ASSESSMENT OF EFFICIENCY OF WASTEWATER TREATMENT BASED ON PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS OF KISII TOWN WASTEWATER TREATMENT PLANT, KENYA

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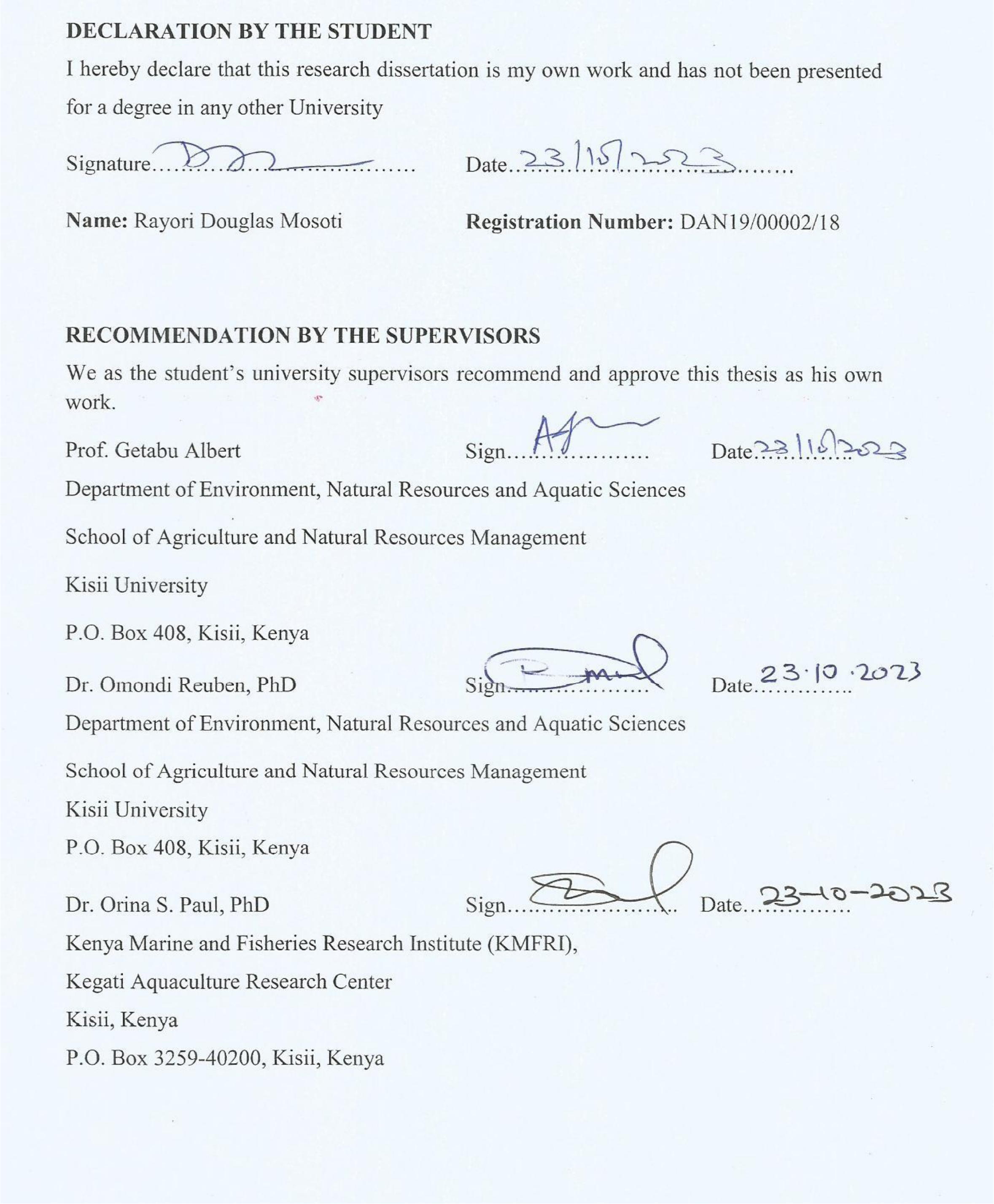

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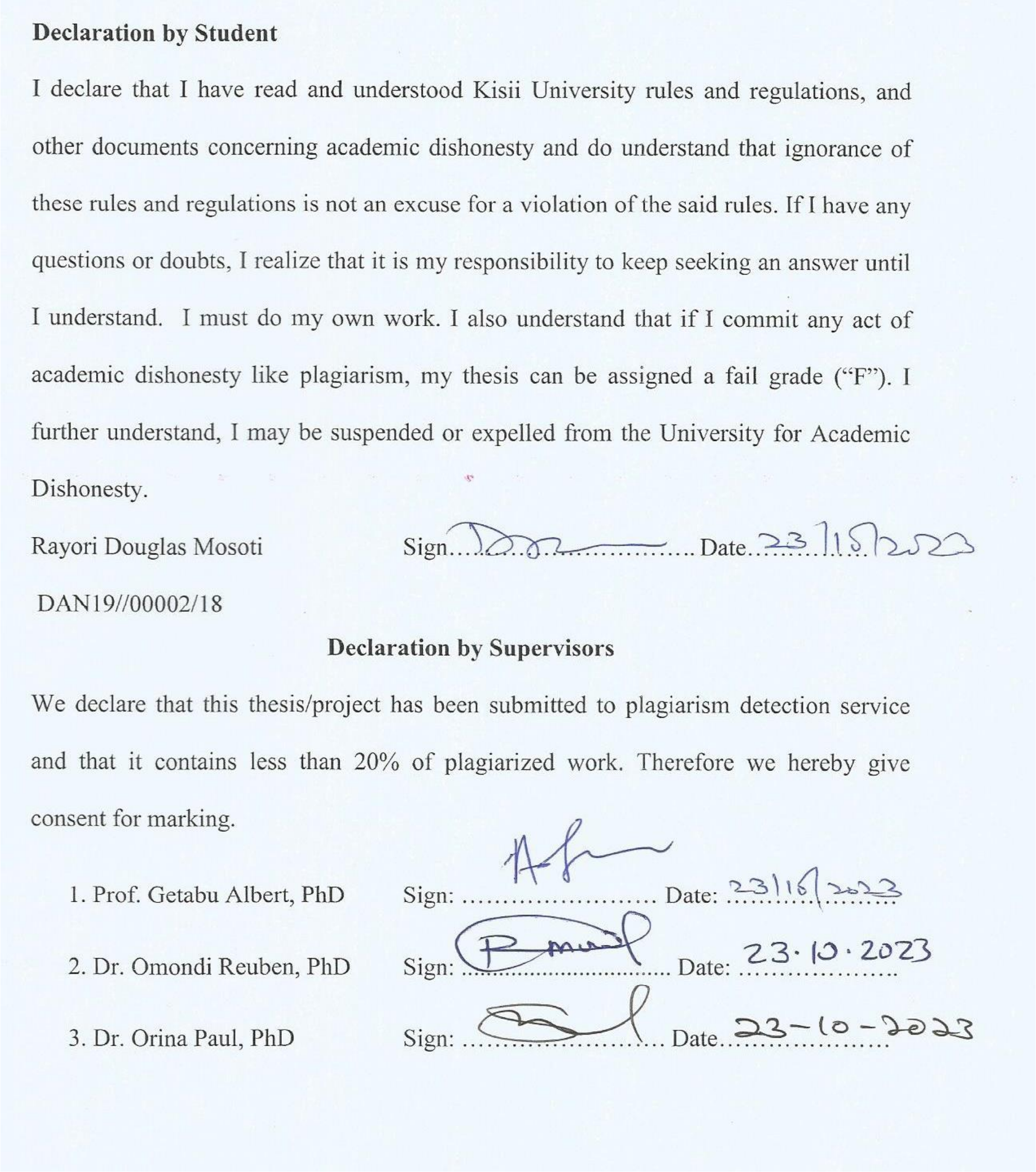

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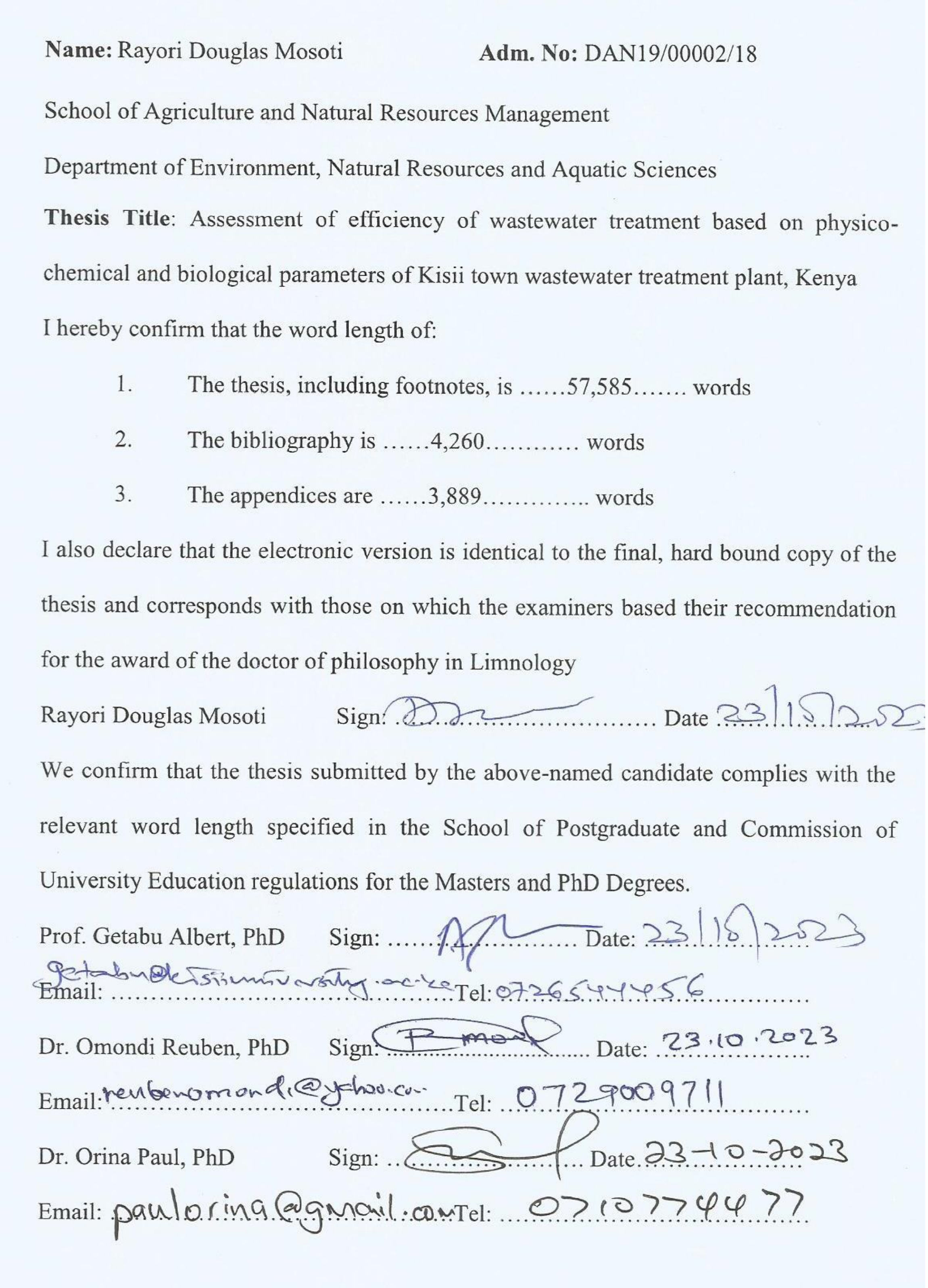

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DEDICATION

This thesis is dedicated to my loving wife, Rose B. Ogata, sons Benedict Mosoti, Francis Mosoti, and daughter Maryteresa Mosoti who have been of great source of motivation and inspiration. I also dedicate it to parents Mr. Pius Marambe Rayori and Mrs. Prisca Bosibori Rayori, whose love, encouragement and continued support have always aimed at bringing the best out of me. Further, I dedicate it to my brothers Ronald, Erick, Hillary, and Sisters Nancy and Teresa. Last but not least, I dedicate it to Prof. Mary Getui and Prof. John Muoma for they are my role models and mentors.

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ABSTRACT

Knowledge of the nature and composition of wastewater is critical in wastewater treatment, re-use, and disposal. Kisii municipality wastewater treatment plant (WWTP) is a lagoon system that treats wastewater, and discharges its effluent into river Riana. The river serves as a source of water for domestic, agricultural, and industrial uses downstream. The WWTP does not have adequate capacity to fully treat all the wastewater from the municipality. The discharge of partially or untreated wastewater into river Riana particularly during system breakdown is of great concern due to the potential health risks it poses to the environment, human and animals. This study aimed at assessing the efficiency of the WWTP in treating wastewater based on analysis of selected physical, chemical and biological parameters, of health concerns. This was done both on the initial and current wastewater treatment plant design during the period 2019 and 2021 respectively to establish whether there was an improvement in wastewater polishing. Monthly samples for physical, chemical and biological parameters were collected for analysis. Temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) were measured *in situ* using YSI multi-parameter probe model 35C. Total suspended solids (TSS), chlorophyll-a, nutrients and Total and Fecal coliforms (TC and FC) were analyzed *ex situ* following standard procedures described in APHA, 2014. Atomic Absorption Spectrophotometry (AAS) was used to determine heavy metals concentrations of Cd, Cu, Pb and Zn in wastewater, sediments, and plankton samples. Inverted microscope (model: Zeiss Axiovert 35) was used to identify and enumerate phytoplankton while a simple light compound microscope (Model: Olympus, Japan) was used to identify and enumerate zooplankton using standard identification keys. Microsoft Excel version 2010 and SPSS version 22 software were used to analyze physical, chemical and biological data while PAST software was specifically used to determine the biodiversity diversity indices of the plankton. The physical, chemical, heavy metals, and biological (coliforms) parameter levels of the effluent were compared with NEMA, WHO, and EPA standards. The mean DO, EC, TSS, TDS, SRP, NO_2-N, NO_3-N, TP and TN differed significantly among the sampling stations (ANOVA; $p < 0.05$) both spatially and monthly before and after renovation of the lagoon. 126 phytoplankton species were identified belonging to 6 families: Euglenaphyceae, Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae, and Zygnematophyceae. The total phytoplankton biovolume recorded was 1066.14 mm^3L^{-1}. For zooplankton, 15 species were identified and they belonged to three major groups: Cladocera, Rotifera, and Copepoda. The total zooplankton abundance recorded was 5745 $IndL^{-1}$. The means of TC and FC for the initial WWTP were 76.3 ± 10.98 and 55.66 ± 9.89 counts/100ml respectively while for the current WWTP were 37.64 ± 3.3 and 17.94 ± 2.3 counts/100ml. The heavy metals identified in the WWTP were copper (Cu), lead (Pb), and zinc (Zn) but cadmium (Cd) was below detection level throughout the study period. The parameters pH, temperature, TDS, NO_3-N, Cu, and Zn were within NEMA standards while others were above, showing that the plant did not efficiently polish the wastewater. Polishing efficacy of the WWTP was below 70% for the majority of the parameters assessed, of major concern it was observed that coliforms (TC and FC) counts, TP, and TN concentrations did not meet the required standards. The two nutrients are responsible for eutrophication and poor water quality of river Riana and the main river Kuja that flows to Lake Victoria. Plankton further contributed in wastewater polishing by incorporation of nutrients and heavy metals into their biomass. Lastly, renovation of the lagoon must have contributed to its improvement in efficiency of wastewater polishing but the design still has challenges dealing with nutrients and coliforms. The current study findings form a baseline for further studies in the lagoon. The Gusii Water and Sanitation Company can use this information to improve on their wastewater treatment processing meet the laid down guidelines for effluent discharge into the environment. The study recommends construction of a wetland for further polishing of effluent discharged in the removal of nutrients and heavy metals.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

APPENDICES

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EPA	Environmental protection Agency
WWTP	Wastewater treatment plant
NEMA	National Environment Management Authority
SPSS	Statistical package for social sciences
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
WHO	World Health Organization
WSP	Wastewater Stabilization Pond

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

United Nations Sustainable Development Goals (SDG), specifically SDG 6, aims at ensuring sustainable management of water and sanitation thus improving water quality by reducing pollution through the discharge of partially or untreated wastewater (UN, 2017). The increase of human population in large urban centres has led to the production of high volumes of municipal wastewater effluent. To ensure that this effluent does not pollute receiving waters, there is need to treat it using various available techniques like wastewater lagoons and trickling treatment works. Anthropogenic activities have led to an increase in demand for clean water of good quality, and the quantity of wastewater produced is continuously increasing. In developed countries, wastewater is treated before being released to the environment, unlike in most developing countries. This is because the cost of treating wastewater is high, underdeveloped and most of developing countries are not able to install expensive infrastructure (UNESCO, 2017).

Wastewater is of poor quality as it is rich in pathogenic micro-organisms, heavy metals, organic and inorganic chemicals, and toxic substances. Hence, it is not suitable for domestic, agricultural, and industrial uses therefore can pollute the environment (UNESCO, 2017). The effects associated with the release of untreated or partially treated wastewater include the degradation of aquatic ecosystems, the outbreak of food poisoning and water-borne diseases (Karimi, 2015; UNESCO, 2017). Therefore, wastewater needs to be treated to provide a reliable alternative source of water in the advent of the ever-growing demand for clean water. On the other hand, the technologies used in wastewater treatment should be environment friendly.

Adequately treated wastewater can be an alternative source of water to be used for domestic and agricultural uses such as irrigation, industrial operations and aquaculture. Treated wastewater use for aquaculture is a common practice in the world (UNESCO, 2017). Asian countries, such as India, Bangladeshi and China in particular, are leading in using treated wastewater in aquaculture with success. The approach was driven by the scarcity of water, lack of nutrients or the cost of quality fish feeds, and environmental protection. At Calcutta city in eastern India, wastewater has been successfully used in aquaculture of silver and grass carps and rhu. This practice is recommended for tropical developed and underdeveloped countries to improve fish production and recover nutrients in wastewater (Bannerji, 2014; Kumar, Hiremath & Asolekar, 2014).

In Kenya, there are more than 40 sewage treatment plants among them being waste stabilization ponds (WSPs) located in most of the large municipalities such as Nairobi, Mombasa, Kisumu, Kisii, and Kericho. The largest WSP treatment plant is Ruai in Nairobi and is the second-largest in Africa (Murray, 2011). Communities living around these plants, use the treated wastewater to produce more food so as to increase household food security and nutrition (Kilingo, et. al., 2021). This is undertaken oblivious of the various hazards associated with the reuse of treated or partially treated wastewater for aquaculture, domestic, industrial and agricultural purposes. These hazards include the presence of excreta related pathogens such as *Cholera vibrio, Salmonella typhi,* and *Schistosomiasis,* skin irritants, vectors of human and animal diseases, and toxic chemicals such as carcinogenic heavy metals (Darko, Azanu & Logo, 2016; Latha & Mohan, 2013).

Despite the success of using treated wastewater for aquaculture and other purposes in India and ready market for the products, in Africa more so Kenya, there are concerns about the safety of the agricultural and aquaculture products due to the quality of the treated wastewater and sludge used. Hence there is lack of ready markets for food crops and fish produced in this manner (Bannerji, 2014; Murray, 2011).

In Kisii County, Gusii Water and Sewerage Company (GWASCO) is charged with the responsibility of collecting and treating sewage wastewater in Kisii town and its surroundings. The population of Kisii municipality is ever increasing and it was estimated to be 149,900 by 2019. This has led to an increasing amount of wastewater produced, which has overwhelmed the wastewater management systems whose capacity is estimated at 8,000m^3/day. This has led to discharge of partially treated wastewater into the receiving waters of Riana river which eventually discharges into river Kuja, a large river in South west Kenya emptying its water into Lake Victoria near Luanda Konyango.

During the rainy season, it has been observed that within the town, the sewer lines tend to overflow spilling the raw sewage into the environment and receiving waters. This renders the surface water unfit for use and environmental pollution that has resulted to public outcry. On the other hand, there has been an increase in demand for alternative cleaner water sources for Kisii town residents. To address these concerns, GWASCO has expanded the wastewater treatment plant (WWTP) capacity from 8,000m^3/day to 15,000m^3/day. Despite this, the capacity is still inadequate in addressing the wastewater treatment of the Kisii Municipality because the sewage distribution network is limited to a smaller area and a larger number of households are still not connected to the sewage distribution network.

Most of the households either use septic tanks and latrines to manage their wastewater (Kisii Integrated Plan 2018-2022).

The effluent from the WWTP is discharged into river Riana, and downstream its water is used for domestic and agricultural purposes. Therefore, due to the potential risks associated with use of semi-treated wastewater, there is need to ensure that it is treated before being discharged into receiving waters so as to protect downstream users from its negative impacts. In this study, the efficiency of the wastewater treatment by the Kisii Town WWTP was evaluated. The findings from this study will be used by water managers to improve on wastewater treatment and also to improve the WWTP design for Kisii municipality.

1.2 Statement of the problem

The knowledge of the nature and composition of wastewater is critical in wastewater treatment, re-use, and disposal. In Kenya, the National Environment Management Authority (NEMA) is the national organization mandated by law to provide guidelines on quality requirements for effluent discharge into the environment in view of sustaining our aquatic ecosystems integrity. Kisii Town's population and its environs have been on the rise in the recent years, thus increasing pressure on the available social resources. In Kisii, there is only one WWTP, that’s the Kisii Town wastewater treatment plant (sometimes referred Suneka sewage), a lagoon system located at Suneka. The WWTP mainly treats domestic wastewater and industrial wastewater to a less extent. The WWTP has been overwhelmed by the increased domestic, institutional, and agricultural wastewater resulting from an increased population. This has led to the discharge of semi-treated wastewater into the receiving waters of Riana river. This renders the surface water unfit for use and environmental pollution. As a result, it necessitated the renovation of the wastewater treatment capacity. The initial WWTP was designed to treat 8,000 m^3/day of wastewater but it has since been renovated and expanded with additional wastewater stabilizing ponds with treatment capacity of 15,000 m^3/day of wastewater. However, due to the aforementioned reasons, the treatment plant is inefficient based on the limited information available, raising concerns on the state of effluent discharged into Riana river, which downstream serves as a source of water for domestic, agricultural and natural aquatic services among others. It is currently assumed that the lagoon retains the pollutants carried with the wastewater channelled from the various water use points; however, this function has limited information. It is critical that this information is available for efficient and long-term management of the Kisii Town WWTP and its utilization for other purposes. This study assessed the efficiency of the Kisii Town WWTP in wastewater polishing based on physico-chemical, and biological parameters before (initial design) and after renovation of the wastewater treatment capacity (current design). With this information, the Management Board of Gusii Water and Sanitation Company can improve on the wastewater treatment processing, thus meeting the laid down standard guidelines for effluent discharge into the environment or open waters, and thus protecting their level of pollution.

1.3 Justification

Kisii Town Wastewater Treatment Plant is the only wastewater treatment plant in Kisii and its environs for wastewater treatment. Poorly treated effluent contains disease pathogens such as those of *Cholera vibrio*, *Salmonella typhi*, and *Schistosomiasis* as well as chemical pollutants. It is important that wastewater treatment is complete so that its discharge into the receiving waters does not adversely affect aquatic communities such as fish, invertebrates and human users downstream.

Information on treated wastewater is essential to stakeholders for decision making on the management of wastewater effluents. The population of Kisii Town in recent years has been on the increase. This growth is attributed to increased number of learning institutions, research organizations, medical facilities, expansion of the banking industry, transport, “Jua kali” sector, and other social amenities. Also, post-election violence of 2007/2008 increased the population of Kisii town. This implies increased wastewater production and possibly its heavy metal load.

The treated wastewater from the WWTP is discharged into Riana river whose water is used downstream for domestic, agricultural, and other uses. This study determined wastewater quality, and the community structure of biota of the WWTP. Also, the relationship between physico-chemical parameters and biota in WWTP was established. Moreover, concentrations of selected heavy metals were determined in wastewater, sediments, and plankton to inform downstream usage that can be used in formulating management advice for downstream usage. Therefore, this study contributes to information on the efficiency of wastewater stabilizing ponds for wastewater treatment, ensures information availability for managing aquatic ecosystems, and provides foundational data for future research

1.4 Objectives of the study

1.4.1 Main objective

The study aimed at assessing the efficiency of Kisii Town Wastewater Treatment Plant on wastewater treatment based on analysis of selected physico-chemical, and biological parameters.

1.4.2 Specific objectives

The specific objectives of the study were as follows:

1. To determine the improvement of selected physico-chemical and biological parameters due to treatment of wastewater by Kisii municipality stabilization ponds
2. To assess differences of abundance and diversity of plankton in the stabilization ponds series brought about by wastewater treatment.
3. To determine the relationship between selected physico-chemical parameters and plankton abundance and diversity in the Kisii town wastewater treatment plant.
4. To assess changes of selected heavy metal concentrations (Pb, Zn, Cd, and Cu) brought about by wastewater treatment by the stabilization ponds
5. To compare the selected physico-chemical parameters of treated effluent with NEMA, WHO and other international accepted water quality standards.

1.5 Research hypotheses

1. There are no significant changes in the physico-chemical, and biological parameters before and after wastewater treatment.
2. There are no significant changes in plankton abundance and diversity in the Kisii town wastewater treatment plant before and after wastewater treatment.
3. The selected physico-chemical parameters do not have any significant relationship with plankton abundance and diversity before and after wastewater treatment.
4. There are no significant changes in the heavy metal concentrations (Pb, Zn, Cd, and Cu) before and after wastewater treatment.

5. There are no significant differences in the water quality standard of the effluent and those of NEMA and those of international water quality regulatory authorities (WHO, and EPA).

1.6 Assumptions

During this study, the following assumptions were made:

1. There were no significant changes in sewage wastewater inflow to the stabilization ponds during the study period.
2. The samples collected for physico-chemical, and biological parameters analyses were sufficient for analysis and representative of the current status of the Kisii town wastewater treatment plant.
3. The standard methods followed during *in situ* measurements, sample collection, and laboratory analysis, including the keys used for plankton identification, provided valid data and information.
4. The wastewater stabilization ponds ecosystem is in dynamic equilibrium, that's it always functions in the same way.

1.7 Scope and limitations of the study

The study was restricted to the assessment of the efficiency of wastewater treatment by Kisii Town WWTP. During the study, *in situ* measurements were limited to pH, temperature, EC, DO, and TDS while further field studies was restricted to obtaining phytoplankton, zooplankton, and coliforms (Total and Fecal coliforms) samples. Laboratory experiments were restricted to determining concentrations of selected heavy metals (Pb, Zn, Cu, and Cd), chlorophyll-a, and nutrients that's silicates (SiO_2), Soluble Reactive Phosphorous (SRP), nitrate (NO_3^-), nitrite (NO_2^-), ammonium ions (NH_4^+), Total

Nitrogen (TN), and Total Phosphorous (TP). In addition, plankton analysis in the laboratory was restricted to determination of their abundance and diversity. Coliform analysis was limited to counts for total and fecal coliforms in 100ml of wastewater. Finally, only the water quality parameters determined in this study were compared with national (NEMA) and international water quality regulatory authorities (they include WHO, and EPA).

1.8 Expected output and Impacts

By the end of this study, it was envisaged that the treated wastewater quality, biota and coliforms of the Kisii Town WWTP would be established. Also, the relationship between physico-chemical parameters and with biota in the WWTP would be established. Therefore, the study findings are a contribution to the information on the capacity of Tropical WWTPs in wastewater polishing. Also, the study findings can be used in the surveillance, prevention, and control of the lotic and lentic ecosystems and their associated terrestrial environment as a result of wastewater treatment and discharged effluent.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter covers the background information on wastewater characteristics, treatment procedures, Kisii Town Wastewater Treatment Plant, and information on National Environmental Management Authority (NEMA) effluent discharge standards requirements as per the Environmental Management and Coordination, (Water Quality) Regulations 2006.

2.2 Characteristics of Wastewater

Wastewater can be defined as a combination of one or more of domestic effluent consisting of blackwater (excreta, urine, and fecal sludge) and greywater (used water from washing and bathing); water from commercial establishments and institutions, including hospitals; industrial effluent, storm water, and other urban runoff; and agricultural, horticultural and aquaculture runoff (UNESCO, 2017). Wastewater comprises 99% water and 1% suspended colloidal and dissolved solids. The sources of wastewater include domestic, municipal, urban runoff, surface runoff, livestock waste, land-based aquaculture effluents, industries, mining activities, energy generation, and the landfill (UNESCO, 2017). From this definition, one can be able to predict the wastewater contaminants that pollute our water ways. Wastewater contaminants can be grouped into physical, and chemical such as heavy metals, oil and grease, and biological. Knowledge of the nature and composition of wastewater is critical in wastewater treatment and disposal.

Discharge of wastewater and agricultural run-off into water bodies has been associated with degradation of aquatic ecosystem integrity. For instance, a study which was conducted by

Sitoki, et. al., (2015) in Lake Victoria basin, they showed that point source pollution affected phytoplankton diversity and abundance in the lake whereby cyanobacteria (blue green algae) dominated polluted areas. In another study conducted in river Nyakomisaro on macroinvertebrates spatial distribution and diversity, it was demonstrated that that some of the genera recorded such as *Ephemeroptera, Plecoptera*, and *Trichoptera* were sensitive to water pollution (Jomo, Omondi, Getabu, & Orwa, 2019). In Kenya, effluent discharge into the environment and surface waters is regulated to curb pollution. Kenya Bureau of Standards (KEBS) and the National Environment Management Authority (NEMA) provide guidelines on quality requirements for effluent discharge to the environment to control pollution (Appendix 1). Selected physical, chemical, and biological parameters that pertain to this study are reviewed in subsequent sub-sections.

2.3 Wastewater physical parameters

The physical wastewater parameters reviewed include: temperature, and Solids comprised of total suspended solids (TSS), and dissolved solids (TDS) and electrical conductivity.

2.3.1 Solids

Solids can be defined as particulate matter suspended or dissolved in water or wastewater (Oghenerobor et. al., 2014). The term “total suspended solids” of a water sample refers to the material residue left on a pre-weighed GF/C filter paper after evaporation and subsequent drying in an oven to a constant weight. The difference of the final weight and that of pre-weighed GF/C filter paper is the quantity of TSS in the water sample. There are two forms of total solids: total suspended solids (TSS) and total dissolved solids (TDS). TDS is therefore the portion of solids that passes through a filter of 0.25µm on vacuum filtration. It is used to measure the amount of material dissolved in water, for example phosphate, sulphates, chlorides, and nitrates, among other ions. The components of TSS in water include decaying organic matter, industrial wastes, sewage, and runoff (Oghenerobor et. al., 2014).

The design of wastewater treatment plants is usually prioritised to improve water quality to meet effluent safety requirements. A study conducted in South Africa involving a rural community wastewater treatment plant in the Eastern Cape by Igbinosa and Okoh, indicated that discharge of semi-treated effluent impacted negatively on the physico-chemical parameters of receiving waters (Igbinosa & Okoh, 2009). Similarly, a study in river Zik, by the University of Ibadan, Nigeria, showed that continued discharge of effluent into the river resulted in poor water quality (Ewemoje & Ihuoma, 2014).

2.3.2 Temperature

Water temperatures can be influenced by turbidity, season, time of the day, depth of the water, and in lotic systems it depends on the air temperature. The temperature of wastewater is higher than that of freshwater. The high temperatures have been associated with increased turbidity which is due to dissolved organic and inorganic matter, silt, and plankton which tend to absorb heat from the sun then dissipate it to water molecules (Ronoh, 2017; Wanjohi et. al., 2019). Temperature changes affect chemical reactions and their rates, and aquatic life. It further increases solubility of metals and other compounds, thus rendering them more toxic. At higher temperatures, the solubility of gases decreases. For instance, high water temperature results in low dissolved oxygen concentrations, accelerated chemical reactions, and increases volatilization of dissolved substances (Chapman, 1996; Waithaka 2017).

2.3.3 Conductivity

Conductivity is a measure of the ability of an aqueous solution to conduct an electric current. Any solution can only conduct electricity if its ionized that's it has both anions and cations. Solutions of inorganic compounds are relatively good conductors compared to those of organic compounds. Temperature can influence conductivity. Fresh waters have a conductivity ranging from 10 to 1,000 μScm^{-1}, while that of wastewaters may exceed 1,000 μScm^{-1} (Chapman, 1996). Accordingly, higher conductivity levels in wastewater can be attributed to presence of dissolved ions such as hydrogen (H^+), hydroxide (OH^-), phosphate and nitrate as a result of dissolved salts, solids, and inorganic compounds (Oghenerobor et. al., 2014). Consequently, higher conductivity levels in wastewater when released into the natural environment like rivers and lakes can have a negative impact on water quality, depletion of clean water resources, and pollution (Ewemoje & Ihuoma, 2014).

2.4 Wastewater chemical parameters

These parameters include: pH, Acidity and Alkalinity, Dissolved oxygen, nutrients, major cations and anions, sulphide, silica, fluoride, boron, cyanide, metals, mineral oil, phenols, pesticides, and surfactants. Selected parameters are reviewed in subsequent sub-sections.

2.4.1 pH and alkalinity

Water's acid and alkalinity are its quantitative capacity to react with a strong base or acid respectively to a designated pH. Measurement of acidity and alkalinity can be done through titration or using portable meters (Chapman, 1996). Some studies have depicted that pH and alkalinity play a significant role in wastewater treatment. This is based on the fact that hydrogen ions are generated from the biological wastewater treatment. Through this process, alkalinity is helpful in maintaining the pH range of wastewater (Igbinosa & Okoh, 2009). However, it is worth noting that when the alkalinity of the wastewater solution is very low, then the extra hydrogen ion present in the solution will not be effectively removed and this leads to a significant drop in pH. Also, the rate of wastewater treatment hampered (Salem, Ouardani, Hassine, & Aouni, 2011). As far as infrastructure and materials are concerned, treated effluent with a higher acidic range can results into a significant corrosion of pipes and toxic metals leaching as well as harm life in aquatic spaces habitats such as rivers and lakes. On the other hand, effluent that is too basic can increase water hardness and cause scale build-up and mineral deposition in pipes (Agoro, Okoh, & Okoh, 2018).

2.4.2 Dissolved oxygen (DO)

The amount of DO in water depends on temperature, salinity, turbulence, photosynthetic algae and plants, and atmospheric pressure. The amount of DO in fresh water at sea level ranges from 15 mgL^{-1} at $0^{\circ}C$ to 8 mgL^{-1} at $25^{\circ}C$. However, for unpolluted water, the amount of DO is usually close to but less than 10 mgL^{-1}. The primary cause of oxygen depletion in wastewater is sewage, excessive algae and phytoplankton growth driven by high levels of phosphorus and nitrogen.

Based on existing studies, some researchers have posited that effluent discharge with a low DO levels can significantly impact lentic and lotic ecosystems. In lotic and lentic ecosystems such as rivers, there are diverse biodiversity that significantly depend on the status and quality of the aquatic environment (Jomo et al., 2019; Sitoki, Ogendi, Getabu, & Akunga, 2015). However, when the wastewater effluent has a dissolved oxygen of below 5.0 mgL^{-1}, the aquatic life is put under stress (hypoxia) and a further DO levels of below 1-

2 mgL^{-1} or no oxygen levels (anoxia) for a few hours can result in large fish kills. On the other hand, lotic ecosystems play a significant role as far as dilution effect is concerned. This is based on the how lotic ecosystems such as rivers change their morphology and flow velocity affect behavior, mixing, and dilution processes. The study by Benit and Roslin, wastewater effluent drawn from Nagercoil town, Kanyakumari district, and Tamilnadu, India varied physico-chemically (Benit & Roslin, 2015). Therefore, dilution factors of lotic ecosystems are a critical component in estimating concentrations of so-called "down-the-drain" chemicals (e.g., pharmaceuticals) in rivers; hence dilution effect can be key in improving the status and quality of aquatic environments. However, in many cases, the detriment of pollution discharge to a river may exceeds its self-purification capacity, and may cause irreparable damages to aquatic ecosystem like in the case of river Nyakomisaro (Jomo et al., 2019).

Rivers still can act as sources of water for domestic, agricultural and industrial uses if there water quality is ascertained. Raji et.al., conducted a study on river Sokoto, Northwestern Nigeria, and recommended its water use for irrigation but not for domestic use unless treated (Raji, Ibrahim, Tytler, & Ehinmidu, 2015). Chapman recommended use of DO as an indicator of the degree of pollution by organic matter, the destruction of organic substances, and the level of self-purification of the water (Chapman, 1996).

2.4.3 Nutrients

Nitrogen gas (N_2) is the major component of the atmosphere. In nature, inorganic nitrogen occurs in the following oxidation states: nitrate (NO_3^-), nitrite (NO_2^-), ammonium ions (NH_4^+), and molecular nitrogen (N_2). Plants and microbes convert inorganic nitrogen to organic forms (Chapman, 1996).

2.4.3.1 Ammonia

Ammonia occurs naturally in water, and is highly soluble and toxic. The sources of ammonia in water include the breakdown of nitrogenous organic and inorganic matter, excretion from plankton, nitrogen reduction by microbes from the atmosphere, industrial waste discharge into water, and domestic waste (Chapman, 1996; Curtin et. al., 2011). High concentration of ammonia in water negatively affects aquatic life. In water, it occurs in the un-ionized state or the ionized state, that's ammonia NH_3 and NH_4^+ respectively, and the two states are at dynamic equilibrium. In addition, ammonia also occurs in complexes and in such processes, it can be adsorbed onto colloidal particles, suspended sediments, and bed sediments (Chapman, 1996). The level of ammonia in unpolluted waters is usually below 3 mgL^{-1}, but in polluted waters, the levels are higher. Conventional wastewater treatment does not remove ammonia and the ammonia that enters the plant is discharged to receiving waters with plant effluent. Therefore, high concentrations of ammonia in water can be used as an indicator of water pollution either from domestic waste, industrial waste, or fertilizer run-off (Chapman, 1996; Dos Santos et. al., 2019).

