UNIVERSITY OF NAIROBI

EVALUATION OF CONSTRUCTED WETLANDS AND CONVENTIONAL WASTEWATER TREATMENT SYSTEMS IN SELECTED KENYAN TEA FACTORIES

BY

SUSAN NZISA MWAKA
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DECLARATIONS

I hereby declare that this thesis is my original work and has not been submitted elsewhere for award of a degree. Where other people's work or my own work has been used, this has been properly acknowledged and referenced in accordance with the University of Nairobi's requirements.

Date: 9th July 2019

SUSAN NZISA MWAKA
DEPARTMENT OF CHEMISTRY
SCHOOL OF PHYSICAL SCIENCES
UNIVERSITY OF NAIROBI

This thesis is submitted with our approval as the university supervisors.

DATE

Dr. Joyce Kithure
Departmnent of Chemisrty   9th July 2019
University of Nairobi
P.O Box 30197-00100
Nairobi Kenya
jkithure@uonbi.ac.ke

Dr. Peterson Guto
Department of Chemistry   9th July 2019
University of Nairobi
P.O Box 30197-00100
Nairobi Kenya
Peterson.guto@uonbi.ac.ke

ABSTRACT

Environmental pollution due to discharge of untreated or poorly treated industrial wastewaters has become a major source of concern with respect to the safety of our environment. Wastewaters from processing of black tea contain harmful substances just like any other industrial effluent and therefore pre-treatment is necessary prior to release. The purpose of this study was to evaluate conventional and constructed wetlands wastewater treatment systems used in Kenya tea factories to establish the most effective system. Eberege tea factory which has a conventional effluent treatment plant and Chinga tea factory using constructed wetlands for effluent treatment were used to represent the two wastewater treatment systems. Test parameters of interest as per the National Environment Management Authority guidelines were: Biological Oxygen Demand, Total Suspended Solids, pH, fecal coliform, Chemical Oxygen Demand, color, organic nitrogen, flow, copper, zinc and surfactants. These parameters were analyzed in both treated and untreated effluent from the selected two factories using approved US EPA testing methods for wastewater analysis. The results obtained from the untreated effluent in both factories had high levels of >48.6mg/L BOD, >150.3mg/L COD and >29.3mg/L TSS while the treated effluent registered a major decrease of pollutants levels with readings of <25.5mg/L BOD, <70.4mg/L COD and <28.8mg/L TSS. Color in the untreated effluent gave readings of >15 hazen units while the treated effluent recorded <12 hazen units with the conventional treatment plant giving the most clear effluent of <6 hazen units. Organic nitrogen levels in the untreated effluent were >7.8 mg/L while the treated effluent levels were <2.8 mg/L with the constructed wetland registering the lowest values. Copper and zinc levels were below the detection limit in all untreated effluent samples with an exception of one sample which recorded zinc levels of 0.543mg/L but was effectively treated since the result of the treated effluent was <0.001mg/L. Surfactants were found to be below detection level in both untreated and treated effluent samples. Fecal coliform bacteria was also absent in all samples. The conventional wastewater treatment plant is recommended for tea factory wastewater treatment since it gave a clearer and the less toxic treated effluent compared to that from the constructed wetland. Further studies should major on designing upgraded treatment plants which combine both conventional and biological modes of treatment while eliminating the disadvantages that come with conventional plants especially the high cost of setting up and maintenance.

DEDICATION

This work is dedicated to my parents Mr. Boniface Mwaka and Mrs. Elizabeth Mwaka for bringing me up as a potential academician.

I also dedicate it to my sister and brothers, for their continued support all through my education.

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ABBREVIATIONS/ACRONYMS AND SYMBOLS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BP1	Broken Pekoe 1
BOD	Biochemical Oxygen Demand
BOD_5	5 days Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CTC	Crush, tear and curl
Cu	Copper
D1	Dust 1
DO	Dissolved Oxygen
E.*coli*	Escherichia coli
EMCA	Environmental Management and Coordination Act
FAS	Ferrous Ammonia Sulfate
F1	Fannings 1
ISO	International Organization for Standardization
KTDA	Kenya Tea Development Agency
LS-AAS	Line Source Atomic Absorption Spectrophotometer
M-FC agar	Medium for fecal coliforms
Mg/L	Milligrams per liter of solution
NEMA	National Environment Management Authority
PD	Pekoe Dust
PF1	Pekoe Fannings 1
pH	Hydrogen activity
TDS	Total Dissolved solids
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
UNEP	United National Environmental Programme
WARMA	Water Resource Management Authority
WHO	World Health Organization
WWTP	Wastewater treatment plant
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Tea in Kenya

Tea is a beverage made from the cured leaves of the *camellia sinensis* plant. Tea was first introduced in Kenya by the Cain brothers in the year 1903. Kenya became a major producer of black tea since 1924 when tea was commercialized. After China and India, Kenya is rated as the third largest producer of tea in the world. Tea is one of the major cash crops in Kenya alongside tourism, coffee and horticulture and has been leading in foreign exchange for the country. It has also recently emerged as a major source of innovation in new varieties of tea and single origin artisan teas (Kariuki *et al.,* 2014).

Kenya Tea Development Agency (KTDA) is responsible for the management of Kenya small scale tea farmers. Currently, there are 66 tea factories across Kenya under KTDA which serve over 500,000 small scale farmers as outlined in Kariuki *et al*. (2014).

Kenya's regions for tea growing are characterized with an ideal climate for tea growing; rainfall which ranges between 1200mm and 1400mm per annum, long sunny days and tropical, volcanic red soils (Owuor, 2011).

1.1.1 Classification of tea and processing

Tea is normally divided into various categories according to the mode of processing. At least six different types are produced which basically refer to the extent of tea oxidation. Oxidation is a natural process also known as fermentation which changes the flavor and color of the leaf. Less oxidized teas usually yield light liquor while highly oxidized yield a dark infusion. The categories of tea as outlined by Owuor (2011) include: black, wilted, crushed and fully oxidized tea; yellow, unwilted and semi oxidized tea; green, unwilted and unoxidized tea; oolong, wilted and partially oxidized tea; post-fermented and green fermented tea.

Black tea is the dominant type of tea produced in Kenya. Greatest percentage of the tea produced in Kenya is processed via the crush, tear, and curl (CTC) method. This makes it suitable for use in popular blends found in most black tea markets which include Britain, North America and India (Owuor, 2011).

Processing of black tea according to Kariuki *et al*. (2014) involves a number of steps. The first step is plucking; this stage involves picking of a terminal bud and two young leaves from *Camellia sinensis* bushes. In order to get higher quality tea, picking is done by hand. The second step is withering; after picking, the leaves are spread thinly to dry. They become pliable enough for rolling. Additionally, this process increases the availability of free caffeine as well as promoting the breakdown of leaf proteins into free amino acids. The third processing stage is rolling; the withered tea leaves are shaken and rolled with an aim of breaking the leaf cells. Oils that give tea its distinctive aroma are released in this process. Oxidation/fermentation is the fourth step; a chemical process where the leaves absorb oxygen. During oxidation, the leaves turn to bright copper in color. This stage is the main determinant of the tea type produced. The fifth step is drying/frying; leaves are moved through hot air chambers to stabilize and lock in the flavor. Active enzymes are killed by the dry heat hence fermentation stops. Drying process is carried out in either a fluid bed drier or in a conventional drier. During firing, the leaves turn black and loose all but about 2% of their moisture. The last stage of tea processing is grading and packing. Due to the absence of a big bulk of tea and manufacture of limited grades, the grading process is simplified. The major grades of Kenyan black tea include; Dust 1 (D1), Pekoe Fannings (PF1), Broken Pekoe (BP1) and Pekoe Dust (PD) as primary grades while DUST and Fannings 1 (F1) are secondary grades.

1.1.2 Chemical compounds in tea

Fresh tea leaves are comprised of various important compounds responsible for the specific tea characteristics which are: taste, flavor and aroma. According to Botha *et al.,* (2004), Etiegni *et al.* (2009), and Omwoyo (2013), these compounds are as outlined.

Polyphenols; compounds composed of phenolic group and are the most prevalent in tea. They are usually derived from amino acids through sunlight. In tea, there are an estimated 30,000 polyphenolic compounds of which flavonoids are the most important and are the source of many

health characteristics surrounding tea especially antioxidants. Flavanols are the most prevalent in flavonoids and are usually converted to theaflavins and thearubigins during oxidation hence giving black teas the dark color and robust flavors.

Amino acids; compounds responsible for tea brothiness. Theanine is the most abundant amino acid contained in tea leaves. L-Theanine which is a type of Theanine is responsible for enhancing relaxation via promoting alpha brain wave activity.

Enzymes; the most important enzymes in tea leaves are Polyphenol oxidase and peroxidase. They catalyze browning of tea leaves following exposure of the polyphenols to oxygen when the leave cell walls are broken. They can be denatured using heat or depriving them moisture for some time hence browning of tea doesn't occur.

Pigments; Carotenoids and chlorophylls are the major pigments found in fresh tea leaves. Chlorophylls green color is converted to black pigments known as pheophytins during oxidation hence the dark appearance of finished oxidized teas. On the other hand, carotenoids are made up of orange carotenes and yellow xanthophylls which also contribute to the color of finished tea leaves.

Carbohydrates; energy stored in tea plants in form of starch and sugars. They fuel enzymatic reactions during oxidation/fermentation and also create polyphenols in young tea leaves.

Methylxanthines; caffeine which is a stimulant alongside theophylline and theobromine compounds. The tea plant creates these chemicals as a natural combatant towards animals.

Minerals; tea flush has been found to contain 28 mineral elements. Tea has higher amounts of manganese, fluorine, selenium, potassium, arsenic, iodine and nickel compared to other plants.

Volatiles; tea flavors and aroma are highly attributed to volatile substances found in tea leaves. Hundreds of flavor and aroma compounds which exist in trace amounts make up the aroma complex of tea. Most of these aromatic compounds are derived from other substances during processing rather than existing naturally in fresh tea leaves.

1.1.3 Tea factory wastewater

Wastewater from tea factories mainly originates from washing the processing equipment and factory premises (Etiegni *et al.,* 2007).This cleaning exercise was found to be done once to thrice in a week. The wastewater is usually characterized by a strong color and turbidity. Major pollutants include both organic and inorganic originating from unprocessed and processed tea, cleaning detergents, grease/oils and metallic particles originating from tear and wear of processing machines (Kumar *et al.,* 2014). Such effluent should therefore be treated prior to release to the environment. The National Environmental Management Authority (EMCA, 2006) in Kenya regulates effluent discharge to the environment and therefore tea factories should comply with the Authority's set guidelines. As per NEMA, all Kenyan industries are required to collect, treat and dispose in a safe manner all kind of wastes generated within their areas of jurisdiction (EMCA, 2006).

Several KTDA factories have employed either conventional or natural biological methods for their wastewater treatment even though some are still struggling with poor quality effluent due to lack of an effective treatment system as discussed in Etiegni *et al*. (2009). The major challenge with the lagoon wastewater treatment systems which is widely used in tea factories is overloading.

1.2 Statement of the Problem

Pollution is of significant ecological/environmental concern. Raw tea factory effluent is characterized with high levels of substances which may have negative implications on the environment if released directly without treatment (Omwoyo, 2013). It has been of a great concern to communities living near tea factories which poorly treat their effluents. Disposal of these wastewaters can be difficult and a costly problem since they must comply with the set NEMA guidelines. Quality parameters of interest as per NEMA in EMCA, (2006) and Water Resource Management Act, (2006) for tea/coffee industry effluent include; Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), pH, Color, Total suspended solids (TSS), fecal coliforms/E.*coli*, organic nitrogen, flow rate, copper, zinc and surfactants. Readings of the said parameters outside the permissible limits imply low quality effluent hence pollution to the environment. To effect compliance, the effluent should be treated prior to disposal in order to

reduce or eliminate high concentrations of the mentioned parameters. Treatment of wastewater can either be via conventional or biological means (Afonso *et al.,* 2017). The degree of treatment in both methods varies hence there is need to compare effluent quality under both systems. Previous studies done in Gitugi tea factory and Nyansiongo tea factory showed the ineffectiveness of the lagoon (waste stabilization ponds) system in treating the factory effluent (Etiegni *et al.,* 2009). In this study, 2 case studies of KTDA factories namely Eberege in Kisii region and Chinga in Nyeri region which use conventional and constructed wetland wastewater treatment plants (WWTP) respectively were studied with an aim of determining their performances. The results of this study will be used to advise policy makers on the best treatment system for tea factory wastewater.

