.05	7.91
EFFLUENT (Outlet)	13.0 – 17.5	92	80	620	5.41	6.91

The performance of the ETP in terms of average graph, that is, the average reading of the wastewater characteristics after the treatment process is shown in the graph below:

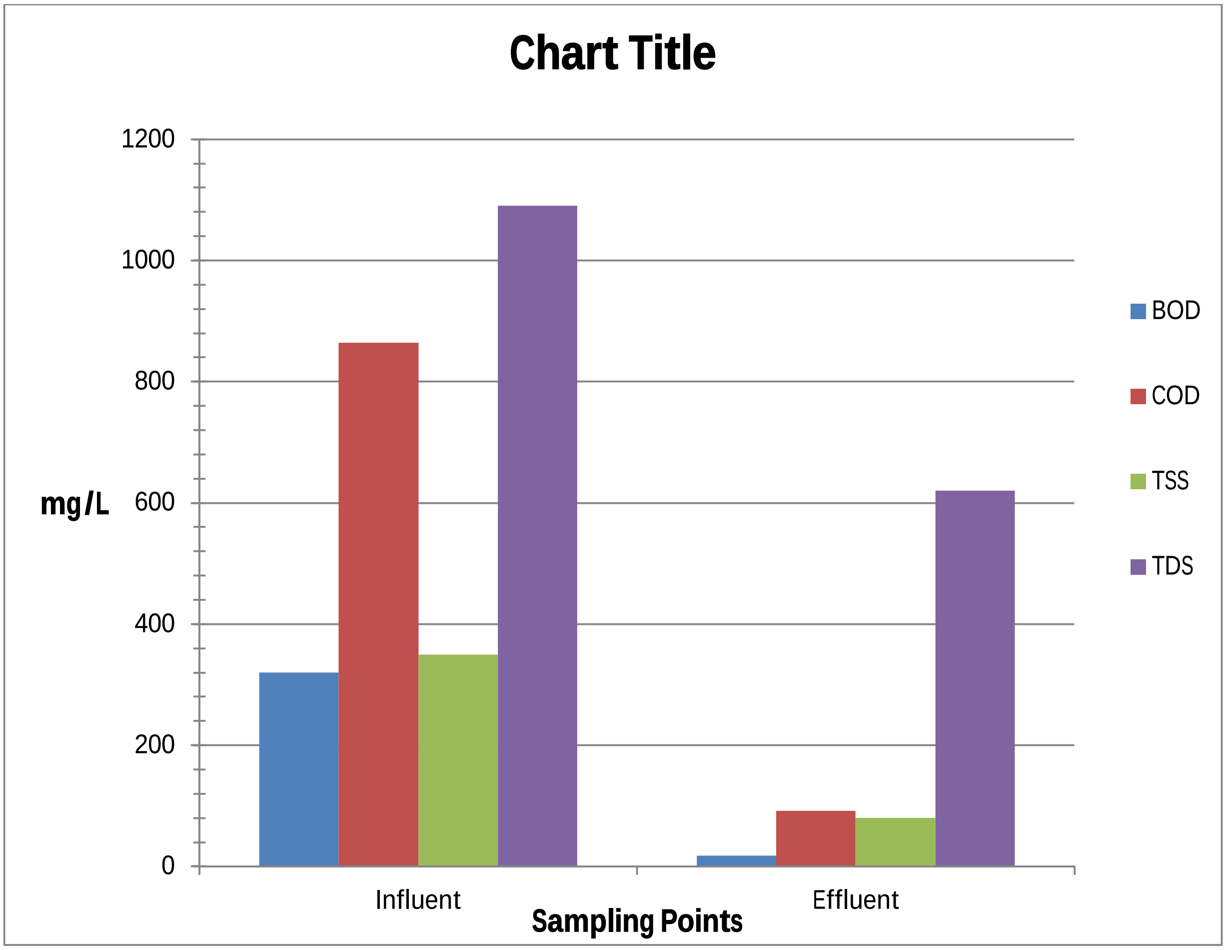

Figure 4.3: Average of different parameters in the ETP (Kabete Flats)

A significant reduction in the final concentrations of the effluent samples was observed. Initial concentrations of BOD, COD, TSS, TDS of 300, 864, 350 and 1090 mg/L were reduced to approximately 15.3, 92, 80 and 620 mg/L respectively, after treatment. 15.3 mg/L BOD was within the WHO treated wastewater re-use standards of 30 mg/L and the effluent was applicable for land application like gardening but only for non-food crops.