2.4.3.2 Nitrates and Nitrites

Nitrates (NO_3^-) are the most oxidized form of nitrogen. nitrates are formed as the end-product of aerobic decomposition of organic nitrogenous matter (Chapman, 1996). Its sources in wastewater apart from aerobic decomposition can be domestic, industrial or agricultural waste (Curtin et. al., 2011). They are relatively low in fresh water often not exceeding 0.1 mgL^{-1} NO_3^-N but can be enhanced by domestic and industrial wastewater effluents. When the nitrate level is more than 5.0 mgL^{-1} NO_3^-N it indicates pollution from human and animal waste. A level of up to 200 mgL-1 NO3-N in water indicates extreme pollution. The WHO's nitrate limit in drinking water is 50 mgL^{-1} (Chapman, 1996). Large levels of nitrates in water stimulate plant growth, especially algae, resulting in eutrophication (Vendramelli et. al., 2017).

Nitrate can also be biochemically reduced to nitrite by denitrifying bacteria through denitrification, which usually occurs under anaerobic conditions. At the same time, the nitrite can be rapidly oxidized to nitrate again (Curtin et. al., 2011). The concentration of nitrites in fresh water compared to nitrates is lower. The nitrite concentration in water is usually approximately 0.001 mgL^{-1} and rarely higher than 1 mgL^{-1} NO_2^- N. Just like nitrates, elevated levels of nitrite in water indicate pollution from industrial and agricultural effluents (Chapman, 1996).

2.4.3.3 Phosphates

Just like nitrogen, phosphorous is an essential nutrient for all living organisms since it is a major component of nucleic acids and other biomolecules. Phosphorous in water occur both in dissolved and particulate forms. They occur in wastewater as orthophosphates, condensed phosphates and or as phosphate. Its sources include: domestic wastes, fertilizers, and biological processes such as decomposition or death plants and animals. Like nitrates, they are essential for the growth of organisms (Chapman, 1996). In surface waters, levels of phosphorous usually range from 0.005 to 0.02 mgL^{-1} PO_4^-P. The low levels of phosphate can be attributed to plants that continuously take it up (Chapman, 1996). Elevated levels of phosphate concentrations in water can be used as an indicator of the presence of pollution and eutrophication (Chapman, 1996; Musungu et. al., 2013; Ronoh, 2017).

2.4.4 Heavy Metals

Wang et. al., (2013) defines heavy metals as elements having high density, and they include transition metals in the periodic table such as metalloids, lanthanides and actinides. They are natural constituents of the environment and they are poisonous even at low concentrations causing serious ecological problems (Chapman, 1996). Due to the toxic nature of heavy metals, it has necessitated extensive and intensive research in their occurrence in nature in soils, plants that are terrestrial and aquatic animals, especially various fish species and sediments. For instance, research conducted along Thika river revealed presence of Cu, Zn, Mn, and Ni in water, sediments, and algae (Asiago, 2018; Ogoyi, Mwita, Nguu, & Shiundu, 2011).

The various forms of research in heavy metals have been driven by their non-biodegradability and their toxicity to animals as they find their way into animals and humans through the food web via processes like bioaccumulation, bio-magnification and bio-concentration. Monitoring of heavy metals concentration in the aquatic environment has been done through determination of their concentrations in water or wastewater, especially sewage and effluent from treatment sites, sludge, sediments, and plankton (phytoplankton and zooplankton). A study conducted by Laffite et. al., on hospital effluent discharge in Kinshasha, Congo, showed that it was rich in heavy metal concentration, and in microbes with antibiotic resistance genes and sediments in receiving waters bioconcentrated the heavy metals (Laffite et al., 2016). A similar study conducted in the Winam and Mwanza gulfs of Lake Victoria, East Africa, revealed presence of the heavy metals Cd, Cr, Pb, Zn, and Hg in water, sediments and microalgae (Ogoyi et al., 2011). Another study conducted in Iraqi national waters, Iraq, showed there was accumulation of heavy metals in zooplankton (Al-Imarah, Khalaf, Ajeel, Khudhair, & Saad, 2018).

Recently, research done on sewage sludge obtained from a wastewater treatment plant in Poland, revealed presence of Zn, Cu, Cd, Cr, and Ni (Tytla, 2019). Also, Karanja (2015) revealed the sludge obtained from Ruai municipal sewage treatment plant, Nairobi, Kenya was not suitable for agricultural applications due to high levels of Pb which was above the recommended limits by NEMA.

2.4.4.1 Sources of heavy metals

Heavy metals occur naturally in the environment, but their concentrations have increased by introduction into the environment through natural sources and anthropogenic activities. The natural sources of heavy metals include weathering of rocks, volcanic activity, wind, and rain. However, anthropogenic activities are the major source of heavy metals to the environment. Some of these activities include wastewater discharge from domestic, municipalities, and industries; use of agricultural inputs which include fertilizers and various chemicals that's pesticides, herbicides, insecticides and fungicides; mining; "Jua kali" sector, among others. In his study, Asiago (2018), attributed Thika river pollution with heavy metals to use of fertilizers in the pineapple farms, discharge of industrial and mining effluents (Asiago, 2018). A number of studies conducted have shown that wastewater, especially from municipal sources, contain heavy metals among other pollutants that are of concern. Some of the heavy metals in wastewater discharged from treatment plants reported, include Zn, Cu, Pb, Ni, Cr and Cd (Laffite et al., 2016; Oghenerobor et. al., 2014).

2.4.4.2 Effects of heavy metals

The increased levels of heavy metals in the environment due to their non-biodegradability and toxicity nature are hazardous to aquatic organisms, animals and plants, despite some of them being essential. When partially or untreated wastewater contaminated with heavy metals is discharged into the environment, it is of grave concern as they cause negative impacts. Heavy metals contaminated effluent discharge into surface water bodies influences the diversity and abundance of aquatic organisms. Moreover, bio-accumulation of heavy metals in aquatic organisms finds its way to humans through their exposure by using and taking heavy metal contaminated water and foods such as fish. Heavy metals in plants have been associated with varied negative impacts. Cd has been associated with decreased enzyme activities and a decrease in seed germination, while Cr has been attributed to decreased plant growth. Pb has been attributed to a decrease in plant growth and chlorophyll production. Cu has been associated with the inhibition of photosynthesis (Oghenerobor et al., 2014).

Upon exposure and ingestion of heavy metals by animals, including humans, they accumulate in body tissues and organs. In turn, these metals do affect the normal physiological functioning of the body. According to World Health Organization (WHO) elevated levels of Cu have been attributed to anemia, liver cirrhosis, DNA mutations, neuronal and mitochondrial damage, and gastrointestinal damage. However, Cu is an essential element, and it forms part of the blood cells responsible for oxygen transport.

Zinc (Zn) is an essential element required by all living organisms in the different physiological processes. Some of the effects associated with Zn deficiency in humans include: damage to the reproductive organs, hair loss, decreased growth, and mental disorders (WHO, 2011).

Lead (Pb) is a non-essential heavy metal and has been linked to brain damage, malfunctioning of the renal system and fertility impairment (WHO, 2011). In addition, Pb in children is considered a great health threat as it affects the normal growth of children, causes damage to the nervous system, and results in learning disabilities. Cd exposure to humans has been shown to cause headaches, nausea, abdominal cramps, renal dysfunction, bone defects, increased blood pressure, and diarrhea. Moreover, Cd is carcinogenic (Oghenerobor et al., 2014).

2.5 Wastewater biological parameters

The biological parameters of wastewater include microbes and plankton that is phytoplankton and zooplankton as well as biodiversity indices, species richness, evenness and dominance. Chlorophyll-a is biological parameter often used to indicate algal biomass.

2.5.1 Microbial composition of wastewater

Wastewater is rich with microorganisms which include viruses, fungi, protozoa, and bacteria. These microbes some are harmful and others not. The harmful ones have been linked to waterborne diseases. Moreover, some of the bacteria have been identified to harbor antibiotic resistance genes. Nevertheless, the aforementioned microbes play a critical role in wastewater treatment as they utilize the inorganic and organic pollutants in their biochemical processes changing them to less harmful state. For instance, saprophytic bacteria dominate and they obtain their energy, cell carbon and other essential nutrients from the organic and inorganic compounds in wastewater. The most common saprophytic bacteria in aerobic treatment systems include Gram-negative, facultative, and heterotrophic rods (Darko et al., 2016; Latha & Mohan, 2013; Murray, 2011).

In wastewater treatment plants, the level of heterotrophic bacteria reduces as the water passes from one treatment pond to the next. On the other hand, excreta-related pathogens are present in wastewater. The excrete related pathogens include bacteria, helminthes, protozoans and viruses (Peter, 2008). During wastewater treatment, some studies have shown that the fecal bacteria present can be removed by the natural treatment process involving solar radiation (toxicity of Uv-light to microbes) (Aghalari et. al., 2020; Biswas & Rana, 2014).

Culturing of fish using wastewater effluent can be hazardous if sewage is not treated. Fish passively accumulate microbial contaminants on or in their organs (Peter, 2008). For instance, previous studies in poor hygienic standards showed that *Escherichia coli, Staphylococcus aureus, Salmonella* sp., and *Vibrio* accumulate in fish cultured in ponds supplied with polluted river water. The accumulation of these pathogenic bacteria and others poses health risks to fish and consumers (Latha & Mohan, 2013; Peter, 2008; UNESCO, 2017). Therefore, there is a need to determine the current microbial diversity in the treated wastewater stabilizing ponds, including the effluent discharged being potential for aquaculture and other uses.

2.5.2 Plankton

Plankton refers to indigenous populations of aquatic organisms. Water plankton includes phytoplankton and zooplankton organisms.

2.5.2.1 Phytoplankton

Phytoplankton are free floating microscopic plants in water and they are the primary producers providing food to aquatic organisms (Emmanuel, 2007). However, water quality affects the species' production and assemblage in diversity, composition, and abundance. The species commonly found in most aquatic environments include: Cyanophytes (blue-green algae), Bacillariophytes (diatoms), Chlorophytes (green algae), and Pyrrophytes (desmids). Recent studies in the Kisumu Bay, showed that cyanopyhtes (cyanobacteria) predominate (Were-Kogogo & Adhiambo, 2017). Also, another study in treated wastewater maturation ponds showed that physico-chemical parameters affect the dominance of

Cyanophyta, Chlorophyta, and Euglenaphyta. At low N:P ratio ≤ 10, Cyanophyta predominate (Pastich, Gavazza, Florencio, & Kato, 2016). Therefore, phytoplankton community structure can be used as a bio-indicator of the health status of wastewater during the treatment process in the ponds (Pastich et al., 2016).

2.5.2.2 Chlorophyll-a

Phytoplankton biomass in water can be determined by measuring the amount of chlorophyll-a. The latter can also be used as an indicator of the level of the trophic status of water (Chapman, 1996). Planktonic algae grow well in waters rich in nutrients (nitrates and phosphates), temperature and light (Chapman, 1996). Waters with low nutrient concentrations has fewer levels of chlorophyll-a concentrations (<2.5µgL^{-1}) however those with high nutrient concentrations, the levels of chlorophyll-a are between 5 to 140µgL^{-1} (Chapman, 1996).

2.5.2.3 Zooplankton

Zooplankton are free-floating animals in aquatic environments. They include microscopic protozoans, rotifers, cladocerans, and copepods. They are a major food source for many aquatic organisms. For example, zooplankton serves as an exogenous source of nutrients in fish ponds for larval stages of fish. On the other hand, larval fish are selective in their feeding habits on zooplankton (Goździejewska & Tucholski, 2011). Moreover, in another study on Olsztynek fish pond fed with treated wastewater showed the presence of taxa the Rotifera and Cladocera, Copepoda and protozoan species were present. while rotifers were the most abundant, crustaceans had a higher biomass (Goździejewska & Tucholski, 2011). However, water quality affects the zooplankton species production and assemblage in terms of diversity, composition, and abundance (Adhikari, Goswami & Mukhopadhyay, 2017; Deksne, 2011; Khune & Parwate, 2017).

2.6 Wastewater treatment

Before wastewater is released into the environment for re-use, it has to be treated. If the wastewater is discharged untreated or partially treated into the environment it results in pollution (UNESCO, 2017). The hazards associated with wastewater include but are not limited to: excreta-related pathogens, toxic chemicals, heavy metals, skin irritants, and vectors that can transmit pathogens (Darko et al., 2016; Laffite et al., 2016). Because of these hazards, raw sewage wastewater need to be treated before re-use and release to the environment (UNESCO, 2017).

Wastewater treatment is intended for reduction of biochemical oxygen demand (BOD), solid waste, ammonia, pathogen levels, and heavy metals, ultimately improving the water quality (Murray, 2011). The treated water can then be available and suitable for agricultural and aquaculture reuse or discharged safely into inland or coastal waters (Mara, 2003). In developed countries, wastewater is treated before being released into the environment, unlike in developing countries. Disposal of wastewater and other forms of waste normally is done through the surface waters (UNESCO, 2017).

Wastewater treatment methods can either be conventional and non-conventional. Conventional methods are automated to some extent and they require trained personnel who operate and maintain them. Moreover, they require pumps and a source of power to run them. They also need expensive chemicals. Typical examples of conventional methods include: activated sludge, rotating biological contactor and trickling methods. Non-conventional methods include wastewater stabilizing ponds, soil aquifer treatment, constructed wetlands and oxidation ditches. Unlike the conventional methods, these methods are low-cost, less sophisticated, and low technology in maintenance and operation (Amoatey & Bani, 2011; FAO, 2006).

In developing countries, Waste Stabilizing Ponds (WSPs) are the most commonly used for domestic and municipal waste treatment due to their low cost of operation favorable climate, low-maintenance, high wastewater treatment efficiency, and sustainability. In WSPs, wastewater goes through a series of ponds, including anaerobic, facultative, and maturation ponds. In General, before wastewater is released to WSPs, the water goes through preliminary screening and grit removal mainly to remove large and heavy solids. In the anaerobic and facultative ponds, primary and secondary treatment takes place respectively. Here, the removal of organic matter, *Vibrio cholerae,* and helminth eggs occur. In the maturation ponds, fecal viruses and bacteria and nutrients (nitrogen and phosphorus) are removed (Amoatey & Bani, 2011; Wang et al*.*, 2013). Previous studies have also shown that the fish ponds play a role in the wastewater treatment process, as the fish utilize the dissolved nutrients and pathogens (Murray, 2011).

2.7 Constructed wetlands in wastewater treatment

Constructed wetlands have been used reliably in treatment of wastewater from sewage, domestic, industrial, and agricultural sources including storm water runoff. Unlike natural wetlands, constructed wetlands operate under controlled conditions. They remove pollutants from wastewater using wetland plants, soils and microbial organisms similar to processes that occur in natural wetlands. Various types of constructed wetlands exist in nature. Generally, they have been classified based on: water level, categorized as free surface flow or subsurface flow; direction of water movement in the system, that's categorized as vertical and horizontal flow systems; and plant vegetation type that's macrophytes. Moreover, to enhance the process of wastewater treatment efficiency, constructed wetlands have been combined in a staged format to form hybrid constructed wetlands (Almuktar et al., 2018).

In terms of treatment performances, constructed wetlands have been shown to remove organics, suspended solids, and nutrients to varied extents including pathogens. For instance, from literature review publications, the removal of organics (BOD_5) and suspended solids is effective in free water surface, horizontal flow, and vertical flow constructed wetlands. However, these constructed wetlands are not efficient in TP and TN removal thus it is recommended to use hybrid constructed wetlands (Vymazal, 2010; Vymazal et. al. 2021; Almuktar et al., 2018). The means by which pollutants are removed include: physical, chemical, and biological means. The physical means include filtration, sedimentation, vitalization and adsorption and UV radiation, while chemical means include adsorption, hydrolysis, precipitation, and redox reactions. The biological means of pollutant removal include: metabolism, and nutrient absorption by plants both micro and macro (Thamke and Khan, 2021).

2.8 Sludge

The formed sewage sludge from the anaerobic and facultative ponds is directed to the sludge drying beds. The sewage sludge is rich with inorganic and organic solids, including heavy metals found in the raw sewage entering the treatment plant (Karanja, 2015). Therefore, before disposal, the sewage sludge is processed further to reduce the amount of water, contaminants, especially the heavy metals and microbial pathogens, to minimal concentrations. The produced and processed sludge is used for agriculture purposes, i.e. as fertilizer in the Kisii town wastewater treatment plant. Still, limited information is available on its conformity to standards recommended for application as a fertilizer. Previous studies conducted on sludge from other treatment plants particularly those that receive industrial effluent have shown that there sludge are rich with heavy metals. For example, a study conducted on sludge from the Ruai sewage treatment plant for agricultural use showed that the sludge did contain heavy metals like Cd, Cu, Zn and Pb among others. However, the sludge was not suitable for use as fertilizer due to Pb levels which were above the recommended limits (Karanja, 2015).

2.9 Treated wastewater uses

The uses of treated wastewater both in developed and developing countries include agricultural use that’s for irrigation, and aquaculture, industrial use, and domestic purposes (UNESCO, 2017). Some of the forces driving the increased use of treated wastewater include water scarcity and rapid population growth exerting pressure on the available social amenities resulting in environmental pollution due to improper wastewater disposal. Moreover, wastewater is readily available throughout the year and contains nutrients that can promote plant and animal growth (WHO, 2006). Therefore, treated wastewater can serve as an alternative water source for domestic, industrial, and agricultural uses among others. However, there are potential various hazards associated with wastewater-fed aquaculture that include: excrete related pathogens, skin irritants, vectors that transmit pathogens and toxic chemicals and heavy metals (Darko et al., 2016; Latha & Mohan, 2013). Nevertheless, wastewater use for aquaculture is a common practice in the world. The Asian countries in particular, are leading in using treated wastewater in aquaculture with success (Bannerji, 2014; Kumar et al., 2014). In addition, previous studies have shown that if the wastewater is properly treated, even the heavy metals tend to be below the safe limits in the fish cultured in ponds fed with wastewater (Darko et al., 2016; Sondhia, 2008).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter covers a description of the study area, research design, sampling procedures, and data analysis.

3.2 Study site

3.2.1 The location

Kisii Town Wastewater Treatment Plant is located at Suneka in Bonchari Sub-County in Kisii County, Kenya. The physical location of the treatment plant is Suneka Division at latitude 0^0 39’ 30’’ S and Longitude 34^0 42’ 30’’ E (Figure 2). The WWTP treats sewage wastewater from Kisii municipality and its environs. Kisii municipality is an urban centre in Kisii County covering approximately $29km^2$. The municipality is densely populated with a population of 149,900 people and density of people 5,170 km^2 by the year 2019 (Kisii County Government (KCG), 2013). Within the municipality, there are a number of learning institutions, national government and County offices, health facilities, banking facilities, and business premises among others. The high population within the municipality has been attributed to rural–urban migration resulting in establishment of a number of informal settlements such as Getare, Daraja mbili, and Botori among others. The increase in the population puts a great demand on the capacity of wastewater treatment facilities. Currently the existing facilities are inadequate to handle wastewater treatment requirements for the entire population (KCG, 2013).

The areas within the municipality covered by the sewer line include: Menyinkwa, Milimani, Jogoo, Nyanchwa, and Daraja Mbili. The sewer line drainage system and the covered areas are shown in Figure 1. The inflow rate of the sewage wastewater into the treatment plant is between 1,800-2,200m^3/day.

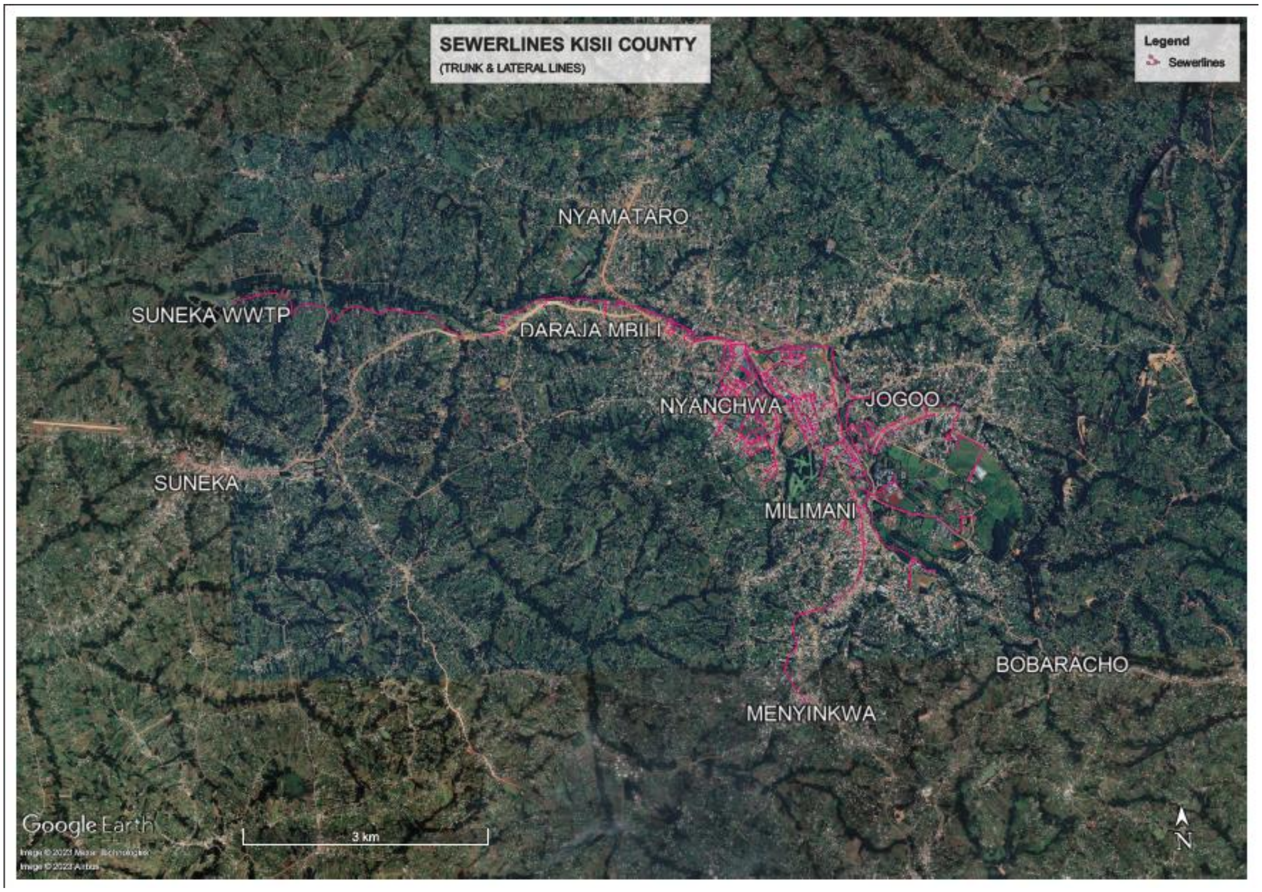

Figure 1: Kisii Municipality wastewater drainage network. (Source: GWASCO, 2022)

3.2.2 Kisii Town Wastewater Treatment Plant design

Kisii Town Wastewater Treatment Plant is the only sewer system that's a lagoon system in Kisii County used for wastewater treatment against Kisii Municipality population of approximately 200,000 people by the year 2021. The treatment plant was designed mainly to treat domestic wastewater (approximately 90%) from Kisii Municipality and its environs and to some extent industrial wastewater (approximately 10%). The current design capacity of the lagoon is 15,000m^3/day and it was renovated up from the previous design capacity of

8,000m^3/day. This was necessitated by the increased amount of domestic and agricultural wastewater it receives resulting from an increased population (Figure 2).

Figure 2: Kisii Town Wastewater Treatment Plant design. (Source: Google Maps)
Key: white line indicates the initial design; Red line is Riana river; White star indicates the WWTP effluent discharge point into Riana river. The alphabet letters indicates: A-Anaerobic pond; F-Facultative pond; M1- Maturation pond 1; M2- Maturation pond 2

The WWTP current design has a total of five functional ponds that's two anaerobic ponds, one facultative pond, and two maturation ponds. The WWTP initial design had three functional ponds arranged in a single series which include: anaerobic, facultative and tertiary pond (Figure 2). Before the wastewater enters the ponds, it goes through the receiving units in screens, and grit chambers. The bar screens removes large and heavy solids from the influent while in the grit chamber, sand and grit particles are removed through sedimentation process. Then the wastewater goes through anaerobic ponds, facultative pond, followed by the maturation ponds for treatment before being discharged into Riana river.

The ponds are shallow basins with varied dimensions, water volume capacity, water retention periods, and biological activities. The anaerobic ponds are square in shape each with a total perimeter length of 264 meters. The depths of the ponds are 3.5 meters with 3 meters liquid depth, and wastewater volume of 10,443 m^3. The wastewater retention period in the lagoon is 10 days. They receive high organic load from the influent and suspended solids are removed by settling in the form of sludge and organic matter broken down by anaerobic microbes.

The facultative pond is rectangle in shape with length of 220 meters, and width of 118 meters. The pond depth is 1.5 meters, liquid depth of 1.2 meters, and wastewater volume of 36, 936 m^3. The wastewater retention period is 17 days. In this pond, the organic load is low compared with the anaerobic pond as a result allowing growth of algae and secondary treatment occurs here. The remaining organic matter from anaerobic pond is removed by being completely broken down into carbon (IV) oxide, and nitrogen and phosphorous removed by using oxygen produced by algae.

The maturation ponds are two in the WWTP current design. The first pond served as the facultative pond in the initial design while the second was the tertiary pond. The depth of the maturation ponds are 1.5 meters, with liquid depth of 1.2 meters. The total perimeter lengths for the first and second pond are 528 meters and 434 meters respectively. Wastewater volume for the first pond is 22,098 m^3 and the second being 15,222 m^3. The wastewater retention period is 10 days for the first pond while its 7 days for the second pond. In general, these ponds are relatively shallow, allowing aerobic conditions. Here, organic matter is further reduced and solar radiation kills the pathogenic microorganisms present. Nutrient removal during wastewater treatment is key as it reduces eutrophication enrichment in the effluent receiving discharge water bodies (Amoatey & Bani, 2011; Wang et al., 2013).

The effluent from the treatment plant is discharged into Riana river. It should always meet the quality standards guidelines by NEMA in Kenya for effluent discharge into the environment to prevent surface water and environmental pollution. However, selected physico-chemical parameters measurements data available from GWASCO indicates the initial design of the WWTP effluent discharged did not meet the specified NEMA standards thus necessitated its renovation (Appendix 1).

3.2.3 Human Activities within Kisii Town Wastewater Treatment Plant

Based on the observations made around the wastewater treatment plant during the study period, people practice subsistence farming of crops and animals and are either benefiting or affected by the wastewater treatment plant. The notable crops grown include maize, bananas, sugarcane, kales and Napier grass among others. The common animals kept are cows, goats, sheep, and chicken. On the other hand, the common source of clean water for domestic and agricultural uses among Riana area households included water springs, boreholes, roof catchment and Riana river (Plate 1).

Plate 1: Anthropogenic activities that take place at Kisii Town WWTP. (Source: Author)
Clockwise: Banana and Sugarcane farming along River Riana; Animals (goats) grazing along river Riana water bank and around the WWTP; Water point source for domestic use; Napier grass planted at the effluent discharge point to river Riana

3.3 Study design

Before the actual study, a recognisance survey of the study area was conducted with the intent of assessing of the accessibility of the wastewater treatment plant, obtaining background information about the plant and services it provides to the people who live around it. In addition, information on the public opinion about the treated wastewater reuse for aquaculture and other options were sought by administering a questionnaire (Appendix 6). During the study, it was observed that the process of renovating the wastewater treatment plant was in progress. The intent of renovation was to improve the wastewater treatment capacity and its efficiency. Therefore, the sampling period covered both the initial design and current design after renovation was completed.

This study was exploratory and the sampling stations were purposively selected. Samples were collected once every month in the period of August-December, 2019 involving the initial wastewater treatment plant and May-August, 2021 involving the current wastewater treatment plant. Sampling was carried out in the morning hours (8-10am). It involved *in situ* measurements namely temperature, pH, electrical conductivity, dissolved oxygen, and total dissolved solids; and *ex situ* analysis for nutrients (namely nitrites, nitrates, ammonium-nitrogen, total nitrogen, soluble reactive phosphorous, total phosphorous, and Silicates), and heavy metals namely, Pb, Zn, Cu, and Cd; and chlorophyll-a. The identified sampling stations are shown in Figure 3.

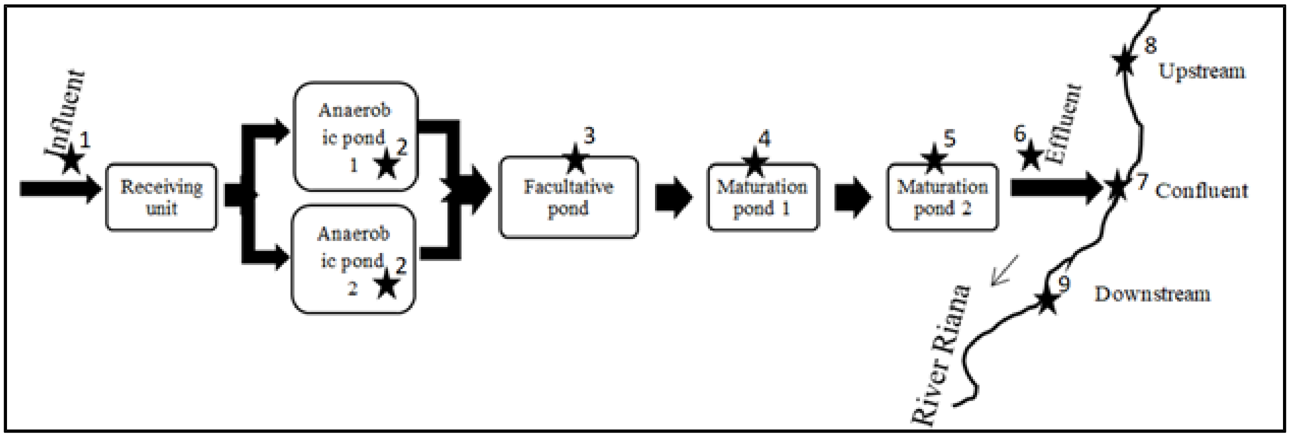

Figure 3: Sketch map of the Kisii Town WWTP indicating the distribution of the sampling points. (Source: Author)

For the initial WWTP, samples for analysis were collected from seven stations which include inlet, anaerobic pond (now anaerobic pond 2), facultative pond which was changed to maturation pond 1, and tertiary pond now being maturation pond 2 including the effluent before discharge into the river besides sampling stations along the river that’s 100 meters up and downstream at the effluent discharge point into the river as shown in Figure 3. After renovation of the existing wastewater treatment plant that’s the initial WWTP, additional ponds were introduced and the dimensions of the ponds were changed giving rise to the current WWTP. From the current WWTP therefore, the sampling stations included: inlet, the two anaerobic ponds (where the collected samples were combined to obtain a composite sample), one facultative, and maturation 1 and 2 ponds including the effluent before discharge into the river besides sampling stations in the river that’s at the confluent and 100 meters up and downstream at the effluent discharge point into river Riana (Figure 3).

3.4 Sampling Procedure

3.4.1 Equipment and apparatus used during study

The apparatus that were used during sampling and laboratory analyses included: 20 L buckets, 500 ml polypropylene plastic sampling bottles for wastewater samples, 100 ml open mouth wide bottles for sediment samples, 100 ml plastic bottles for plankton samples, volumetric flasks (500ml, 250ml, 100ml, and 50ml), 250ml, 100ml, and 10 ml measuring cylinders, and filter funnels. Also, varied sizes of beakers and conical flasks (Pyrex) were used including a stainless steel hand auger (used for sediment sampling). Other equipment used included an inverted microscope with camera connected to video display, Utermohl chambers, Sedgewick-Rafter cell chamber, hand vacuum pumps, centrifuges, UV-IR spectrophotometer, incubators, ovens, analytical balances, AAS, volumetric pipette, dissection microscopes. Washing of glass wares, plastics, and apparatus were washed using detergents and double rinsed with distilled water. Those used for heavy metal sampling, were further rinsed with dilute nitric acid. Dilution of samples was done using deionized water. For digestion of samples, nitric acid (AR, 69%) and Hydrochloric acid were used.

3.4.2 Sampling procedure for physical and chemical parameters

Wastewater temperature ($^{\circ}$C), pH, electrical conductivity (µScm^{-1}), dissolved oxygen concentrations (DO) (mgL^{-1}), and total dissolved solids (TDS) (mgL^{-}1) were measured *in situ* using calibrated portable professional series (YSI) multi-parameter meter model 35C at sub-surface level. At each sampling site, the probes were thoroughly rinsed using deionized water before and after each measurement. The probes were lowered 30-40 cm into the wastewater and allowed the readings to stabilize before recording. The readings were taken in triplicates.

For total suspended solids (TSS), chlorophyll-*a*, and nutrients (namely nitrites, nitrates, ammonium-nitrogen, total nitrogen, soluble reactive phosphorous, total phosphorous, and Silicates), and chlorophyll-a, wastewater samples were collected at sub-surface level in triplicate using pre-washed 500 ml polypropylene plastic bottles rinsed with double distilled water. The filled bottles with wastewater were clearly labeled and then immediately kept in a cooler boxer at 4°C and transported to the laboratory for analysis.

3.4.3 Sampling procedure for biological parameters

3.4.3.1 Phytoplankton sampling procedure

Phytoplankton samples were collected at sub-surface level in triplicate by filtering 20 liters of wastewater through 20µm mesh size plankton net and then the net contents were poured into pre-cleaned well labelled 500ml plastic bottles at each sampling station. The collected samples were immediately preserved by adding 2-3 drops of 1% acidic Lugol's iodine solution after which they were kept in a cool box and transported to Kenya Marine and Fisheries Research Institute (KMFRI), Kisumu centre laboratory for analysis.

3.4.3.2 Zooplankton sampling procedure

Zooplankton samples they were collected in triplicates from the identified sampling stations by filtering 20 litres of wastewater through a 60µm mesh zooplankton net. Samples were emptied into clearly labelled pre-cleaned plastic bottles and preserved using 4% formalin. For the current design, the anaerobic sampling station the samples which were collected from the two stations were combined to obtain triplicate composite sample. To prevent contamination of the samples during collection, the sampling net was rinsed with distilled water before and after each sampling. The preserved zooplankton samples were transported to Kenya Marine and Fisheries Research Institute (KMFRI), Kisumu centre laboratory for further analysis.

3.4.3.3 Sampling procedure for Total and Fecal Coliforms

500 ml sterile plastic bottles were used during collection of wastewater samples for total and fecal coliforms analysis. At each sampling point, sterile bottle was rinsed thrice using the wastewater before sample collection. Wastewater samples were collected in triplicate from each sampling point. The collected samples from each point were then combined forming a composite sample. The samples were then clearly labeled and put in an ice cool box at 4 °C and transported immediately to the laboratory for analysis.

3.4.4 Collection of samples for heavy metal analyses

Before the field for sampling, sampling containers and equipment were thoroughly cleaned to minimize contamination. The borosilicate glass bottles for heavy metal samples were washed with a detergent and double rinsed with distilled water followed by 10% HNO_3 acid prior to the field. The selected heavy metals that were analysed during this study included Zn, Pb, Cu, and Cd. These metals were analysed in wastewater, sediments, phytoplankton and zooplankton samples collected from the Kisii town wastewater treatment plant besides three stations along river Riana.

Wastewater samples were collected in duplicate using 500 ml different bottles from the identified sampling stations at subsurface level. The samples were preserved by adding 5 ml concentrated HNO_3. They were clearly labelled, packed, and then transported to the laboratory in an ice-cooler box.

Sediment samples were collected in duplicate with a stainless steel hand auger and put into wide-mouthed pre-cleaned sample bottles which had been cleaned and rinsed with distilled water. To each sediment sample, 1 ml conc. nitric acid was added to preserve it, thus preventing any form of microbial activity that could alter the actual concentrations of the metals. The collected sediment samples were clearly labelled, packed, and put into an ice-cool box and transported to the laboratory for heavy metal analysis.

For phytoplankton and zooplankton samples, respective plankton nets (20µm, and 60µm respectively) were used at each sampling point, by filtering 20ltrs of wastewater. The collected samples were put into pre-cleaned sample bottles and preserved by adding 1 ml concentrated nitric acid. The samples were clearly labelled, packed, put into an ice cool box, and transported to the laboratory for analysis.

3.5 Laboratory analyses of samples

3.5.1 Total suspended solids (TSS)

In the laboratory, the filters that were used for the determination of TSS were pre-weighed using analytical balance (Model: Shimadzu-ATX224). The filter paper was then transferred to the top of filtration flask followed by the screwing in of the filtration cap. Water sample measuring 100ml was put into the filtration flask, followed by switching on the vacuum pump to initiate the filtration process. After filtration process, the filter papers were carefully removed from filtration apparatus using forceps, transferred to a glass weighing dish as a support and dried for 1 hour at 110°C to constant weight in drying oven. This was followed by removing the filter from the petridish and reweighing it. The TSS was calculated as follows:

$$TSS\left(\frac{mg}{L}\right)=\frac{(Residue+Filter)(mg)-Filter(mg)}{Sample\ filtered\ (mL)}\ x\ 1000\left(\frac{mL}{L}\right)\ \ldots\ldots\ldots\ldots Equation\ 1$$

3.5.2 Nutrients analyses

Nutrient analysis was done using the spectrophotometric method for the determination of water and wastewater as described in APHA (2014). The nutrients which were analysed included soluble reactive phosphorous (SRP), silicates (SiO_2), nitrites (NO_2-N), nitrates (NO_3-N), total nitrogen (TN), total phosphorous (TP), and ammonium (NH_4-N).

3.5.2.1 Soluble reactive phosphorous (SRP)

25 ml of the collected wastewater samples were filtered with GF/C filter papers and then put into a bottle. Two drops of freshly prepared phenolphthalein indicator was added to each of the samples including the blank. The phenolphthalein indicator was prepared by dissolving 0.5 g of phenolphthalein in 50 ml of ethyl alcohol and 50 ml of distilled water. Then 4 ml of the reagent prepared from 50 ml of sulphuric acid, 15 ml Ammonium molybdate, 30 ml of Ascorbic acid and 5 ml of Potassium antimonyl tartrate was added to each measured sample including the blank with indicator and mixed by swirling and left to stand for 20 minutes to allow colour development. 10 ml of both treated sample and reagent blanks were put into a 1 cm path length cuvette and then transferred to a UV-IR spectrophotometer for determination of concentrations. Absorbance measurements were read at 880 nm (APHA, 2014). The obtained absorbance was used to read-off the concentrations of SRP from a standard curve prepared from a dilution series.