1.3 Objectives

1.3.1 General objective

The overall objective of this research was to evaluate the effectiveness of wastewater treatment by constructed wetlands and conventional wastewater treatment systems used in Kenyan tea factories.

1.3.2 Specific objectives

i.   To determine the pollution load in untreated and treated wastewater from Eberege and Chinga tea factories.

i.   To assess the compliance of the treated and untreated wastewater with the regulatory body NEMA guidelines for wastewater disposal to the environment.

ii. To establish the effectiveness of contaminants removal from tea factory wastewater by the conventional and constructed wetlands treatment systems.

1.4 Justification and Significance of the Study

Release of untreated effluent directly to the environment can be detrimental to humans, animals and the environment at large. Effluent discharge may end up combining with other surface waters or sip into underground water leading to contamination. The quality of the receiving waters is therefore compromised and use of such waters will have negative implications on the environment (Chen *et al.,* 2015). Tea factory effluent is among industrial effluents which require regular monitoring to ensure it is within the set permissible limits. To maintain compliance and avoid negative impacts to the environment via release of harmful effluent, it's necessary to treat the effluent prior to release.

Several KTDA factories have employed either conventional or natural biological methods for their wastewater treatment even though some are still struggling with poor quality effluent due to lack of an effective treatment system. Each treatment method has its pros and cons. Therefore, selected factories using conventional and constructed wetlands systems of treatment were studied with an aim of establishing their performance. Results of this study will be used by tea factories in identifying a suitable treatment system for their wastewaters.

CHAPTER 2

LITERATURE REVIEW

2.1 Wastewater treatment

The chief objective of treatment of wastewater is to avoid possible danger to human health or intolerable damage to the natural environment by disposing toxic domestic and industrial effluents. Effluent released to the environment usually finds its way in surface waters which are mostly used for agricultural purposes. Treated effluent quality in agriculture has a high effect on performance and operation of plant-soil-wastewater system (Alkali *et al.,* 2011). The most suitable wastewater treatment for use in agricultural purposes is that which produces quality wastewater at minimal operational costs. Such effluent should adhere to the recommended chemical quality and microbiological guidelines. In developing countries, it's necessary to adopt a low level of treatment due to difficulties in operating complex systems as well as costing. It's advisable to design the re-use system to accommodate a low grade treated effluent other than relying on advanced costly treatment systems which yield a high-quality effluent (Kivaisi, 2001).

Treatment plants are designed with an aim of reducing or eliminating suspended solids and organic loads hence limiting pollution to the environment. Removal of pathogens is usually not a priority but in agriculture, it's necessary hence processes should be designed accordingly (Asith *et al*, 2012). Removal of wastewater constituents which might cause harm to plants and animals is possible technically via treatment but not feasible economically.

Agricultural and food operations industry effluents have distinctive characteristics from those of municipal wastewater. They are normally nontoxic and biodegradable. Nevertheless, they have high levels of total suspended solids (TSS) and biochemical oxygen demand (BOD). According to Storhaug (1990) the components of agricultural and food wastewater are unpredictable due to differences in pH and BOD in effluents from different sources such as meat products, fruits and vegetables.

Wastewater treatment is achieved via two major systems: conventional treatment and natural biological treatment (Afonso *et al.,* 2017)

2.1.1 Conventional wastewater treatment system

This refers to a system consisting of chemical, biological and physical processes combined which aid in removal of contaminants from wastewater. As outlined in Bandala *et al.* (2017), wastewater undergoes various stages as shown in scheme 2.1.
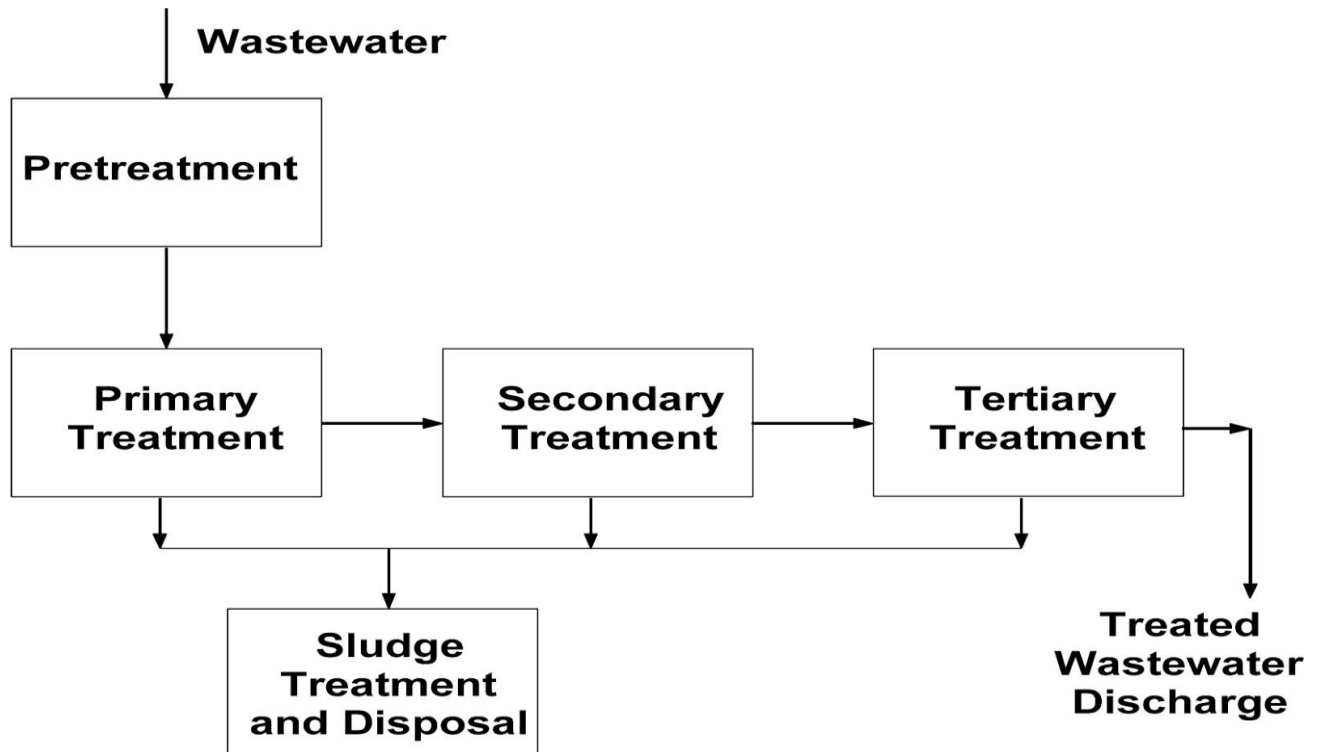
Scheme 2.1: Conventional wastewater treatment system

Preliminary treatment is the first stage of wastewater treatment. During this stage, incoming raw effluent from the factory is barred to get rid of all big objects that make their way into the treatment system. Bar screens of different sizes are incorporated to get rid of these items. The wastewater flows across the screens, objects trapped, removed from the water and then scrapped off the screens mechanically or manually. In addition to the screening, the velocity of incoming wastewater is controlled carefully to allow stones, sand and grit to settle at the bottom while keeping organic material suspended in the water.

The second stage is the primary treatment. The aim of this stage is to remove inorganic and organic solids which can settle via sedimentation. About 65% of oil and grease, 50-70% of TSS and 25-30% of BOD are removed. Large sedimentation tanks known as clarifiers are used to allow sludge to settle at the bottom while floating materials are skimmed off. Scrapers which are mechanically driven are usually incorporated in the clarifiers to aid in driving the sludge collected to the base of the tank for further treatment. Water which is clarified proceeds to the next treatment step.

The third stage is the secondary treatment step. It involves use of biological treatment processes which remove organic matter in wastewater up to 90%. Aerobic treatment processes which use microorganism in the presence of oxygen to break down organic matter are performed. The end products of this aerobic treatment include; ammonia, carbon (IV) oxide and water. Sedimentation tanks similar to those of primary treatment are used to separate the microorganisms from the clarified water. Sludge retrieved from secondary treatment is combined with that of primary treatment for sludge treatment. Oxidation ditches, biofilters or trickling filters, rotating biological contactors and activated sludge processes are among the most common methods used in secondary treatment (Oller *et al.,* 2011). When combined with primary treatment, these processes remove up to 85 % of TSS and BOD in wastewater. Addition of disinfection step provides considerable level of bacteria removal. Nevertheless, very little of nitrogen, dissolved minerals and phosphorous are removed. Activated sludge process produces effluent of slightly higher quality as compared to the other process which is a film made up of media where the biomass grows when wastewater flows over the surface (Storhaug, 1990). Activated sludge process is a suspended process where the biomass is mixed with the effluent.

The fourth stage is the tertiary treatment step. This stage involves generation of a higher quality effluent through use of advanced treatment processes. Individual processes are required to get rid of phosphorous, nitrogen, dissolved as well as suspended solids. Treated effluent from secondary stage is introduced into a flocculation tank where calcium hydroxide is added to eliminate phosphates as $Ca_2(PO_4)(OH)$. The effluent is then introduced to the ammonia striping tower which removes nitrogen in the form of ammonium ions (NH_4^+) which is converted to gaseous form at high pH values. The remaining organic materials are removed by adsorption on activated charcoal.

Disinfection is the final step of the treatment process. Its main aim is to eliminate or reduce the number of micro organisms present in wastewater. The common mode of disinfection is the use of chlorine solution whose contact time with the wastewater is normally 30 minutes. The contact time can go as long as 120 minutes in case advanced water treatment is required. Chlorine bactericidal effects among other disinfectants depend on contact time, temperature of the effluent and pH. Other modes of disinfection are ozonation and use of UV lamps.

The advantages of a conventional wastewater treatment plant include: minimal land requirements, high efficiency in removing contaminants and applicability to small scale water treatment. However, this type of wastewater treatment has several disadvantages which are: it relies on heavy machinery and chemicals, high energy requirement and some require technical knowledge to operate (Sundara and Kumara, 2010)

Effluent treatment plants using conventional wastewater treatment system have been recently set up in several KTDA factories (Etiegni *et al.,* 2009). Among the factories include Nyansiongo and Eberege tea factories. No studies have been done yet on the effectiveness of the WWTP's in treating the factory effluent. Previous studies on Nyansiongo tea factory highlighted the ineffectiveness of the stabilization ponds used by then due to overloading hence a treatment system failure (Kumar *et al.,* 2017).

2.1.2 Natural biological treatment systems

These are low rate natural systems which use biological processes to treat organic wastewater. Therefore, they are less sophisticated, easy to operate and lower in cost (Storhaug, 1990). Although these systems are land intensive, if properly designed and not overloaded, they are effective in removing pathogens. Land treatments and stabilization ponds are among natural biological treatment systems which have been used successfully worldwide (Nzengy'a and Wishitemi 2001). These systems use microorganisms to break down organic wastes via normal cellular processes.

The biological processes used to treat wastewater include subsurface applications, such as septic or aerobic tank disposal systems; a wide variety of types of aeration, including surface and spray aeration; activated sludge processes; ponds and lagoons; trickling filters; and anaerobic

digestion. Constructed wetlands and various types of filtration are among biological treatment processes too (Kropfelova and Vymazal 2008).

These types of wastewater treatment methods can generally be divided into aerobic (those that use oxygen) and anaerobic (those that don't use oxygen) processes (Etinosa *et al.,* 2007).