The final COD value was found to be slightly above the WHO recommended standard limits of 50 mg/l for the discharged of wastewater into surface water and the effluent would require further treatment if surface water disposal is intended. However, the COD value is below the WHO recommended standard limit of 1000 mg/l for discharge of wastewater into public sewers.

The final pH of the effluent dropped from an initial pH of 7.91 to 6.91which is within the WHO tolerance limits of 6.0-9.0 for the discharged of wastewater to natural water or public sewers. This effluent can be re-used in the flushing of toilets.

4.3.1. REMOVAL EFFICIENCY

Table 4.4: Removal Efficiency (Kabete Flats)

Wastewater Characterization (mg/L)	Removal Efficiencies (%)
BOD	94.53
COD	89.35
TSS	77.14
TDS	43.12

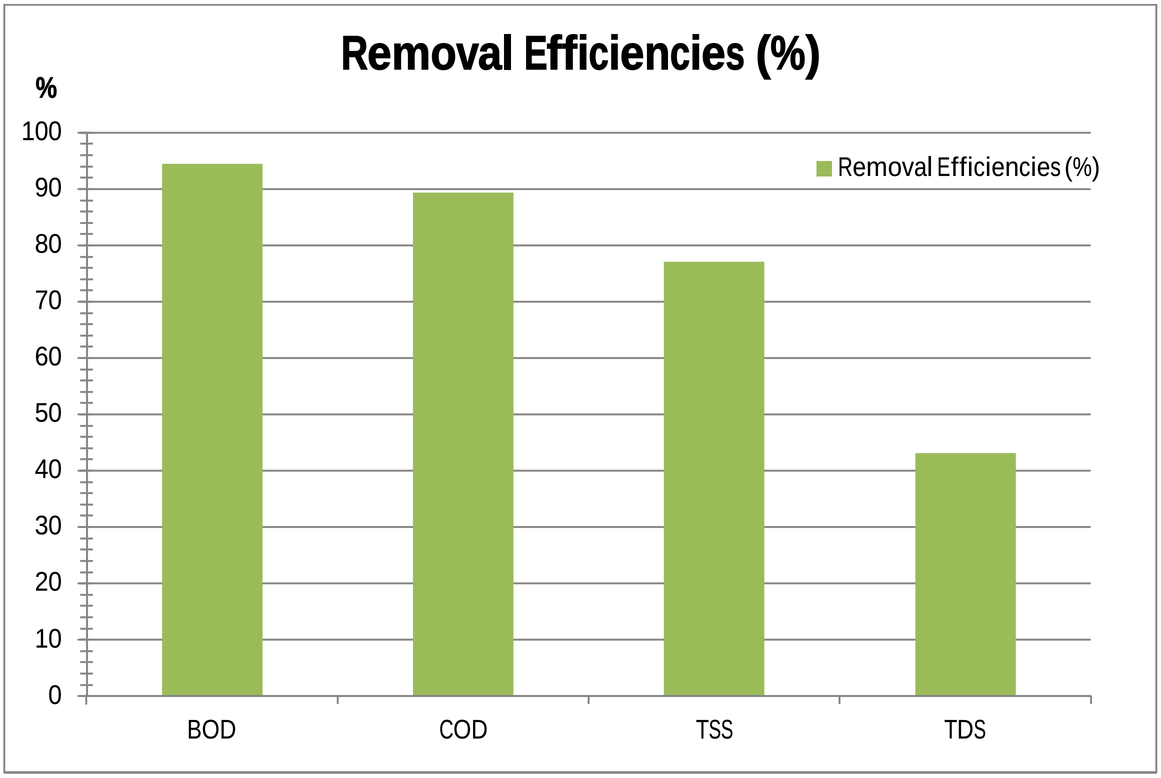

Figure 4.4: Graphical Representation of Removal Efficiencies (Kabete Flats)

Percentage removal of up to 94.5% of BOD, 89.4% COD, 77.1% TSS and 43.1% TDS was recorded for each. From the results it could be concluded that the OWTS showed great efficiency in terms of treatment.

CHAPTER FIVE

5. CONCLUSIONS

In view of the above data obtained, the following conclusions were arrived at:

1. The ratio of BOD_5 to COD in the samples tested was in the range 0.4 to 0.7 for untreated effluent and 0.1 to 0.2 for the final treated effluent. This is typical of domestic/municipal sewage wastes where the BOD_5 to COD ratio is between 0.3 to 0.8 and 0.1 to 0.3 for untreated and treated effluent, respectively.