3.5.2.2 Determination of nitrates in wastewater

50 ml of wastewater sample for nitrates-nitrogen determination were filtered using ash free GF/C filter papers of pore size 0.45um filters and put into separate clean bottles and 1 ml of a buffer solution was added to each. The buffer solution was prepared by weighing 50 g ammonium chloride, 10 g of sodium tetraborate and 0.5 g of disodium EDTA which were dissolved in 500 ml of deionised water. The samples with buffer were then passed through

the Cadmium reduction column to reduce nitrates to nitrites. To each sample 1 ml of sulphanilamide was added and thoroughly mixed. This was followed by adding 1 ml N-1-Naphthyl ethylene diamine dihydrochloride and mixed thoroughly by swirling and left to stand for 10 minutes to allow the pink colour to change. Absorbance was read at 543 nm (APHA, 2014). The obtained absorbance was used to read-off concentrations of nitrates from a standard curve prepared from a dilution series.

3.5.2.3 Determination of nitrites in wastewater

The concentration of nitrite-nitrogen in wastewater was determined using diazotization method. To each 50 ml of filtered sample, sulphanilamide was added followed by N-1-Napthyl ethylene diaminedi hydrochloride catalyst forming a coloured compound and left to stand for about 8 minutes. Absorbance was read at 543 nm (APHA, 2014). The obtained absorbance was used to read-off concentrations of nitrites from a standard curve prepared from a dilution series.

3.5.2.4 Determination of ammonium

Indophenol method involving oxidation with sodium hypochlorite and phenol solution was used for the determination of ammonium. 50 ml of each sample were measured separately and then 2 ml and 5ml of phenol solution and sodium hypochlorite respectively were added to each sample and mixed thoroughly. Then the samples were then left to stand for 1 hour at room temperature for colour development. Absorbance measurements were read at 630 nm using a UV-IR Spectrophotometer (APHA, 2014). The obtained absorbance was used to read-off concentrations from a standard curve prepared from a dilution series.

3.5.2.5 Determination of silicates

The reagents that were used for the determination of silicates includes: 0.25M hydrochloric acid (HCl), 5% Ammonium molybdate, 1% disodium EDTA, and 17% sodium sulphates

($NaSO_3$). 0.25 M of HCl was prepared by mixing 22 ml of HCl with distilled water and then diluted to 1 litre. For preparation of 5% Ammonium molybdate, 52 g of Ammonium molybdate was weighed using analytical balance and then dissolved in 1 litre of distilled water. 10 g of Disodium EDTA was weighed and then dissolved in 1 litre of distilled water. For preparation of 17% $NaSO_3$, 170 g of the salt was weighed and then dissolved in 1 litre of distilled water. Acidic ammonium molybdate was reacted with silicon solution as $H4SiO_2/SiO2^{-2}$ to form silicomolybdate complex with a yellow colour. Then the complex was then reduced by sodium sulphite to form the yellow complex. Absorbance measurements were read at 700 nm using a UV-IR Spectrophotometer (APHA, 2014). The obtained absorbance was used to read-off concentrations from a standard curve prepared from a dilution series.

3.5.2.6 Determination of Total Nitrogen (TN)

Total nitrogen was determined from collected unfiltered samples using Persulphate method and two buffers were used that’s Buffer I and II. Buffer I solution was prepared by weighing 10 g of ammonium chloride salt and dissolving it in 1000 ml in a volumetric flask using distilled water. 5 drops of sodium hydroxide were then added. Buffer II was prepared by weighing 50 g of ammonium chloride, 10 g of sodium tetraborate and 0.5 g of disodium EDTA then all were placed into a conical flask and dissolved by 500 ml of deionized water. 10 ml of each unfiltered samples were measured and the put into separate clean bottles. For the blank, in the place of sample, distilled water was measured. To each sample and the blank, 5ml of potassium persulphate was added and then autoclaved for 30 minutes for digestion until a green colour was observed. The digested samples were then left to cool at room temperature. After they had cooled, 50 ml of Buffer I solution was added to each sample and then 1ml of Buffer II solution was also added then swirled to mix. The samples and the blank were then passed through a Cadmium reduction chamber filled with copper turnings and only 25 ml of the solution was retained for analysis while the rest was used for rinsing the column then discarded. 1 ml of N-1-Napthyl ethylene diamine dihydrochloride was then added and swirled and left to stand for approximately 10 minutes to allow the pink colour to change. Absorbance measurements were read at 543 nm using a UV-IR Spectrophotometer (APHA, 2014). The obtained absorbance was used to read-off concentrations from a standard curve prepared from a dilution series.

3.5.2.7 Determination Total Phosphorous (TP) concentration

50ml of each unfiltered sample collected from each station were measured using a measuring cylinder and then put into pre-cleaned triplicate bottles separately and then to each 2 drops of phenolphthalein indicator was added and swirled. 1 ml aqueous sulphuric acid was measured and then added to the each sample using a volumetric pipette and mixed by swirling. 10 ml potassium persulphate was added and swirled to mix. The samples were then put into an autoclave for 30 minutes for digestion until green colour was attained. The samples were then cooled at room temperature. After cooling, 2 drops of phenolphthalein indicator was added to each sample and swirled to mix. Sulphuric acid was added to each sample and the colour changed to pink afterwards sodium hydroxide was added until the pink colour faded. Then the samples volumes were topped to 100ml using distilled water. From each sample, 25 ml was measured using clean measuring cylinders and transferred into clean separate bottles. 4 ml of mixed reagent was then added to each sample and mixed and then left to stand for 20 minutes to allow colour change. Absorbance measurements were read at 880 nm using a UV-IR Spectrophotometer (APHA, 2014). The obtained absorbance was used to read-off concentrations from a standard curve prepared from a dilution series.

3.5.3 Analyses of biological samples

3.5.3.1 Phytoplankton identification and enumeration

Once in the laboratory, each sample was poured into separate 250 ml measuring cylinder. To enhance the process of algal cells sedimentation, 1 ml of 1% Lugol's solution was added and then the samples were allowed to settle overnight. After sedimentation, the top volume (approximately 90 ml) from each sample was pipetted out slowly without disturbing the settled algal cells. The remaining volume (approximately 10 ml) of each sample was then poured into algal vials for microscopic examination of phytoplankton species identification and enumeration. Zeiss Axiovert 35 inverted microscope was used at 400x magnification. Identification of phytoplankton taxa was carried out using standard identification keys following the methods of Huber-Pestalozzi et al. (1968) and Cocquyt *et al.* (1993) keys to the genus and species level where possible.

3.5.3.2 Determination of phytoplankton biomass

The phytoplankton biomass was determined as biovolume (mm^3L^{-1}). For each taxonomic group identified, the cell dimension that's cell length, width, and depth were measured from at least twenty specimen samples which were randomly selected. Geometric approximations method was used to calculate biovolume. Algal cells density per unit of the projection area of the colony was estimated at higher magnification (400X) except for Microcystis colonies which were measured at lower magnification of 40X. To estimate the depth of each colony, we used the fine adjustment of the microscope to focus on the top and bottom of each colony. Biovolume was calculated using the formula below as described by Rott, 1981; Wetzel & Likens, 2000;

$$Biovolume\ (\mu g/L) = Geometric\ shape\ x\ Number\ of\ counts\ x\ Factor$$

…………………*Equation 2*

Where: Factor is the dimensions of the counting chamber and the microscope at magnification level i.e 400X

3.5.3.3 Determination of Chlorophyll-*a*

50 ml of each of the wastewater samples were filtered through a Whatman GF/C glass-fibre filter paper pore size 0.45 µm paper into Erlenmeyer conical flask connected to hand vacuum pump with plastic tube. After filtration, using forceps the filter paper was rolled up and inserted into a test tube containing 10ml ethanol. The test tube was wrapped in aluminium foil. The wrapped up samples were put into a deep freezer at -4°C overnight to allow extraction of chlorophyll-a into the ethanol. The filter paper was removed from the test tube and the remaining chlorophyll-a on it was squeezed back into the test tube. This was followed by pouring the chlorophyll-a from the test tube into centrifuge cuvette which were then centrifuged for 10 minutes at 2500 revolution per minute (rpm). 1 ml of the supernatant with chlorophyll-*a* was put into spectrophotometer cuvettes of path length 1 cm and absorbance measured at 665 and 750 nm wavelengths. To obtain the chlorophyll-*a* absorbance, the difference between the two absorbencies was calculated then the concentration was calculated by using methods described by Talling and Driver (1961). using the formula below:

$$Chlorophyll\ a\ (\mu\mathrm{g/L}) = \frac{[11.40(\mathrm{E665}-\mathrm{E750})\,x\,V1]}{\mathrm{V2}\,x\,L} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 3}$$

Where: 11.40 is the absorption coefficient for chlorophyll-a

V1 = Volume of extract in ml

V2 = Volume of the filtered water sample in litres

L = light path length of the cuvette in cm

E665, E750 = optical densities of the sample

3.5.3.4 Zooplankton identification and enumeration

In the laboratory, each of the wastewater samples was adjusted to a known volume from which three sub-samples of 2 ml was placed in a counting chamber for identification and enumeration. The specimens were sorted, identified and counted under a dissection microscope (X50). Detailed identification was carried out using a light compound microscope (Model: Olympus, Japan) of 100-400X magnification. Identification of zooplankton taxa was carried out using standard identification keys. Cladocera were identified by following the methods by Edmondson (1959), and Smirnov (1996); Rotifera were identified following the methods by Pennak (1978), and Segers (1995); while Copepoda were identified by following the methods by Jeje and Fernando (1986) and Patterson and Hedley (1992).

The number of individuals per litre (IndL^{-1}) of zooplankton was determined using the formula below (Omondi, Yasindi, & Magana, 2011).

$$\boldsymbol{D = N/V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 4}$$

Where:

N = number of organisms in sample calculated by the formula

$$= \frac{(number\ in\ wastewater\ sub-\ sample)\ X\ (volume\ of\ sample)}{(volume\ of\ sub\text{-}sample)}$$

V = volume of wastewater filtered

3.5.3.5 Determination of plankton diversity

To determine the phytoplankton and zooplankton diversity and abundance across the different sampling stations, four diversity indices were computed that's Shannon-Wiener (*H'*), Margalef's Index (d), Dominance (D), and species evenness) by following formulas according to Ogbeigbu (2005) and Eyo et al. (2013).

Shannon-Weiner diversity index in a given habitat is the uncertainty of identity of unknown individual calculated using the formula below;

- **Shannon-Wiener Index** $H' = \sum_i P_i Ln_i \; P_i$ ………*Equation 5*

Where P_i is the proportion (n/N) of all the phytoplankton which belongs to the i^{th} species, Ln is the natural log and $\sum$ is the sum of the calculation.

In the Shannon-Wiener Diversity Index computation, it is assumed that all species are represented in a sample and are randomly selected. Also, it accounts for both the abundance and evenness of the species present. After calculation, the value obtained normally ranges between 0 and 4. If the index value obtained after calculation is high, then it indicates greater number complexity that's a diverse number of species within a community in the sampling site.

Species richness is the number of species in a species list and calculated using the following equation;

- **Margalef's Index (d)** determined as; $d = \frac{s-1}{Ln(N)}$ …………*Equation 6*

Where S is the total number of species, Ln is the Natural log and N is the total number of individuals.

Species evenness, is the closeness in numbers each species in a given habitat. Calculated as follows;

- **Evenness (E)** was given as; $E = \frac{H'}{\log S}$ …………*Equation 7*

Where H' is the Shannon-Wiener diversity index and S is the total number of species

3.5.3.6 Determination of Total and Fecal Coliforms

Membrane filtration method was used for Total and Fecal coliforms enumeration. The sterility of the membrane filters used was checked by incubating them on an ager media. 100 ml of each wastewater samples were filtered through a 0.45 µm, 47 mm membrane filter placed on a filter funnel into Erlenmeyer conical flask connected to vacuum pump with plastic tube and switched on. After filtration, using sterile forceps the filter paper was transferred to a 5 ml petri dish (which the top side was gridded) of MI ager. Each petri dish was clearly labeled. All the petri dishes with membrane filters were then incubated upside down for 24 hours at 35 °C. The bacterial colonies were observed under an inverted microscope (Model: ZEIS) at x100 magnification. In each agar plate, the blue (for fecal coliforms) and green colonies were counted and recorded to obtain the total fecal (E. coli) and total coliforms counts. Total fecal and total coliforms counts in 100 ml of wastewater were calculated using the following equations;

$$\frac{Total\ fecal\ coliform}{100}\ ml = \frac{Number\ of\ blue\ colonies}{Volume\ of\ wstewater\ sample\ filtered\ (ml)}\ x\ 100\ \ldots\ldots\ldots\ldots\ Equation\ 8$$

$$\frac{Total\ \ coliform}{100}\ ml = \frac{Number\ of\ blue\ colonies + Number\ of\ green\ colonies}{Volume\ of\ wstewater\ sample\ filtered\ (ml)}\ x\ 100\ \ldots\ldots\ldots\ Equation\ 9$$

3.5.4 Determination of heavy metal concentrations in wastewater, sediments, and plankton

3.5.4.1 Wastewater samples digestion

100 ml of each wastewater sample was measured using a measuring cylinder and then transferred into 250 ml separate beakers. Each sample was digested on a hot plate using 10 ml of Aquaregia (a mixture of HNO_3 and HCl in the ratio 3:1) inside a fume hood. The digested solution of each sample was then filtered using Whatman No. 42 filter paper and transferred into a separate 100 ml volumetric flask. The solution was diluted to the mark

with distilled water. Finally, the samples were transferred into separate plastic bottles which were clearly labelled. For the blank, distilled water was used in the place of a sample, and the same procedure for digestion was followed. Heavy metal analysis was done using the flame atomic absorption spectrophotometer, AA 7000 Shimadzu, Japan model.

3.5.4.2 Sediment samples digestion

Sediment samples were dried using an oven (Model: Wisd-SWOF 50, 250VAC, 750W) at 105°C for 24 hours until there was no further change in weight. The dried samples were crushed with a mortar and pestle to a fine powder to increase surface area for heavy metal extraction. The obtained powders were sieved using a 10-mesh (2 mm) sieve. 2mg of each dried ground sample was weighed using an electronic analytical balance (Model: Shimadzu-ATX224) and wet digested using Aquaregia (a mixture of HNO_3/HCl in the ratio 3:1). The digested samples were then filtered using Whatman No. 42 filter paper and transferred into separate 100 ml volumetric flasks and the solution was diluted to the mark with distilled water then, the samples were transferred into separate plastic bottles, which were clearly labelled awaiting heavy metal analysis. Heavy metal concentration analysis was done using the atomic absorption spectrophotometer; model AA 7000 Shimadzu, Japan.

3.5.4.3 Phytoplankton and zooplankton samples digestion

Each of the phytoplankton and zooplankton samples were filtered through a pre-weighed 42 Whatman GF/C filter paper in the laboratory. The filter papers and the samples were then dried in a horizontal flow oven (Model: Wisd-SWOF 50, 250VAC, 750W) to a constant weight. The weight of the dried filter paper with sample was then determined using an electronic analytical balance with an accuracy of 0.1mg (Model: Shimadzu-ATX224). To obtain the dry weight of the phytoplankton and zooplankton, the initial weight of the filter paper was subtracted from the final weight of the dried filter paper with the sample. The dried filter papers with the samples were then ground into a fine powder using a mortar and pestle. Each obtained powder was then put into separate pre-cleaned beakers. Wet digestion was conducted using Aquaregia (a mixture of HNO_3/HCl in the ratio 3:1). The digested samples were then filtered using Whatman No. 42 filter paper, and the obtained filtrate was transferred into a separate 100 ml volumetric flask and the solution was diluted to the mark with distilled water then, the samples were transferred into separate plastic bottles, which were clearly labelled awaiting heavy metal analysis. For the blank, it was prepared identically using a plain filter paper following similar steps above, and in the place of a sample, distilled water was used. Heavy metal concentration analysis was done using the atomic absorption spectrophotometer model AA 7000 Shimadzu, Japan.

3.5.4.4 Atomic Absorption Spectrophotometer (AAS) principle and operating conditions

The model of flame atomic absorption spectrophotometer that was used for heavy metal analysis was AA 7000 Shimadzu, Japan. The principle of the AAS is that the specific atoms in the ground state can absorb radiant energy of their specific resonance wavelength when passed through a solution containing the specific atoms. The amount of absorption usually is equivalent to the number of excited-state atoms present in the flame. The AAS operating conditions for heavy metals analysis are summarized in Table 1. Moreover, the operating conditions were as per the manufacturer's recommended conditions.

Table 1: Atomic absorption spectrophotometer operational parameters for the heavy metals assessed in this study

Metal	Pb	Zn	Cu	Cd
Wavelength (nm)	283.22	213.73	324.8	228.87
Slit width (nm)	0.7	0.7	0.7	0.7
Lamp current (mA)	10.0	8.0	8.0	8.0
Oxidant flow rate (L/min)	15.0	15.0	15.0	15.0
Fuel flow rate (L/min)	2.0	1.80	1.80	1.80
Burner height (mm)	7.0	7.0	7.0	7.0
Flame used	Air/Acetylene	Air/Acetylene	Air/Acetylene	Air/Acetylene

3.5.4.5 Stock solutions, working standards and calibration curves

All the standards used during this study were freshly prepared during any time of analysis. Stock solutions of 1000 ppm for each metal were prepared using analytical grade salts which were dried and cooled before weighing. Intermediate standard solutions were prepared for each element using serial dilution in 50 ml volumetric flasks from the prepared stock standard solutions. Eppendoff, Micro-pipettes of different volumes were used to measure small volumes for accuracy during preparation of the working standards.

To prepare lead standards, analytical grade of lead nitrate salt was used. 500 ppm of lead nitrate standard was prepared by weighing 0.799 g of lead nitrate salt by using analytical balance. The weighed salt was then dissolved in deionized water and diluted to 500 ml to obtain 500 ppm of lead standard. Then, serial dilution was done using the prepared standard to prepare 0.1, 1, 5, 10, and 15 ppm standards of lead.

Copper standards were prepared by weighing 0.9832 g of copper sulphate ($CuSO_4.5H_2O$) salt dissolved in 500 ml of deionized water to prepare 500 ppm of copper standard. Then, 0.5, 1, 5, and 10 ppm standards of copper were prepared by serial dilution using the prepared 500 ppm standard.

To prepare 500 ppm of Zinc standard, 1.0995 g of zinc sulphate ($ZnSO_4.5H_2O$) salt was carefully weighed and then dissolved in 500 ml of deionized water. Using the 500 ppm standard, 0.5, 1, 5, and 10 ppm zinc standards were prepared by serial dilution.

Cadmium standard was prepared by dissolving 1.0516 g of cadmium nitrate in 500 ml of deionized water to obtain 500 ppm of cadmium standard. Serial dilution was done to prepare 0.5, 1, 5, and 10 ppm of cadmium standards from the 500 ppm cadmium standard.

The prepared standards for each element were then aspirated into the AAS using capillary tube one after the other and their absorbance were recorded. Then the calibration curves were plotted for each element using the absorbance against series standard dilution concentrations. To obtain the Y- intercept for each element curve, extrapolation was done while excel provided the gradient for each curve. As a result, the equation for each element curve was determined as shown in Table 2.

Table 2: Intercept, slope, calibration curve equation and R^2 value for heavy metal determinations

Element	Y- intercept	Slope	Equation	R^2 value
Lead	0.0191	0.0047	$y = 0.0047x + 0.0191$	0.9997
Copper	-0.0066	0.0384	$y = 0.0384x - 0.0066$	0.999
Zinc	-0.0034	0.0892	$y = 0.0892x - 0.0034$	0.9996
Cadmium	0.039	0.1624	$y = 0.1624x + 0.039$	1

Each metal calibration curve obtained was used to determine the respective metal concentration in the digested samples of wastewater, sediments, phytoplankton and zooplankton.

3.5.4.6 Limit of detection

The limit of detection for the AAS instrument for the four heavy metals Cd, Cu, Pb and Zn (Table 3) was calculated according to the equation below.

$$Limit\ of\ detection = 3.3\ x\ SD\ of\ intercept \ldots\ldots\ldots\ldots \textit{Equation 10}$$

The SD value was determined by using the formula below

$$SD\ of\ intercept\ = SE\ of\ intercept \ldots\ldots\ldots\ \textit{Equation 11}$$

The SE value was obtained using Microsoft Excel, a data analysis tool kit from regression.

Table 3: Atomic absorption spectrophotometer instrument detection limits for Cd, Cu, Pb, and Zn.

Element	Limit of detection (ppm)
Cadmium	0.0092
Copper	0.0508
Lead	0.0038
Zinc	0.0798

3.5.4.7 Method validation and percentage recovery tests

To validate the method used for heavy metal analysis and ascertain the accuracy of the AAS analytical procedure, samples with unknown heavy metal concentrations were spiked with standards of known concentrations and percentage recovery was determined for the respective heavy metals. Briefly, a sample with an unknown metal concentration was spiked with a known standard metal concentration and then digested. Then, the amount of spiked metal recovered after digestion of the spiked sample was used to calculate the percentage recovery using the formula below.

$$Percentage\ recovery = \left(\frac{Conc.of\ spiked\ sample - conc.of\ unspiked\ sample}{Conc.of\ spike\ added}\right)\ x\ 100$$

….*Equation 12*

If the calculated values were within 80 – 120%, they indicated good accuracy for the analysis procedure (Agoro, Adeniji, Adefisoye & Okoh, 2020).

Then, the calibrations prepared were used to determine the concentration of heavy metals in the digested samples.

3.6 Effectiveness of the treatment plant

3.6.1 Percentage reduction efficiency

Any wastewater treatment plant is deemed effective in wastewater polishing when pollutants are removed so that the effluent discharged does meet the required standards i.e NEMA, World Health Organisation (WHO), and United States Environmental Protection Agency (EPA) standards in our case, the standards could be drinking water, fisheries, and industrial. For this study, the standards used were for effluent discharge into the environment was NEMA, WHO, and EPA standards. Therefore, the management usually uses the percentage pollutant removal to maintain the effective performance of the wastewater treatment plant.

To determine the effectiveness of the Kisii Town WWTPs in wastewater polishing, pollutant removal efficiency was calculated for selected physico-chemical parameters, and heavy metals using the equation below (Agoro *et al.*, 2020):

$$Percentage\ reduction = \left(\frac{Conc.of polluntant\ \ influent - conc.of\ effluent}{Conc.of\ influent}\right)\ x\ 100 \ldots Equation\ 13$$

On the other hand, improvement on wastewater quality during polishing can be measured by the increase in the levels of pH, temperature and DO concentration between the influent and effluent. Therefore, calculation in their increase was calculated by the equation below:

$$Percentage\ increase = \left(\frac{Conc.of parameter\ \ in\ effleunt - conc.of\ parameter\ in\ influent}{Conc.of\ parameter\ in\ effleunt}\right)\ x\ 100 \ldots Equation\ 14$$

3.6.2 Compliance and compliance index

Compliance was evaluated by comparing effluent discharge physico-chemical parameters compliance to national (NEMA standards) and international standards (WHO and EPA standards). The compliance index value is calculated to show the effectiveness of a treatment plant design in wastewater polishing. If the index value is less than 1 (<1), it indicates compliance with the set standards for effluent discharge. On the other hand, if the index value is above 1 (>1), it implies non-compliance to the set standards for effluent discharge into the environment or surface water. In this study we used NEMA maximum threshold values when calculating the compliance index. Compliance index for selected parameters were calculated using the equation below (Agoro *et al.*, 2020):

$$Compliance\ index = \left(\frac{Conc.of\ pollunt\ effluent}{Maximum\ allowable\ value}\right) \ldots\ldots\ldots\ldots\ldots\ Equation\ 15$$

3.6.3 Comparison between the initial and current wastewater treatment plants in wastewater polishing

The calculated means of physico-chemical parameters of the effluent discharged from the initial and current designs of the Kisii Town WWTP were used to reveal whether there was a significant difference between the two WWTPs. Independent sample t-test was performed to determine the variation in the mean values of the physico-chemical parameters between the treatment plant designs. The significance differences were determined at $p < 0.05$.

3.7 Data analysis

3.7.1 Physico-chemical parameters data analyses

Microsoft Excel version 2010 was used to organize the obtained physico-chemical data from the different sampling stations. Descriptive statistics were calculated with the help of SPSS version 22. Spatial and monthly differences in the physico-chemical parameters were determined by Two-Way Analysis of Variance (ANOVA) at a pre-determined *alpha* value of 0.05 to test for significant differences. Where the variations in means were significant, *post hoc* analysis was done using the Tukey pairwise comparisons under SPSS version 22 to establish where the differences existed between the sampling stations and months.

3.7.2 Biological data analyses

3.7.2.1 Phytoplankton and zooplankton data analyses

Data were entered in Microsoft Excel version 2010. PAST software was used to determine phytoplankton diversity indices. Spatial and monthly variations of plankton were determined by One Way Analysis of Variance (ANOVA) at *alpha* value of 0.05 using Microsoft Excel version 2010. The relationship between selected physico-chemical parameters and plankton abundances were determined using Pearson in Microsoft Excel version 2010.

3.7.2.2 Total and Fecal coliforms data analyses

The obtained data was entered in Microsoft Excel version 2010. The total and fecal coliforms were reported as total counts per 100 ml of wastewater sample. Spatial and monthly variations of the total and fecal coliforms counts were determined by Two Way Analysis of Variance (ANOVA) at *alpha* value of 0.05 using SPSS version 22 software.

3.7.3 Heavy metals data analyses

Spatial variations of heavy metal concentration were determined by Analysis of Variance (ANOVA) using SPSS version 22 to test for significant differences between the sampling stations. For monthly variations, independent sample t-test was performed to determine variation in the mean value of the heavy metal concentration between the sampling months. The significance differences were determined at $p < 0.05$. After analysis, the obtained results were presented in the form of tables and figures.

3.8 Ethical issues

Before the start of this study, a research permit was obtained from the National Commission for Science Technology and Innovation (NACOSTI) and permission to access the Kisii Town WWTP for data collection was sort from the Gusii Water and Sewerage Company, Kisii County. Also, permission to use laboratory facilities was obtained from the Kenya Marine and Fisheries Research Institute (KMFRI) and the Technical University of Kenya, Nairobi (TUK). The experimental materials that were handled were disposed-off as per ethical regulations. Moreover, the chemical wastes were disposed following laid down procedures. Finally, the study adhered to scientific research ethics that relate to accuracy, validity, reliability, and the systematic nature of scientific information and biasness in data collection, analysis and interpretation.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This chapter presents the results of the study on: spatial and monthly variations of the selected physico-chemical parameters; phytoplankton and zooplankton diversity and abundances; the results on the correlation between the physico-chemical parameters and phytoplankton and zooplankton abundance; selected heavy metals concentrations in wastewater, sediments, phytoplankton and zooplankton; Total and Fecal coliforms counts/100ml. A comparison between the two wastewater treatment plant designs results on their effectiveness in wastewater treatment before (that's initial WWTP) and after renovation (that's the current WWTP) are presented.

4.2 Initial Kisii Town Wastewater Treatment Plant

4.2.1 Spatial and monthly variations of physico-chemical parameters

4.2.1.1 pH

The mean pH values recorded ranged from strongly acidic to alkaline levels that's from 2.0 to 8.83. The upstream station on the Riana river just before the discharge point from the wastewater treatment plant (WWTP) had the highest mean pH of 7.73 ± 0.09 indicating a neutral environment. The anaerobic pond sampling station recorded the lowest mean pH of 6.04 ± 0.68, showing a weakly acidic environment. There was a general slight increase in the mean pH from acidic to alkaline levels that's from influent to effluent sampling stations as the wastewater underwent polishing (Figure 4).

Monthly, the month of November recorded the highest mean (± SE) pH of 8.10 ± 0.09, followed by the month of September which recorded a mean of 7.95 ± 0.08 while the month of December had the lowest mean of 4.43 ± 0.46. The results obtained indicate a slight increase in the mean pH from August to November then a sharp decline in the month of December (Figure 5).

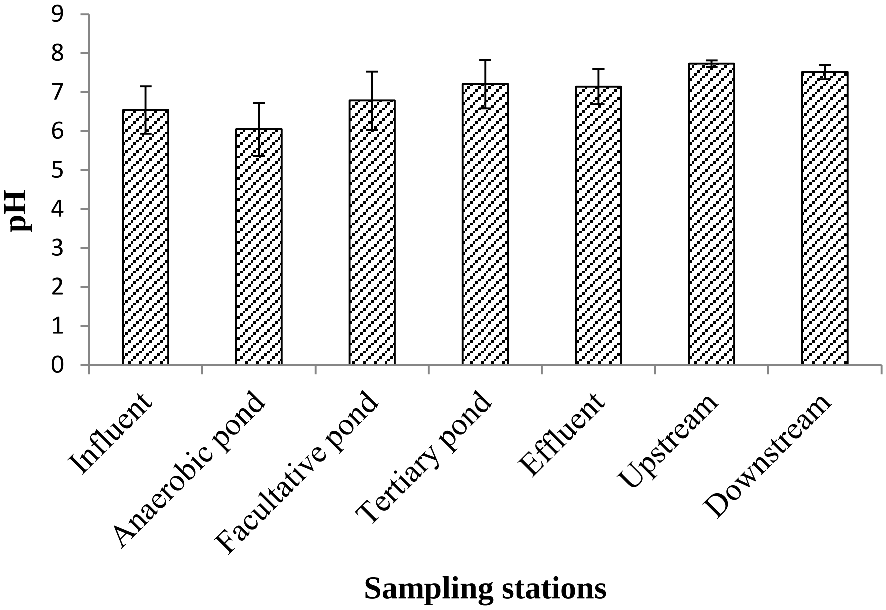

Figure 4: Spatial variation of the pH parameter for the initial Kisii Town WWTP.

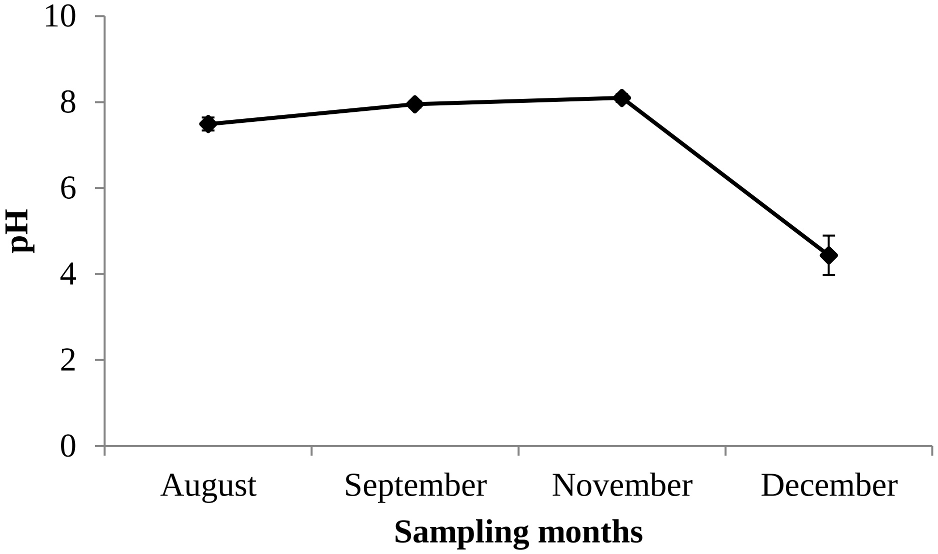

Figure 5: Monthly variations of pH parameter for the initial Kisii Town WWTP.

4.2.1.2 Conductivity

The mean conductivity of WWTP ranged from 78.3 μScm^{-1} to 3445.7 μScm^{-1} with a mean of 725.93 ± 66.40 μScm^{-1}. The influent station had the highest mean conductivity value of 1404.0 ± 325.7 μScm^{-1} while the upstream sampling station along river Riana just before the WWTP discharge point had the lowest mean conductivity of 128.2 ± 7.9 μScm^{-1}. These results indicate a considerable decreasing trend in the mean conductivity from influent to effluent (Figure 6). Two way ANOVA test showed that differences of the mean conductivity at different sampling stations were statistically significant ($F_{(6, 84)} = 341.75$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that conductivity mean for the influent station (1404 ± 325.7 μScm^{-1}) was significantly higher than that of upstream station (128.2 ± 7.9 μScm^{-1}). The mean conductivity for the anaerobic (878.9 ± 79.2 μScm^{-1}) sampling station was not significantly different from that of facultative (888 ± 81.7 μScm^{-1}) and tertiary (926.1 ± 78.2 μScm^{-1}) sampling stations (Figure 6).

In terms of monthly differences, the recorded mean (± SE) conductivity for the months of August, September and November were 1125.8 ± 211.3 μScm^{-1}, 774.0 ± 93.0 μScm^{-1} and 565.3 ± 64.1 μscm^{-1} respectively. The month of December had the lowest mean conductivity of 438.5 ± 47.4 μscm^{-1}. From the results obtained, they indicate a considerable decreasing trend in the mean conductivity during the study period (Figure 7). Two factor ANOVA showed that mean conductivity was statistically significant between the sampling months ($F_{(3, 84)} = 280.35$; $p = 0.000$). The mean conductivity of August value was significantly higher than that of November, September, and December (Figure 7).

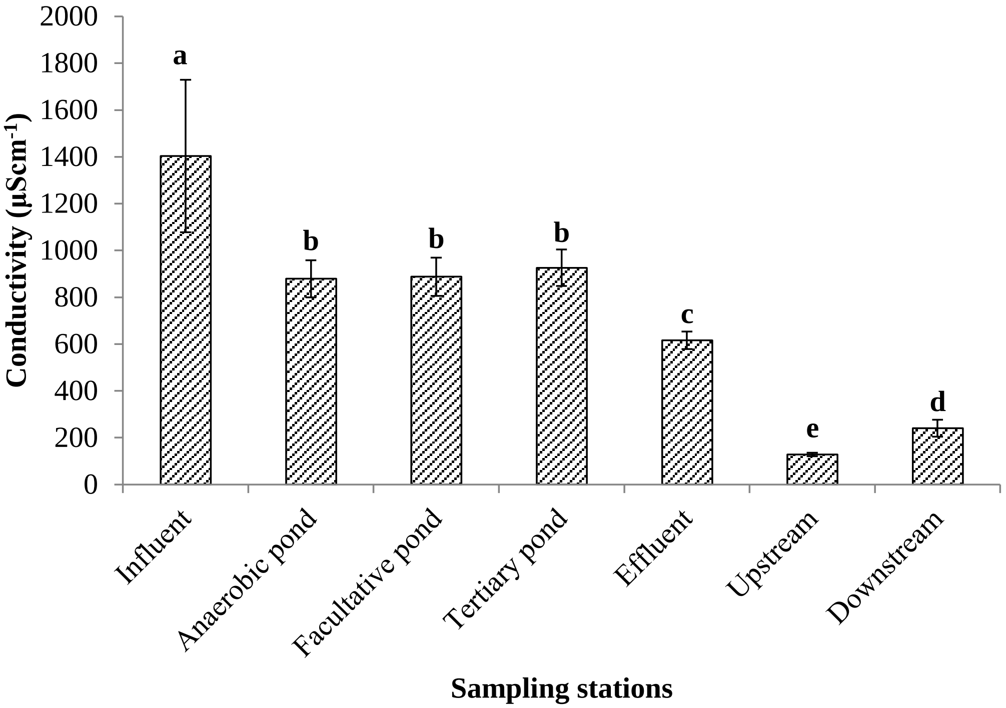

Figure 6: Spatial variation of conductivity for the initial Kisii Town WWTP.

Different letters (a, b, c, d, e) signify that the means are significantly different (*p* < 0.05).

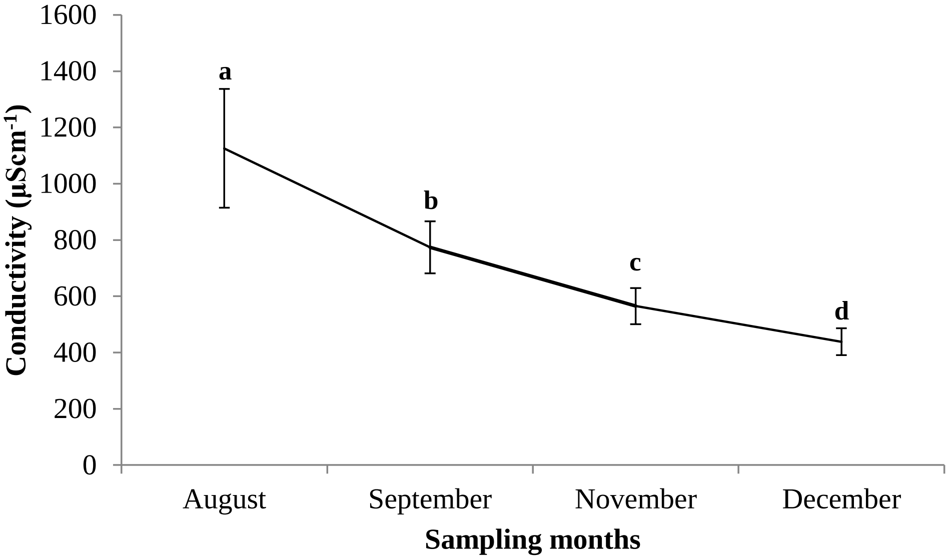

Figure 7: Monthly variations of conductivity for the initial Kisii Town WWTP.

Different letters (a, b, c, d) signify that the means are significantly different (*p* < 0.05).