Examples of aerobic wastewater treatment processes include; activated sludge, oxidation ditches, lagoon based treatments, trickling filter and aerobic digestion. These processes use bacteria in the presence of oxygen to decompose organic substances in the wastewater being treated. Anaerobic wastewater treatment processes on the other hand use bacteria to help organic material deteriorate in an oxygen free environment (Ahmad and Khan, 1992). Examples of such include lagoons and septic tanks.

The most common natural biological wastewater treatment processes used in Kenyan tea factories are lagoons and constructed wetlands (Alkali *et al.,* 2011).

2.1.2.1 Wastewater stabilization ponds (Lagoons)

Scheme 2.2 outlines the lagoon system of wastewater treatment as discussed by Amahmid (2002). Depending on the effluent quality required and the organic strength of the incoming effluent, wastewater stabilization pond (lagoon) systems are properly designed to achieve different treatment forms which can go up to three stages arranged in series. Incoming effluent with BOD of about 300 mg/l is introduced to the first pond where most of the organic load is removed. Removal of BOD and solids occurs via sedimentation and via subsequent anaerobic digestion inside the accumulated sludge. Organic carbon is converted into methane by anaerobic bacteria hence up to 60% of BOD is removed. From the anaerobic pond, the effluent proceeds to the facultative pond where further anaerobic treatment takes place. The maturation pond is the last stage of treatment where aerobic processes dominate allowing further reduction of pathogenic bacteria. Aerobic ponds are the shallowest in order to allow sunlight penetration for photosynthesis to occur in algae (Barbosa *et al.,* 2017).
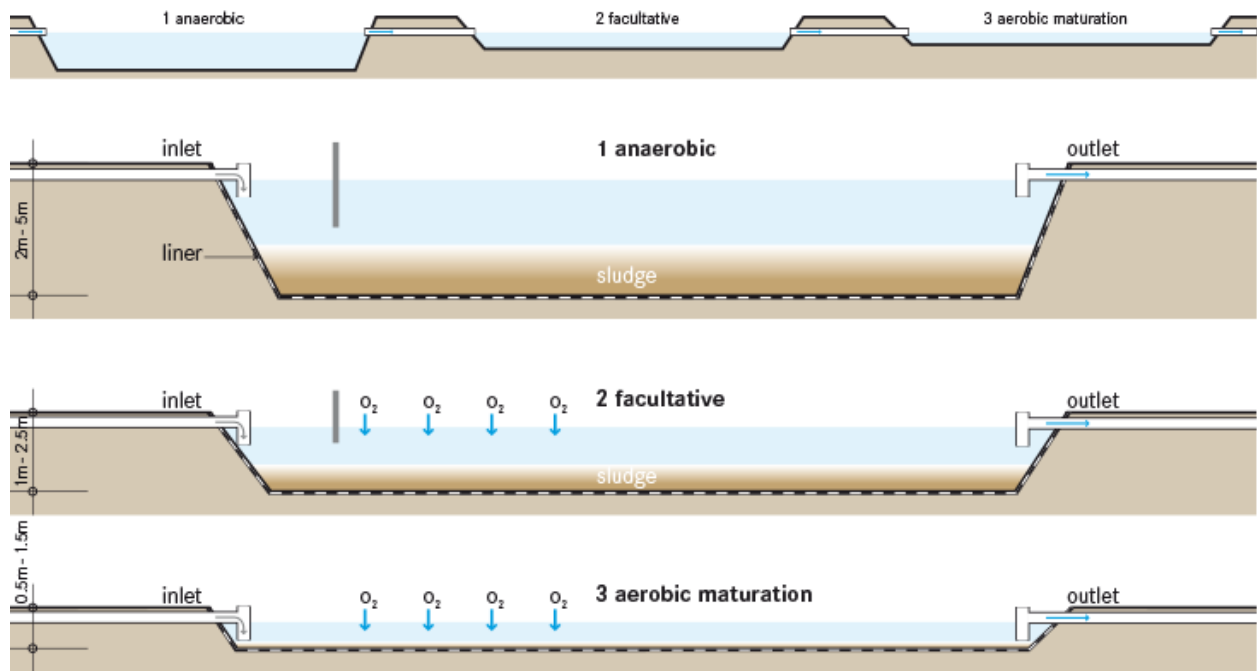
Scheme 2.2: Lagoon wastewater treatment system

In Kenya, waste stabilization ponds systems of wastewater treatment have been used successfully in various industries including Chemilil Sugar Company and Chemoni tea factory (Etiegni. *et al.,* 2009) Ruai sewerage treatment plant in Nairobi has also applied lagoon system in large scale which has been successful too. On the other hand, failure of the lagoon system has been experienced in Nyansiongo and Gitugi tea factories according to Kumar *et al.* (2014). This was due to overloading and poor design.

2.1.2.2 Constructed wetlands

A constructed wetland as outlined in scheme 2.3 by (Phragmites karka) is an artificial swamp, wetland or swamp which uses aquatic plants to treat wastewater (Vymazal, 2010). It consists of a shallow 18 feet deep pit lined with 30 feet plastic, filled with gravel planted with evenly spaced wetland plants which act as biofilters; effectively removing pollutants and sediments from the wastewater. The wetland is usually surrounded with a border which holds the liner in place and keeps surface water from infiltrating the wetland. Effluent from the factory slowly flows through the pipes into the filter material where the wetland plants take over the effluent treatment. At the

root system is where this process normally occurs with diseases causing bacteria and nutrients from wastewater degraded (Haiming *et al.,* 2017).
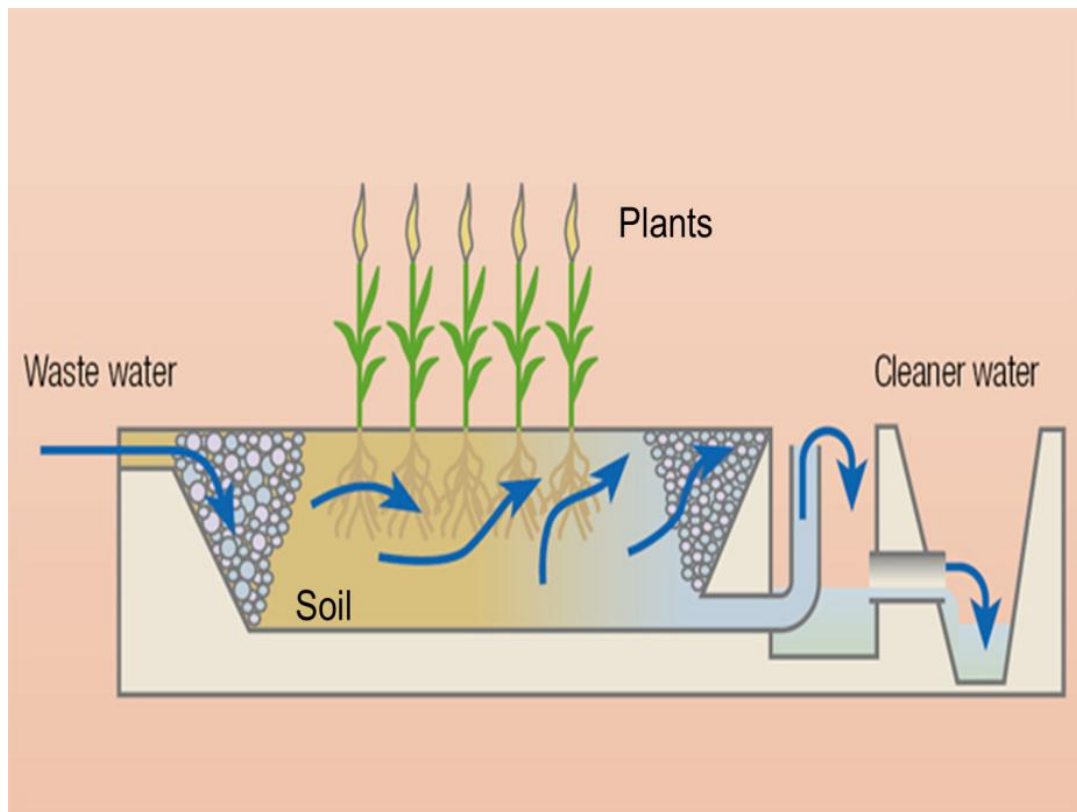
Scheme 2.3: Constructed wetlands wastewater treatment system.

There are three types of constructed wetlands as outlined by Nzengy'a and Wishitemi (2001).

Horizontal Subsurface-flow constructed wetlands; this type takes a higher load of wastewater compared to surface flow type. It's commonly used for treatment of domestic wastewater aerobically. It's composed of an aquifer with a thick layer of gravel which holds a layer of still air above it. Wastewater is forced through the matrix while establishing complete contact between water and the root plant zone bacteria. This type provides a very reliable aerobic pre treatment method.

Vertical Subsurface-flow constructed wetlands; major aim of the design of this type is to reduce the size of constructed wetlands. The root zone is aerated by the wastewater which sucks up air in the wetland, preceded by periodic pumping of water on top of the wetland. Nitrates are removed under anoxic conditions since deeper in the matrix; there is low level of oxygen.

Advantages of sub surface flow constructed wetlands are; they are less supportable to mosquitoes and require less land for water treatment (Kivaisi, 2001).

Surface-flow constructed wetlands; effluent moves in a swamp or marsh above the soil (Bastian *et al.,* 2000). Helophyte plants which have a unique characteristic of acting as oxygen pumps via their roots, lead to sediments aeration by providing dissolved oxygen to the micro organisms.

In overall, the advantages of constructed wetlands are: easy maintenance, production of high quality effluent at an economical cost and uses of natural treatment processes hence sustainable. Nevertheless, several disadvantages are associated with this system of treatment. These are: large space requirement, materials used may not be available, mostly appropriate in areas where required native plants are available and periodic removal of excess plant material necessary (Vymazal, 2010).

Constructed wetlands operating in Kenya are many. Examples; Naivasha horticultural farm wetland which removes agro-chemicals from run off before it enters the lake while another handles commercial laundry effluent. Moreover, a constructed wetland treats sewage at the Maasai Mara game reserve (Nzengy'a and Wishitemi, 2001). Several tea factories have in the past few years commissioned their constructed wetlands which include; Nandi hills, Tirgaga and Kapkoros tea factories. This was preceded by an invitation to tender by KTDA head office in 2012 for construction and commissioning of constructed wetlands after the lagoon treatment system used by most factories became inefficient.

2.2 National environmental legal framework

The ministry of environment, natural resources and regional development authorities is tasked with all issues relating to protection of the environment including effluent discharge. The Environmental Management and Coordination Act (EMCA), 1999, in Kenya is the framework law on environmental conservation and management. It establishes the National Environment Management Authority (NEMA) among other institutions. NEMA was instituted as the main tool of the government charged with general coordination, supervision and implementation of all matters relating to the environment (EMCA, 2006).

2.2.1 Water quality Regulations, 2006 (legal notice No.121)

EMCA (water quality) regulations, 2006 apply to water used for domestic, industrial and any other purposes. These regulations are meant to protect all water sources, for example, rivers, springs, lakes and streams.

The major aim of the regulations is to forbid the release of effluent to the environment or public sewer against the set standards. The regulations also provide limits for the various contaminants found in wastewater before release to either environment or public sewer. Discharge of wastewater from industry, sewage treatment or any other source should be done by someone issued with a valid effluent discharge license by NEMA. EMCA 4th schedule outlines the guide for monitoring effluent discharge into the environment for various discharging facilities including tea/coffee industries.

2.2.2 Composition of tea factory wastewater and effects

Tea factory wastewater is composed of several unwanted substances which when released to the environment would cause detrimental effects. These substances range from organic to inorganic. As per EMCA 4th schedule, variables of interest in tea factory wastewater and their effects are as discussed;

2.2.2.1 Biochemical Oxygen Demand (BOD)

This is the amount of dissolved oxygen required by micro organisms in a water sample to aerobically break down organic matter at a certain temperature for a specific period of time. BOD value is normally expressed in mg/l i.e. milligrams of oxygen used per liter of sample for an incubation period of 5 days at 20°C. This is the major test which gives a rough idea on the level of pollution of any sample (Abdullah *et al.,* 2017). High levels of BOD in wastewaters signify pollution since the organic substances deprive the water its dissolved oxygen (DO) required by aquatic species for survival.