2. The Maasai Mall *JET Inc.*® OWTS reduced the BOD, COD and TSS influent parameters from 674, 1088 and 200 mg/L, respectively, to 19, 56 and 60 mg/L which was equivalent to 95.6, 94.9 and 70.0% removal, respectively. The Lower Kabete Flats *JET Inc.*® OWTS reduced the BOD, COD, and TSS influent parameters from 300, 864 and 350 mg/L to 15.3, 92 and 80 mg/L at a percentage removal of 94.5, 89.4 and 77.1% respectively.

3. The *JET Inc.*® OWTS achieved the NEMA and WHO standards for wastewater effluent discharge whose acceptable limitsare 30 and 50mg/L for BOD_5 and COD, respectively.

4. The effluent was within standards for treated wastewater re-use in flushing of toilets and gardening. The effluent from both Maasai Mall and Kabete Flats OWTS were within the BOD parameters for discharge into the environment and re-use in irrigation and flushing of toilets.

CHAPTER SIX

6. RECOMMENDATIONS

Based on the results of the study, it is recommended that:

1. Further studies and improvement be made in the reduction of COD and TSS so that the effluent characteristics can be within the standards for re-use of treated wastewater according to WHO requirements.

2. Chlorination, which is the main means of disinfection in the *JET Inc.*® OWTS, is affected by chlorine demand. An alternative disinfection method can be the combined use of chlorine and ammonia- chloroamines – which form more stable residual than chlorine alone, less toxic disinfection by-products and less taste and odour-causing compounds in water.

3. TDS has the least percent removal, therefore, additional chemical treatment could be considered in the case where a significant reduction in dissolved solids is required.

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APPENDICES

CALCULATIONS

Parameter	Calculation Examples	Output
BOD_5	$$BOD = \frac{D_1 - D_2}{P}\ (mg/L)$$ e.g. Initial DO, $(D_1) = 7.2$ mg/L Final DO, $(D_2) = 0.8$ mg/L Fraction of sample used, P = 0.02 Therefore, $$BOD = \frac{7.2 - 0.8}{0.02} = 320\ mg/L$$	BOD = 320 mg/L
COD	$$COD = \frac{(a - b) \times N \times 8000}{ml\ of\ sample}\ (mg/L)$$ e.g. Titrant used for the blank sample, a = 25.6 mL Titrant for the original sample, b = 24.2 Normality of the sample = N = 0.1 Dilution = Therefore, $$COD = \frac{(25.6 - 24.2) \times 0.1 \times 8000}{20} = 56\ mg/L$$	COD = 56 mg/L
TSS, TDS	$$TSS = \frac{W \times 10^6}{V}\ (mg/L)$$ e.g. Residue obtained, W = (44.952 – 44.843) = 0.109 g Volume of sample taken for filtration, V = 100 mL Therefore, $$TSS = \frac{0.109 \times 10^6}{100} = 1090\ mg/L$$	TSS = 1090 mg/L

Efficiency	$$\text{Ef iciency (\%)} = \frac{C_{in} - C_{out}}{C_{in}} \times 100$$ e.g. Influent concentration, C_{in} = 798 mg/L Effluent concentration, C_{out} = 35 mg/L Therefore, $$\text{Ef iciency} = \frac{798 - 35}{798} \times 100 = 95.61\%$$	Efficiency = 95.61%

NEMA GUIDELINES

Standards for Effluent Discharge into the Environment

Parameter	Unit	Max Allowable Units
5 – day BOD at 20ºC	mg/L	30
COD	mg/L	50
Lead	mg/L	0.01
TDS	mg/L	1200
Colour (in Hazen units)	H.U	15
Nitrate	mg/L	100
Sulphide	mg/L	0.1
Zinc	mg/L	0.5

TREATED WASTEWATER RE-USE STANDARDS (EPA)

Irrigation Type	BOD_5 (mg/L)	SS (mg/L)	Required Treatment
Non-food crops	20 - 30	20 - 30	Biological treatment and disinfection
Food crops	20	5	Secondary treatment, filtration and disinfection

INTERRELATIONSHIP BETWEEN BOD AND COD

Type of Wastewater	BOD/COD
Untreated	0.3 - 0.8
After primary settling	0.4 - 0.6
Final Effluent	0.1 – 0.3