4.2.1.3 Temperature

The mean spatial (± SE) temperature of the WWTP was 24.31± 0.25 °C with minimum and maximum temperature of 20.50 °C and 32.6 °C respectively. The facultative pond had the highest mean temperature value of 26.53 ± 0.84 °C while the influent sampling station recorded the lowest mean temperature value of 22.27 ± 0.21 °C. There was a general slight increase in the mean temperature from the influent to effluent sampling station as the wastewater underwent polishing through the WWTP system (Figure 8). Two way ANOVA showed that mean temperature among the different sampling stations were significantly different ($F_{(6,\ 84)} = 30.27$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean temperature of the influent (22.3 ± 2.0 °C) was significantly lower than that of anaerobic station (24.0 ± 0.41 °C). The facultative station mean temperature (26.5 ± 4.45 °C) was not significantly different from tertiary (26.2 ± 3.07 °C) and effluent (25.9 ± 5.57 °C) sampling stations (Figure 8).

In terms of monthly variations, the month of August had the highest mean (± SE) temperature of 25.23 ± 0.68 °C, followed by September with mean of 24.76 ± 0.49 °C and the month of December recorded the least mean temperature of 23.44 ± 0.26 °C. The recorded results indicate that there was a decrease in mean temperature values toward December (Figure 9). Two factor ANOVA showed that mean temperature were significantly different between the sampling months ($F_{(3,\ 84)} = 10.22$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean temperature in August (25.23 ± 0.68 °C) was significantly higher than that of December (23.44 ± 0.26 °C) (Figure 9).

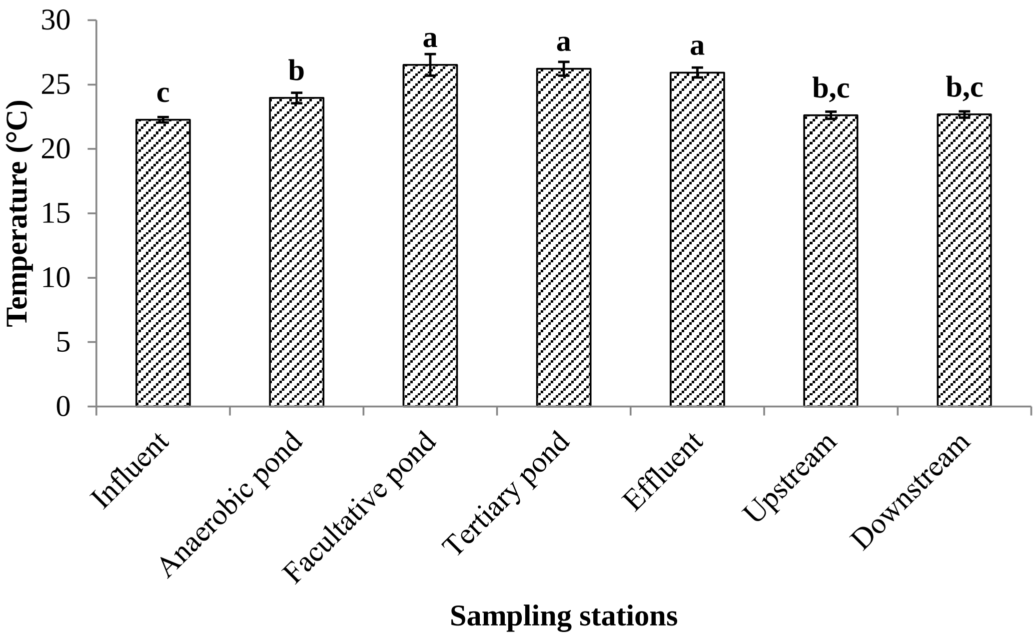

Figure 8: Spatial variations of temperature (°C) for the initial Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

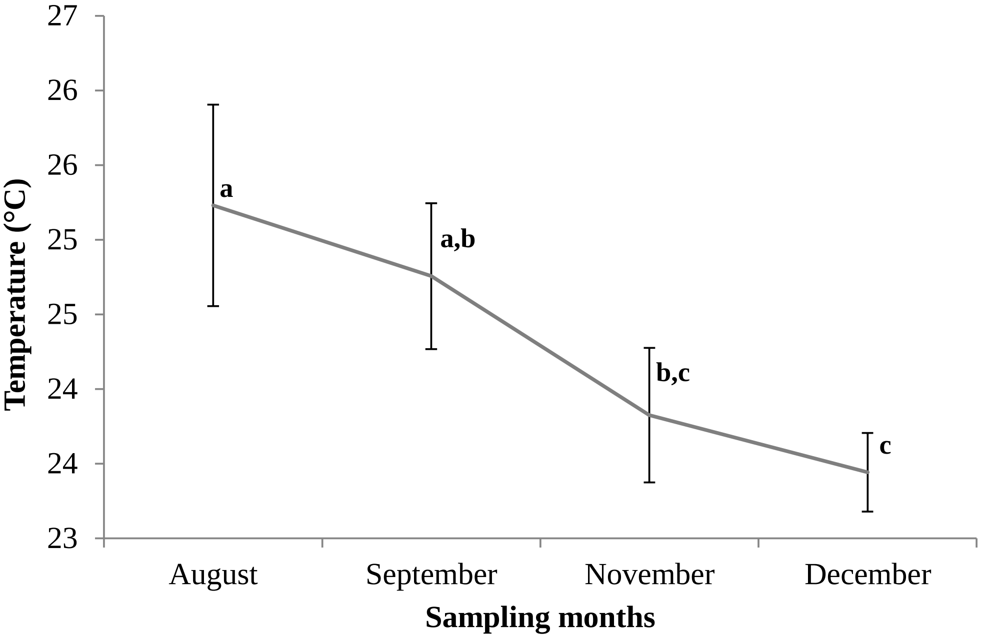

Figure 9: Monthly variations of temperature (°C) for the initial Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

4.2.1.4 Dissolved Oxygen (DO)

The mean (± SE) dissolved oxygen concentration which was recorded for the initial WWTP was 4.04 ± 0.38 mgL^{-1} with a minimum and maximum value of 0.01 mgL^{-1} and 12.18 mgL^{-1} respectively. The effluent had mean dissolved oxygen of 5.57 ± 1.08 mgL^{-1} which was higher compared than the of influent sampling station (2.00 ± 0.73 mgL^{-1}) while the anaerobic pond had the least mean dissolved oxygen of 0.41 ± 0.17 mgL^{-1}. In terms of trend, in general there was an increase in the mean dissolved oxygen concentration between the influent through the wastewater stabilizing ponds to the effluent similar to pH, and temperature (Figure 10). Two way ANOVA indicated there was significant differences between the sampling stations in the mean dissolved oxygen concentrations ($F_{(6,\ 84)} = 129.3$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean dissolved oxygen of the anaerobic station (0.4 ± 0.2 mgL^{-1}) was significantly lower than that of downstream sampling station (in river Riana just after effluent discharge point) (7.1 ± 0.2 mgL^{-1}) which was highest among all the sampling stations. The effluent (5.6 ± 1.1 mgL^{-1}) and upstream (5.6 ± 1.0 mgL^{-1}) mean DO concentrations were not significantly different (Figure 10).

Monthly, the month of August had the highest mean (± SE) DO concentrations of 6.19 ± 0.77 mgL^{-1} while the month of September had the lowest mean of 1.17 ± 0.51 mgL^{-1}. In terms of trend, the mean DO concentrations fluctuated during the study period (Figure 11). Two factor ANOVA revealed that the mean DO concentrations were statistically different between the sampling months ($F_{(3,\ 84)} = 184.5$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean DO of August (6.19 ± 0.77 mgL^{-1}) was significantly higher compared with that of September (1.17 ± 0.51 mgL^{-1}) being the lowest (Figure 11).

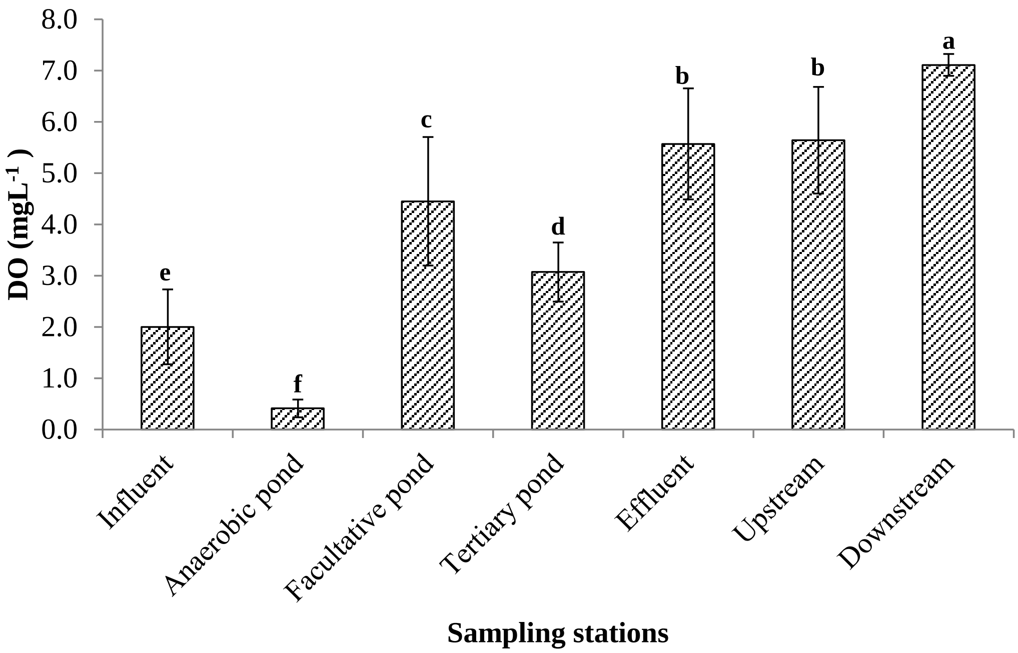

Figure 10: Spatial variations of Dissolved Oxygen (mgL^{-1}) for the initial Kisii Town WWTP. Different letters (a, b, c, d, e, f) signify that the means are significantly different (*p* < 0.05).

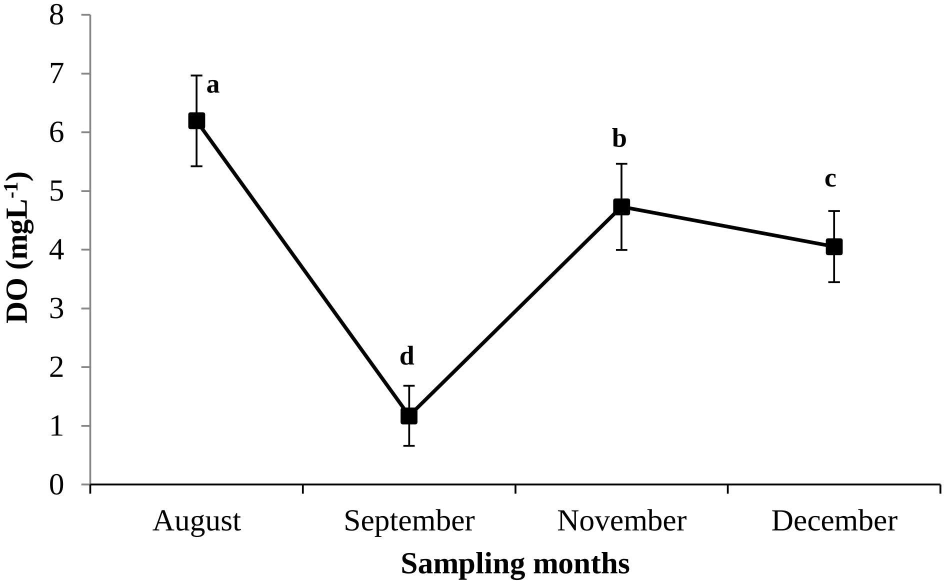

Figure 11: Monthly variations of dissolved oxygen (mgL^{-1}) for the initial Kisii Town WWTP. Different letters (a, b, c, d) denote that the means are significantly different (*p* < 0.05).

4.2.1.5 Total suspended solids (TSS)

The mean (± SE) value of TSS recorded for the sampling stations was 127.5 ± 12.14 mgL^{-1} with a minimum value of 12.0 mgL^{-1} and maximum value of 335.0 mgL^{-1}. The highest mean of TSS was recorded in the facultative station with 205.31 ± 38.5 mgL^{-1}. The effluent station recorded the least mean of TSS of 30.02 ± 2.4 mgL^{-1}. Just like electrical conductivity, there was a declining trend in TSS mean concentrations as the wastewater was being polished (Figure 12). Two way ANOVA indicated that there was significant differences in the mean TSS values between the sampling stations ($F_{(6, 84)} = 72.6$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TSS of the facultative (205.31 ± 38.4 mgL^{-1}) station was higher compared with effluent (30.02 ± 2.4 mgL^{-1}) station which recorded the lowest. The mean TSS for the anaerobic (137.0 ± 20.5 mgL^{-1}) station was not significantly different with the upstream (137.41 ± 32.9 mgL^{-1}) sampling station (Figure 12).

In terms of monthly variations, the highest means of TSS were recorded in the months of November and December with similar values of 166.5 ± 26.09 mgL^{-1}. The month of August recorded a mean of 115.7 ± 23.03 mgL^{-1} while September recorded the least value of 61.4 ± 13.24 mgL^{-1}. The trend for TSS between influent and effluent sampling stations was fluctuating but with an increasing trend (Figure 13). Two way ANOVA indicated there was significant differences in mean TSS between the sampling months ($F_{(3, 84)} = 86.0$; $p = 0.000$). *Post hoc* Tukey Pairwise comparisons revealed that the mean TSS value for the month of November and December were not significantly different but they were different to the month of August and September (Figure 13).

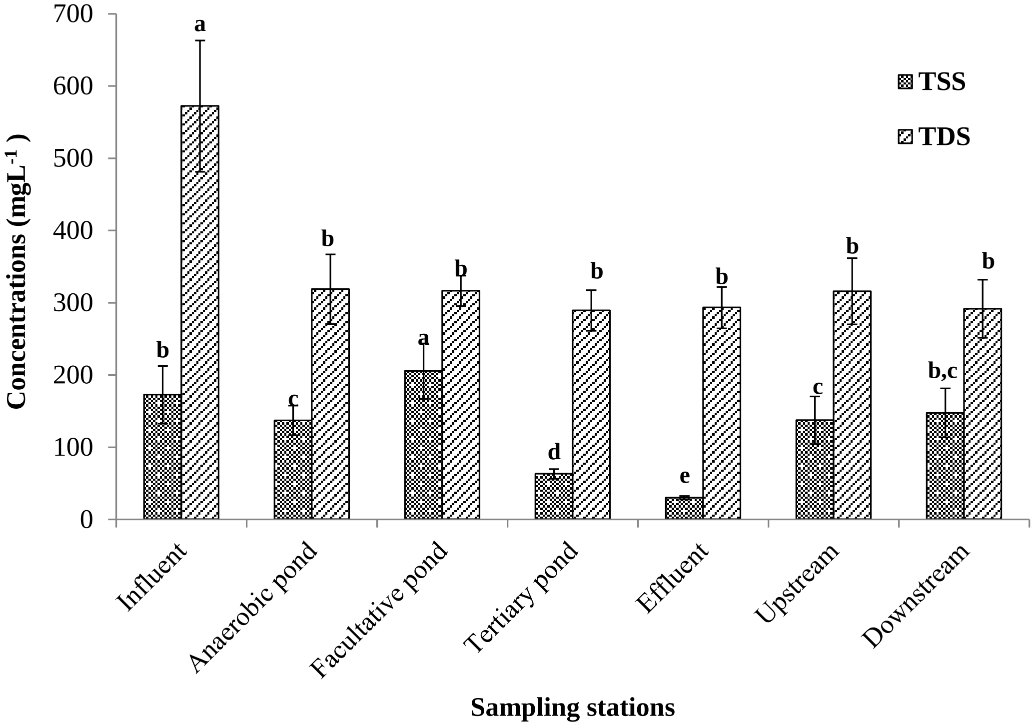

Figure 12: Spatial variations of TSS and TDS concentrations for the initial Kisii Town WWTP. Different letters (a, b, c, d, e) signify that the means are significantly different (*p* < 0.05).

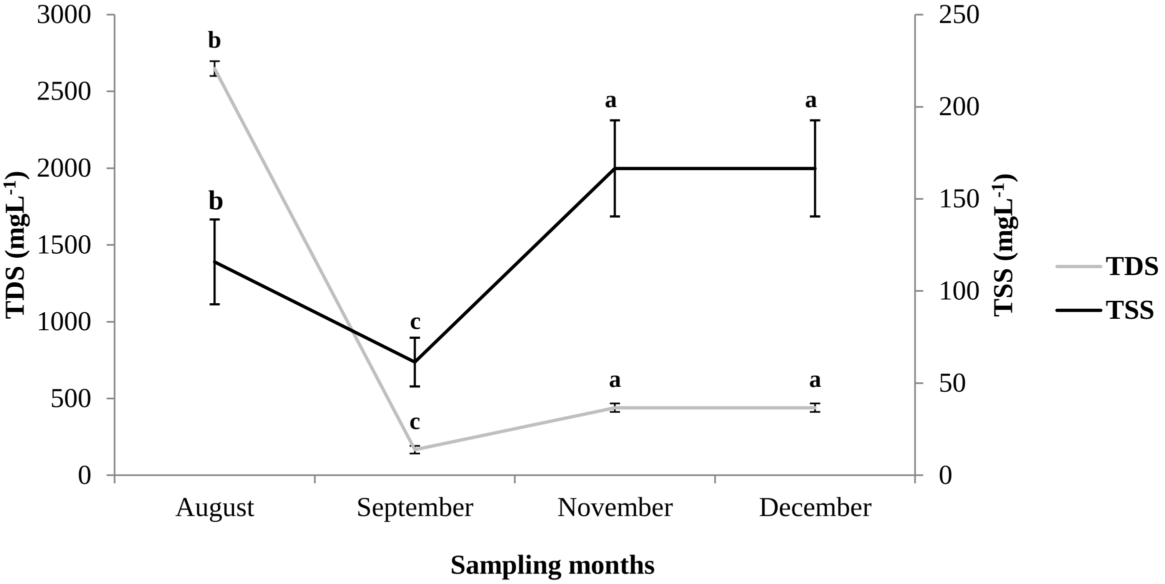

Figure 13: Monthly variations of TSS and TDS concentrations for the initial Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different (*p* < 0.05).

4.2.1.6 Total Dissolved Solids (TDS)

The mean (± SE) of TDS that was recorded was 342.4 ± 20.43 mgL^{-1} while the minimum and maximum values recorded were 18.0 mgL^{-1} and 809.1 mgL^{-1}. The highest mean value was recorded at the influent station with 572.2 ± 91.0 mgL^{-1} while the lowest value was recorded at the tertiary station with 289.2 ± 28.1 mgL^{-1}. In terms of trend, there was a decline in mean TDS concentration between the influent and effluent sampling stations, an indication of wastewater polishing (Figure 12). Two way ANOVA indicated there was significant differences between the sampling stations ($F_{(6, 84)} = 80.11$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean of the influent was significantly different compared with the other stations which were not significantly different among themselves.

Monthly, the highest mean of TDS value of 439.6 ± 27.5 mgL^{-1} was recorded for both November and December while value of 323.7 ± 47.8 mgL^{-1} was recorded in the month of August. The least value was in the month of September with 167.0 ± 25.1 mgL^{-1}. In terms of trend, there was a general decline in mean TDS concentrations between August and December during the study period just like with temperature (Figure 13). Two factor ANOVA showed that the mean TDS levels was statistically significant between the sampling months ($F_{(3, 84)} = 22.48$; $p < 0.05$). *Post hoc* Tukey Pairwise comparisons revealed that the mean TDS value for the month of November and December were not significantly different but they were different with the months of August and September.

4.2.2 Nutrients

4.2.2.1 Silicates

The mean silicate concentration that was recorded for the initial wastewater treatment plant was 32.93 ± 2.56 mgL^{-1}. The minimum value recorded was 0.506 mgL^{-1} and maximum value was 78.93 mgL^{-1} of silicate. The anaerobic pond recorded the highest mean silicate value of 35.32 ± 7.0 mgL^{-1} while the effluent had the least value of 30.42 ± 5.7 mgL^{-1}. In terms of trend, the changes in mean silicates concentrations fluctuated with no significant trend (Figure 14). Two factor ANOVA showed that silicate was not significantly different among the sampled stations (F $_{(6, 84)}$ = 1.332; *p* = 0.259).

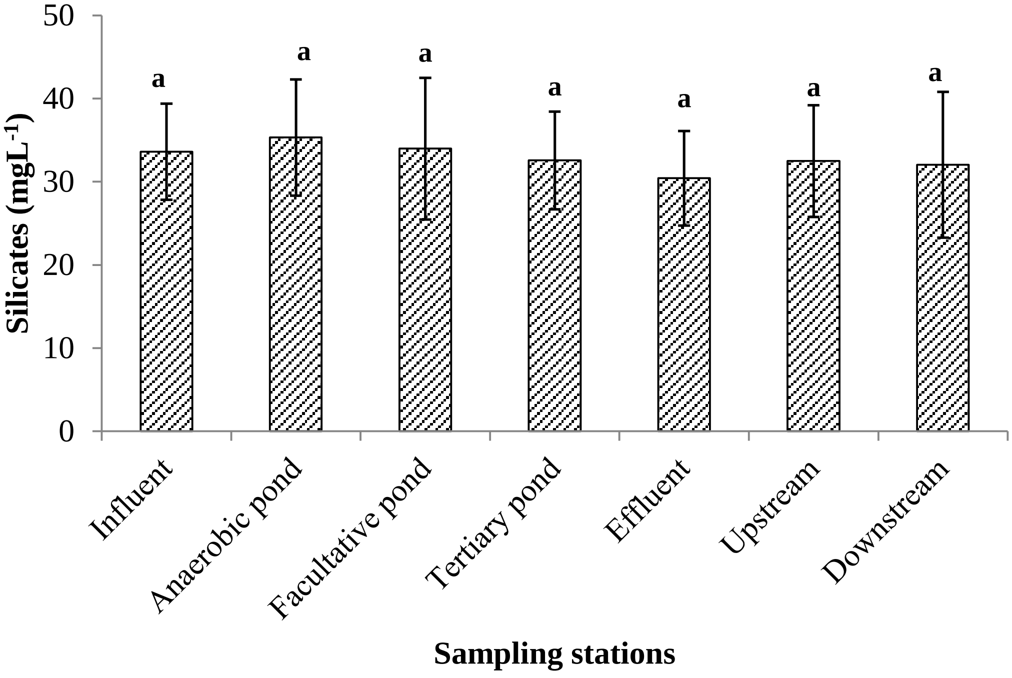

Figure 14: Spatial variations of silicate concentration for the initial Kisii Town WWTP. Means followed by the same letters are not significantly different (*p* > 0.05).

In terms of monthly variation, the month of November had the highest silicates mean (± SE) values of 63.26 ± 2.1 mgL^{-1}; followed by August with 37.81 ± 1.55 mgL^{-1}. The mean silicate of September was 28.73 ± 2.3 mgL^{-1}. The month of December had the lowest silicates mean value of 1.90 ± 0.36 mgL^{-1} (Figure 15). Two factor ANOVA showed that silicate concentrations was significantly different among the sampling months ($F_{(3, 84)} = 611.06$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean silicates concentrations for the month of December (1.9 ± 0.36 mgL^{-1}) was significantly lower compared with the month of November (63.3 ± 2.1 mgL^{-1}) which recorded the highest mean silicates concentration (Figure 15).

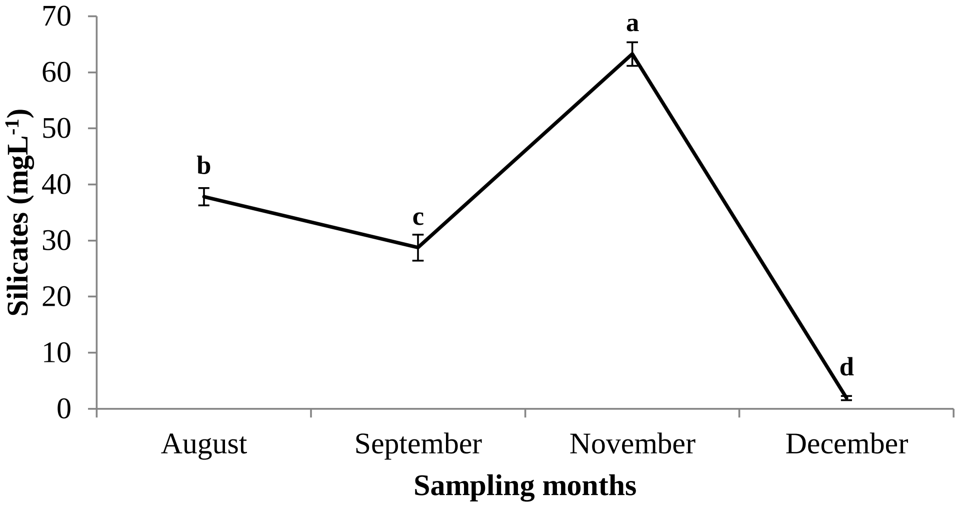

Figure 15: Monthly variations of silicate concentrations for the initial Kisii Town WWTP. Different letters (a, b, c, d) signify that the means are significantly different (*p* < 0.05).

4.2.2.2 Soluble Reactive Phosphorous (SRP)

The mean (μgL^{-1}) of soluble reactive phosphorous (SRP) that was recorded during the sampling period was 677.6 ± 61.34 μgL^{-1} with a minimum value of 24.5 μgL^{-1} and a maximum value of 1976.1 μgL^{-1}. The influent sampling station had the highest mean SRP of 1121.0 ± 82.5 μgL^{-1} while the effluent discharge had a lower SRP mean of 479.9 ± 89.0 μgL^{-1}. In terms of trend, there was a decline in mean SRP as the wastewater passed through the stabilizing ponds during treatment, showing that the wastewater treatment was effective (Figure 16).

Two factor ANOVA showed that SRP was significantly different among the sampled stations ($F_{(6, 84)} = 58.74$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that significantly lower SRP values were recorded in downstream station (209 ± 74.1 μgL^{-1}) compared to the other stations. The SRP values for the influent station did not differ significantly with facultative station but significantly differed with anaerobic station which in turn didn't differ with tertiary station. The effluent and upstream sampling stations mean SRP values recorded were not significantly different (Figure 16).

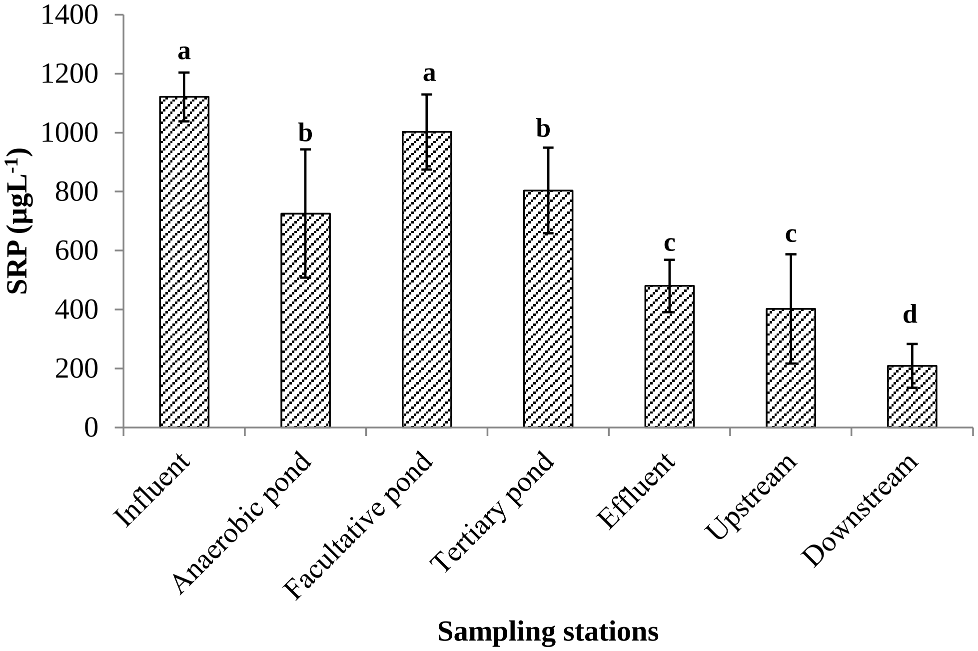

Figure 16: Spatial variations of SRP (μgL^{-1}) concentrations for the initial Kisii Town WWTP. Different letters (a, b, c, d) signifies that the means are significantly different ($p < 0.05$).

Monthly, the month of August recorded the highest mean SRP value of 1032.5 ± 129.7 μgL^{-1} while the month of September recorded the least mean SRP value of 437.0 ± 100.0 μgL^{-1}. In terms of trend, there was a considerable decline in mean SRP from August to September then a slight increase in mean SRP towards the month of December and this can be attributed to domestic wastewater volumes received (Figure 17).

Two factor ANOVA showed that the mean SRP values were significantly different among the sampling months (F $_{(3, 84)}$ = 60.16; *p* = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean SRP value that was recorded for the month of August (1032 ± 129.7 µgL^{-1}) was significantly higher compared with September (437 ± 100.0 µgL^{-1}) which recorded the lowest values. During November (596 ± 132.1 µgL^{-1}) and December (645 ± 92.8 µgL^{-1}), mean SRP values were not significantly different (Figure 17).

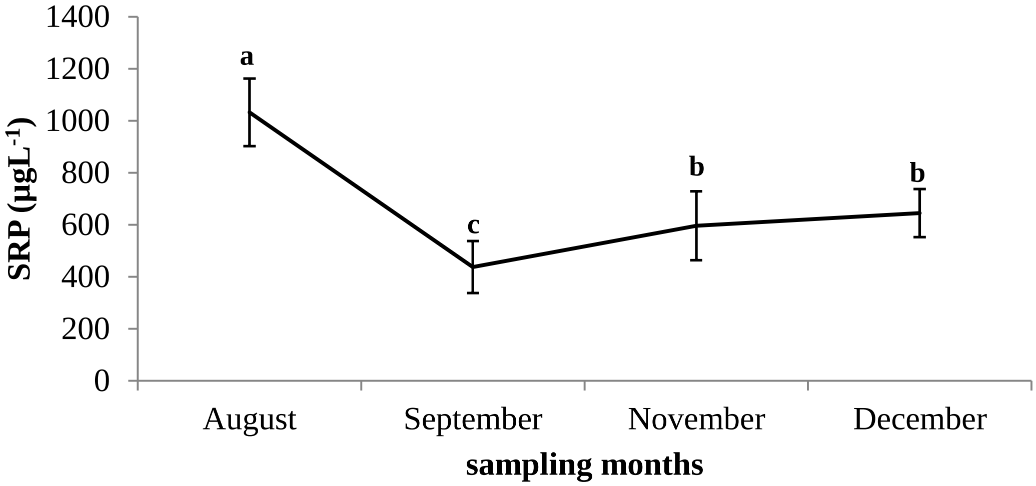

Figure 17: Monthly variations of SRP (µgL^{-1}) concentrations for the initial Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different (*p* < 0.05).

4.2.2.3 Nitrite-Nitrogen (NO_2^--N)

The mean concentration of nitrite-nitrogen recorded among the sampling stations was 30.11 ± 2.33 µgL^{-1}. The minimum and maximum values recorded were 3.09 µgL^{-1} and 87.97 µgL^{-1}. The influent had the highest mean value of 43.31 ± 9.12 µgL^{-1} while the anaerobic had the least value of 19.18 ± 3.78 µgL^{-1} .Despite showing no trend, the nitrite concentration in the influent were higher than those in the effluents, showing that the parameter was attenuated by the WWTP system (Figure 18).

Two factor ANOVA showed that the mean nitrite-nitrogen values were significantly different among the sampled stations (F $_{(6,\ 84)}$ = 42.6; *p* = 0.000). *Post hoc* Tukey pairwise comparisons revealed that the mean nitrite-nitrogen for the influent (43 ± 9.1 µgL^{-1}) was the highest and it differed significantly from the rest of the sampled stations. The mean nitrite-nitrogen for the anaerobic (19 ± 3.8 µgL^{-1}) and facultative (19 ± 4.8 µgL^{-1}) stations didn't differ significantly (Figure 18).

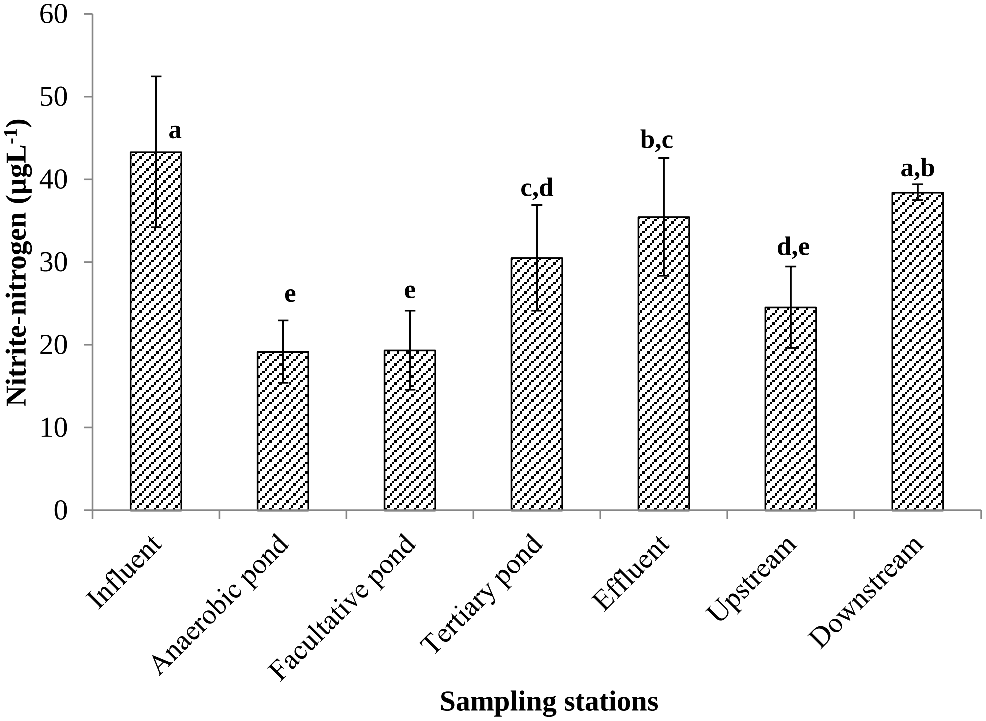

Figure 18: Spatial variations of nitrite-nitrogen (µgL^{-1}) concentrations for the initial Kisii Town WWTP.
Different letters (a, b, c, d, e) denotes that the means are significantly different (*p* < 0.05).

In terms of monthly variations, the month of September recorded the highest mean (± SE) value of 47.16 ± 4.37 µgL^{-1} while November had the least value of 17.50 ± 2.32 µgL^{-1}. For August and December, their recorded mean values were 20.45 ± 2.45 µgL^{-1} and 35.33 ± 5.55 µgL^{-1} (Figure 19). Two factor ANOVA showed that the mean nitrite-nitrogen values were significantly different among the sampling months (F $_{(3,\ 84)}$ = 157.9; *p* = 0.000). *Post* *hoc* Tukey pairwise comparisons revealed that the mean nitrite-nitrogen of September (47.2 ± 4.4 µgL^{-1}) differed significantly from those of December (35.3 ± 5.6 µgL^{-1}), August (20.4 ± 2.4 µgL^{-1}), and November (17.5 ± 2.3 µgL^{-1}) but the mean of August and November did not differ significantly. The nitrite concentration showed a fluctuating trend during the study period (Figure 19).

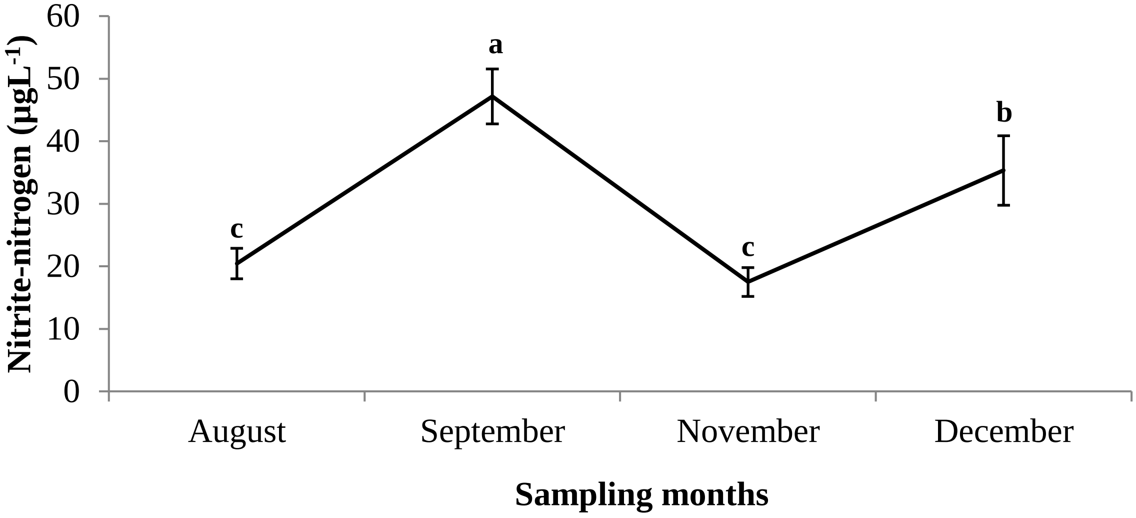

Figure 19: Monthly variations of nitrite-nitrogen (µgL^{-1}) concentrations for the initial Kisii Town WWTP.
Different letters (a, b, c) signify that the means are significantly different (*p* < 0.05).

4.2.2.4 Nitrate-Nitrogen (NO_3^--N)

The mean (± SE) value for nitrate-nitrogen that was recorded for the initial WWTP was 52.47 ± 3.54 µgL^{-1} with minimum and maximum values of 9.49 µgL^{-1} and 116.08 µgL^{-1}. The influent station recorded the highest mean value of 67.08 ± 11.98 µgL^{-1} compared to the effluent with 45.73 ± 7.25 µgL^{-1} (Figure 20). In terms of trend, there was a decline in nitrate-nitrogen concentration between the influent and effluent sampling stations, indication that there concentrations were being reduced as the wastewater underwent polishing. Two way ANOVA showed that nitrate-nitrogen concentration was significantly different among the sampled stations ($F_{(6, 77)} = 1.89$; $p = 0.093$). *Post hoc* Tukey Pairwise

Comparisons revealed that the mean nitrate-nitrogen value for the facultative (31.11 ± 4.3 µgL^{-1}) station was the lowest and differed significantly with the other sampling stations (Figure 20).