2.2.2.2 Total Suspended Solids (TSS)

TSS refers to dry weight of particles not larger than 2 microns from a water column trapped in a filter. They comprise inorganic and organic materials ranging from sand, silt, algae, plankton and

sediment. The level of total suspended solids in water affects water clarity. The more the solids, the less clear the water will be. Uncontrolled suspended materials can weaken water quality for both human and aquatic life (Sur *et al.,* 2008). Presence of suspended particles in water increases temperature while reducing amount of dissolved oxygen. Elevation of water temperature is due to absorbance of solar heat by the particles, which is then transferred to water via conduction. Warm water holds less oxygen compared to cold water therefore the levels of DO will drop.

2.2.2.3 pH

Removal of contaminants in wastewater involves pH adjustments by addition of either basic or acidic chemicals since it allows the dissolved waste to be separated from the water. Excess hydrogen ions in acidic pH lead to break down of organic matter cells hence destroying them. On the other hand, basic pH catalyses formation of ion bonds with positive metal therefore forming denser settleable insoluble metal particle. Treated effluent should therefore have its pH readjusted to neutral prior to release to the environment in order to avoid damage to living cells of organisms it might come to contact with (Oller *et al.,* 2011).

2.2.2.4 Fecal Coliform/E.coli

The coliform bacteria test gives a rough idea of the safeness of water since it measures the presence of bacteria associated with pathogenic activity. Fecal coliform belong to total coliform group while E.*coli* belong to fecal coliform sub group. Coliform bacteria are not pathogenic but presence in large numbers would signify probability of other disease causing organisms. It's easy to culture coliform bacteria in the laboratory hence commonly used as a primary indicator for pathogen presence. Pollution of waters with coliform bacteria reduces the levels of DO since it's used up in breaking the organic material that contains the fecal coliform. Consequently, aquatic life is killed (Amahmid et al., 2002).

2.2.2.5 Chemical Oxygen Demand (COD)

COD analysis is a test used to measure the amount of organic matter present in water indirectly. COD applications mostly determine the amount of organic contaminants in surface waters hence a common measure of water quality. The amount of oxygen expressed in milligrams required to chemically oxidize organic matter in water per liter of sample solution is what COD measures.

Additionally, it's often used to estimate BOD as a strong correlation exists between the two (Asith *et al.,* 2012).

2.2.2.6 Color/pigment/dye

Color is not a toxic characteristic but is listed as a secondary (aesthetic) parameter affecting water quality. The most common source of color in water is decaying organic matter as well contaminants such as iron. Most of the color in environmental waters is either from dissolved or suspended materials. Tannin which originates from leaves, roots and plant material organic matter is among the dissolved substances which cause effluent to be colored as in the case with tea effluent. Algae growth and aquatic plants are affected by highly colored water since it limits sunlight penetration. Consequently, it can lead to a long term impairment of the ecosystem since it cannot sustain aquatic life (Bouzan *et al.,* 2010)

2.2.2.7 Organic nitrogen

This refers to living organisms byproduct and includes materials such as; nucleic acids, urea, peptides and proteins. Organic nitrogen can be oxidized to nitrites and nitrates in water by nitrifying bacteria. Presence of nitrogen containing substances in water stimulates excessive growth of plant and algae. Their decomposition by bacteria can deplete dissolved oxygen, adversely affecting fish and other aquatic animal (Haiming *et al.,* 2017).

2.2.2.8 Copper

Copper is one of the heavy metal undesirable in water. When copper finds its way to the environment, it leads to adverse effects. Accumulation in plants and animals takes place when copper present in soils attaches to minerals and organic matter and since copper doesn't break down in the environment, it's taken up by plants and animals. Consequently, it inhibits mineralization of nutrients such as phosphorous and nitrogen. Excess copper damages the kidneys, nervous systems and livers of most water organisms. High levels of zinc in plants cause yellowing and wilting of roots due to inhibition of iron uptake (Melvin and Leusch 2016).

2.2.2.9 Zinc

Zinc is an essential trace element for human health but its uncontrolled presence in environmental waters has detrimental effects. Environmental waters can be polluted with zinc in wastewater from industrial plants. The consequences of zinc polluted waters include increased acidity of waters and toxicity to aquatic life especially fish (Natalambi, 2009). Intake of large amounts of zinc leads to damage of the pancreas, disturbance of protein metabolism as well as inhibition of copper uptake. Presence of excess zinc in plants leads to inhibition of root growth, in addition to interference of iron uptake (Melvin and Leusch 2016).

2.2.2.10 Surfactants

Surfactants are substances which lower the surface tension between a liquid and a solid or between two liquids. They can act as wetting agents, emulsifiers, dispersants and foaming agents. The use of synthetic detergents containing the surface active agents or surfactants has resulted in the release of surfactants in natural waters. The common surfactant occurring in raw water is the more biodegradable linear alkylate Sulphonate (LAS). Surfactants find their way in industrial wastewater via cleaning exercise which uses detergents. Discharge of surfactant polluted water into the environment could have serious effects on the ecosystem (Liu *et al*., 2014).

Standards for effluent discharge into the environment as per third schedule of the water quality regulations are as shown in table 2.1 (EMCA, 2006).

Table 2.1: EMCA 3rd schedule - Standards for effluent discharge into the environment

Parameter	Maximum allowable (Limits)
BOD (5 days at 20°C) (mg/l)	30
TSS (mg/l)	30
pH (hydrogen ion activity-non marine)	6.5 – 8.5
Fecal coliform (counts /100 ml)	Nil
COD (mg/l)	50
Color/dye/pigment	15 hazen units
Organic nitrogen as N (mg/l)	100
Flow	Not defined
Copper (mg/l)	1.0
Zinc (mg/l)	0.5
Surfactants (mg/l)	Nil

CHAPTER 3

MATERIALS AND METHODS

This chapter presents the research design, sampling sites, sampling plan, method validation procedures, materials and data analysis.

3.1 Research design

This study used an experimental research design to collect, measure and analyze data. An experimental research design is one which establishes a relationship between the cause and effect of a situation. The effect caused on a dependent variable by an independent variable is studied (Liu *et al.,* 2014). Similarly in this study, the effect of using two different types of wastewater treatment systems on tea factory wastewater was studied with an aim of establishing which system best reduces the toxicity of the wastewater.

3.2 Sampling sites

3.2.1 Eberege tea factory

Eberege tea factory is one of the KTDA factories in region 6 –Kisii highlands, which is located in Kanyenya sub county, Kisii county, about 46 kilometers off Kisii-kilgoris road along Mogonga-Eberege all weather road. It lies at 34.7^0E and 0.9^0S with an altitude of 1735 meters (Google maps).

Figure 3.1: Eberege tea factory Google map retrieved from KTDA web mapping services

The main components of Eberege tea factory conventional wastewater treatment plant were as outlined: Preliminary stage which entails screens of different sizes screening off the solid wastes in the effluent; equalation tank/flocculation tank where the effluent is mixed with 4 liters of lime water i.e. $Ca(OH)_2$ used as a coagulant to remove particles and phosphates as well as adjusting the pH; reaction mixing tank whereby aluminum sulfate is added which acts as a coagulating agent hence removing the fine particles by allowing them to settle at the bottom as denser particles; aeration tank containing cow dung which supplies microorganisms for aerobic breakdown of organic matter in the effluent; settling tank that allows the effluent from the aeration tank to settle hence separating the treated effluent from the activated sludge; treated water tank stores the treated effluent prior to release; chlorination follows whereby chlorine is added to the treated effluent in order to get rid of any pathogenic bacteria present; pressure filtering and activated carbon filtering make up the last stage where the treated water is pressure filtered in activated charcoal which gets rid of possible traces of color left before it's released to the environment.

Figure 3.2 is a pictorial representation of the Eberege Conventional Wastewater Treatment Plant. The pictures were taken at the study site.

Figure 3.2: Eberege conventional wastewater treatment plant flow diagram

3.2.2 Chinga tea factory

Chinga tea factory is in region 2-Aberdare Ranges of KTDA managed factories. It's situated 170 km north of Nairobi and 12 km south of Othaya in Kirinyanga County. It lies at 36.9°E and 0.61°S with an attitude of 2,061 meters (Google maps).

Figure 3.3: Chinga tea factory Google map retrieved from KTDA web mapping services.

The components of Chinga tea factory constructed wetland wastewater treatment plant were as outlined: Interceptor stage where the incoming effluent from the factory is intercepted for removal of large objects; filtration stage made up of 3 ponds each having a screen of a different size hence removing different sized particles in the effluent in each filtration stage; sedimentation pond which is covered with water hyacinth plant (*Eichhornia Crassipes*) that is able to convert the organic waste present in the wastewater into simple inorganic material by use of microorganisms; gravel bed hydroponic cell composed of water hyacinth plants that are supported by a gravel bed further purify the wastewater by drawing their nutrients from the wastewater; three successive plants ponds further remove biological waste in the wastewater; aeration waterfalls where the effluent from the plant ponds flows freely hence mixing with

oxygen; and finally the fish pond which receives the treated effluent that can be used to culture fish.

Figure 3.4 is a pictorial representation of the Chinga constructed wetland. The pictures were taken at the study site.
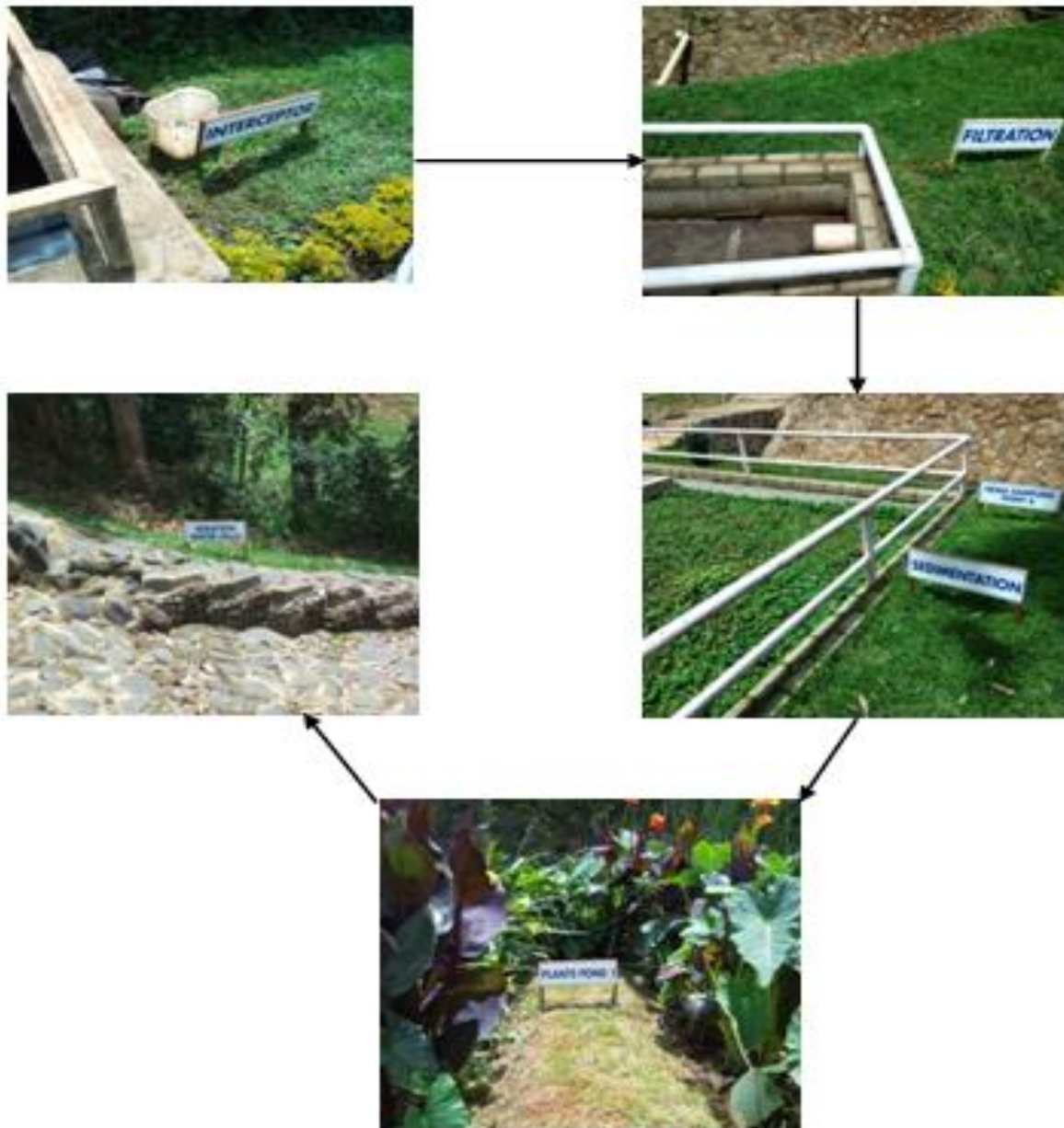
Figure 3.4: Chinga Constructed wetland wastewater treatment plant flow diagram