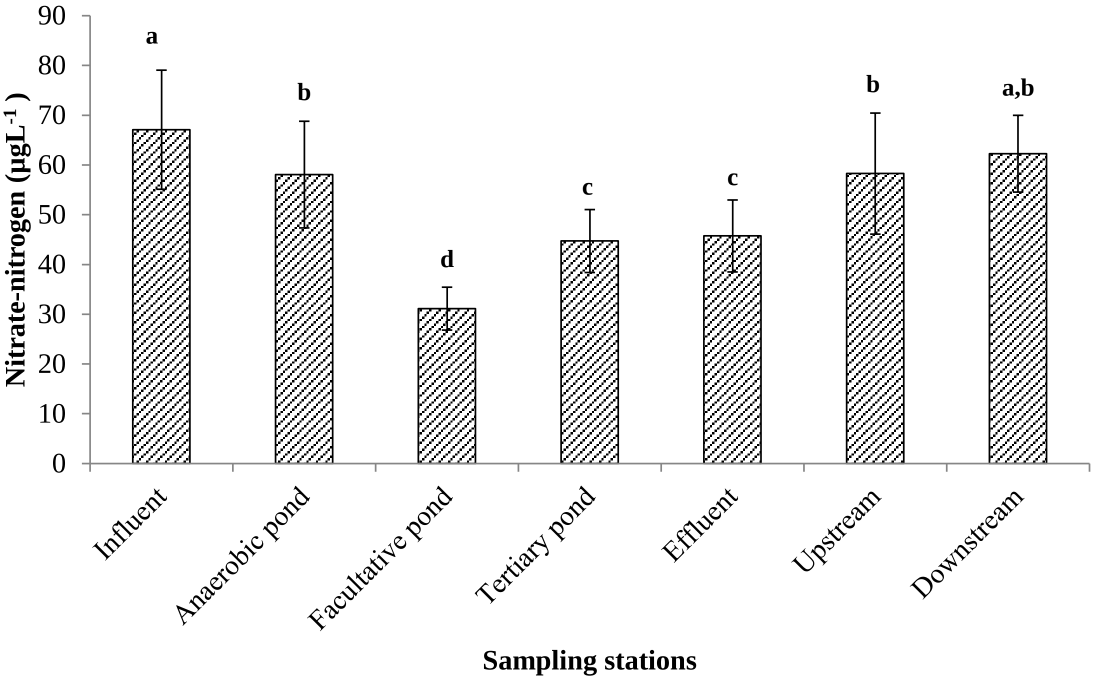

Figure 20: Spatial variations of nitrate-nitrogen (µgL^{-1}) concentrations for the initial Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the highest nitrate-nitrogen mean value was recorded in the month of September with 78.51 ± 7.74 µgL^{-1} followed by the month of December with 60.58 ± 6.59 µgL^{-1}. The month of August had the least mean value of 27.19 ± 3.46 µgL^{-1} (Figure 21). Two factor ANOVA showed that the mean nitrate-nitrogen values were significantly different among the sampling months ($F_{(3,\ 84)} = 218.72$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean nitrate-nitrogen value of the month of August (27.2 ± 3.5 µgL^{-1}) was significantly lower and differed significantly with those of

September (78.5 ± 7.7 μgL^{-1}), November (43.6 ± 4.5 μgL^{-1}), and December (60.6 ± 6.6 μgL^{-1}) (Figure 21).

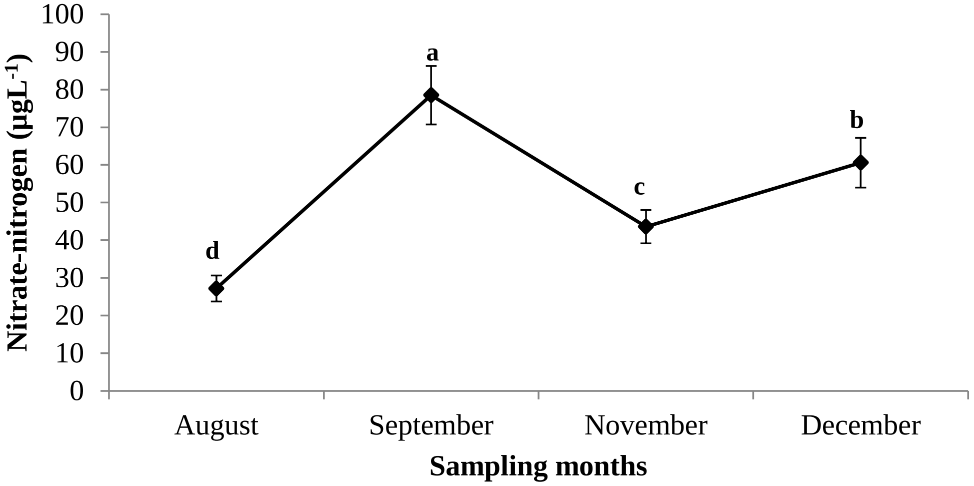

Figure 21: Monthly variations of nitrate-nitrogen (μgL^{-1}) concentrations for the initial Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

4.2.2.5 Ammonium-Nitrogen (NH_4^--N)

The mean (± SE) value for ammonium-nitrogen that was recorded was 772. 92 ± 60.18 μgL^{-1} with minimum and maximum values of 46.9 μgL^{-1} and 1797.0 μgL^{-1}. The facultative station had the highest mean ammonium-nitrogen of 1090.0 ± 194.91 μgL^{-1} while the influent station had the least mean ammonium-nitrogen of 464.1 ± 147.93 μgL^{-1}. In terms of trend, the ammonium-nitrogen mean concentrations fluctuated with increasing trend between the influent and effluent sampling station (Figure 22). Two way ANOVA indicated significant differences between the sampling stations ($F_{(6, 84)} = 19.9$; $p = 0.000$) for ammonium-nitrogen concentrations.

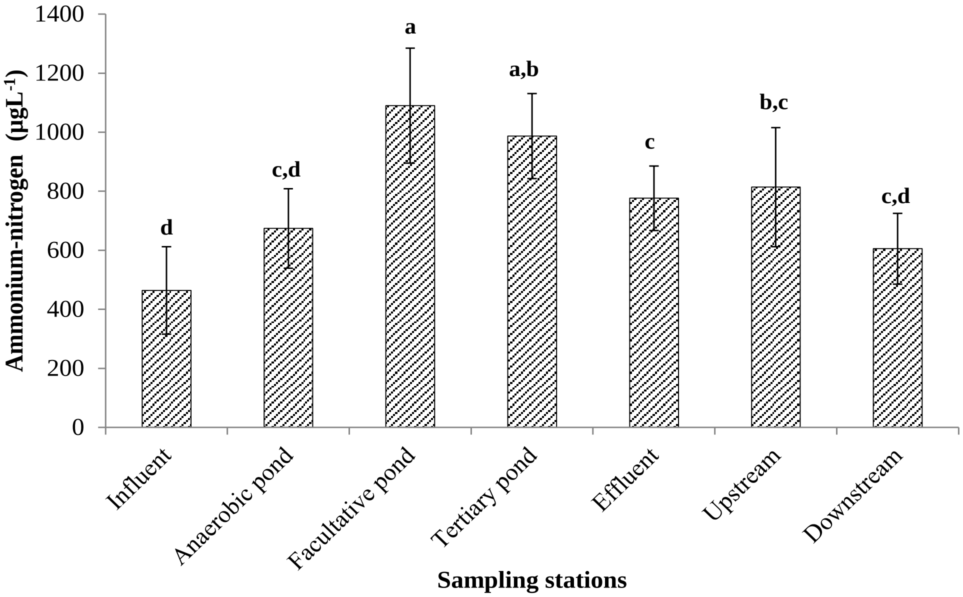

Figure 22: Spatial variations of ammonium-nitrogen (µgL^{-1}) concentrations for the initial Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different (*p* < 0.05).

Monthly, the month of August recorded the lowest mean Ammonium-nitrogen of 750.8 ± 96.17 µgL^{-1} while the month of November the highest mean of 811.2 ± 137.34 µgL^{-1} was recorded. For the month of September and December recorded the mean of 781.5 ± 133.37 µgL^{-1} and 748.1 ± 118.72 µgL^{-1} respectively. In terms of trend, there was no trend neither increasing nor decreasing in ammonium-nitrogen concentration as the wastewater underwent polishing in the WWTP system (Figure 23). Two factor ANOVA showed that ammonium-nitrogen was not statistically significant between the sampling months ($F_{(3, 84)} = 0.654$; $p = 0.584$).

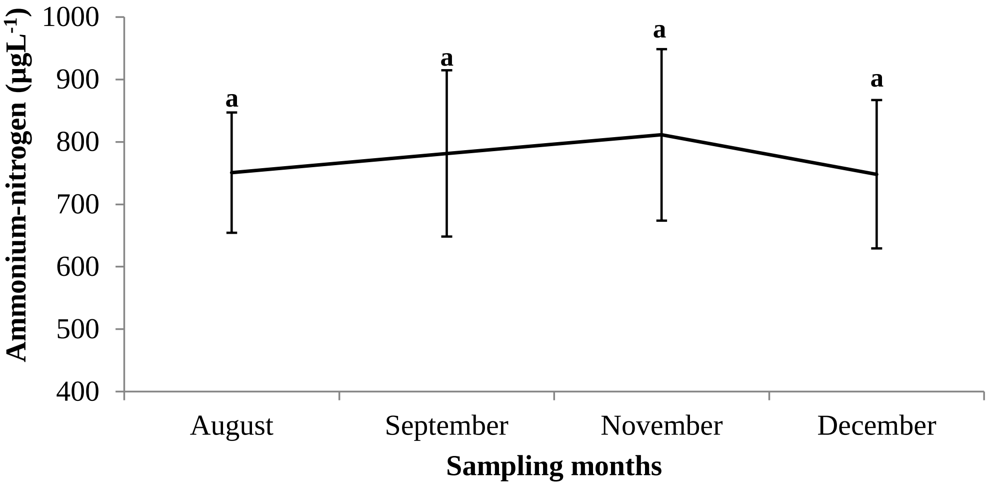

Figure 23: Monthly variations of ammonium-nitrogen (µgL^{-1}) concentrations for the initial Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different (*p* < 0.05).

4.2.2.6 Total Nitrogen (TN)

The mean (± SE) TN recorded was 917.5 ± 87.69 µgL^{-1} with a minimum and maximum value of 51.2 µgL^{-1} and 3723.6 µgL^{-1} respectively. The anaerobic pond sampling station had the least mean TN of 409.0 ± 58.15 µgL^{-1}. The Upstream sampling station along Riana river had a lower TN mean of 764.7 ± 193.43 µgL^{-1} compared with the downstream station which had TN mean of 856.1 ± 264.16 µgL^{-1} (Figure 24). In terms of trend, the mean of TN showed no clear trend between the influent and effluent sampling stations. Two way ANOVA showed that TN was significantly different among the sampled stations ($F_{(6, 84)}$ = 17.48; p = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TN of anaerobic (409.0 ± 58.1 µgL^{-1}) station was significantly low and differed significantly with other sampling stations; facultative (1280.7 ± 233.5 µgL^{-1}) did not differ significantly with tertiary (1231.4 ± 296.5 µgL^{-1}) station while the influent (800.1 ± 201.6 µgL^{-1}) did not significantly differ with the downstream (856.1 ± 264.2 µgL^{-1}) station (Figure 24).

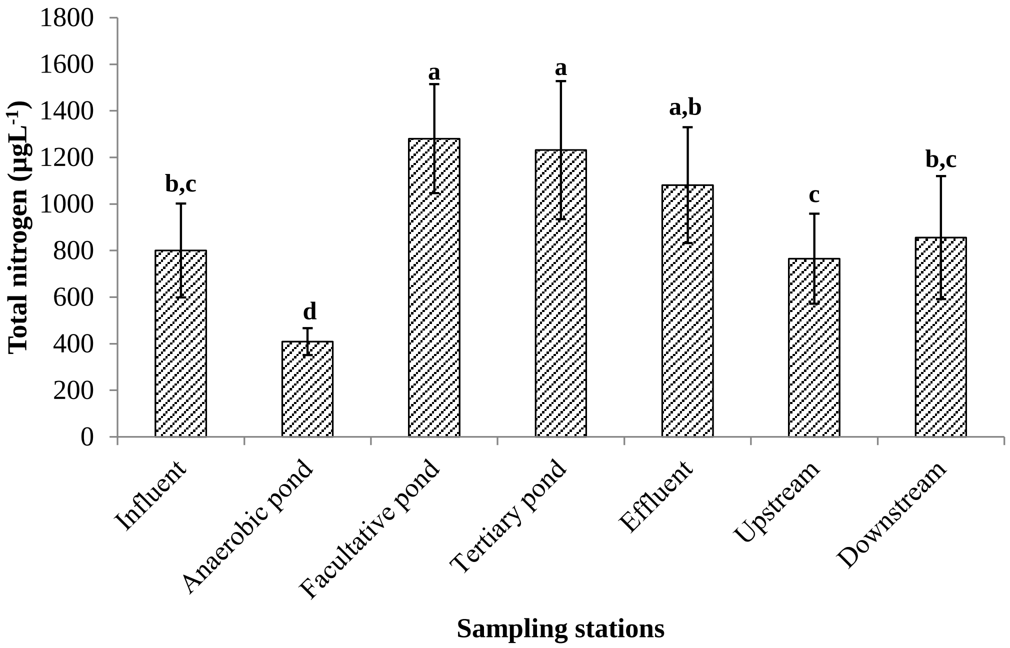

Figure 24: Spatial variations of TN (µgL^{-1}) concentrations for the initial Kisii Town WWTP. Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the month of August had the highest mean of TN of 1623.5 ± 206.63 µgL^{-1}, followed by the month of December with mean of 1233.3 ± 125.36 µgL^{-1}. The month of November and September had mean TN of 459.1 ± 100.50 µgL^{-1} and 354.1 ± 53.39 µgL^{-1} respectively (Figure 25). In terms of trend, the TN fluctuated with no clear trend during the entire study period. Two factor ANOVA showed that TN was statistically significant between the sampling months ($F_{(3, 84)} = 123.74$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TN of August (1623.5 ± 206.6 µgL^{-1}) differed significantly with December (1233.3 ± 125.4 µgL^{-1}), September (354.1 ± 53.4 µgL^{-1}), and November (459.1 ± 100.5). However, the mean TN of September did not differ significantly with that of November (Figure 25).

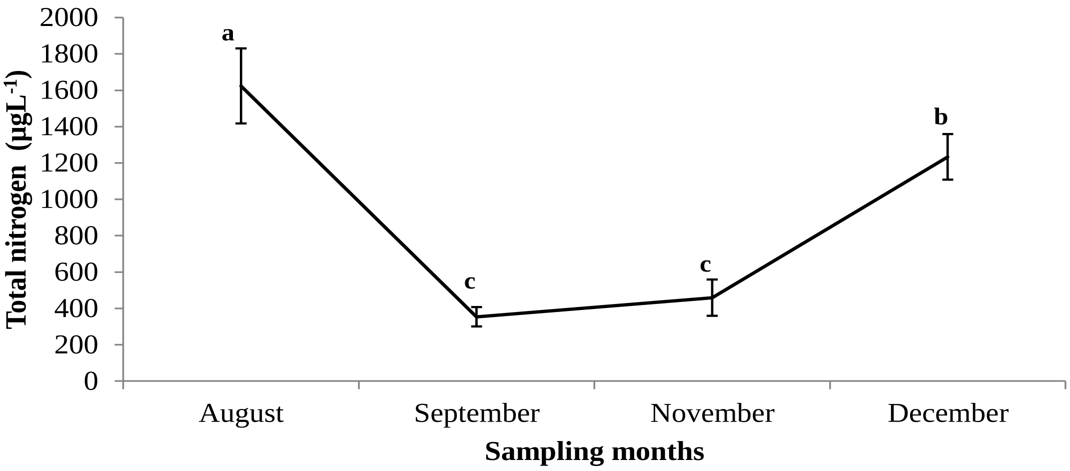

Figure 25: Monthly variations of TN (µgL^{-1}) concentrations for the initial Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

4.2.2.7 Total Phosphorous (TP)

The mean of TP that was recorded for the initial wastewater treatment plant was 1367 ± 106.78 µgL^{-1} with minimum and maximum values of 111 µgL^{-1} and 3513 µgL^{-1} respectively. The effluent station had TP mean of 1443.38 ± 243.97 µgL^{-1} which was lower compared to the influent station TP mean of 1604.2 ± 213.36 µgL^{-1} (Figure 26). In terms of trend, there was fluctuation in mean TP concentrations with no clear trend spatially during the sampling period. Two way ANOVA showed that TP was significantly different among the sampled stations ($F_{(6, 84)} = 8.12$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TP values for all the sampling stations differed significantly (Figure 26).

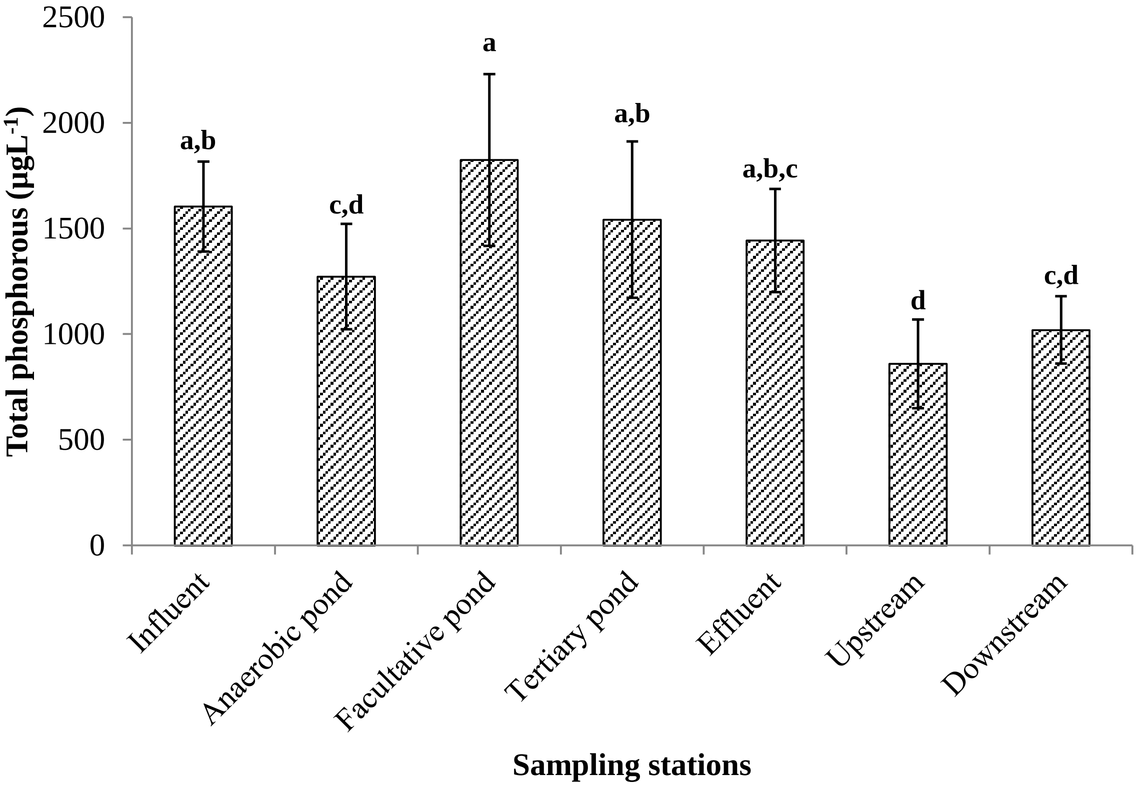

Figure 26: Spatial variations of TP (µgL^{-1}) concentrations for the initial Kisii Town WWTP. Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the month of August recorded the highest mean TP of 1866.3 ± 218.51 µgL^{-1}, followed by the month of September with mean of 1407.5 ± 275.59 µgL^{-1} and the month of November recorded the lowest TP mean of 883.7 ± 104.49 µgL^{-1} (Figure 27). In terms of trend, there was fluctuation in mean TP concentrations during the sampling period with a declining trend. Two factor ANOVA showed that TP was statistically significant between the sampling months ($F_{(3, 84)} = 20.11$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TP value for the month of August (1866.3 ± 218.59) was significantly higher compared with the month of November (883.7 ± 104.49) with was the lowest (Figure 27).

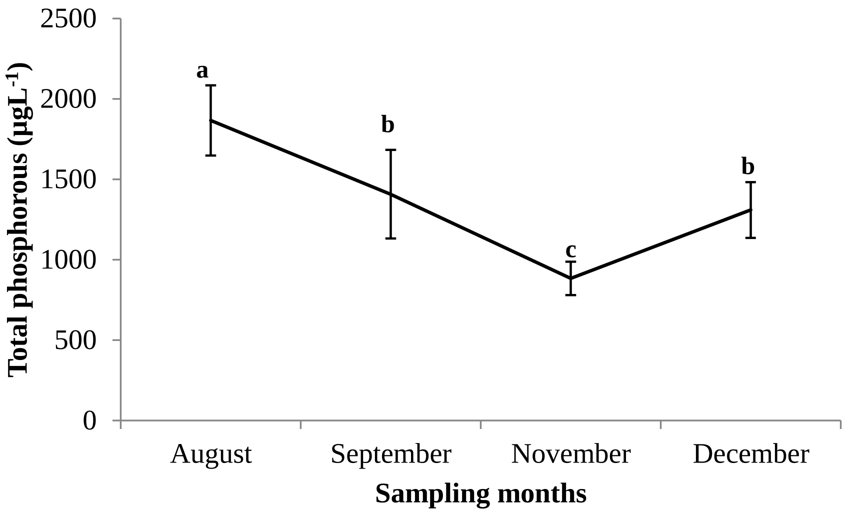

Figure 27: Monthly variations of TP (μgL^{-1}) concentrations for the initial Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

4.2.3 Heavy metals in wastewater

Figure 28 shows the obtained calibration curves that were used for the determination of the respective heavy metals concentrations in the various samples that were collected from Kisii Town Wastewater Treatment Plant and the three stations along river Riana.

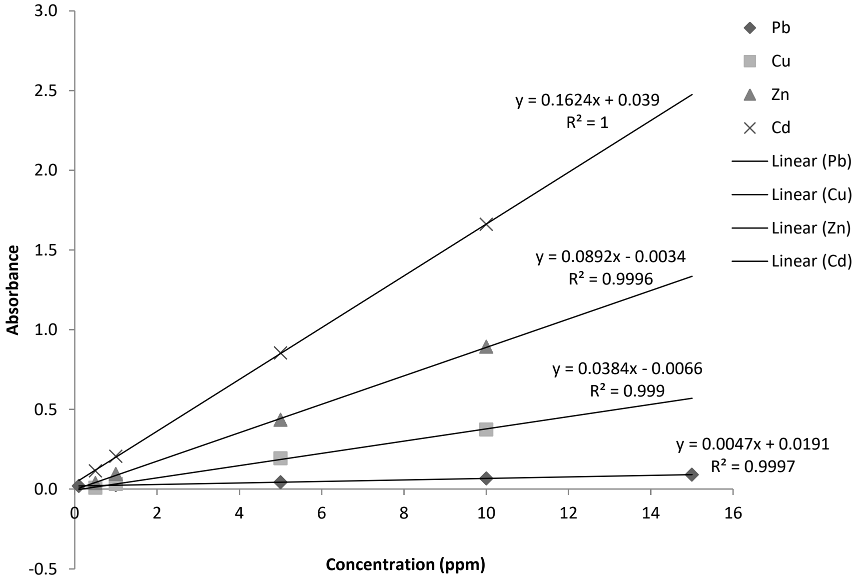

Figure 28: Calibration curves for the determination of the concentrations of respective heavy metal concentrations in samples.

4.2.3.1 Spatial variations of heavy metals concentrations in wastewater

The determination of heavy metals (Cu, Cd, Pb, and Zn) concentrations in wastewater samples from Kisii Town WWTP was investigated. The results obtained for mean heavy metal concentrations with standard errors (± SE) recorded are shown in Figure 29 for the initial WWTP. Cd concentrations were below the detection limits in all the sampling sites. The Pb mean concentration of the sampling stations ranged from 0.02 ± 0.003ppm to 0.17 ± 0.008ppm. The tertiary pond had the highest Pb mean concentration with 0.17 ± 0.008ppm. One-way ANOVA test showed that mean Pb concentration was not significantly different among the sampling stations ($F_{(6, 13}$= 0.9841; p = 0.4996).

The mean concentration of Zn of the sampling stations also ranged from 0.0412 ± 0.0ppm to 0.1511 ± 0.0004ppm. The influent sampling station had the highest Zn concentration with 0.1511 ± 0.0004ppm. One-way ANOVA test showed that the mean Zn concentration was not significant among the sampling stations ($F_{(6, 13)}$ = 1.852; p = 0.219).

The mean concentration of Cu of the sampling stations also ranged from 0.06 ± 0.03ppm to 0.1445 ± 0.04ppm. The upstream sampling station had the highest concentration of Cu with 0.1445 ± 0.04ppm. One-way ANOVA test showed that the mean Cu concentration was not significant among the sampling stations ($F_{(6, 13)}$ = 0.6404; p = 0.6983).

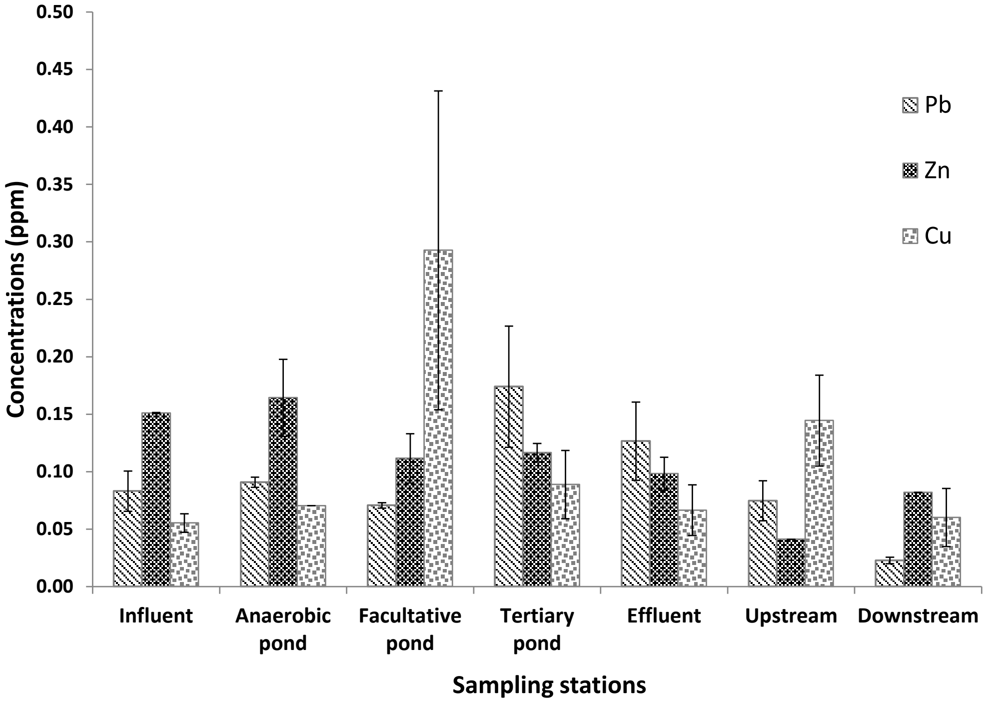

Figure 29: Spatial variations of heavy metal concentrations (in ppm) in wastewater samples from the initial Kisii Town WWTP.

4.2.3.2 Monthly variation of the heavy metals concentrations in wastewater

The mean heavy metal concentrations in wastewater samples collected during the two months are summarized in Table 4. The mean Pb concentration recorded for the month of September (0.098 ± 0.03ppm) was higher than the mean concentration (0.086 ± 0.02ppm) recorded in November. The independent sample t-test showed that mean Pb concentration was not significantly different between the sampling months ($t_{(7)} = 2.447$; $p = 0.764$).

The mean Zn concentration recorded for the month of November was 0.122 ± 0.02ppm which was higher compared to that of the month of September (0.096 ± 0.01ppm). The independent sample t-test showed that mean Zn concentration was not significantly different between the sampling months ($t_{(7)} = 2.447$; $p = 0.293$).

The Cu concentration measured in the month of November was 0.127 ± 0.07ppm which was higher compared to the month of September which had a mean Zn concentration of 0.096 ± 0.03ppm. The independent sample t-test showed that mean Cu concentration was not significantly different between the sampling months ($t_{(7)} = 2.447$; $p = 0.731$). The mean concentration of Cd was below the detection limit in both sampling months during the study period.

Table 4: Monthly variations of heavy metal concentrations (in ppm) in wastewater samples from the initial Kisii Town WWTP

Sampling months	**Heavy metal concentrations (ppm)**			
	Pb	**Zn**	**Cu**	**Cd**
September	0.098 ± 0.03	0.096 ± 0.01	0.096 ± 0.03	BDL
November	0.086 ± 0.02	0.122 ± 0.02	0.127 ± 0.07	BDL
***t*- value**	$t_{(7)} = 2.447$; $p = 0.764$	$t_{(7)} = 2.447$; $p = 0.293$	$t_{(34)} = 2.447$; $p = 0.731$	

4.2.4 Pearson's Correlation between physico-chemical parameters, nutrients and heavy metals in the initial wastewater treatment plant design

By carrying out Pearson's correlation analysis we determined the relationship among the different 16 parameters. The different Pearson's correlation coefficient (*r*) values obtained were interpreted as having significant strong positive/negative relationship if the value was above +/- 0.70 to 1; strong positive/negative (+/- 0.40 ≤ +/- 0.69); moderate positive/negative (+/- 0.30 ≤ +/- 0.39); weak positive/negative (+/- 0.20 ≤ +/- 0.29); negligible (+/- 0.01 ≤ +/- 0.19); and No relationship/ zero correlation (0) as described by Haldun Akoglu, (2018).

Table **5** shows the obtained linear correlation matrices at 5% level of significance and only those parameters with Pearson coefficients equal or higher than 0.50 ($r = 0.50$) were significant. There was a significant very strong positive correlation between pH and DO, EC with SRP and TP, temperature and NH_4-N, and between SRP and TP. In contrast, there was a significant very strong negative correlation between EC and DO, temperature and NO_3-N, DO and SiO_2, and between NO_3-N with NH_4-N, and TN.

The results for linear correlation matrices at 5% level of significance between physico-chemical parameters and heavy metals for the initial WWTP are shown in Table 6. There was a significant very strong positive correlation between EC and Zn. On the other hand, very strong negative correlation was between pH and Zn, and between DO and Zn. However there was no significant correlation between nutrients and heavy metals as shown in Table 7.

Table 5: Pearson's Correlation coefficients among different physico-chemical parameters and nutrients for the initial Kisii Town WWTP

	pH	**EC (µscm-1)**	**Temp (°C)**	**DO (mgL^{-1})**	**TSS (mgL^{-1})**	**TDS (mgL^{-1})**	**SiO$_2$ (mgL^{-1})**	**SRP (µgL^{-1})**	**NH$_4$-N (µgL^{-1})**	**NO$_2$-N (µgL^{-1})**	**NO$_3$-N (µgL^{-1})**	**TN (µgL^{-1})**	**TP (µgL^{-1})**	**Chlo-a (mgM^{-3})**
pH	1													
EC (µscm-1)	-0.753	1												
Temp. (°C)	-0.113	0.196	1											
DO (mg/L)	.865*	-.755*	-0.025	1										
TSS (mgL^{-1})	-0.263	0.167	-0.368	-0.124	1									
TDS (mgL^{-1})	-0.393	0.682	-0.496	-0.432	0.403	1								
SiO2 (mgL^{-1})	-0.735	0.463	-0.123	-.757*	0.663	0.282	1							
SRP (µgL^{-1})	-0.662	.920**	0.26	-0.696	0.37	0.625	0.569	1						
NH4-N (µgL^{-1})	0.205	-0.129	.813*	0.161	-0.092	-0.61	-0.021	0.128	1					
NO2-N (µgL^{-1})	0.236	0.171	-0.394	0.246	-0.228	0.519	-0.535	-0.083	-0.645	1				
NO3-N (µgL^{-1})	-0.015	-0.053	-.930**	-0.138	0.102	0.506	0.071	-0.243	-.919**	0.524	1			
TN (µgL^{-1})	0.381	0.084	0.71	0.419	-0.186	-0.225	-0.449	0.198	0.691	0.081	-.760*	1		
TP (µgL^{-1})	-0.524	.806*	0.647	-0.385	0.118	0.303	0.224	.832*	0.355	-0.02	-0.593	0.57	1	
Chlo-a (mgM^{-3})	-0.49	0.177	0.704	-0.131	-0.125	-0.368	0.088	0.151	0.374	-0.423	-0.647	0.196	0.508	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 6: Pearson's Correlation coefficients between physico-chemical parameters and heavy metals concentrations for the initial Kisii Town WWTP

	pH	EC (µscm-1)	Temp (°C)	DO (mgL^{-1})	TSS (mgL^{-1})	TDS (mgL^{-1})	Pb (ppm)	Zn (ppm)	Cu (ppm)
pH	1								
EC (µscm-1)	-0.753	1							
Temp. (°C)	-0.113	0.196	1						
DO (mg/L)	.865*	-.755*	-0.025	1					
TSS (mgL^{-1})	-0.263	0.167	-0.368	-0.124	1				
TDS (mgL^{-1})	-0.393	0.682	-0.496	-0.432	0.403	1			
Pb (ppm)	-0.101	0.375	0.611	-0.375	-0.706	-0.122	1		
Zn (ppm)	-.940**	.858*	0.132	-.857*	0.129	0.456	0.237	1	
Cu (ppm)	0.042	-0.041	0.457	0.161	0.521	-0.219	-0.153	-0.22	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 7: Pearson's Correlation coefficients between nutrients and heavy metals for the initial Kisii Town WWTP

	SiO_2 (mgL^{-1})	**SRP (μgL^{-1})**	**NH_4-N (μgL^{-1})**	**NO_2-N (μgL^{-1})**	**NO_3-N (μgL^{-1})**	**TN (μgL^{-1})**	**TP (μgL^{-1})**	**Pb (ppm)**	**Zn (ppm)**	**Cu (ppm)**
SiO_2 (mgL^{-1})	1									
SRP (μgL^{-1})	0.569	1								
NH_4-N (μgL^{-1})	-0.021	0.128	1							
NO_2-N (μgL^{-1})	-0.535	-0.083	-0.645	1						
NO_3-N (μgL^{-1})	0.071	-0.243	-.919**	0.524	1					
TN (μgL^{-1})	-0.449	0.198	0.691	0.081	-.760*	1				
TP (μgL^{-1})	0.224	.832*	0.355	-0.02	-0.593	0.57	1			
Pb (ppm)	-0.166	0.316	0.4	-0.05	-0.374	0.37	0.394	1		
Zn (ppm)	0.617	0.688	-0.265	0.007	0.072	-0.257	0.595	0.237	1	
Cu (ppm)	0.265	0.312	0.754	-0.64	-0.741	0.492	0.386	-0.153	-0.22	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

4.2.5 Initial Kisii Town wastewater treatment plant efficiency

The performance of the initial Kisii Town WWTP was assessed in terms of the percentage reduction or increase of the respective physico-chemical parameter, and heavy metals. The obtained results are presented in Table 8. TSS removal efficiency was 83% while it was 49% for TDS between the influent and the effluent sampling stations. For silicates, the percentage removal was 9% while it was 57% for SRP. The influent nitrite-nitrogen was reduced by 18% at the effluent. Similarly, nitrate-nitrogen value was reduced by 32% in wastewater during polishing. For TP, the reduction level was 10%. On the other hand, there was an increase of 67% of ammonium-nitrogen from that of influent value. Similarly, there was a slight increase level of TN by 35% between the effluent and influent sampling stations. However, for pH, temperature and DO, efficiency of wastewater polishing was measured based on their increase between the influent and effluent. Therefore, there was an increase in level of pH, temperature, and DO by 8.4 %, 14 %, and 64.3 % respectively, indication of wastewater polishing (Table 8).

Effluent discharge physico-chemical parameters compliance to national and international standards are summarized in Table 8 for the initial Kisii Town WWTP. pH, electrical conductivity, temperature, TDS, NH_4-N, NO_2-N, NO_3-N, and TP for were within the allowable limits by NEMA, WHO, and EPA standards. Moreover, there compliance indices were below 1 an indication of compliance. TSS mean concentration exceeded NEMA set limits including those of WHO and EPA standards. For the other parameters, due to the lack of NEMA standard limits for the corresponding parameters it was not possible generalize whether the discharged effluent met the set standards. Also, their respective compliance indices were not calculated and referenced for the initial WWTP. Nevertheless, the recorded mean of SRP, and TN met the EPA standards while TP met the NEMA and EPA standards but exceeded the WHO maximum set standards.

Table 8: Water quality Parameters of effluent discharge compared with national and international quality standards for the initial Kisii Town WWTP.