3.3 Sampling plan

Three batches of samples were drawn during the months of October, November and January from the two factories wastewater treatment plants. The corresponding seasons were dry, wet and dry respectively. Composite sampling method whereby a group of unit samples were collected at regular intervals over a specific time period was used (Sundara and Kumara, 2010). Influent and effluent samples were collected in 500ml sterile polyethylene bottles over a sampling period of 2 hours with intervals of 30 minutes. The individual sample aliquots were preserved at sample collection in a cooler box. After the 2 hours sampling period, the separate samples were thoroughly mixed before pouring them into a composite, dark and sterile container which was capped securely. The sample was then labeled, stored in a cooler box at 4ºC to avoid biological degradation and thereafter transported to the laboratory within the following 12 hours for analysis. All the effluent samples (untreated and treated) collected were analyzed in duplicate. The parameters analyzed in this study included; BOD, COD, TSS, pH, color, fecal coliform, organic nitrogen, copper, zinc and surfactants.

Exclusive safety measures put in place while sampling included; new set of clean disposable gloves were worn each time a sample was drawn., sampling containers including the one drawing the sample were autoclaved prior to sampling in order to ensure sterility and each influent and effluent sample were stored in an individual ice chest for transportation to the lab.

3.4 Sample analysis methods validation

The Standard operating procedures used were in line with (U.S. EPA, 1983) and (APHA, 2012) methods for water and wastewater analysis. Various techniques used for analysis included; gravimetric, electrochemical, titrimetric, chromatography, spectroscopic and visual. The analytical procedures were validated as documented in US EPA and ISO/IEC 17025 manuals using reference materials as well as blanks. Spectrophotometric technique used for zinc, copper and surfactants analysis involved use of standard solutions for analytical equipment calibration purposes.

3.5 Sample analysis

The refrigerated samples were mixed thoroughly each time, and a sample drawn for analysis of the following parameters

3.5.1 Biochemical Oxygen Demand (BOD)

3.5.1.1 Materials

The apparatus used for analyzing the samples for BOD were: BOD incubator, 300 ml glass stoppered BOD bottles, burette and burette stand. Reagents and chemicals used were as follows: manganous sulphate solution, ammonium chloride, alkaline iodide sodium azide Solution, di hydrogen phosphate, sodium thiosulphate stock solution, di potassium hydrogen phosphate, starch indicator, anhydrous calcium chloride, magnesium sulphate solution, ferric chloride solution and dilution water.

3.5.1.2 Procedure

Two 300 ml stoppered BOD bottles for the sample and other two for the blank labeled accordingly were used. 10 ml of sample was added to each of the 2 BOD bottles and topped up with dilution water. The other 2 bottles were set aside for the blank hence had dilution water only. The BOD bottles were stoppered immediately. A blank and a sample were preserved at $20^{\circ}C$ for 5 days in a BOD incubator while the other two were analyzed immediately. 3 ml of manganese sulfate was put in the BOD bottle followed by 3 ml of alkali-iodide-azide reagent. The mixture was given sufficient time to settle so as to completely react with oxygen. 2 ml of concentrated sulfuric acid was added to the floc after it had settled down and inverted several times to dissolve it. Titration with sodium thiosulphate began immediately. Titration was continued until the liberated iodine color yellow faded out. 2 ml of starch solution was added and titration continued till the disappearance of the blue color. Sodium thiosulphate volume used was noted down. The volume gave the DO in mg/l. Titration was repeated for consistent values. BOD bottles in the incubator were taken out after the 5 days and analyzed too.

3.5.2 Chemical Oxygen demand (COD)

3.5.2.1 Materials

The apparatus used for COD analysis included: Reflux apparatus, consisting of a 250 ml erlenmeyer flask and 300 mm jacket liebig condenser; heating surface capable of producing at least $1.4W/cm^2$ of heat; precision burette of capacity 10 ml, graduated in divisions of 0.02 ml; and pipettes. In addition, chemical and reagents used were: potassium dichromate solution containing mercury salt, sulfuric acid, silver sulfate, ferrous ammonium sulfate (FAS) standard, ferroin indicator, potassium hydrogen phthalate standard and mercury sulfate powder.

3.5.2.2 Procedure

10 ml of the sample was pipetted into a reaction flask. 5 ml of the potassium dichromate solution was added; several glass beads and thereafter 15 ml silver sulfate was slowly added. The mixture was brought to boiling within 10 min and boiling continued for another 110 min at 150^oC. Afterwards, the flask was cooled in cold water to about 60^oC. The mixture was diluted with distilled water to double its volume, cooled and thereafter excess dichromate titrated with ammonium (ii) sulfate using 2-3 drops of ferroin indicator. First sharp color change from blue-green to reddish-brown signified the endpoint. Blank test was carried out in parallel with the sample by replacing the test portion with 10 ml of distilled water.

3.5.3 Surfactants

3.5.3.1 Materials

The instruments used in the analysis of surfactants were: UV spectrophotometer, separating funnels, clamp and stand. Moreover, reagents and chemicals were: 1M sodium hydroxide (NaOH), 1M sulfuric acid (H_2SO_4), chloroform ($CHCl_3$), methylene blue reagent and wash solution.

3.5.3.2 Procedure

100 ml of sample was put in a separating funnel. 1M NaOH was added slowly after the addition of phenolphthalein and thereafter the pink color discharged by drop wise addition of sulfuric

acid. 10 ml of chloroform and 25 ml methylene blue reagent was added to the separating funnel. Extraction was done for 35 seconds after which the phases settled. The bottom organic layer was filtered and extraction redone twice with 10 ml chloroform. The chloroform extracts were combined together in a second separating funnel and shaken with 500 ml wash solution. The organic extract was withdrawn into a 100 ml volumetric flask and topped up with chloroform. Absorbance of the extract was measured spectrophotometrically at 652 nm against a $CHCl_3$ blank. 0.1 ppm standard solution of sodium lauryl ether sulfate was prepared from which working standards were prepared. They were run in the UV spectrophotometer in order to obtain a calibration curve.

3.5.4 Organic nitrogen

3.5.4.1 Materials

Apparatus involved during analysis of organic nitrogen included: macro kjeldahl digestion unit, distillation apparatus, 50 ml burette, heating unit and a fume hood. In addition, reagents and chemicals used were: mixed indicator solution, standard sulfuric acid titrant 0.02N, indicating boric acid solution, mercuric sulfate solution, digestion reagent: potassium sulfate- mercuric sulfate solution, borate buffer, sodium thiosulfate-sodium hydroxide reagent and 6 N Sodium hydroxide solution.

3.5.4.2 Procedure

20 ml of sample was placed in a 500 ml kjeldahl digestion flask which was then diluted to 300 ml. 20 ml borate buffer was added to the sample in order to remove ammonia nitrogen and thereafter sodium hydroxide until *pH* 9.5 was attained. Glass beads were added for smooth boiling and the solution boiled off to 300 ml. The residue was then used for organic nitrogen determination.

50 ml of digestion reagent was added to the distillation flask after cooling. The mixture was heated under a fume hood with few glass beads inside. Boiling continued until the volume was greatly reduced and dense white fumes observed. Colored samples changed to straw color within the next 30 minutes of boiling. After digestion, the mixture was left to cool and afterwards

diluted with distilled water free from ammonia to 300 ml while mixing. The flask was tilted and 50 ml of hydroxide thiosulphate carefully added to form an alkaline layer at flask bottom. The flask was thereafter connected to a steamed -out distillation apparatus, after which thorough mixing was done for complete mixing. 200 ml of distillate was collected below the surface of 50 ml boric acid absorbing solution.

Titrimetric procedure for the determination of ammonia nitrogen was used. The sample was titrated with standard sulfuric acid till the endpoint. The entire procedure was repeated using ammonia free distilled water blank and the necessary corrections done to the results.

3.5.5 Zinc and copper

3.5.5.1 Materials

The equipment and glassware involved in the analysis of copper and zinc were: flame atomic absorption spectrophotometer, volumetric flasks and measuring cylinders. Reagents used in the analysis included: concentrated nitric acid, distilled water, reference materials and stock solutions of copper and zinc

3.5.5.2 Procedure

contrAA® 700, a combined graphite and flame furnace atomic absorption spectrophotometer using air – acetylene flame was used for copper and zinc analysis. Working standard solutions for both copper and zinc were prepared via serial dilutions from their stock solutions made of high purity metal salts dissolved in high purity acids. Samples were prepared by acidifying 99 ml of sample with 1 ml concentrated nitric acid. The sample was shaken thoroughly and thereafter filtered. A blank sample of distilled water was treated to the same procedure. The working standards were used to calibrate the AAS for purposes of obtaining calibration curves for each metal. Analysis was done using the most sensitive wavelengths for the metals i.e. 213.9 nm for zinc and 324.8 nm for copper (Bader, 2011). After calibration of the AAS, samples, blank and a reference material were run while noting down their absorbance values. The metals concentration in the sample were realized from the calibration curves; using the absorbance values obtained.

3.5.6 Total Suspended Solids

3.5.6.1 Materials

Apparatus used in determination of total suspended solids were: filtration apparatus, evaporating dish, oven, desiccators, analytical balance, graduated cylinders, dish tongs, whatman filter paper, vacuum pumps, wash bottles and forceps. The reagent used for the same analysis was distilled water.

3.5.6.2 Procedure

A dried whatman filter paper whose weight was known was placed in a filter flask in the filtration apparatus. The filtration apparatus was prepared by applying suction to the filter flask followed by seating the filter with distilled water. 20ml of a well-mixed sample in a measuring cylinder was poured into the apparatus and sucked through the filter into a flask. Distilled water was used to rinse the measuring cylinder. After final rinse filtration, suction went on for 4 minutes and thereafter oven drying at $105^{o}C$ for one hour. Afterwards, the filter paper was cooled at room temperature in a desiccator and thereafter its weight was recorded.

3.5.7 pH

3.5.7.1 Materials

The apparatus involved in the determination of pH were: pH meter, beaker, flasks, funnel, forceps, magnetic stirrer, wash bottle and paper towels. Moreover, reagents used were distilled water and buffer solutions of pH 4.0, 7.0 and 9.2.

3.5.7.2 Procedure

The instrument was calibrated using the three buffers each at a time. Buffer solution of pH 9.2 was put in a 100 ml beaker and stirred well in a magnetic stirrer. Adjustments were made to ensure correct reading. The electrode was then placed in the stirred buffer and the pH meter reading taken. Thereafter, the electrode was withdrawn from the buffer, washed well, wiped and the same procedure repeated with buffer solution 7.0 and lastly buffer 4.0.