Parameter	Influent	Effluent	% Increase/ Reduction	Compliance index	NEMA	WHO	EPA
pH	6.54 ± 0.6	7.14 ± 0.4	8.4**	0.84	6.5 - 8.5	6.5 - 8.5	6-9
Temp (°C) based on ambient temperature.	22.3 ± 0.2	25.9 ± 0.4	14**	0.74	Ambient temperature ±3	Ambient	< 40
DO (mgL^{-1})	2.0 ± 0.7	5.6 ± 1.1	64.3**	-	*	> 4	
Conductivity (μScm^{-1})	1404.0 ± 325.7	616.1 ± 37.1	56	0.31	≤2000	1000	1500
TSS (mgL^{-1})	172.6 ± 39.8	30.0 ± 2.4	83	1	≤30	50	50
TDS (mgL^{-1})	572.2 ± 91.0	293.2 ± 28.6	49	0.24	1200	500	1000
SiO2 (mgL^{-1})	33.6 ± 5.8	30.4 ± 5.7	10	-	*		
SRP (μgL^{-1})	1121 ± 82.5	479.9 ± 89.0	57	-	*		1000
NH4-N (μgL^{-1})	464.1 ± 147.9	776.1 ± 109.5	67**	0.01	100 ,000		1000
NO2-N (μgL^{-1})	43.3 ± 9.1	35.5 ± 7.1	18	0.04	100 ,000		1000
NO3-N (μgL^{-1})	67.1 ± 12.0	45.7 ± 7.3	32	0.05	100 ,000	40000	10000
TN (μgL^{-1})	800.1 ± 201.6	1080.5 ± 248.7	35**	-	2 Guideline value		50000
TP (μgL^{-1})	1604.2 ± 213.4	1443.4 ± 244.0	10	0.72	≤2000	500	2000

Where: * denotes non-existence of a NEMA standard for the concentration levels of the corresponding parameter. ** denotes increase in percentage of the respective parameter between the influent and effluent. – denotes compliance index was not calculated for the corresponding parameter due to the lack of NEMA standard limit for the corresponding parameter.

For heavy metals, the compliance index for Cadmium was not calculated and referenced for the treatment plant as its concentration was below detection limit. The indices for zinc (0.2) and copper (0.075) were below 1 indication compliance to NEMA, EPA and WHO standards. However, the compliance index value for Lead was 13, and the value is greater than 1, indication non-compliance to the specified NEMA, EPA, and WHO standards for heavy metals effluent discharge to the environment. The mean concentration of copper measured was within the recommended limits by NEMA, EPA, and WHO standards (Table 9).

Table 9: Heavy metal effluent discharge concentrations of the initial Kisii Town WWTP compared with national and international quality standards

Metal	Influent	Effluent discharge	Compliance index value	NEMA standards	EPA	WHO
Lead (ppm)	0.08 ± 0.02	0.13 ± 0.03	13	0.01	0.006	0.01
Cadmium (ppm)	BDL	BDL	-	0.01	0.01	0.003
Zinc (ppm)	0.15 ± 0.0	0.10 ± 0.01	0.2	0.5	2	0.2
Copper (ppm)	0.06 ± 0.01	0.07 ± 0.02	0.075	1.0	0.5	1.0

4.2.6 Phytoplankton

4.2.6.1 Phytoplankton diversity and species composition

The checklist of the phytoplankton species recorded in the initial Kisii Town WWTP they are presented in Table 10. 124 phytoplankton species belonging to six (6) taxonomic groups were identified. The family Bacillariophyceae was represented by 36 species consisting of 29 % by species composition, followed by the family Chlorophyceae, which was represented by 34 species consisting of 28 % by species composition. The family Cyanophyceae was represented by 31 species leading to a 25 % species composition. Other taxonomic families included Euglenaphyceae, Zygnemophyceae, and Dinophyceae represented by 10 (8%), 9 (7%), and 4 (3%) species respectively.

Table 10: A list of phytoplankton taxa found in the initial Kisii Town WWTP

Chlorophyceae

Ankistrodesmus falcatus
Botryococcus braunii
Coelastrum microporum
Crucigenia menenghiana
Crucigenia sp
Dictyosphaerium sp
Kirchnella contorta
Kirchnella lunaris
Kirchneriella schimidle
Monoraphidium sp
Oocystis nageli
Oocystis parva
Oscillatoria gemirata
Oscillatoria tenuis
Pediastrum boryanum
Pediastrum duplex
Pediastrum tetras
Rhapidium braunii
Scenedesmus curvatus
Scenedesmus quadricauda
Scenedesmus acuminatus
Scenedesmus maximus
Scenedesmus obliquus
Schroidera setigera
Surirella elegans
Tetraedron arthromisforme
Tetraedron inflatum
Tetraedron triangulare
Tetraedron trigonum

Euglenaphyceae

Euglena acus
Euglena virids
Euglenaphytalena acus
Euglenaphytalena virids
Phacus longicauda
Phacus sp
Phacus pleuronectes
Strombomonas sp

Cyanophyceae

Anabaena circinalis
Anabaena flos-aquae
Anabaena limnetica
Aphanocapsa pularva
Aphanocapsa rivularis
Aphanothece sp
Chodatella longiseta
Chroococcus dispersus
Chroococcus limnetica
Chroococcus limneticus
Chroococcus turgidus
Coelomoron merostoides
Coelomoron vestitoz
Cylindrospermopsis africana
Merismopedia punctate
Merismopedia tennuissima
Microcystis aeruginosa
Microcystis flos-aquae
Microcystis wasenbergii
Oscillatoria tanganyikae
Oscillatoria tenuis
Plankolyngbya tallingii
Planktolyngbya circumcreta
Planktolyngbya limnetica
Planktolyngbya talingii
Pseudo-anabaena tanganyikae
Romeria ankensis
Romeria elegans
Spirulina princeps
Spirulina sp
Surirella affins

Zygnematophyceae

Closterium navicula
Cosmarium launderii
Cosmarium lundella
Cosmarium menenghiana
Cosmarium paradoxum
Crucigenia menenghiana

Bacillariophyceae

Amphora sp
Aulacoseira ambigua
Aulacoseira nyasensis
Aulacoseira schroidera
Chodatella sp
Chodatella longiseta
Cyclotella kutzinghiana
Cyclotella ocellata
Cymbella cistula
Diatoma elongatum
Diatoma hemiale
Diatoma vulgare
Euglenaphytalena vivids
Eunotia flexuosa
Flagilaria athiopica
Flagilaria construens
Fragilaria crotonensis
Navicula sp
Navicula gastrum
Navicula granatum
Navicula pupula
Navicula salicuta
Navicula simplex
Nitzschia lacustris
Nitzschia palea
Nitzschia recta
Nitzschia sub acicularis
Pinnularia subcepitata
Stephanodiscus astrea
Stephanodiscus sp
Surirella affins
Surirella sp
Surirella tenera
Synedra cunningtonii
Synedra ulna
Tubellaria sp

Dinophyceae

Ceratinium branchycerous

Trachelomonas armata	*Crucigenia* sp	*Glenodinium pernardii*
Trachelomonas volvocina	*Straurastum limnetica*	*Glenodinium pulvasistoz*
	Straurastum paradoxum	

The facultative sampling station had the highest species number of 51 (17.3%), followed by the effluent station with 50 (17.0%) species while the lowest numbers of species were recorded in the influent sampling station with 32 (10.6%). During this study, the Shannon-Wiener (H), Species evenness (E), and Margalef's diversity (d) indices were determined. The Shannon-Wiener (H') diversity index ranged from 0.7596 at the influent to 3.055 at the downstream sampling station. The dominant index (D) had a maximum value above 0.6917 on the influent and the effluent with the least value of 0.4125. In terms of Margalef's diversity that's species richness (d), the effluent was richer (with a value of 5.829) while the influent was with the least (3.409) (Table 11).

Table 11: The phytoplankton diversity indices of the initial Kisii Town WWTP

	Influent	Anaerobic pond	Facultative pond	Tertiary pond	Effluent	Upstream	Downstream
Taxa (s)	32	44	51	47	50	36	34
Individuals	8887	7026	16094	9079	4473	3448	391
Shannon_H	0.7596	1.373	0.9265	1.349	1.759	1.54	3.055
Dominance_D	0.6917	0.5185	0.6787	0.524	0.4125	0.345	0.066309
Margalef (Species richness)	3.409	4.855	5.162	5.047	5.829	4.297	5.529
Evenness_e^H/S	0.06679	0.08971	0.04952	0.08203	0.1161	0.1296	0.6239

4.2.6.2 Phytoplankton abundance

During this study, the total phytoplankton biovolume for the initial WWTP was 385.24 mm^3L^{-1} with a mean of 64.2 ± 51.9 mm^3L^{-1}. The family Euglenaphyceae was contributing to 35.86% followed by Dinophyceae with 28.17% while Chlorophyceae contributed the least with 3.81% of the total phytoplankton biovolume (Table 12).

Table 12: Phytoplankton biovolume of water samples from the initial Kisii Town WWTP

Taxonomic group	Phytoplankton Biovolume (mm^3L^{-1})	Percentage Biovolume (%)
Chlorophyceae	14.68	3.81
Cyanophyceae	59.66	15.49
Bacillariophyceae	59.57	15.46
Dinophyceae	108.51	28.17
Euglenaphyceae	138.16	35.86
Zygnematophyceae	4.65	1.21
Total	**385.24**	**100.00**

4.2.6.2.1 Spatial variation

The results obtained on the total phytoplankton biovolume depicted that there was variation between the sampling stations in the treatment plant. The anaerobic pond had the highest total phytoplankton biovolume by composition with 27.01% while the downstream sampling station recorded the least biovolume by composition with 2.03% (Table 13). The biovolume of algea showed a systematic increase from the influent down the wastewater treatment pond series, indicative of availability of nutrients as a result of biological breakdown of nutrients which encourages growth of algae. Single factor ANOVA showed that the total phytoplankton biovolume variation was not statistically significant between the sampling stations ($F_{(6, 35)} = 1.23$; $p = 0.3148$).

Table 13: Spatial variations of phytoplankton biovolume of water samples from the initial Kisii Town WWTP

Sampling stations	Phytoplankton Biovolume (mm^3L^{-1})	Percentage (%)
Influent	38.18	9.91
Anaerobic pond	104.04	27.01
Facultative pond	94.64	24.57
Tertiary pond	77.43	20.10
Effluent	48.91	12.70
Upstream	14.22	3.69
Downstream	7.82	2.03

The results on the composition of each family in the sampling stations in the initial design of the Kisii Town WWTP are as shown in Figure 30.

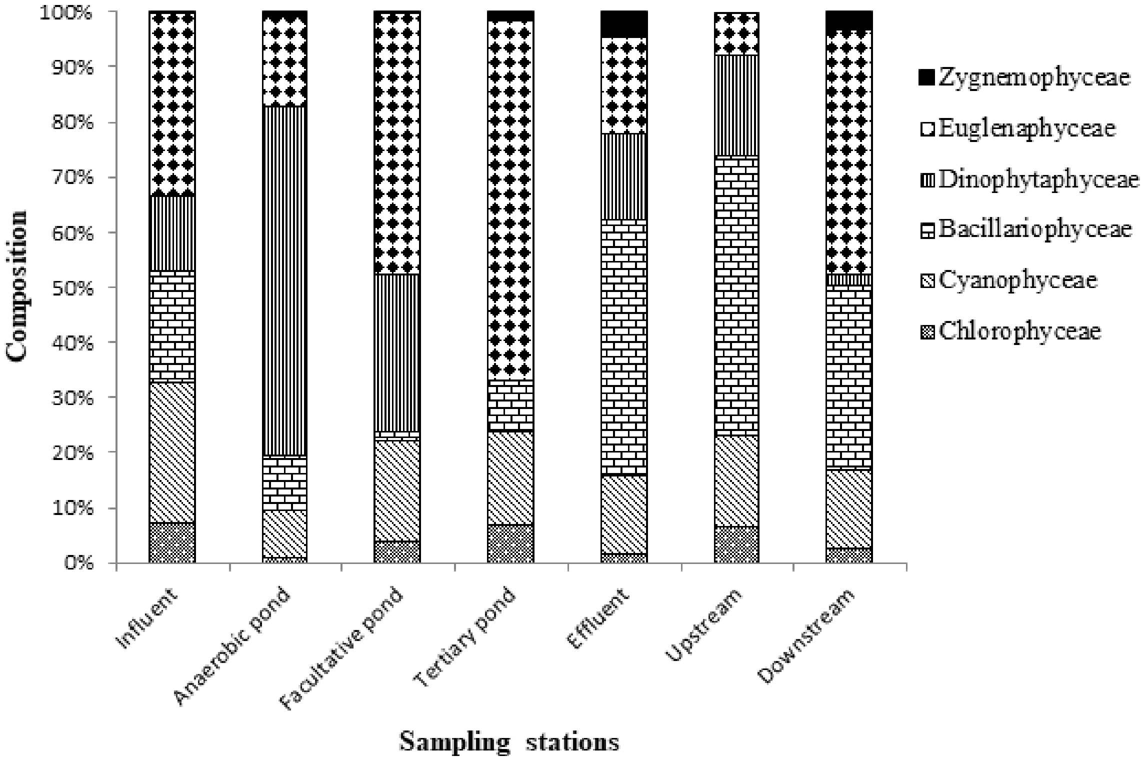

Figure 30: Relative abundance of phytoplankton taxa in sampling stations in the initial Kisii Town WWTP.

In the influent sampling station, the family Euglenaphyceae recorded the highest percentage closely followed by Cyanophyceae and Bacillariophyceae while the family Zygnematophyceae recorded the least relative percentage composition. The family Dinophyceae dominated in the anaerobic pond while Zygnematophyceae accounted for the least percentage. The order of dominance of families in the facultative pond was Euglenaphyceae which was the highest, followed by Dinophyceae, Cyanophyceae, Chlorophyceae, Bacillariophyceae then Zygnematophyceae recorded the least percentage. In the tertiary pond, the family Euglenaphyceae dominated while Bacillariophyceae largely dominated in the effluent. In the upstream sampling station, the family Bacillariophyceae dominated followed by Cyanophyceae then Dinophyceae while Zygnematophyceae was not recorded in this station. In the downstream sampling station, the family Euglenaphyceae dominated closely followed by Bacillariophyceae. The family Cyanophyceae was followed by Zygnematophyceae while Dinophyceae was not recorded in this sampling station.

The changes in the composition of different algal taxa between the influent and effluent indicate that the WWTP is treating the wastewater effluent. This also indicates there is progressive degradation of organic matter in wastewater thus releasing nutrients into the water column which together with other breakdown of organic substances lead to variation in the environmental conditions within the water treatment pond series. The environmental variation encourages dominance of different algal taxa in the different ponds that's from anaerobic, facultative, and maturation ponds (Figure 30).

Evidence that the WWTP is polishing the effluent can be assessed by comparing the algal composition within the WWTP pond series with that of upstream sampling station which in this case serves as the control and indicates that Bacillariophyceae were the dominate taxa there. Bacillariophyceae which represent the diatoms are indicators of good water quality. The increasing representativeness of Bacillariophyceae along the pond treatment series towards the effluent attests to the fact that ponds are treating the wastewater.

4.2.6.2.2 Monthly variations

In terms of monthly variation, the total phytoplankton biovolume showed variation between the sampling months in the initial design of the wastewater treatment plant, but this was not significant (Figure 31).

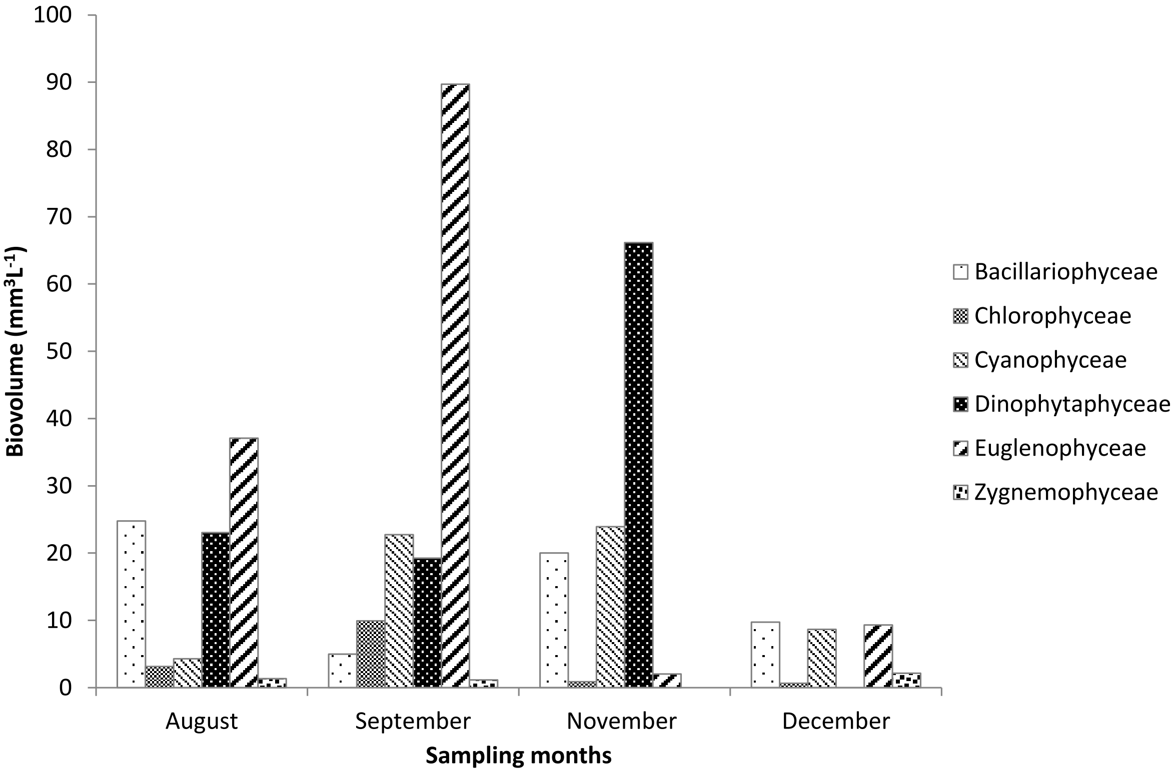

Figure 31: Monthly variations of phytoplankton biovolume in water samples from the initial Kisii Town WWTP

The month of September recorded the highest biovolume, followed by the month of November then August while December recorded the least total phytoplankton biovolume. The family Euglenaphyceae dominated the months of August and September, while Dinophyceae dominated in the months November followed by August then September. The family Cyanophyceae biovolume was high in September and November but least in August. The family of Bacillariophyceae dominated in August, November, and December. The families Chlorophyceae and Zygnematophyceae had a relatively low total phytoplankton biovolume throughout the sampling months. However, single factor ANOVA test showed that the total phytoplankton biovolume variation was not statistically significant between the sampling months ($F_{(3, 20)} = 0.8195$; $p = 0.4983$).

Within the initial Kisii Town WWTP, there were frequent occurrences of algal/plankton bloom formations on the water surface in all the ponds but mostly in the facultative and tertiary ponds. These algal blooms are an indicator of presence of algal toxins in the WWTP. The predominant algae species observed in this study such as *Microcystis aeruginosa* are known to produce potent algal toxins known as microcystins which can cause serious illness or death to humans, wildlife, and livestock. The aspect of algal toxins was not an objective of this study but attention of their possible existence in the WWTP is here drawn.

4.2.6.3 Chlorophyll-a

For the initial wastewater treatment plant, the mean (± SE) chlorophyll-a concentration calculated was 61.39 ± 7.91 mgM^{-3} with a minimum value of 0.88 mgM^{-3} and maximum value of 258.67 mgM^{-3}. Therefore, this parameter exhibited high variability. The highest chlorophyll-a mean of 88.95 ± 28.58 mgM^{-3} measured was in the facultative sampling point while the upstream station recorded the least mean value of 31.13 ± 11.24 mgM^{-3}. This can be attributed to presence of higher nutrient levels in the WWTP pond series compared to those in the Riana river (upstream sampling point). Two-way ANOVA indicated there was a significant difference between the sampling stations ($F_{(6, 84)} = 600.89$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean chlorophyll-a of the upstream station was significantly lower compared to the other stations. The mean chlorophyll-a for the facultative station didn’t differ significantly with that of the effluent station. Similarly, the tertiary pond mean chlorophyll-a didn’t differ with the downstream sampling station (Figure 32).

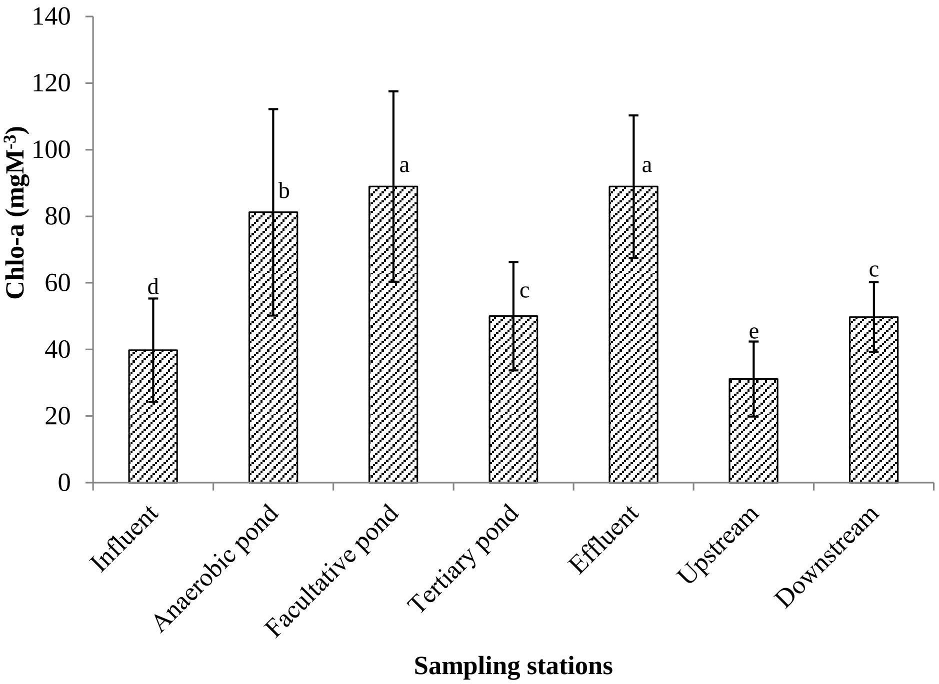

Figure 32: Spatial variations of chlorophyll-a concentration for the initial Kisii Town WWTP. Means followed by different letters (a, b, c, d, e) are significantly different ($p < 0.05$).

Monthly, the month of November had the highest mean chlorophyll-a concentration of 169.33 ± 13.83 mgM^{-3} and the month of August had the lowest mean of 18.43 ± 2.65 mgM^{-3}. The month of September and November had chlorophyll-a mean concentration of 29.14 ± 4.52 mgM^{-3} and 28.66 ± 13.83 mgM^{-3} respectively. Two factor ANOVA showed that chlorophyll-a was statistically significant between the sampling months ($F_{(3, 84)} = 92.28$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean chlorophyll-a of November was significantly higher compared with the other months (Figure 33).

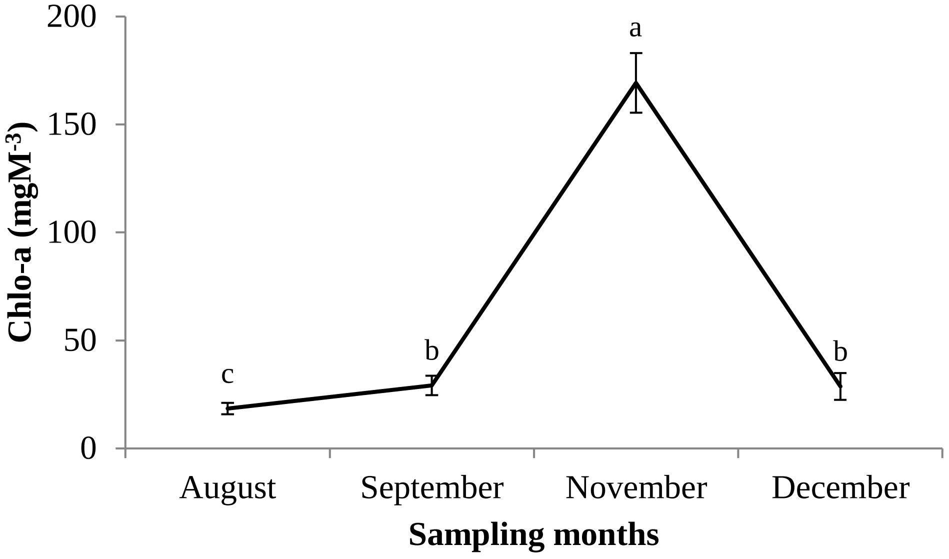

Figure 33: Monthly variations of chlorophyll-a concentration for the initial Kisii Town WWTP. Means followed by different letters (a, b, c) are significantly different ($p < 0.05$).

4.2.6.4 Correlation between physico-chemical parameters and phytoplankton abundance in Kisii Town Wastewater Treatment Plant

By carrying out correlation analysis, the relationship between the physico-chemical parameters and the phytoplankton were shown. Table 14 shows the obtained correlation matrices at 5% level of significance and only those variables with Pearson coefficients equal or higher than 0.50 ($r = 0.50$) were significant. Among the 14 variables analyzed, only some of them showed significant correlation relationship with phytoplankton.

For the initial wastewater treatment plant, Bacillariophyceae showed a strong negative correlation to conductivity ($r = -0.5276$), TSS ($r = -0.6815$), TDS ($r = -0.537$), silicates ($r = -0.507$) and SRP ($r = -0.6399$). Chlorophyceae showed a strong negative correlation to temperature ($r = -0.5514$), TP ($r = -0.5138$) and very strong negative correlation to chlorophyll a ($r = -0.7087$). For Cyanophyceae, they showed a very strong positive correlation to ammonium-nitrogen ($r = 0.7222$); strong positive correlation to temperature (r = 0.6056), TN (r = 0.6642) and chlorophyll-a (r = 0.5093); and strong negative correlation to nitrate-nitrogen (r = -0.8293). Dinophyceae had a strong positive correlation to silicate (r = 0.8081); strong positive correlation to TSS (r = 0.5302); very strong negative correlation to pH (r = -0.8475); strong negative correlation to DO (r = -0.6790), nitrite-nitrogen (r = -0.5115) and TN (r = -0.5145). Euglenaphyceae showed strong negative correlation to DO (r = -0.6212); strong positive correlation to conductivity (r = 0.6986) and SRP (r = 0.6822) while Zygnematophyceae had a strong negative correlation to TSS (r = -0.6221) (Table 14).

Table 14: Pearson Correlation Coefficient (r) matrix for abundance of phytoplankton taxa with water quality parameters in the initial Kisii Town WWTP at 95 % confidence interval

	PH	Temp (°C)	DO (mgL^{-1})	Conductivity (µscm^{-1})	TSS (mgL^{-1})	TDS (mgL^{-1})	SiO2 (mgL^{-1})	SRP (µgL^{-1})	NH4-N (µgL^{-1})	NO2-N (µgL^{-1})	NO3-N (µgL^{-1})	TN (µgL^{-1})	TP (µgL^{-1})	Chlo-a (mgM^{-1})
Bacillariophyceae	0.1876	0.1391	0.2675	**-0.5276**	**-0.6815**	**-0.537**	**-0.507**	**-0.6399**	-0.0177	-0.1189	-0.0312	-0.2097	-0.4331	0.3687
Chlorophyceae	0.4754	**-0.5514**	0.1974	-0.3374	0.1598	0.2605	-0.1066	-0.1413	-0.1315	0.0207	0.3725	-0.2146	**-0.5138**	**-0.7087**
Cyanophyceae	0.1888	**0.6056**	0.4102	-0.1389	0.1946	-0.3130	-0.1680	0.1280	**0.7222**	-0.4104	**-0.8293**	**0.6642**	0.4141	**0.5093**
Dinophyceae	**-0.8475**	-0.0621	**-0.6790**	0.4358	**0.5302**	0.3015	**0.8081**	**0.5036**	-0.1272	**-0.5115**	0.0069	**-0.5145**	0.2720	0.4447
Euglenaphyceae	-0.3565	0.0857	**-0.6212**	**0.6986**	0.1599	0.4075	0.4829	**0.6822**	0.0609	0.0855	0.0258	0.1396	0.4728	-0.3010
Zygnematophyceae	-0.3240	0.2576	-0.2659	-0.0357	**-0.6221**	-0.4545	-0.0425	-0.3105	-0.1078	-0.0925	0.0293	-0.3019	-0.1148	0.4688

4.2.7 Zooplankton

A total of fifteen zooplankton species belonging to three broad taxonomic groups were identified in the initial Kisii town wastewater treatment plant. Rotifera had the highest number of species represented by 8 species followed by Cladocera, which was represented by 4 species. The Copepoda, species identification was done but for cyclopoida species, they were identified further as immature or mature stages (Table 15).

Table 15: A list of zooplankton species in water samples from the initial Kisii Town WWTP

Cladocera	**Rotifera**
Ceriodaphnia cornuta	*Asplanchna* sp
Daphnia lumholtzi	*Brachionus angularis*
Diaphanosoma excisum	*Brachionus calyciflorus*
Moina micrura	*Brachionus quadridentatus*
	Filinia sp
Copepoda	*Hexarthra* sp
Nauplii	*Polyarthra* sp
Cyclopoida	*Trichocerca* sp

4.2.7.1 Zooplankton Diversity

Zooplankton diversity indices recorded during the study period for the initial wastewater treatment plant are summarized in Table 16 The total number of zooplankton species recorded ranged between 2 and 9 at different sampling stations of which the highest total number was recorded in the tertiary pond with 9 species while the upstream sampling point recorded the least number (2 species). Shannon-Wiener (H), Species evenness (E), and Margalef's diversity (d) indices were determined. The Shannon-Wiener (H') diversity index ranged from 0.3669 at the upstream to 1.648 at the tertiary sampling station. The dominant index (D) had a maximum value above 0.788 at the upstream and the influent with the least value of 0.2302. In terms of species richness (d), the downstream station was richer (with a value of 1.537) while the upstream had the least value (0.3107).

Table 16: Zooplankton diversity indices of water samples from the initial Kisii Town WWTP

	Influent	Anaerobic pond	Facultative pond	Tertiary pond	Effluent	Upstream	Downstream
Taxa (s)	5	5	8	9	7	2	9
Shannon-Weiner (*H'*)	1.523	1.353	1.044	1.648	1.083	0.3669	1.415
Dominance (D)	0.2302	0.321	0.4126	0.2364	0.4314	0.788	0.3305
Evenness e^H/S	0.9169	0.7741	0.4056	0.6496	0.422	0.7216	0.4574
Margalef	1.077	1.116	0.7038	1.309	1.104	0.3107	1.537

4.2.7.2 Spatial variations

The spatial variations of total zooplankton abundance across the stations are summarized in Table 17. The facultative pond recorded the highest total zooplankton abundance followed by the effluent station while the least total abundance was recorded in the upstream sampling station. The highest total abundance of Cladocera species was recorded in the facultative pond while none in the anaerobic pond. *Moina micrura* was the most dominant in and peaked in the facultative pond station (2872 IndL^{-1}) followed by *Ceriodaphnia cornuta* with an abundance of 1133 IndL^{-1}.

Copepoda highest abundance was recorded in the tertiary pond and the least abundance being recorded at the effluent sampling station. On the other hand, mature stages of Cyclopoida were recorded in all sampling stations except the upstream one. Nauplii were only observed at the tertiary pond, effluent and upstream sampling stations. Rotifera highest total species abundance was recorded at the effluent closely followed by the facultative pond while none was recorded in the upstream sampling station. *Asplanchna* sp. abundance ranged between 3 – 5 IndL^{-1}. *Brachionus angularis* was only recorded in the facultative pond with abundance of 17 IndL^{-1}. *Trichocerca* sp. abundance was recorded in three sampling stations and ranged between 5 – 28 IndL^{-1}. The highest total abundance was recorded in the facultative sampling point.

Table 17: Spatial distribution of zooplankton taxonomic groups in water samples from different sampling sites in initial Kisii Town WWTP

	Abundance (IndL^{-1})						
Taxa	**Influent**	**Anaerobic pond**	**Facultative pond**	**Tertiary pond**	**Effluent**	**Upstream**	**Downstream**
Cladocera							
Ceriodaphnia cornuta			1133		1		84
Daphnia lumholtzi				3			
Diaphanosoma excisum	10		970	55	26	22	6
Moina micrura			2872	75	137		60
Total	**10**		**4974**	**133**	**164**	**22**	**150**
Copepoda							
Nauplii				22	2	3	
Cyclopoida	11	18	13	33	1		13
Total	**11**	**18**	**13**	**55**	**3**	**3**	**13**
Rotifera							
Asphlanchna sp		3		5			5
Brachionus angularis			17				
Brachionus calyciflorus			5				3
Brachionus quadridentatus							4
Fillinia sp				12	56		
Hexarthra sp					6		6
Polyarthra sp							1
Trichocerca sp	11	5	28				
Total	**11**	**8**	**50**	**17**	**62**		**18**
Total zooplankton abundance	**32**	**25**	**5038**	**205**	**228**	**25**	**181**

4.2.7.3 Monthly variations

In the initial wastewater treatment plant, as shown in Table 18, there was variation in total zooplankton abundance during the study period with the month of September and December recording the highest total zooplankton abundance.

Table 18: Monthly variation of zooplankton abundance in water samples from the initial Kisii Town WWTP

Month	No. of species	Abundance (IndL^{-1})	Percentage (%)
August	7	131	2.3
September	7	3111	54.1
November	11	190	3.3
December	7	2314	40.3

Figure 34 shows monthly distribution of zooplankton total abundance for each taxonomic group during the sampling period for the initial wastewater treatment plant.

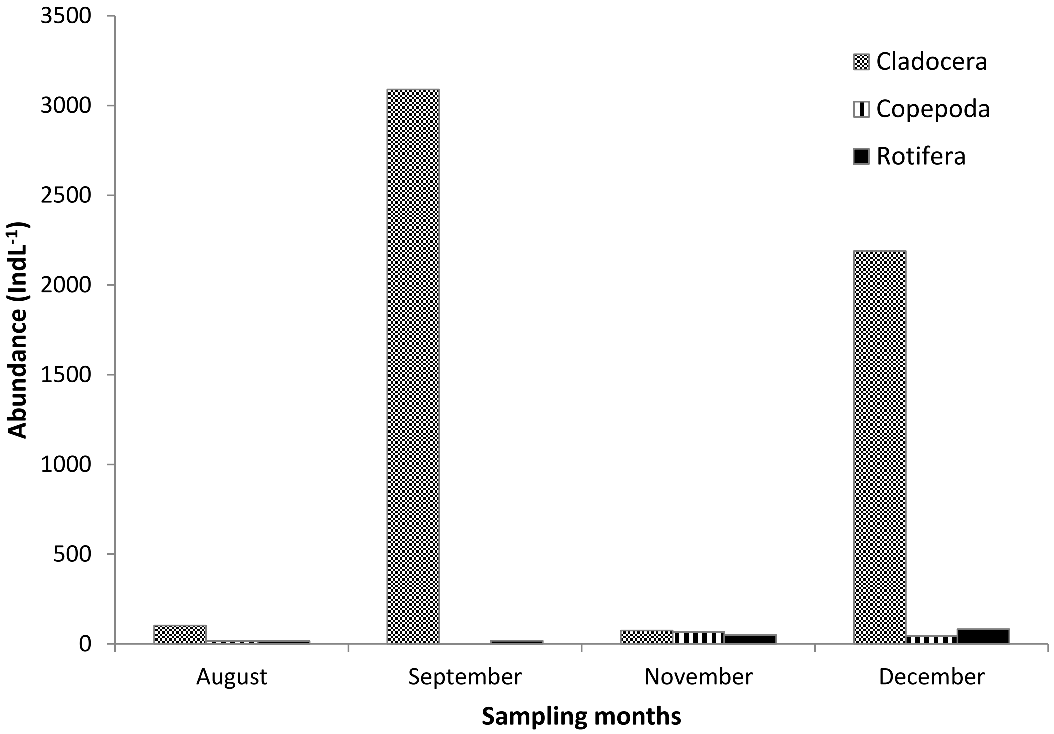

Figure 34: Monthly distribution of zooplankton taxa in water samples from the initial Kisii Town WWTP

The family Cladocera dominated the months of September and December. *Moina micrura* species abundance was dominant in September and December while *Ceriodaphnia cornuta* and *Diaphanosoma excisum* species were dominant in September. For Copepoda, the highest total abundance was recorded in the month of November with the least abundance being recorded in the month of September with the mature stages that's cyclopoida dominating throughout the study period. For Rotifera, the highest total abundance was recorded during the month of December with *Trichocerca* sp. dominating.

4.2.7.4 Correlation between physico-chemical parameters and zooplankton abundance and distribution in the initial Kisii Town Wastewater Treatment Plant

By carrying out correlation analysis the relationship between the physico-chemical parameters and the zooplankton abundance were shown. Table 19 shows the obtained correlation matrices at 5% level of significance and only those variables with Pearson coefficients equal or higher than 0.50 (r = 0.50) were significant. Among the 14 variables analyzed, only some of them showed significant correlation relationship with zooplankton abundance. Cladocera had a strong positive correlation with temperature (r = 0.5396), ammonium-nitrogen (r = 0.6564), TN (r = 0.5503) and TP (r = 0.5989) but with a very strong negative correlation to nitrate-nitrogen (r = -0.7684). For Rotifera, there was a strong positive correlation to TN (r = 0.6455) and TP (r = 0.5564); with a very strong positive correlation with temperature (r = 0.7230) and very strong negative correlation to nitrate-nitrogen (r = -0.7129).

Table 19: Pearson Correlation Coefficient (r) matrix of zooplankton abundance and physico-chemical parameters for the initial Kisii Town WWTP at 95 % confidence interval

	PH	Temp (°C)	DO (mgL^{-1})	Conductivity (µScm-1)	TSS (mgL^{-1})	TDS (mgL^{-1})	SiO$_2$ (mgL^{-1})	SRP (µgL^{-1})	NH$_4$-N (µgL^{-1})	NO$_2$-N (µgL^{-1})	NO$_3$-N (µgL^{-1})	TN (µgL^{-1})	TP (µgL^{-1})
Cladocera	-0.1408	**0.5396**	0.1024	0.1510	**0.5399**	-0.1328	0.2714	0.4161	**0.6564**	-0.4883	**-0.7684**	**0.5503**	**0.5989**
Copepoda	-0.1051	0.3933	-0.3973	0.3625	-0.2790	-0.1366	0.1844	0.3063	0.3420	-0.0528	-0.2062	0.2974	0.3085
Rotifera	-0.0068	**0.7230**	0.3261	0.0715	-0.2704	-0.2715	-0.4486	0.0611	0.4166	0.0067	-**0.7129**	**0.6455**	**0.5564**

4.2.8 Total and Fecal coliforms

The total and fecal coliforms (TC and FC) counts of wastewater samples obtained from Kisii Town WWTP initial design are presented in Table 20. From the results, TC and FC were present in all wastewater samples collected from the WWTP pond series including the three sampling stations along Riana river. The mean for TC recorded was 76.3 ± 10.98 counts/100ml with minimum and maximum values of 12 and 250 counts/100ml. The influent station had the highest mean of 145.25 ± 48.64 counts/100ml compared with the effluent with 44.5 ± 16.61 counts/100ml. The upstream sampling station had lower mean for TC counts compared with the downstream station. In terms of trend, there was a decline in total coliform counts between the influent and effluent sampling stations, indication that there numbers were being reduced as the wastewater underwent polishing. One-way ANOVA showed that TC counts were not significantly different among the sampling stations ($F_{(6, 21)} = 2.026$; $p = 0.107$).