After calibration, the sample was treated to the same procedure as that of the buffer solutions but with no pH reading adjustment.

3.5.8 Fecal Coliform

3.5.8.1 Materials

The apparatus used in the determination of fecal coliform bacteria included: incubator, colony counter, petri dishes and membrane filter. In addition, reagents used were: M-FC agar culture medium and dilution water.

3.5.8.2 Procedure

Fecal coliform agar culture medium was poured onto an absorbent pad in a Petri dish. The sample was shaken vigorously and 100 ml taken. A membrane filter of 47 mm diameter and mean pore size of 0.45µm was used to filter the sample. The funnel was rinsed with approximately 30 ml of dilution water. The filter was then placed on a pad in Petri dish with the selected medium. The inverted plate was incubated at $44.5^{\circ}C$ for 24 hours. Afterwards, the blue colonies were counted. Appropriate blanks known as positive and negative were also run.

3.5.9 Color

3.5.9.1 Materials

Apparatus used in color determination were: color comparator, measuring cylinders, clear glass bottles, 1000 ml volumetric flasks and 50 ml nessler tubes. In addition, reagents used were: potassium-hexachloroplatinate, cobalt chloride, hydrochloric acid and distilled water.

3.5.9.2 Procedure

The hazen parent solution (cobalt number 500) was prepared by dissolving 1.246 g of potassium-hexachloroplatinate and 1.1 g of crystallized cobalt chloride in l00 ml of hydrochloric acid and topped up to 1000 ml with distilled water. Reference solutions for intermediate steps were prepared freshly by different levels of dilutions of the parent solution. Thereafter, the sample was passed through a filter in case of any visible turbidity and introduced into a 50 ml nessler.

The tube was capped, placed in a comparator and compared with the standards. The standard closest to the sample was determined and color standard number reported in hazen units.

3.6 Data analysis

Raw data obtained during analysis of the effluent as outlined in the previous subsections was analyzed as follows;

i) BOD

Biochemical oxygen demand was calculated as outlined in equation (1)

$$\textbf{BOD} \left(\frac{\textbf{mg}}{\textbf{L}}\right) = \frac{(\textbf{Do} - \textbf{D5} - \textbf{BC}) \times \textbf{Volume of diluted sample}}{\textbf{Volume of sample}} (1)$$

Whereby Do was diluted sample initial DO, D5 was the diluted sample DO at day 5 while BC was the blank correction.

ii) COD

The Chemical Oxygen Demand was calculated as follows;

$$\textbf{COD (mg/L)} = \frac{(\textbf{A} - \textbf{B}) \times \textbf{8000}}{\textbf{ml of sample}} (2)$$

Whereby A was FAS blank volume, B was the FAS sample volume, M was the molarity of FAS while 8000 was the milliequivalent oxygen weight $\times 1000$ml/L.

iii) Surfactants

Determination of surfactants was done using the UV spectrophotometer. A calibration curve obtained by running working standards was as shown in figure 3.5.
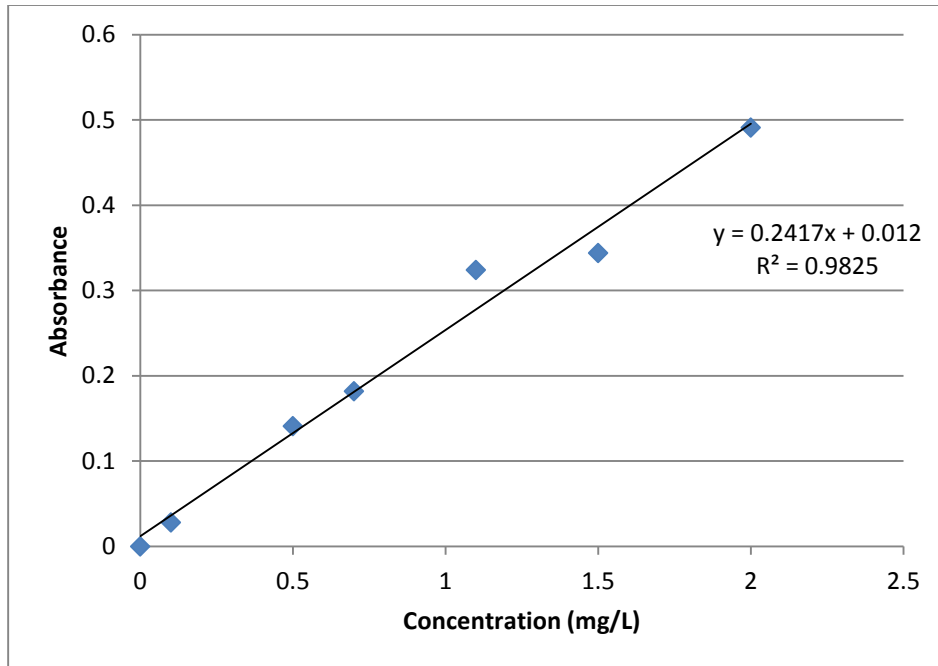
Figure 3.5: Surfactants calibration curve

The surfactants concentration in the various samples was therefore determined against the corresponding absorbance.

iv) Organic nitrogen

The formula used to determine the concentration of organic nitrogen was;

$$\textbf{Organic nitrogen} \left(\frac{\textbf{mg}}{\textbf{L}}\right) = \frac{(\textbf{A}-\textbf{B})\times\textbf{280}}{\textbf{V}} \, (3)$$

Where A - Volume of sulfuric acid used in sample

B – Volume of sulfuric acid used in blank

V – Volume of test sample

v) Zinc & copper

The concentration of zinc and copper was determined spectrophotometrically using a Flame AAS. Corresponding calibration curves obtained were as shown in figures 3.6 and 3.7.
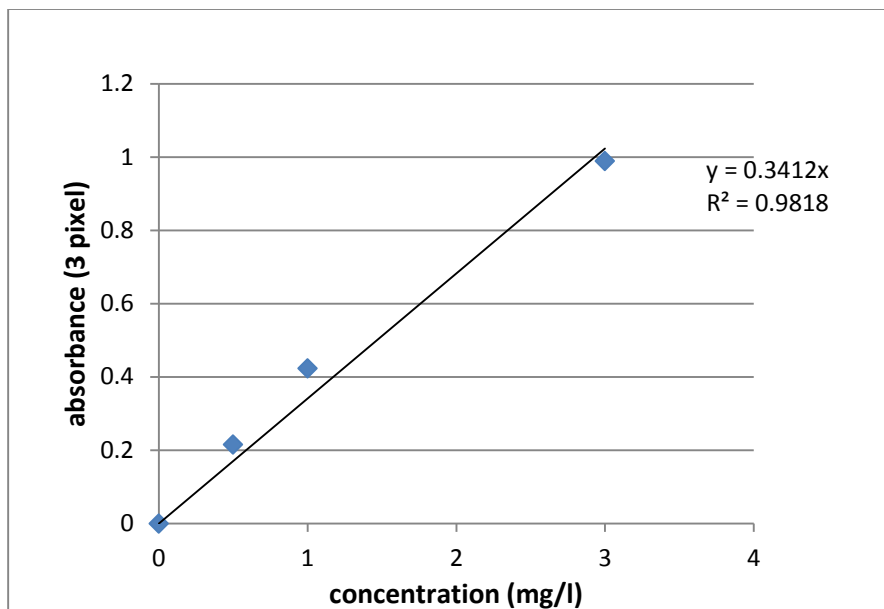
Figure 3.6: Zinc calibration curve
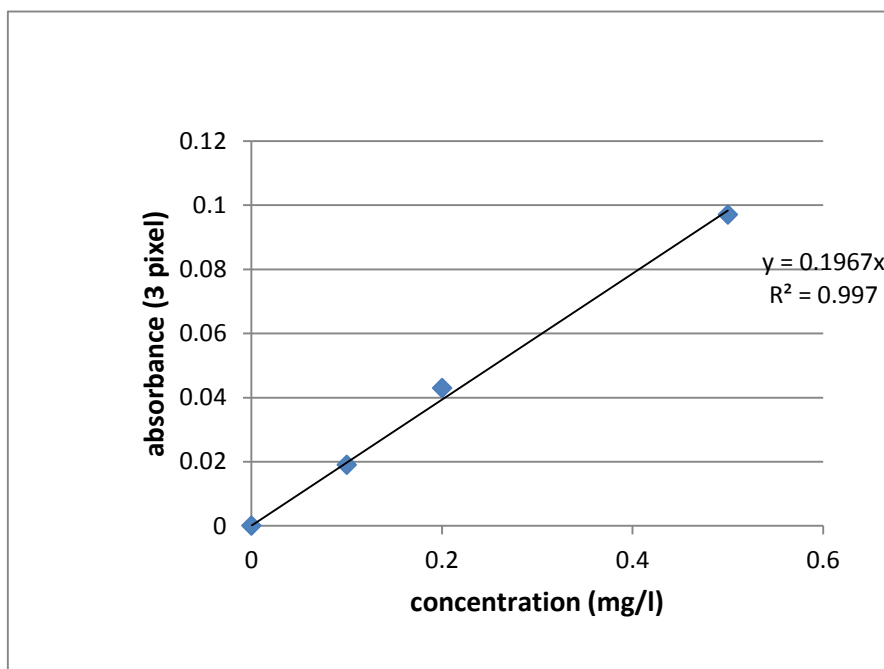
 Figure 3.7: Copper calibration curve

The zinc and copper concentration in the samples was therefore determined against corresponding absorbance.

vi) TSS

The total suspended solids were calculated as shown in equation (4)

$$\text{TSS in mg/L} = \frac{W_2 - W_1}{V} \ (4)$$

Whereby, W_2 was the mass of the residue and filter paper, W_1 was the mass of the clean filter paper while V was the volume of sample.

vii) pH

The pH values for the various samples were read directly from the pH meter after calibration.

viii) Fecal coliform

Calculation of coliform density was done as follows;

$$\text{Coliforms in 100ml} = \frac{\text{coliform colonies} \times 100}{\text{ml of sample filtered}} \ (5)$$

ix) Color

Determination of color was done as shown in equation (6)

$$\text{Colour in hazen units} = \frac{A \times 50}{B} \ (6)$$

Whereby, A was the estimated color of the diluted sample while B was the volume of sample taken for dilution.

The mean value of each parameter was calculated and the results presented in the form of mean value $\pm$ SD.

In addition, a t-test which is also known as a student's T test was carried out on the data. The mean values obtained for each parameter of interest were subjected to a t-test in Microsoft excel in order to establish if the before and after treatment results were significantly different. A paired two sample t-test that is run on dependent samples was used to analyze the before treatment and after treatment groups of data for each parameter as indicated in chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, results obtained from analysis of the various effluent samples will be presented and discussed. In addition, comparison of pollutant levels to NEMA limits will be discussed as well as performance of the two different systems of wastewater treatment.

4.2 Pollutant levels in untreated and treated wastewater

The results obtained for each parameter were as presented in the subsequent subsections. High concentration levels of BOD, COD, TSS, organic nitrogen and color were recorded. Nevertheless, levels of organic nitrogen and zinc were considerably low. In addition, copper, fecal coliform and surfactants concentrations were below the limit of detection. On the other hand, the treated effluent from both factories was characterized with a substantial decrease of pollutant concentration since the values of the test parameters greatly reduced even though the efficiency of pollutant removal differed in the two factories.

The results are further discussed as follows;

4.1.1 BOD

Biochemical oxygen demand of the incoming effluent in both factories was found to be higher than 48.6mg/L while the treated effluent recorded readings of less than 26.5mg/L as tabulated in table 4.1
The t-test was conducted for the two samples that were analysed before and after treatment and gave less values of t-critical compared to the t-statistic. Since the t-statistic was greater than t-critical, the results were significantly different. Therefore, there was a significant reduction of BOD in the treated effluent from both treatment plants.

Table 4.1: Mean levels of BOD in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	60.8 ± 1.2	20.2 ± 2.3	57.3 ± 1.2	22.6 ± 0.3
November 2017	75.8 ± 0.3	18.1 ± 1.1	48.6 ± 0.6	24.6 ± 0.4
January 2018	50.4 ± 0.2	20.5 ± 0.3	55.2 ± 0.1	26.5 ± 0.2
T test	t-critical = 4.3 t-statistic = 5.3		t-critical = 4.3 t-statistic = 9.4	

4.1.2 TSS

The untreated effluent recorded high concentration values of up to 32.2mg/L of TSS while the treated effluent recorded values which were less than 30.2mg/L. The paired t-test conducted on the 2 sets of data for Eberege plant gave a t-statistic less than t-critical meaning the differences in the mean values, before and after treatment was not significant. On the other hand, the t-statistic for Chinga plant was greater than the t-critical hence significant differences in the means of the before and after treatment sets of data.

Table 4.2: Mean levels of TSS in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	29.6 ± 1.1	27.4 ± 0.5	30.3 ± 0.2	28.5 ± 0.9
November 2017	31.5 ± 0.7	26.3 ± 0.7	30.7 ± 0.5	28.8 ± 0.2
January 2018	30.7 ± 0.2	25.4 ± 0.3	29.3 ± 0.1	27.7 ± 0.1
T test	t-critical = 4.3 t-statistic = 4.2		t-critical = 4.3 t-statistic = 15.6	

4.1.3 pH

The pH of the untreated effluent was found to range between 6.3 – 6.5 while the treated effluent pH was within 6.3 – 6.8 range. It was noted that upon treatment, the pH was drifting towards the neutral position of 7.

The t-statistic for the Eberege plant was higher than the t-critical hence the mean differences before and after treatment were significant. However the t-statistic for the Chinga plant was less than the t-critical indicating a non-significant mean differences between the 2 sets of data.

Table 4.3: Mean levels of pH levels in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	6.3±0.2	6.5±0.3	6.4±0.1	6.5±0.2
November 2017	6.5±0.1	6.8±0.1	6.3±0.2	6.3±0.1
January 2018	6.5±0.3	6.7±0.2	6.5±0.2	6.5±0.1
T test	t-critical = 4.3 t-statistic = 7		t-critical = 4.3 t-statistic = 1	

4.1.4 Fecal coliform

Fecal coliform bacteria were not detected in any of the effluent samples. Therefore, there was negligible or no contamination of the effluent by disease causing organisms.

The results obtained were as tabulated in table 4.4

Table 4. 4: Mean levels of fecal coliform counts/100mL in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	Not detected	Not detected	Not detected	Not detected
November 2017	Not detected	Not detected	Not detected	Not detected
January 2018	Not detected	Not detected	Not detected	Not detected

4.1.5 COD

The incoming effluent from both factories was characterized with high concentrations of up to 179.2mg/L of COD. After treatment, the COD greatly reduced to values less than 60.6mg/L. Upon subjecting the 2 sets of data to a t-test, both plants recorded a t-statistic higher than the t-critical hence the before treatment and after treatment sets of data were significantly different.

Table 4.5: Mean levels of COD in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	164±2.2	50.4±1.3	179.2±0.5	60.6±1.2
November 2017	164.4±1.4	55.63±0.3	150.26±0.9	45.8±0.4
January 2018	170.8±0.2	58.57±0.3	168.62±0.3	59.1±0.4
T test	t-critical = 4.3 t-statistic = 77.6		t-critical = 4.3 t-statistic = 26.9	

4.1.6 Color

The untreated effluent from both factories was characterized by a dark color hence recorded values greater than 15 hazen units. After treatment, the color was lighter and gave values of less than 12 hazen units.

The t-test conducted on the 2 sets of data for both plants gave t-statistic values higher than the t-critical implying a significant difference between the before and after treatment data.

Table 4.6: Mean levels of color in hazen units in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	20	5	16	12
November 2017	18	6	15	10
January 2018	17	5	17	11
T test	t-critical = 4.3 t-statistic = 13		t-critical = 4.3 t-statistic = 8.7	

4.1.7 Organic nitrogen

The organic nitrogen concentrations in the raw effluent were greater than 7.8mg/L. However, after treatment there was a significant decrease to values less than 3.1mg/L. The mean differences between the 2 groups of data were significantly different as supported by the t-test.

Table 4.7: Mean levels of organic nitrogen in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	11.2±0.2	2.8±0.1	8.5±0.1	0.5±0.1
November 2017	12.8±0.3	3.1±0.1	7.8±0.2	0.2±0.1
January 2018	13.2±0.2	2.3±0.3	12.4±0.2	0.4±0.3
T test	t-critical = 4.3 t-statistic = 13		t-critical = 4.3 t-statistic = 6.5	

4.1.8 Copper

The concentration of copper in all the effluents was below the detection limit as indicated in table 4.8. Therefore, there was no significant difference between the data obtained before and after treatment.

Table 4.8: Mean levels of copper in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	<0.001	<0.001	<0.001	<0.001
November 2017	<0.001	<0.001	<0.001	<0.001
January 2018	<0.001	<0.001	<0.001	<0.001

4.1.9 Zinc

The zinc concentration values were below the detection limit for most of the effluent samples with an exception of one sample that recorded a value of 0.543mg/L. After treatment of the effluent, the sample concentration was below the detection limit. There was no statistical significant difference between the 2 two sets of data.

Table 4.9: Mean levels of zinc in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	Effluent	Influent	Effluent
October 2017	0.543±0.002	<0.001	<0.001	<0.001
November 2017	<0.001	<0.001	<0.001	<0.001
January 2018	<0.001	<0.001	<0.001	<0.001
T test	t-critical = 4.3 t-statistic = 1		N/A	

4.1.10: Surfactants

The concentration of surfactants in all the effluent samples was below the detection limit as indicated in table 4.10. Therefore, there was no statistical significant difference between the data obtained before and after treatment.

Table 4.10: Mean levels of surfactants in mg/L in influent and effluent samples obtained from Eberege and Chinga treatment plants.

Sampling season	Eberege tea factory		Chinga tea factory	
	Influent	**Effluent**	**Influent**	**Effluent**
October 2017	Not detected	Not detected	Not detected	Not detected
November 2017	Not detected	Not detected	Not detected	Not detected
January 2018	Not detected	Not detected	Not detected	Not detected

In summary, it's evident that the untreated wastewater from the two factories was polluted. Presence of unprocessed and processed tea remains in the raw effluent corresponded to high concentrations of BOD, COD, TSS and color. Organic nitrogen was present in considerable amounts too. Heavy metals in the raw effluent were below the limit of detection with exception of one sample that recorded a concentration value of 0.543mg/L zinc. Heavy metals in the factory wastewater originate from tear and wear of the processing equipment hence the possible cause of zinc presence in the raw effluent. Upon treatment of the raw effluent, there was a substantial decrease of the pollutants concentrations in both treatment plants.

The seasonal changes were observed to have little effect on the wastewater treatment process. The conventional wastewater treatment plant was enclosed hence outside weather conditions did not interfere much with the treatment process hence the results realized were closely related. On the other hand, the constructed wetland effluent quality was affected since the system was exposed hence interference by environmental factors. TSS levels were high during the rainy season due to surface run off while BOD and color were relatively low since the rains had a dilution effect.

Lastly, most of the physico-chemical parameters were found to be highly dependent on each other. The darker the color was, the higher the BOD and COD since organic matter and color are closely associated with particles. Heavy metals in water are highly depended on the physico-

chemical parameters of   water such as turbidity, conductivity, pH and TDS (Bader, 2011). The solubility of metals in water increases with decrease in pH. Trace metal removal mechanism used in this study was chemical precipitation using lime as the precipitant. Adjustment of pH to basic conditions is the major determinant which significantly makes the metal removal by chemical precipitation successful (Ahluwalia and Goyal 2007). Therefore, increase in pH was accompanied by decrease in heavy metal levels as it was noted in the case of zinc removal.

4.3 Comparison of pollutant levels with NEMA permissible limits in treated and untreated effluent

In reference to the results obtained, the untreated wastewater was not compliant with the set NEMA guidelines. As per the standard for tea factory discharge to the environment, BOD, COD, TSS and color readings should not exceed 30mg/L, 50mg/L, 30mg/L and 15 hazen units respectively. However, the levels obtained were beyond the set limits. One raw effluent sample recorded a reading of 0.543mg/L zinc which was above the recommended limit of 0.5mg/L. On the contrary, organic nitrogen, copper and surfactants levels were within the set NEMA limits of 100mg/L, 1mg/L, and below detection limit respectively.

On the other hand, the treated wastewater complied with NEMA guidelines for most of the test parameters. A major decrease in all the pollutant concentrations was noted even though the COD levels were slightly above the allowed maximum limits. Similarly, TSS readings were slightly above the permissible levels in Chinga treatment plant.

Comparison of both the untreated and treated effluent contaminants levels with NEMA limits is further illustrated in the following figures;
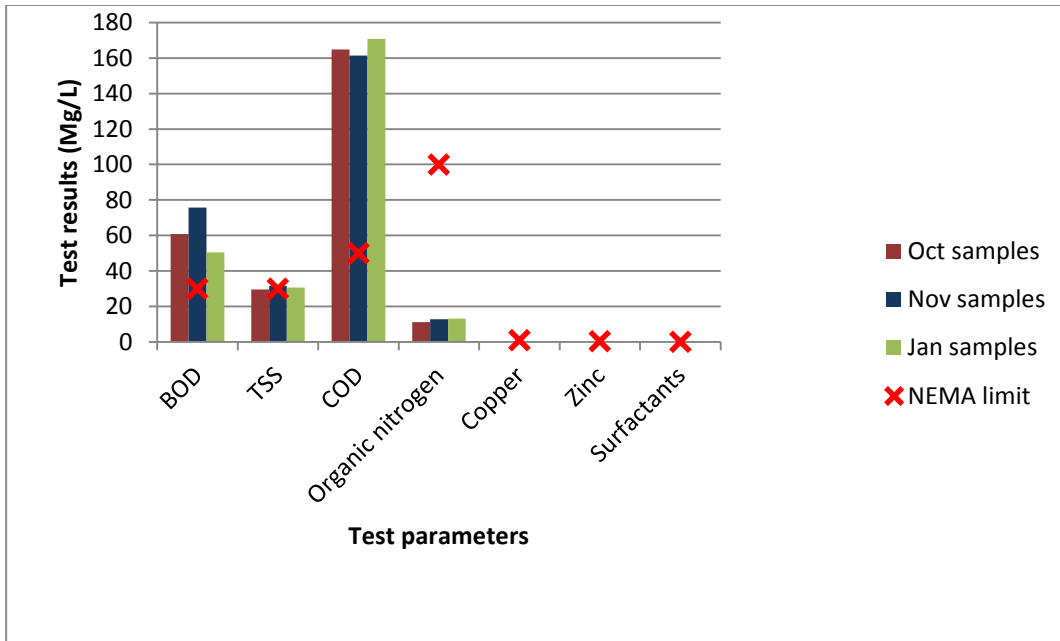
Figure 4.1: Eberege untreated effluent pollutant levels in comparison with NEMA limits
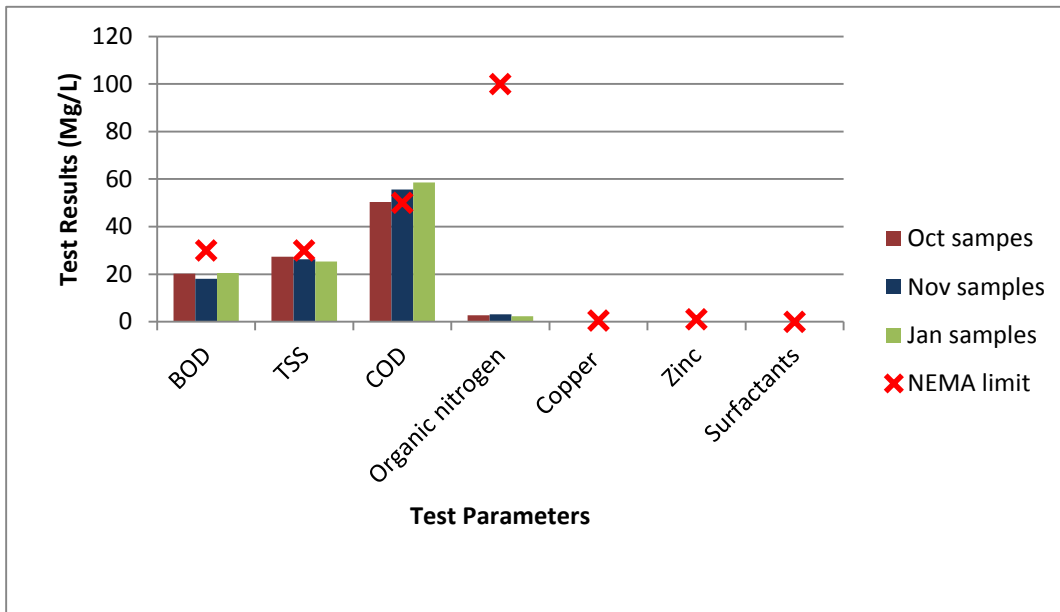