The mean for fecal coliforms recorded was 55.66 ± 9.89 counts/100ml with minimum and maximum values of 1 and 250 counts/100ml. The influent station had the highest mean of 119.63 ± 49.68 counts/100ml compared with the effluent (45.25 ± 14.73 counts/100ml). The upstream sampling station had a lower FC mean (30.5 ± 12.98 counts/100ml) compared with the downstream station (39.88 ± 14.52 counts/100ml). In terms of trend, there was a decline in fecal coliform counts between the influent and effluent sampling stations, indication that there numbers were being reduced as the wastewater underwent polishing in the WWTP system. One-way ANOVA showed that TC counts were not significantly different among the sampled stations ($F_{(6, 21)} = 1.59$; $p = 0.2$) (Table 20).

The performance of the WWTP initial design in total and fecal coliform removal efficiency was assessed in terms of their percentage reduction. The TC removal efficiency was 69.4 % while for FC was 62.2 % between the influent and the effluent sampling stations, indication that there numbers were being reduced as the wastewater underwent polishing as it passed through the WWTP pond series. However, in terms of effluent discharge TC and FC compliance to national and international standards, they were not within the allowable limits by NEMA standards as shown in Table 20.

Table 20: Spatial variations of Total and Fecal coliforms counts in water samples from the initial Kisii Town WWTP

	TC (counts/100ml)	FC (counts/100ml)
Influent	145.25 ± 48.64	119.63 ± 49.683
Anaerobic pond	109.5 ± 38.115	71.63 ± 25.89
Facultative pond	69.75 ± 12.466	44.88 ± 17.543
Tertiary pond	62.5 ± 19.453	37.88 ± 13.785
Effluent	44.5 ± 16.61	45.25 ± 14.733
Upstream	49.75 ± 7.983	30.5 ± 12.978
Downstream	52.88 ± 10.94	39.88 ± 14.524
% Increase/ Reduction	69.4	62.2
NEMA	≤30	Nil

In terms of monthly variations, the total and fecal coliform counts results are presented in Table 21. The mean of TC recorded was 76.3 ± 10.98 counts/100ml with minimum and maximum values of 12 and 250 counts/100ml. The highest TC mean was recorded in the month of December with 110.1 ± 15.65 counts/100ml followed by the month of August with 101.7 ± 28.65 counts/100ml. The month of November had the least mean value of 25.4 ± 6.6 counts/100ml. One-way ANOVA showed that mean TC counts were significantly different among the sampling months ($F_{(3,\ 24)} = 4.15$; $p = 0.017$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TC counts for the month of November (25.4 ± 6.6 Counts/100ml) were significantly lower and differed significantly with those of the other months.

The mean for FC count recorded was 55.66 ± 9.89 counts/100ml with minimum and maximum values of 1 and 250 counts/100ml. The month of August had the highest count with 102.86 ± 25.56 counts/100ml while November with the least (5.14 ± 1.34 counts/100ml). One-way ANOVA showed that FC counts were significantly different among the sampling months ($F_{(3,\ 24)} = 6.74$; $p = 0.02$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean FC count for November (5.14 ± 1.34 Counts/100ml) was significantly lower compared with the other months (Table 21).

Table 21: Monthly variations of total and fecal coliform counts/100ml in water samples from the initial Kisii Town WWTP

Months	**TC (Counts/100ml)**	**FC (Counts/100ml)**
August	101.7 ± 28.65^{a}	102.86 ± 25.56^{a}
September	$67.9 \pm 17.88^{a,b}$	$52.93 \pm 11.79^{a,b}$
November	25.4 ± 6.6^{b}	5.14 ± 1.34^{b}
December	110.1 ± 15.65^{a}	$61.71 \pm 12.68^{a,b}$

Where: Means with different letters (a and b) in the same column they are significantly different

4.3 Current Kisii Town Wastewater Treatment Plant

4.3.1 Spatial and monthly variations of physico-chemical parameters

4.3.1.1 pH

The mean pH values recorded ranged from weakly acidic to alkaline levels that is from 6.58 to 8.40. The influent sampling station had a neutral mean PH of 7.33 ± 0.08 which was lower compared with the effluent station (7.77 ± 0.06), indicating an improvement in wastewater polishing. Among the wastewater stabilizing ponds, the facultative pond had the highest mean pH of 7.77 ± 0.13 also indicating of a neutral environment. Along river Riana sampling stations, the confluent had the highest mean pH of 7.64 ± 0.07 similarly indicating a neutral environment. There was a general increase in the mean pH as the wastewater underwent polishing between the influent and effluent a further indication an improvement in wastewater quality (Figure 35).

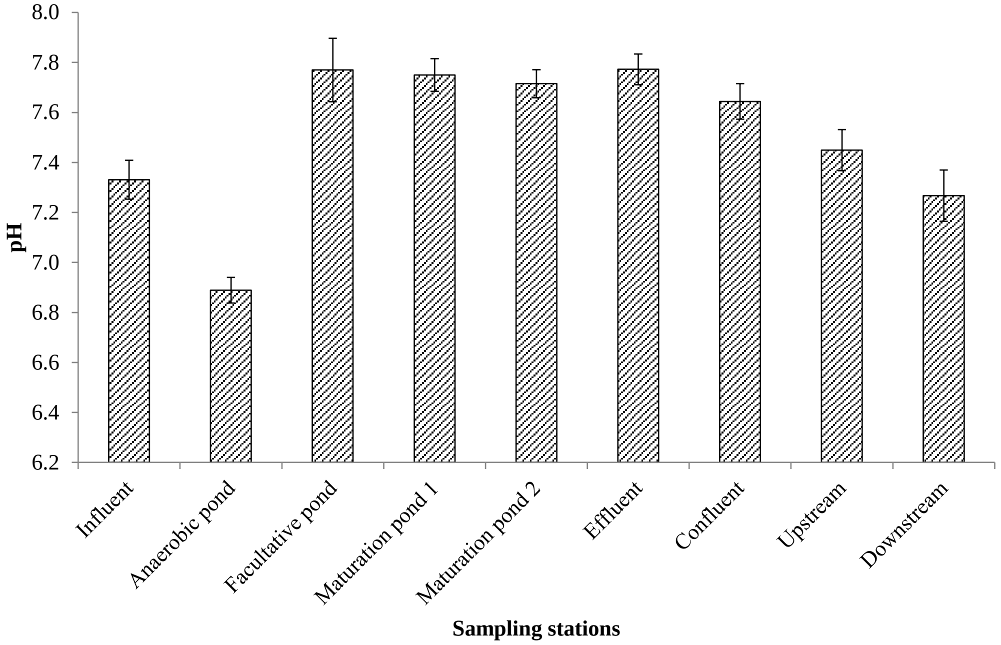

Figure 35: Spatial variations of pH for the current Kisii Town WWTP.

Monthly, the month of June had the highest mean pH of 7.67 ± 0.07 followed by August with 7.6 ± 0.07 while May had the lowest mean of 7.19 ± 0.07. The results depicted that there was an increase in the mean pH values from May towards the month of August (Figure 36).

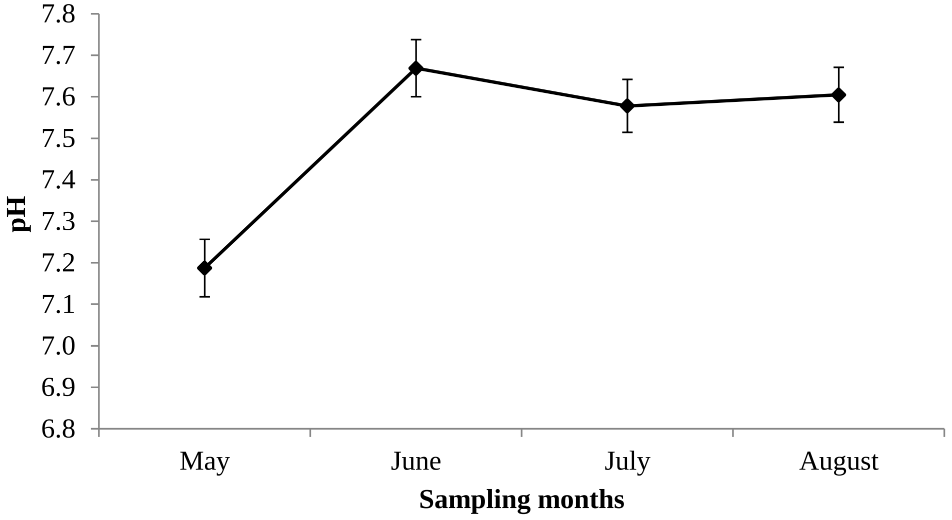

Figure 36: Monthly variations of pH for the current Kisii Town WWTP.

4.3.1.2 Conductivity

The mean conductivity of the current WWTP recorded was 568. 24 ± 34.97 μScm^{-1} and ranged from 99.0 μScm^{-1} to 2134.0 μScm^{-1}. The influent sampling station had the highest mean of 1097.75 ± 128.92 μScm^{-1} while the upstream sampling station along river Riana just before the WWTP discharge point had the lowest mean conductivity of 115.75 ± 2.27 μScm^{-1}. These results indicate a considerable declining trend in the mean conductivity from the influent to effluent as the wastewater underwent polishing (Figure 37). Two factor ANOVA showed that differences of the mean conductivity at different sampling stations were statistically significant ($F_{(8,\ 108)} = 210.15$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the conductivity mean for the influent (1097.75 ± 128.92 μScm^{-1}) station was significantly higher than that of anaerobic station (752.75 ± 83.95 μScm^{-1}).

However, anaerobic pond sampling station mean conductivity was not significantly different from that of facultative (704.92 ± 48.92 µScm^{-1}), maturation pond 1 (676.83 ± 46.79 µScm^{-1}), maturation pond 2 (658.25 ± 46.92 µScm^{-1}), and effluent (665.58 ± 41.17 µScm^{-1}) stations (Figure 37).

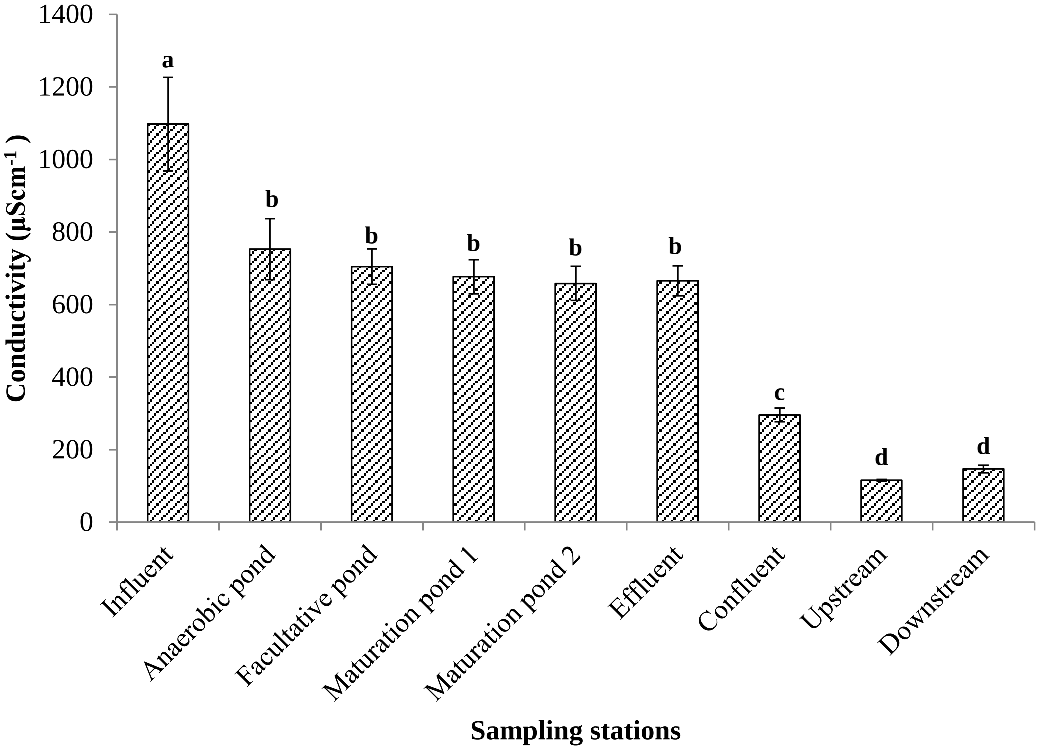

Figure 37: Spatial variations of conductivity for the current Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the mean conductivity of the WWTP ranged from 335.11 ± 31.30 µScm^{-1} to 666.44 ± 90.91 µScm^{-1}. The month of June had the highest mean conductivity value of 666.44 ± 90.91 µScm^{-1} while May had the least mean conductivity of 335.11 ± 31.30 µScm^{-1}. There was a sharp increase in mean conductivity between May and June then fluctuated towards the month of August (Figure 38). Two factor ANOVA showed that the mean conductivity levels were statistically significant between the sampling months ($F_{(3,\ 108)} = 114.29$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean conductivity for the month of May (335.11 ± 31.3) was the lowest and differed significantly with those of the other months (Figure 38).

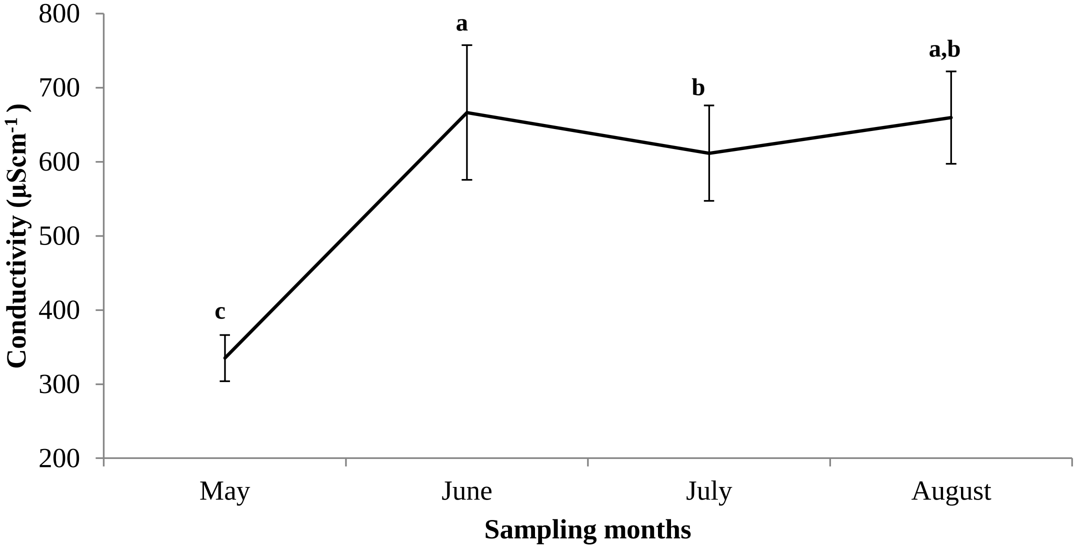

Figure 38: Monthly variations of conductivity for the current Kisii Town WWTP. Different letters (a, b, c) signifies that the means are significantly different ($p < 0.05$).

4.3.1.3 Temperature

For the current wastewater treatment plant, the mean spatial temperature of the WWTP was 24.36 ± 0.21°C with minimum and maximum temperature of 20.0°C and 28.5°C respectively. The maturation pond 2 had the highest mean temperature of 27.36 ± 0.3°C closely followed by maturation pond 1 with 26.1 ± 0.21°C then by effluent sampling station with 26.09 ± 0.16°C. Like pH, there was an increase in the mean temperature from the influent to the effluent as wastewater underwent polishing through the WWTP (Figure 39).

Two factor ANOVA showed that the mean temperature among the different sampling stations were significantly different ($F_{(8, 108)} = 73.21$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean temperature of the maturation pond 2 (27.4 ± 0.3°C) was significantly higher compared with those of the other sampling stations. The influent station mean temperature did not differ significantly with that of the confluent, upstream and downstream sampling stations. Similarly, the anaerobic station mean temperature did not differ significantly with those of the facultative, maturation pond 1, and effluent sampling stations (Figure 39).

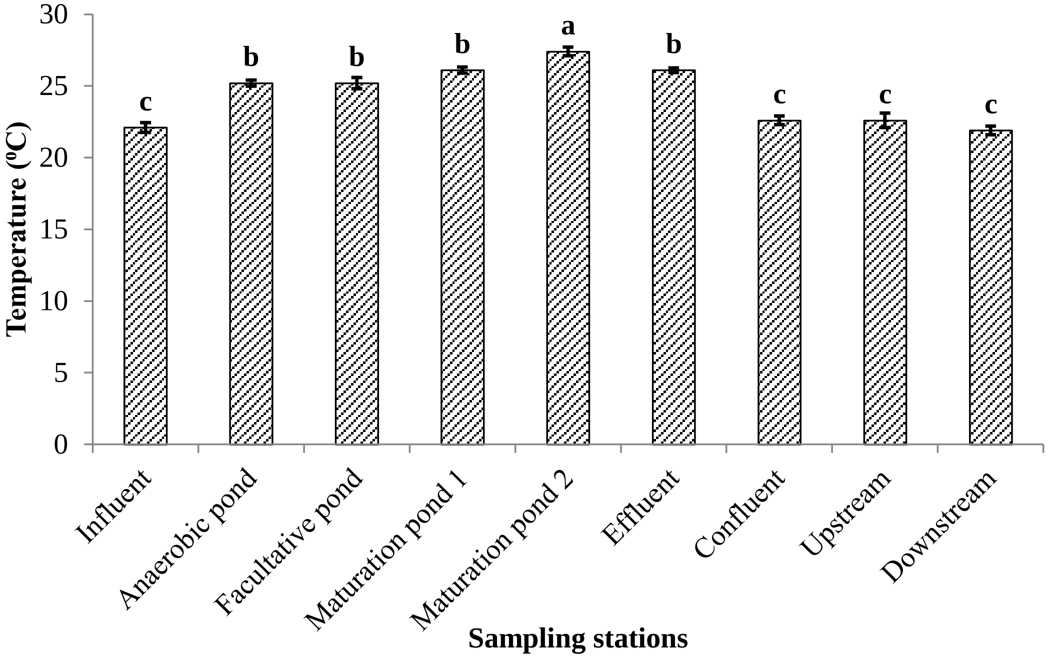

Figure 39: Spatial variations of temperature (^{0}C) for the current Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

Monthly, the mean (± SE) temperature values ranged from 23.95 ± 0.49°C to 25.04 ± 0.35°C. The month of July had the lowest mean temperature of 23.95 ± 0.49°C while the month of May recorded the highest mean temperature of 25.04 ± 0.35°C. In terms of trend, the recorded results indicate that there was a general decline in temperature between May and July then slight increase towards the month of August (Figure 40).

Two factor ANOVA showed that mean temperature were significantly different between the sampling months ($F_{(3,\ 108)} = 8.71$, $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean temperature of May (25.04 ± 0.35°C) differed significantly with the mean temperature in June (24.21 ± 0.49°C), July (23.95 ± 0.49°C), and August (24.24 ± 0.36°C). However, the mean temperature for June, July, and August they did not differ significantly (Figure 40).

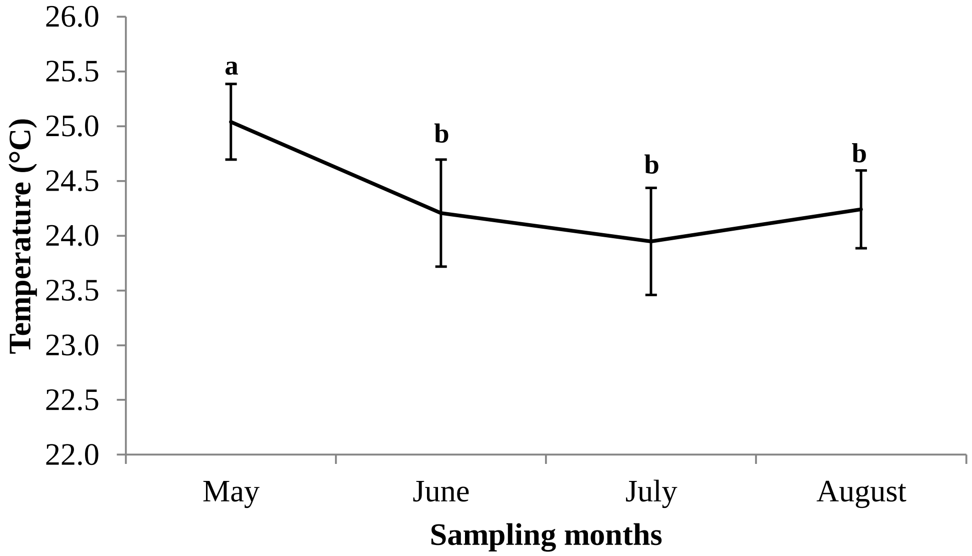

Figure 40: Monthly variations of temperature (°C) for the current Kisii Town WWTP. Different letters (a, b) signify that the means are significantly different ($p < 0.05$).

4.3.1.4 Dissolved Oxygen (DO)

The recorded mean dissolved oxygen concentration was 2.45 ± 0.24 mgL^{-1} with a minimum and maximum concentration of 0.1 mgL^{-1} and 10.0 mgL^{-1} respectively. The facultative pond had the highest mean DO concentration of 3.53 ± 3.5 mgL^{-1}. The effluent station mean dissolved oxygen concentration was 2.67 ± 2.7 mgL^{-1} higher than that of the influent sampling station (0.23 ± 0.2 mgL^{-1}). In terms of trend, in general there was an increase in the mean of dissolved oxygen concentration between the influent through the WWTP system to the effluent sampling station similar with the trends for pH, and temperature. Two way ANOVA indicated there were significant differences between the sampling stations in the mean dissolved oxygen concentrations ($F_{(8, 108)} = 227.8$; $p = 0.000$). *Post hoc*

Tukey Pairwise Comparisons revealed that the mean dissolved oxygen of the influent (0.23 ± 0.2 mgL^{-1}) was significantly lower compared with those of other sampling stations (Figure 41).

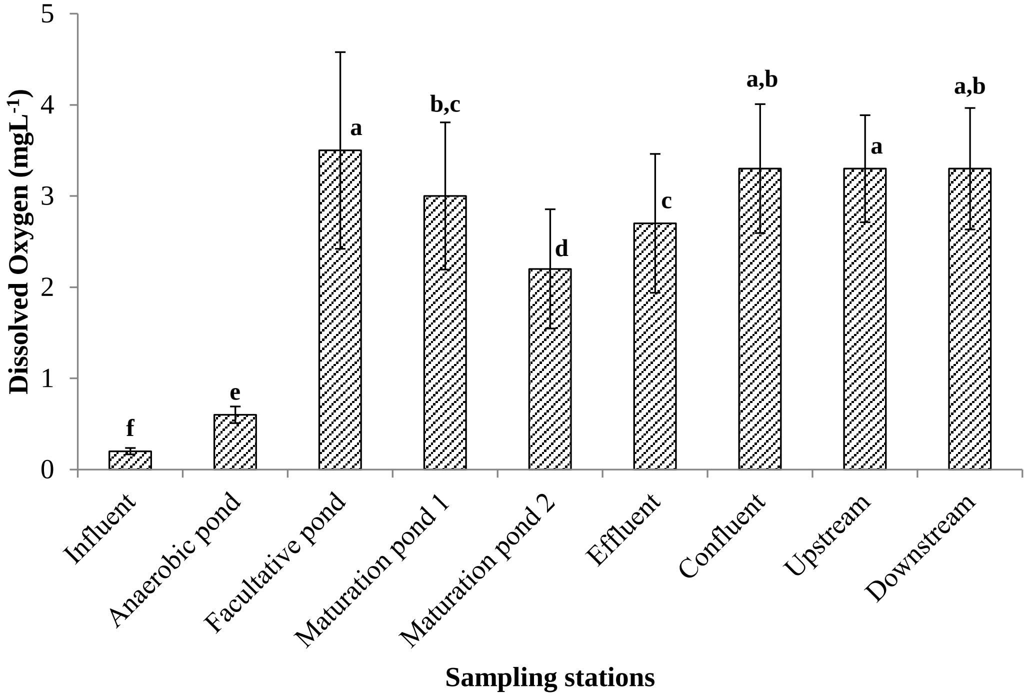

Figure 41: Spatial variations of dissolved oxygen (mgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d, e, f) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variation, the month of August had the highest mean (± SE) dissolved oxygen concentration of 5.67 ± 0.58 mgL^{-1} while the month of May had the least DO concentration of 0.62 ± 0.07 mgL^{-1}. The month of June and July each recorded a mean dissolved oxygen concentration of 1.76 ± 0.19 mgL^{-1}, and 1.74 ± 0.19 mgL^{-1}. In terms of trend, in general there was an increase in the mean dissolved oxygen concentration during the study period and it was significant and similar to the trend of pH. Two factor ANOVA revealed that the mean DO concentrations were statistically different between the sampling months ($F_{(3,\ 108)} = 16.89$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean dissolved oxygen concentration of May was significantly lower compared with that of August (Figure 42).

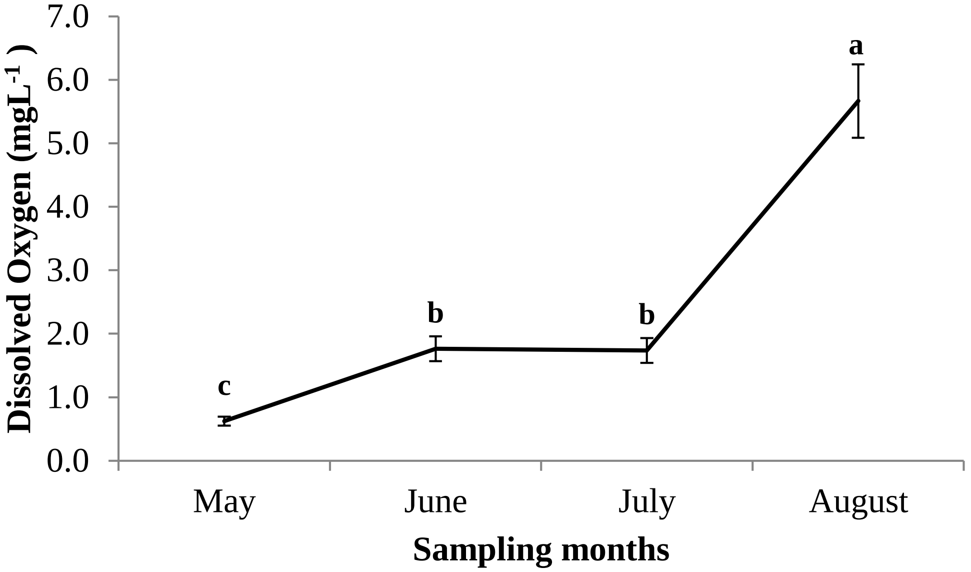

Figure 42: Monthly variations of dissolved oxygen (mgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c) signify that the means are significantly different (p < 0.05).

4.3.1.5 Total Suspended Solids (TSS)

The mean (± SE) TSS concentration recorded for the sampling stations was 61.45 ± 3.14 mgL^{-1} with a minimum and maximum values of 7.76 mgL^{-1} and 132.0 mgL^{-1} respectively. The highest mean of TSS was recorded in the downstream sampling station with 79.78 ± 13.2 mgL^{-1}. The confluent sampling station had the lowest mean of 35.22 ± 2.62 mgL^{-1}. In terms of trend, TSS mean concentrations fluctuated with no significant trend between the inlet and effluent. Two way ANOVA indicated that there were significant differences in the mean TSS values between the sampling stations ($F_{(8,\ 108)} = 551.5$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TSS of the influent station (65.34 ± 7.4 mgL^{-1}) was significantly lower from that of the effluent (77.16 ± 6.0 mgL^{-1}), but the latter mean TSS was not significantly different from that of the downstream sampling station (79.78 ± 13.2 mgL^{-1}) (Figure 43).

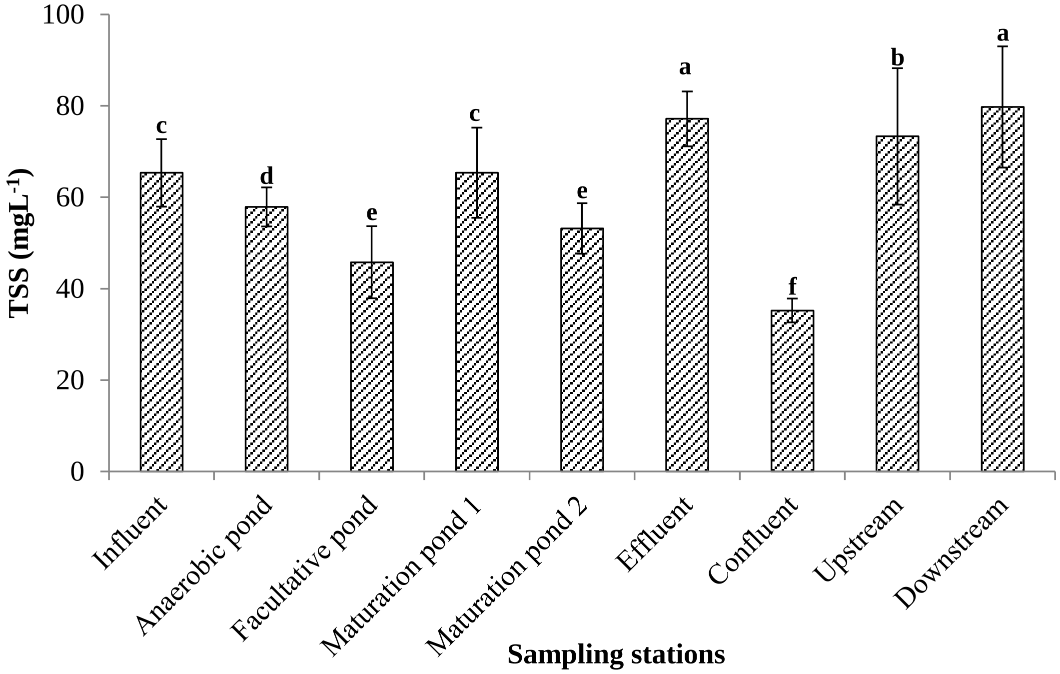

Figure 43: Spatial variations of TSS concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d, e, f) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variation, the highest mean concentration of TSS was recorded in the month of June (76.61 ± 6.06 mgL^{-1}) followed by that of July (74.74 ± 4.98 mgL^{-1}). The month of May had a mean TSS of 70.27 ± 4.91 mgL^{-1} while the lowest value was recorded in the month of August with 24.18 ± 2.28 mgL^{-1}. The mean TSS concentration fluctuated with a significant decreasing trend (Figure 44). Two way ANOVA indicated there were significant differences in mean TSS between the sampling months ($F_{(3,\ 108)} = 35.00$; $p = 0.000$). *Post hoc* Tukey Pairwise comparisons revealed that the mean TSS concentration for the month of May (70.27 ± 4.91 mgL^{-1}) was significantly different from those of June (76.61 ± 6.06 mgL^{-1}), July (74.74 ± 4.98 mgL^{-1}), and August (24.18 ± 2.28 mgL^{-1}) (Figure 44).

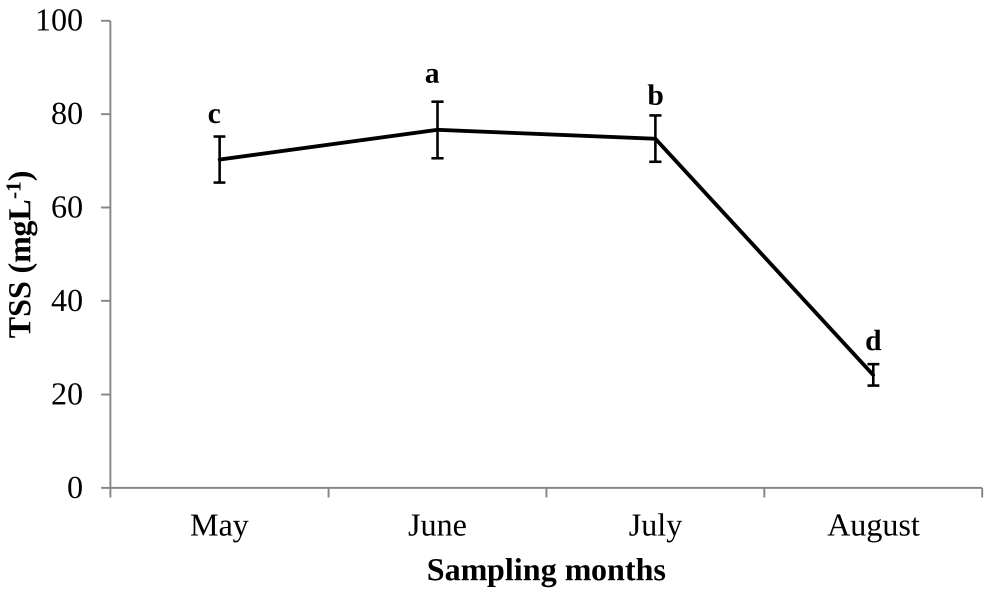

Figure 44: Monthly variations of TSS concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

4.3.1.6 Total Dissolved Solids (TDS)

The mean (± SE) TDS recorded was 230.3 ± 18.35 mgL^{-1} with minimum and maximum values of 18.9 mgL^{-1} and 10.68 mgL^{-1} respectively. The influent and anaerobic sampling stations had the highest mean values of 438.3 ± 79.5 mgL^{-1} and 400.3 ± 57.0 mgL^{-1} respectively. The downstream and upstream stations had the lowest mean values of 67.1 ± 6.7 mgL^{-1} and 59.9 ± 1.9 mgL^{-1} respectively. In terms of trend, there was a steady decline in mean TDS concentration between the influent and effluent sampling stations, an indication of wastewater polishing (Figure 45).

Two way ANOVA indicated significant differences between the sampling stations ($F_{(8, 108)} = 32.48$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean of the influent station (438.3 ± 79.5 mgL^{-1}) was higher and significantly different from that of the effluent (259.0 ± 42.5 mgL^{-1}). The latter had no significant difference with that of maturation pond 1 and 2 (Figure 45).

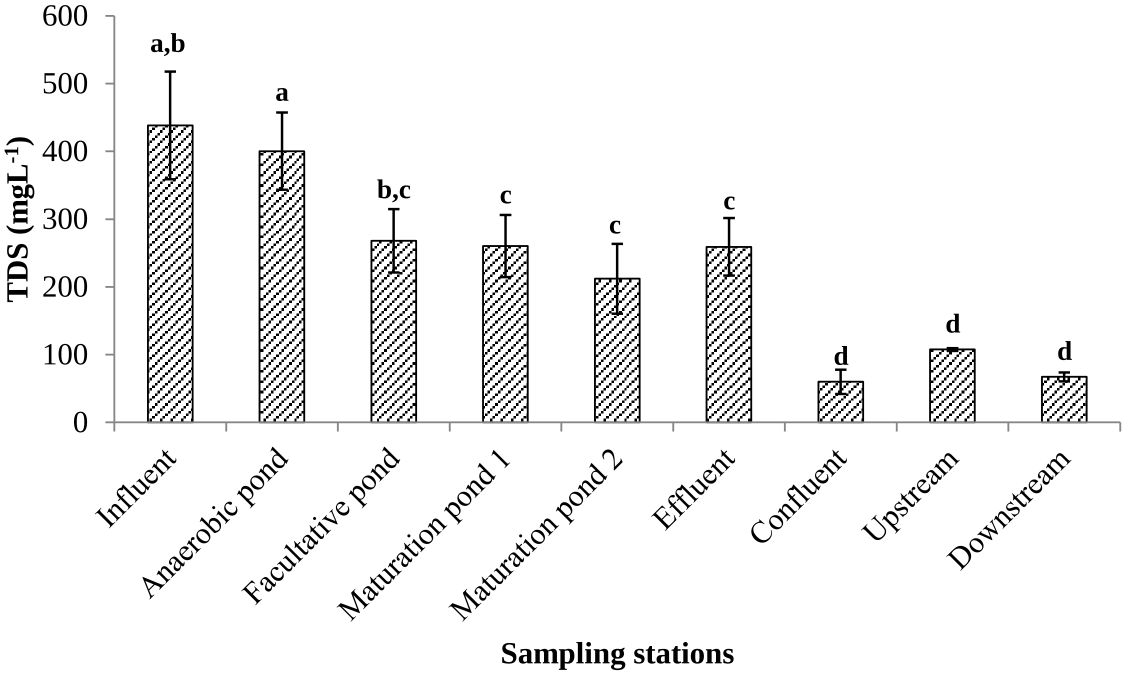

Figure 45: Spatial variations of TDS concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variation, the month of June had the highest mean TDS concentration of 343.5 ± 41.1 mgL^{-1} followed by the month of August with 330.0 ± 31.2 mgL^{-1}. The month of May had a mean TDS value of 198.4 ± 30.9 mgL^{-1} while July had the lowest mean of 49.2 ± 4.3 mgL^{-1}. In terms of trend, the mean TDS concentrations fluctuated with no significant trend (Figure 46).

Two factor ANOVA showed that the mean TDS levels were statistically significant between the sampling months ($F_{(3,\ 108)} = 81.12$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TDS for July (49.2 ± 4.3 mgL^{-1}) was significantly lower than those of other months (Figure 46).