Figure 4.2: Eberege treated effluent pollutant levels in comparison with NEMA limits
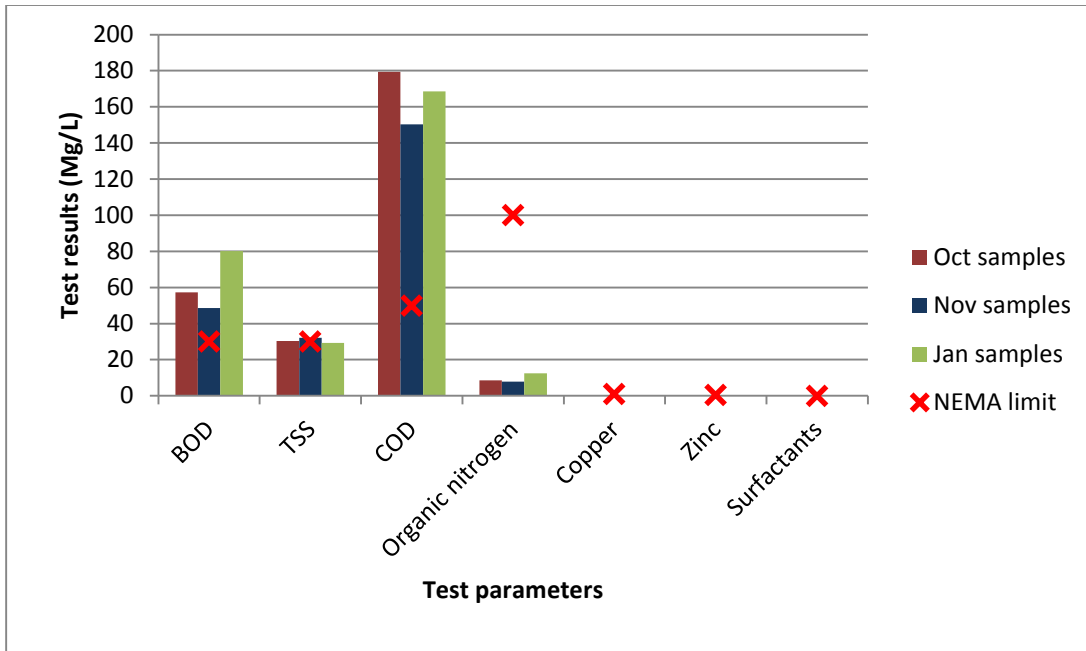
Figure 4.3: Chinga untreated effluent pollutant levels in comparison with NEMA limits
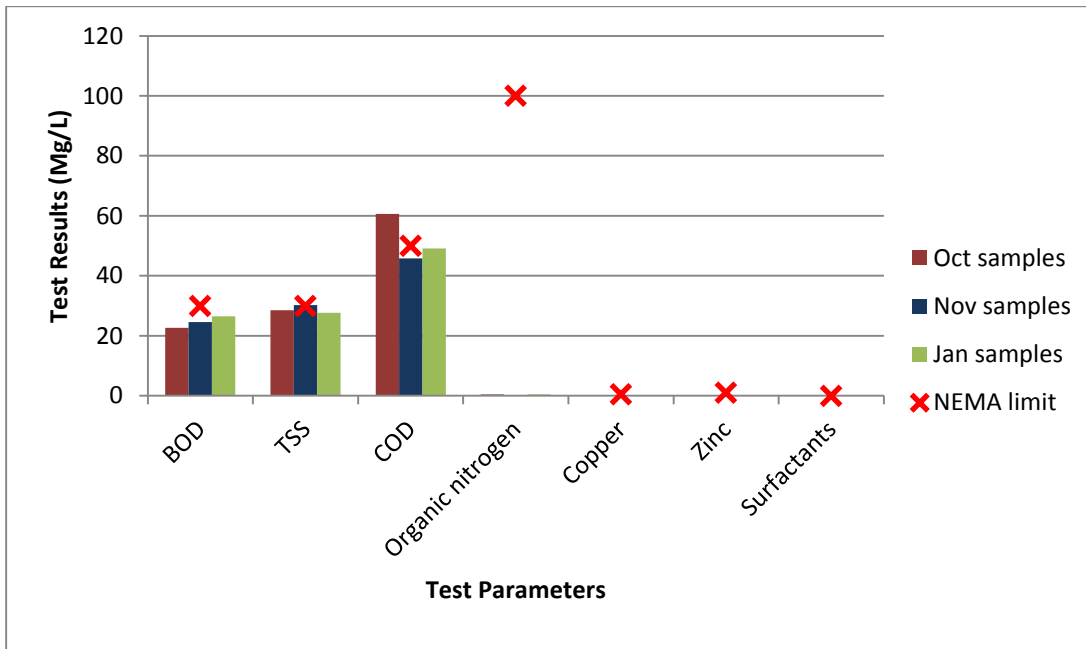

Figure 4.4: Chinga treated effluent pollutant levels in comparison with NEMA limits

4.6 Performance of the conventional and constructed wetlands wastewater treatment systems in contaminants removal

Both systems of wastewater treatment were able to treat the raw effluent even though the efficiency of treatment varied between the two systems as seen in table 4.11. Percent pollutant removal efficiency as discussed in Bandala *et al.* (2017) was calculated as follows:

$$\% \ removal \ efficiency = \frac{(influent \ pollutant \ concentration - effluent \ pollutant \ concentration)}{influent \ pollutat \ level} \times 100$$

In overall, the conventional treatment plant in Eberege tea factory was more effective in treating the tea factory effluent. BOD, TSS, COD and color percentage reduction was higher in Eberege conventional plant with percentage removal efficiency of 59.3─76.1, 7.4─17.3, 59.3─69.4 and 66.7─75 respectively. Moreover Chinga constructed wetland recorded percentage removal efficiency values of 49.4─60.6 BOD, 5.5─6.2 TSS, 58.3─70.9 COD and 25─35.3 color.

The major difference in the contaminants removal efficiency between the two systems can be attributed to the incorporation of activated sludge processes and coagulants in the conventional wastewater treatment plant which greatly reduced the organic load as well as fine particles, hence reducing the values of BOD, COD, TSS, and trace metals by a big margin. Color reduction was more in Eberege conventional plant due to the use of coagulant $Ca(OH)_2$ which removed particles in colloid form hence most of the color was removed since it's usually associated with the particles. In addition, the lime water also made the water basic hence increasing the treated effluent pH. Nevertheless, organic nitrogen percentage removal was higher in Chinga constructed wetland plant compared to Eberege conventional plant. Organic nitrogen was removed via nitrification and denitrification processes whereby ammonium was oxidized to nitrite by the bacterium *Nitrosomonas* while the nitrite was oxidized to nitrate by the bacterium *Nitrobacter*. Nitrate was thereafter reduced to harmless nitrogen which enters the atmosphere. This process took place at the root zone of the aquatic plants (Rajagopalan, 2017).

Table 4.11: Comparison of contaminants removal efficiency between conventional and constructed wetlands wastewater treatment systems

Variables		Eberege tea factory - conventional WWTP			Chinga tea factory - Constructed wetland WWTP		
		Before treatment	After treatment	% removal efficiency	Before treatment	After treatment	% removal efficiency
BOD (mg/L)	1st Batch	60.8	20.2	66.8	57.3	22.6	60.6
	2nd batch	75.8	18.1	76.1	48.6	24.6	49.4
	3rd batch	50.4	20.5	59.3	55.2	26.5	52
TSS (mg/L)	1st Batch	29.6	27.4	7.4	30.3	28.5	5.9
	2nd batch	31.5	26.3	16.5	30.7	28.8	6.2
	3rd batch	30.7	25.4	17.3	29.3	27.7	5.5
pH	1st Batch	6.3	6.5	N/A	6.4	6.5	N/A
	2nd batch	6.5	6.8	N/A	6.3	6.3	N/A
	3rd batch	6.5	6.7	N/A	6.5	6.5	N/A
Fecal coliform (counts/100 mL)	1st Batch	Not detected	Not detected	N/A	Not detected	Not detected	N/A
	2nd batch	Not detected	Not detected	N/A	Not detected	Not detected	N/A
	3rd batch	Not detected	Not detected	N/A	Not detected	Not detected	N/A
COD (mg/L)	1st Batch	164.8	50.4	69.4	179.2	60.6	66.2
	2nd batch	161.4	65.63	59.3	150.26	45.8	58.3
	3rd batch	170.8	58.57	65.7	168.62	59.1	65
Color (H.U)	1st Batch	20	5	75	16	12	25
	2nd batch	18	6	66.7	15	10	33.3
	3rd batch	17	5	70.6	17	11	35.3
Organic nitrogen (mg/L)	1st Batch	11.2	2.8	75	8.5	0.5	94.1
	2nd batch	12.8	3.1	75.8	7.8	0.2	97.4
	3rd batch	13.2	2.3	82.6	12.4	0.4	96.7
Copper (mg/L)	1st Batch	<0.001	<0.001	N/A	<0.001	<0.001	N/A
	2nd batch	<0.001	<0.001	N/A	<0.001	<0.001	N/A
	3rd batch	<0.001	<0.001	N/A	<0.001	<0.001	N/A
Zinc (mg/L)	1st Batch	0.543±0.002	<0.001	100	<0.001	<0.001	N/A
	2nd batch	<0.001	<0.001	N/A	<0.001	<0.001	N/A
	3rd batch	<0.001	<0.001	N/A	<0.001	<0.001	N/A
Surfactants (mg/L)	1st Batch	Not detected	Not detected	N/A	Not detected	Not detected	N/A
	2nd batch	Not detected	Not detected	N/A	Not detected	Not detected	N/A
	3rd batch	Not detected	Not detected	N/A	Not detected	Not detected	N/A

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this study were successfully achieved.

The pollution load in the untreated effluent from the factory was found to be high and above NEMA acceptable limits. It was characterized by high concentrations of BOD, TSS and COD. The effluent color was beyond 15 hazen units. Nevertheless, the values of pH, organic nitrogen, copper, zinc and surfactants were within the set permissible limits.

In addition, the treated effluent from both factories recorded lower levels of all the contaminants although the COD levels were slightly above the NEMA permissible limit. In overall, the treated wastewater was compliant with NEMA guidelines with an exception of COD.

The conventional wastewater treatment plant was found to perform better in removal of pollutants as compared to the constructed wetland.

With respect to tea factory wastewaters, both systems were able to treat the effluent effectively despite the fact that the conventional treatment plant gave a higher degree of treatment in overall.

A conventional wastewater treatment system can therefore be recommended to tea factories policy makers for wastewater treatment hence solving the challenge of dealing with poorly performing lagoon system in Kenyan tea factories.

I recommend further studies to centre on upgrading the existing wastewater treatment systems to more effective systems which incorporate physical, chemical and biological modes of treatment while eliminating the shortcomings that come with conventional and constructed wetlands systems.

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