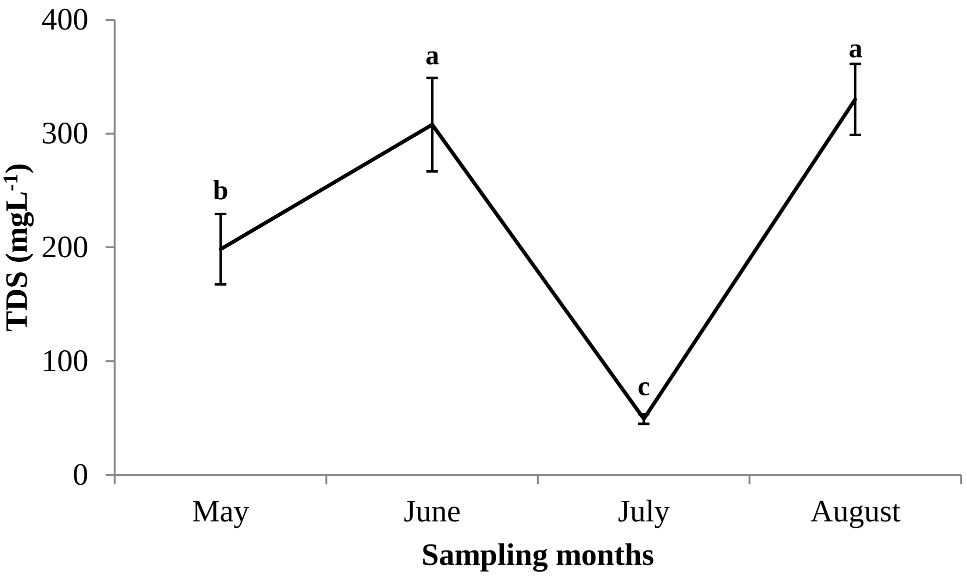

Figure 46: Monthly variations of TDS concentrations for the current Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

4.3.2 Nutrients

4.3.2.1 Silicates

The mean silicate concentration recorded was 21.57 ± 1.12 mgL^{-1}. The minimum value recorded was 0.5 mgL^{-1} and the maximum 44.62 mgL^{-1}. The facultative pond had the highest mean silicate concentration of 27.1 ± 2.93 mgL^{-1} while the upstream sampling station had the lowest mean value of 14.60 ± 4.21 mgL^{-1}. Similar to the TSS trend, the changes in mean silicates concentrations fluctuated with no significant trend. Two factor ANOVA showed that silicate concentrations were significantly different among the sampled stations ($F_{(8, 108)} = 437.58$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean silicate concentrations for the influent (20.6 ± 5.3 mgL^{-1}) and effluent (21.3 ± 2.1 mgL^{-1}) stations did not differ significantly while that of the upstream (14.60 ± 4.21 mgL^{-1}) station differed significantly with the mean silicates recorded in the downstream station (21.3 ± 3.3 mgL^{-1}) (Figure 47).

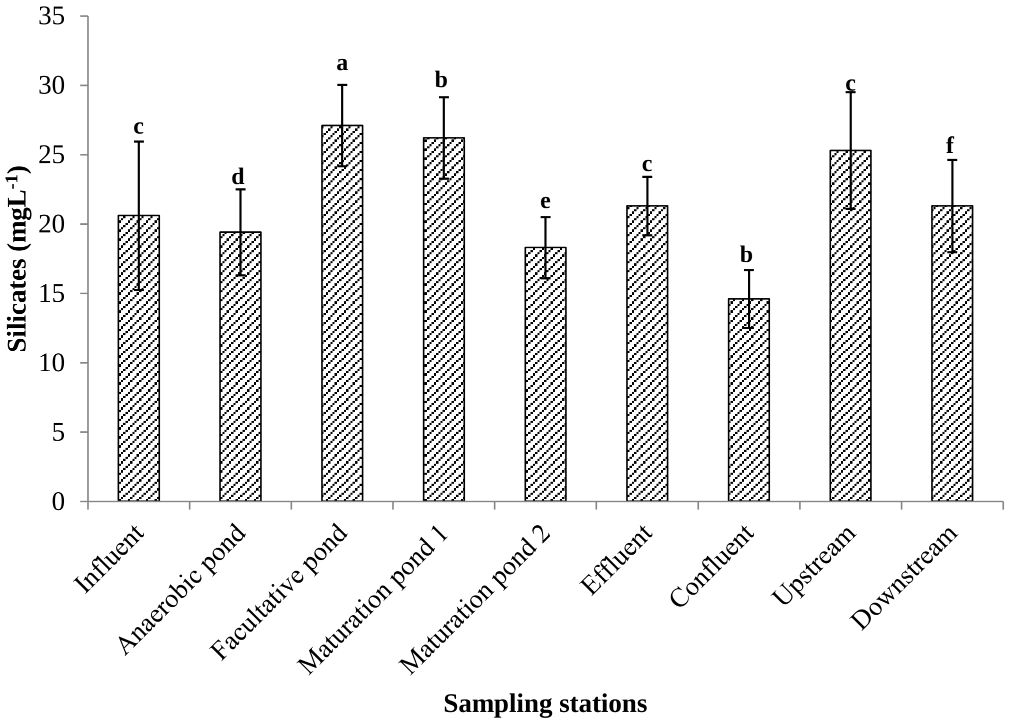

Figure 47: Spatial variations of silicates (mgL^{-1}) concentration for the current Kisii Town WWTP. Different letters (a, b, c, d, e, f) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variation, the month of August had the highest silicates mean concentration of 33.4 ± 0.7 mgL^{-1} followed by the month of May with 26.14 ± 2.29 mgL^{-1}. June had silicates mean concentration of 13.94 ± 1.26 mgL^{-1} while the month of July had the least mean of 12.78 ± 1.38 mgL^{-1}. In terms of trend, the mean silicate concentration declined between May and July but then increased towards the month of August similar to the mean temperature trend. Two factor ANOVA showed that silicate concentrations were significantly different among the sampling months ($F_{(3,\ 108)} = 592.12$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean silicate concentrations for the month of May (26.14 ± 2.29 mgL^{-1}) was significantly different from that of June (13.94 ± 1.26 mgL^{-1}), July (12.78 ± 1.38 mgL^{-1}), and August (33.4 ± 0.7 mgL^{-1}) (Figure 48).

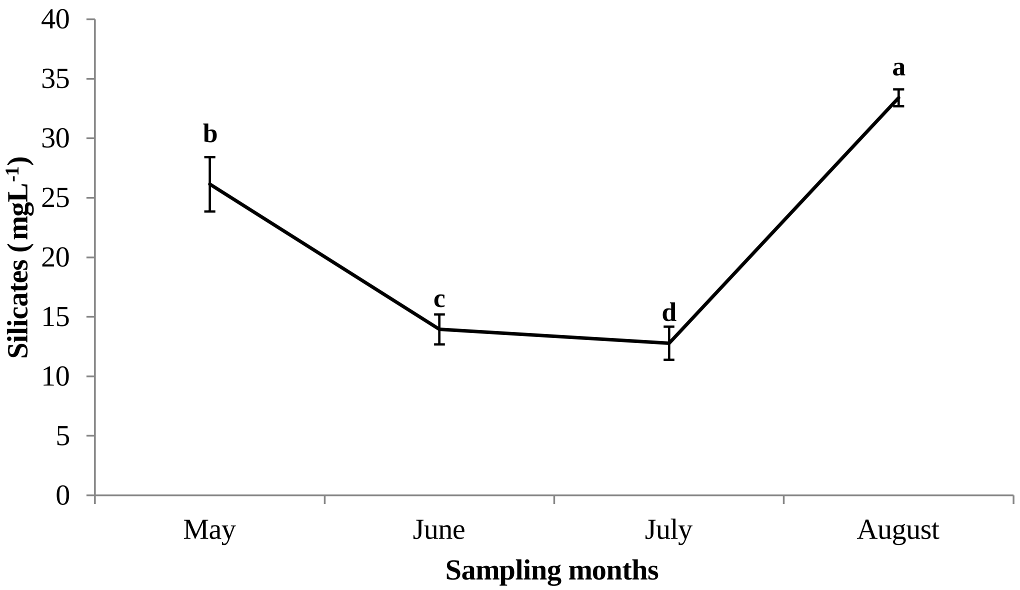

Figure 48: Monthly differences of silicate (mgL^{-1}) concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d) denotes that the means are significantly different ($p < 0.05$).

4.3.2.2 Soluble Reactive Phosphorous (SRP)

The mean concentration of soluble reactive phosphorous (SRP) recorded for the current wastewater treatment plant design during the sampling period was 491.3 ± 51.33 µgL^{-1} with a minimum value of 0.320 µgL^{-1} and a maximum of 1509.5 µgL^{-1}. The anaerobic sampling station had the highest mean SRP concentration of 777.3 ± 188.2 µgL^{-1} while the upstream station had the lowest mean SRP concentration of 61.9 ± 23.5 µgL^{-1}. Like the mean trends of electrical conductivity, and TDS, there was a decline in mean SRP concentrations as the wastewater passed through the stabilizing ponds during treatment, an indication that the WWTP is effective in wastewater polishing (Figure 49).

Two factor ANOVA showed that SRP concentrations were significantly different among the sampled stations ($F_{(8,\ 108)} = 2.17$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean SRP concentration recorded in the influent sampling station (664.8 ± 202.5 µgL^{-1}) did not differ significantly with that of facultative pond (654.9 ± 167.9 µgL^{-1}).

The latter differed significantly with the mean value of effluent (557.0 ± 137.9 µgL^{-1}) (Figure 49).

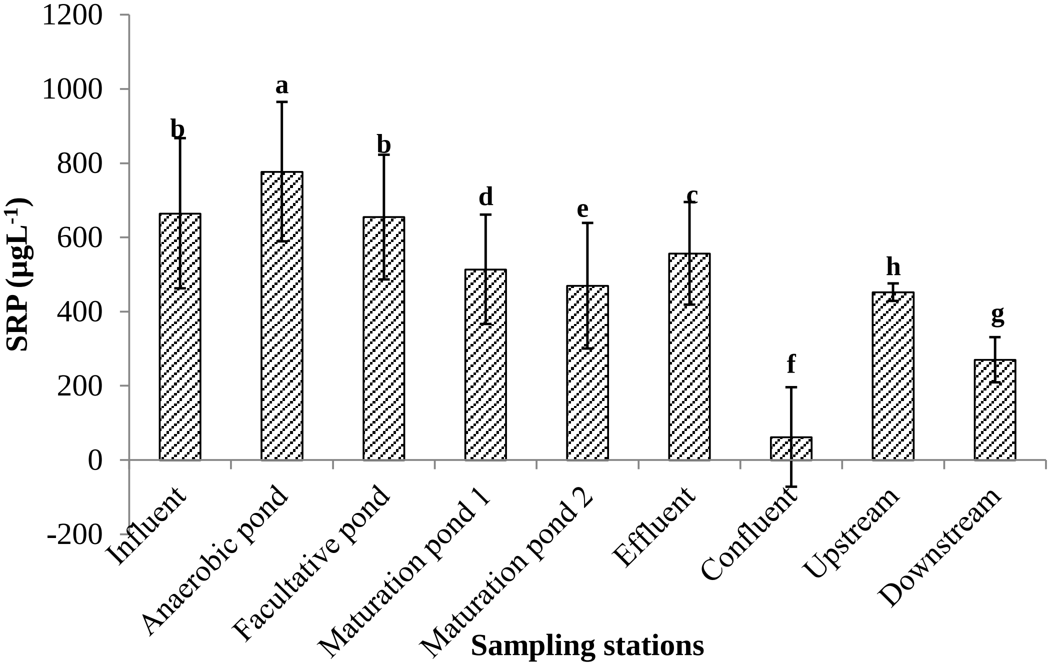

Figure 49: Spatial variations of SRP (µgL^{-1}) concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d, e, f, g, h) denotes that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the month of August had the highest mean SRP concentration of 1114.9 ± 87.9 µgL^{-1} followed by May with 653.5 ± 84.5 µgL^{-1}. The month of July had the least mean of 95.4 ± 12.6 µgL^{-1}. In terms of trend, the mean SRP concentration declined between May and July but then increased towards the month of August, this was similar to the trends of mean temperature, and silicates (Figure 50).

Two factor ANOVA showed that the mean SRP values were significantly different among the sampling months ($F_{(3, 108)} = 62.10$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean SRP concentrations that were recorded for the month of May (653.5 ± 84.5 µgL^{-1}) differed with those of June (101.60 ± 13.5 µgL^{-1}), July (95.4 ± 12.6 µgL^{-1}), and August (1114.9 ± 87.9 µgL^{-1}) (Figure 50).

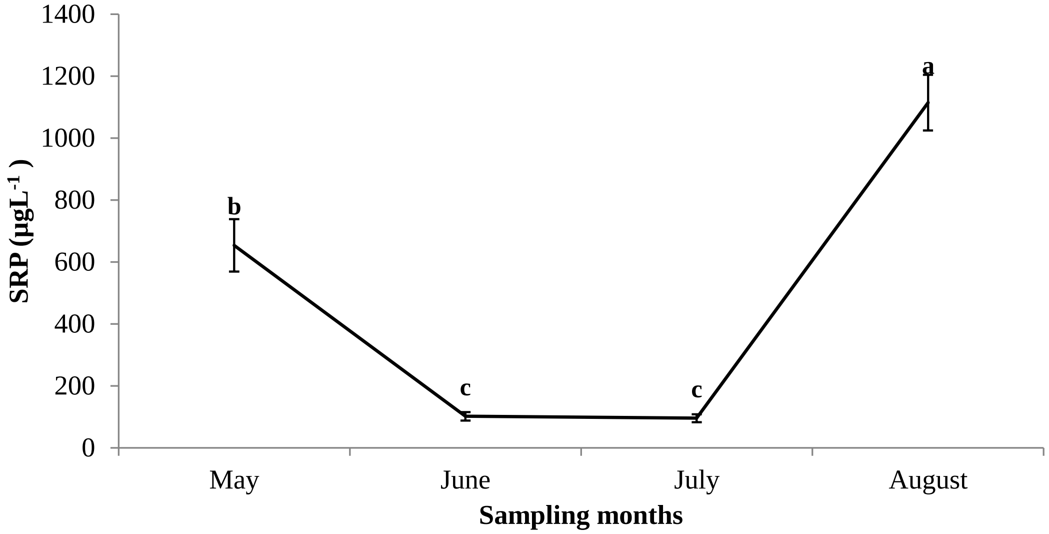

Figure 50: Monthly differences of SRP (µgL^{-1}) concentrations for the current Kisii Town WWTP. Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

4.3.2.3 Nitrite-Nitrogen (NO_2^--N)

The mean concentration of nitrite-nitrogen recorded among the sampling stations was 25.35 ± 2.41 µgL^{-1}. The minimum and maximum concentrations were 0.176 µgL^{-1} and 89.87 µgL^{-1} respectively. The effluent and maturation pond 2 stations had the lowest means of 8.42 ± 0.99 µgL^{-1} and 7.0 ± 1.38 µgL^{-1} respectively. In terms of trend, there was a decline in mean nitrite-nitrogen concentrations from the influent through the WWTP system to the effluent, indicating the parameter was being attenuated by the WWTP (Figure 51).

Two factor ANOVA showed that the mean nitrite-nitrogen values were significantly different among the sampled stations ($F_{(8, 108)} = 13.95$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean nitrite-nitrogen concentration for the influent (20.20 ± 1.44 µgL^{-1}) was significantly different from that of effluent station (8.42 ± 0.99 µgL^{-1}) but the latter did not differ significantly from that of maturation pond 2 (7.0 ± 1.38 µgL^{-1}) (Figure 51).

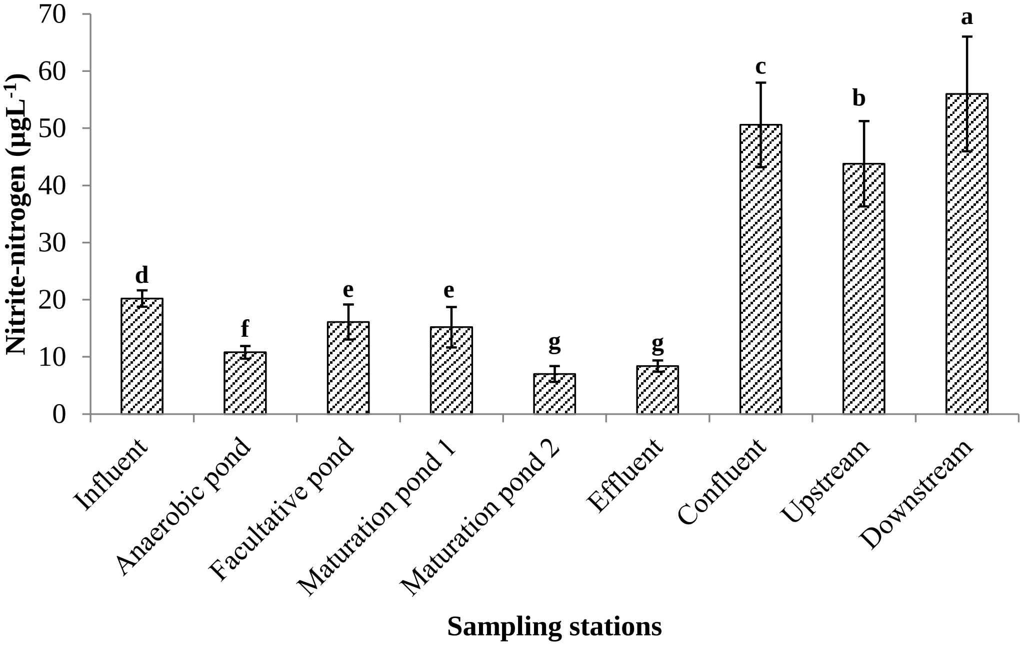

Figure 51: Spatial variations of nitrite-nitrogen (μgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d, e,f , g, h) signify that the means are significantly different ($p < 0.05$).

In terms of Monthly variations, the mean (± SE) nitrite-nitrogen concentration was higher in the month of June, followed by July and then May with means of 38.58 ± 5.59 μgL^{-1}, 32.84 ± 5.73 μgL^{-1} and 20.98 ± 3.17 μgL^{-1} respectively. The month of August had the lowest mean concentration of 8.99 ± 1.25 μgL^{-1}. In terms of trend, the nitrite-nitrogen concentrations increased between the month of May and June but then steadily declined towards August (Figure 52).

Two factor ANOVA showed that the mean nitrite-nitrogen values were significantly different among the sampling months ($F_{(3, 108)} = 1496$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean nitrite-nitrogen of May (20.98 ± 3.17 μgL^{-1}) differed significantly from those of June (38.58 ± 5.59 μgL^{-1}), July (32.84 ± 5.73 μgL^{-1}), and August (8.99 ± 1.25 μgL^{-1}) (Figure 52).

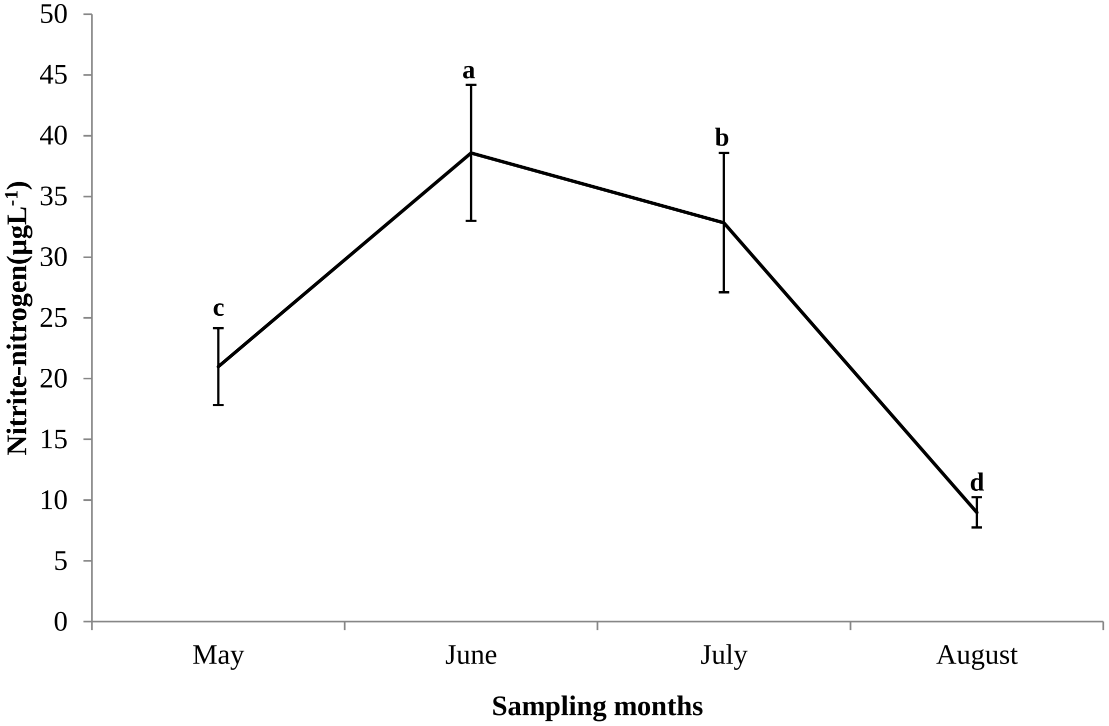

Figure 52: Monthly variations of nitrite-nitrogen (µgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

4.3.2.4 Nitrate-Nitrogen (NO_3^--N)

The mean (± SE) nitrate-nitrogen concentration recorded was 71.23 ± 6.50 µgL^{-1} with minimum values of 6.14 µgL^{-1} and maximum 218.56 µgL^{-1}. The Confluent sampling station had highest mean of 146.99 ± 18.53 µgL^{-1} while the effluent sampling station had the least value of 26.38 ± 4.77 µgL^{-1}. In terms of trend, the nitrate-nitrogen mean concentrations fluctuated from the influent to the effluent sampling station with no significant trend, similar to those of TSS, and silicates (Figure 53).

Two way ANOVA showed that nitrate-nitrogen concentration was significantly different among the sampled stations ($F_{(8,\ 108)} = 1085.46$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean nitrate-nitrogen value for the influent (62.9 ± 11.18

µgL^{-1}) sampling station differed significantly with the mean of the effluent (26.38 ± 4.77 µgL^{-1}) sampling station. Similarly, the upstream (147.0 ± 26.19 µgL^{-1}) mean nitrate-nitrogen value differed significantly with that of the downstream (104.5 ± 23.32 µgL^{-1}) sampling station (Figure 53).

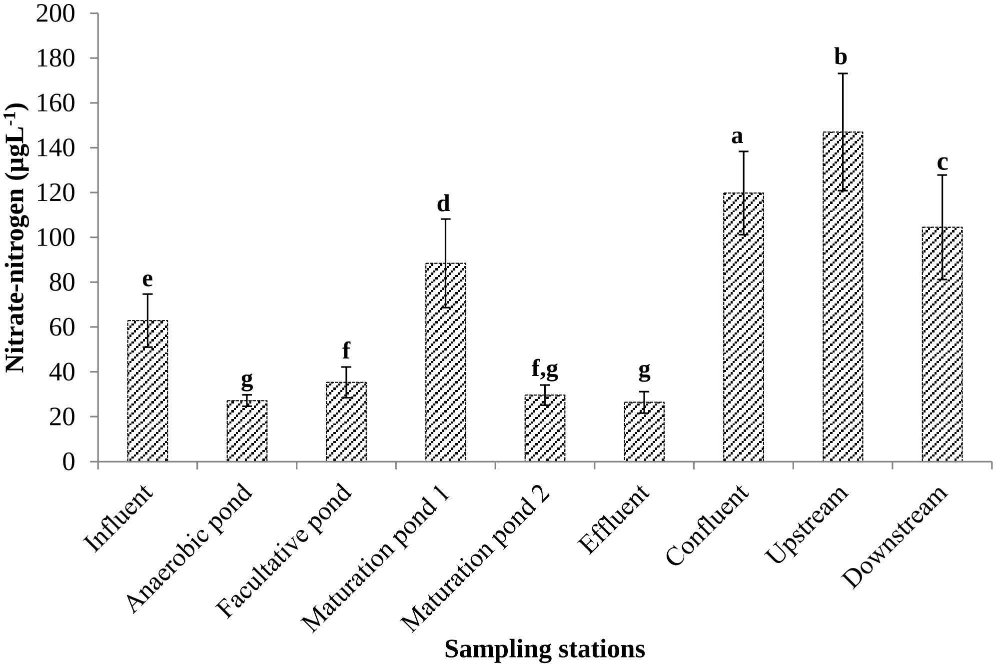

Figure 53: Spatial variations of nitrate-nitrogen (µgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d, e, f, g) denotes that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the highest mean nitrate-nitrogen concentration was recorded in the month of June with 116.74 ± 13.92 µgL^{-1} followed by the month of July with 96.12 ± 13.74 µgL^{-1}. The month of May had the lowest mean concentration of 31.53 ± 3.83 µgL^{-1}. In terms of trend, the mean nitrate-nitrogen concentration increased between the months of May to June then declined towards the month of August similar to the nitrite-nitrogen mean trend (Figure 54).

Two factor ANOVA showed that the mean nitrate-nitrogen values were significantly different among the sampling months (F $_{(3,\ 108)}$ = 2051.02; *p* = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean nitrate-nitrogen concentration of the month of May was significantly lower to that of June (116.74 ± 13.92 µgL^{-1}) (Figure 54).

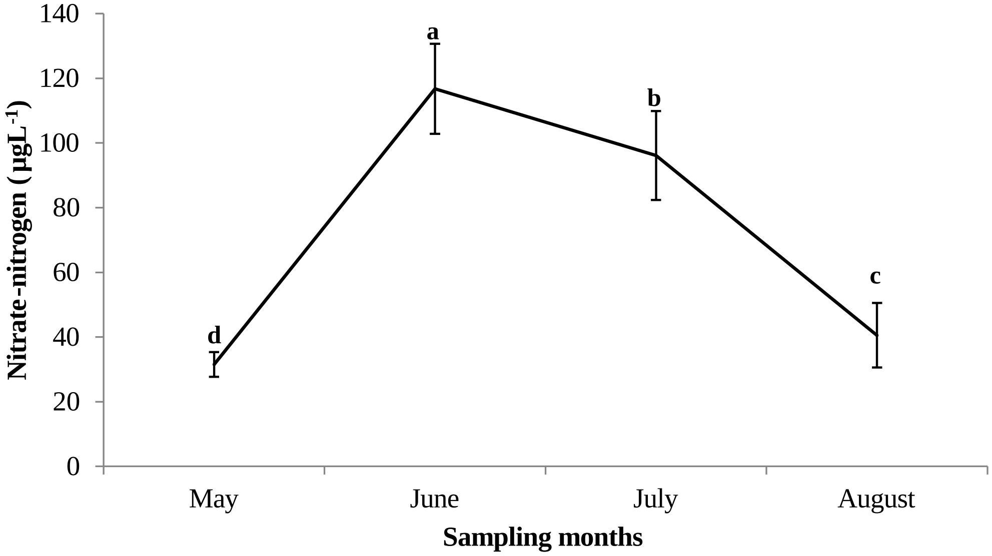

Figure 54: Monthly variations of nitrate-nitrogen (µgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d) denotes that the means are significantly different ($p < 0.05$).

4.3.2.5 Ammonium-Nitrogen (NH_4^--N)

For the current wastewater treatment plant, the mean concentration for ammonium-nitrogen recorded was 144.8 ± 29.59 µgL^{-1} with minimum and maximum values of 0.56 µgL^{-1} and 1088.5 µgL^{-1} respectively. The effluent sampling station had the highest mean value of 276.9 ± 141.30 µgL^{-1} while the maturation pond 2 sampling station had the least value of 4.3 ± 0.94 µgL^{-1}. In terms of trend, the ammonium-nitrogen mean concentrations fluctuated with increasing trend between the influent and effluent sampling station (Figure 55). Two way ANOVA indicated significant differences between the sampling stations (F $_{(8,\ 108)}$ =

1.35; *p* = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean ammonium-nitrogen of the maturation pond 2 was significantly lower and different compared with the other sampling stations (4.3 ± 0.94 µgL^{-1}). The upstream (271.8 ± 50.15 µgL^{-1}) mean ammonium-nitrogen value differed significantly with the downstream (87.8 ± 44.45 µgL^{-1}) sampling station.

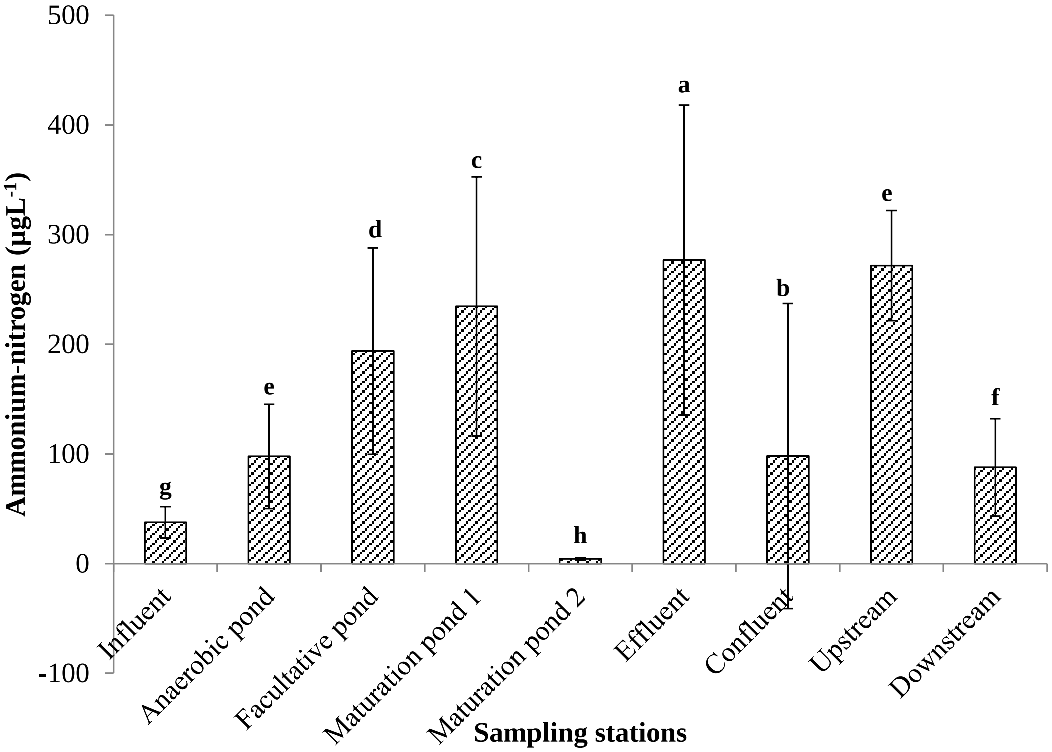

Figure 55: Spatial variations of ammonium-nitrogen (µgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d, e, f, g) signify that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the month of May had the highest mean of ammonium-nitrogen concentrations of 558.8 ± 74.95 µgL^{-1}, and the month of July had the lowest mean ammonium-nitrogen of 3.5 ± 0.40 µgL^{-1}. In terms of trend, generally the ammonium-nitrogen concentration had a declining trend (Figure 56).

Two factor ANOVA showed that ammonium-nitrogen was statistically significant between the sampling stations (F $_{(3, 108)}$ = 54.24; *p* = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean of ammonium-nitrogen of May (558.8 ± 74.95 µgL^{-1}) differed significantly with those of June (4.2 ± 0.61 µgL^{-1}), July (3.5 ± 0.40 µgL^{-1}), and August (12.5 ± 1.26 µgL^{-1}) (Figure 56).

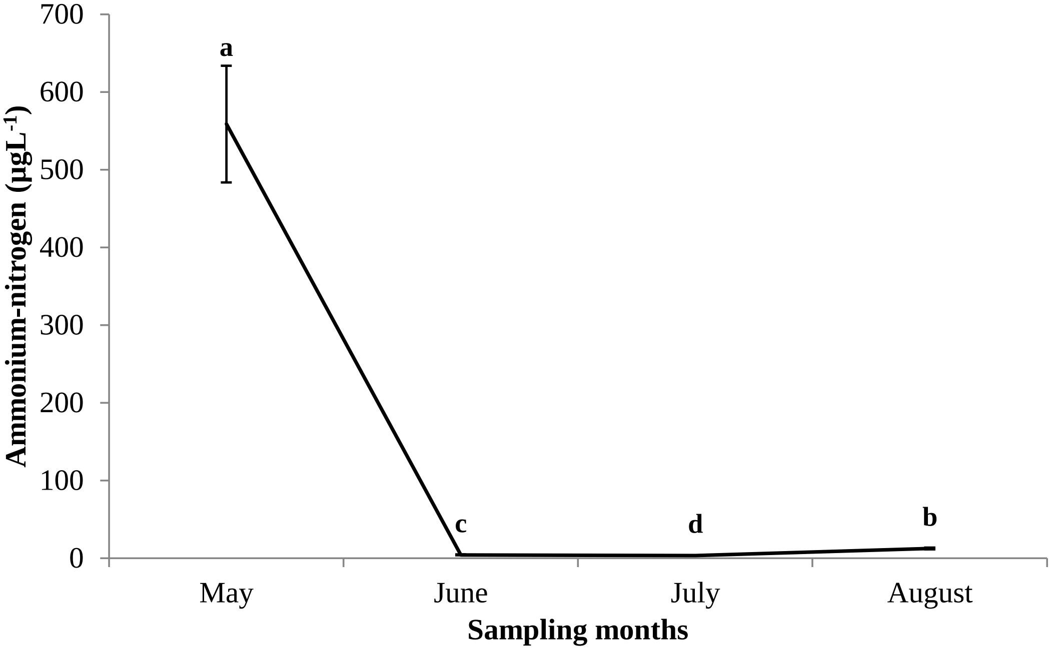

Figure 56: Monthly variations of ammonium-nitrogen (µgL^{-1}) concentrations for the current Kisii Town WWTP.
Different letters (a, b, c, d) signify that the means are significantly different ($p < 0.05$).

4.3.2.6 Total Nitrogen (TN)

The mean of TN concentration recorded was 233.1 ± 17.83 µgL^{-1} with minimum and maximum values of 22.0 µgL^{-1} and 745.2 µgL^{-1}. The effluent sampling station had the highest mean TN concentration of 390.7 ± 64.88 µgL^{-1} while the downstream sampling station had lowest mean of 110.1 ± 21.93 µgL^{-1}. In terms of trend, the mean of TN concentration showed no spatial trend between the influent and effluent sampling stations (Figure 57).

Two way ANOVA showed that TN was significantly different among the sampled stations ($F_{(8, 108)} = 344.62$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TN concentration of influent station (236.2 ± 28.84 µgL^{-1}) differed significantly with the effluent station (390.7 ± 64.88 µgL^{-1}), while the upstream station (226.6 ± 39.7 µgL^{-1}) differed significantly with the downstream (110.1 ± 21.93 µgL^{-1}) station (Figure 57).

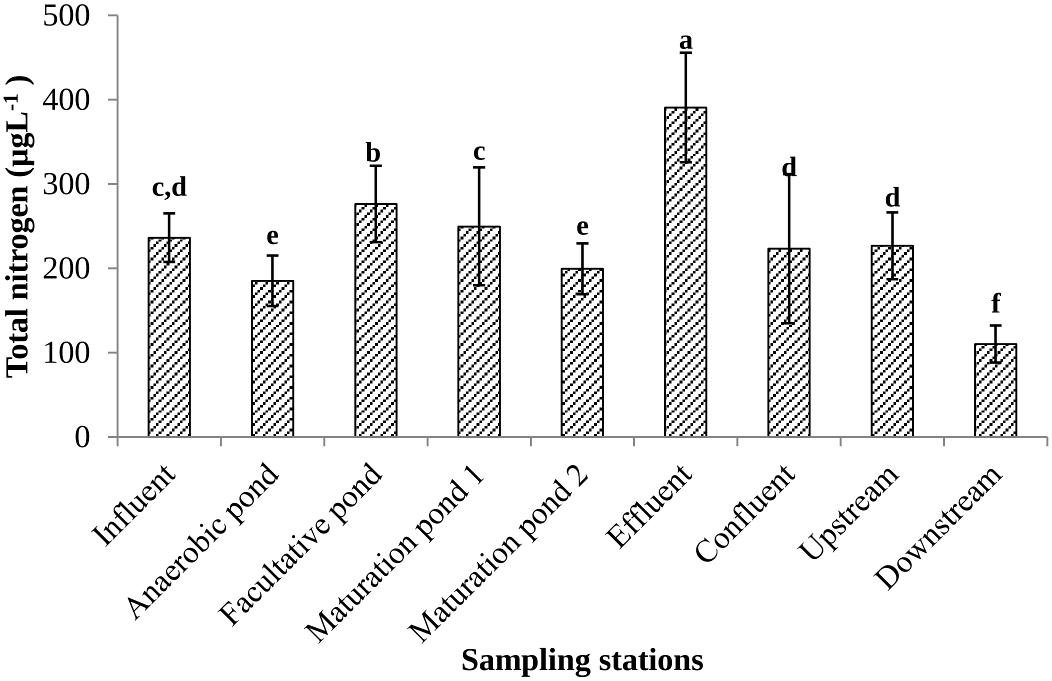

Figure 57: Spatial variations of TN (µgL^{-1}) concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d, e, f) denotes that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the month of May had the highest mean of TN concentration 408.3 ± 45.60 µgL^{-1}, followed by the month of July with mean of 198.1 ± 21.69 µgL^{-1}. The month of August had the lowest mean concentration of TN (140.5 ± 25.63 µgL^{-1}). In terms of trend, the TN mean concentrations had a decreasing trend during the study period (Figure 58).

Two factor ANOVA showed that mean TN concentrations were statistically significant between the sampling months ($F_{(3,\ 108)} = 1936.43$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TN of May (408.3 ± 45.60 µgL^{-1}) differed significantly with those of June (185.2 ± 19.5 μgL^{-1}) , July (198.1 ± 21.69 μgL^{-1}), and August (140.5 ± 25.63 μgL^{-1}) (Figure 58).

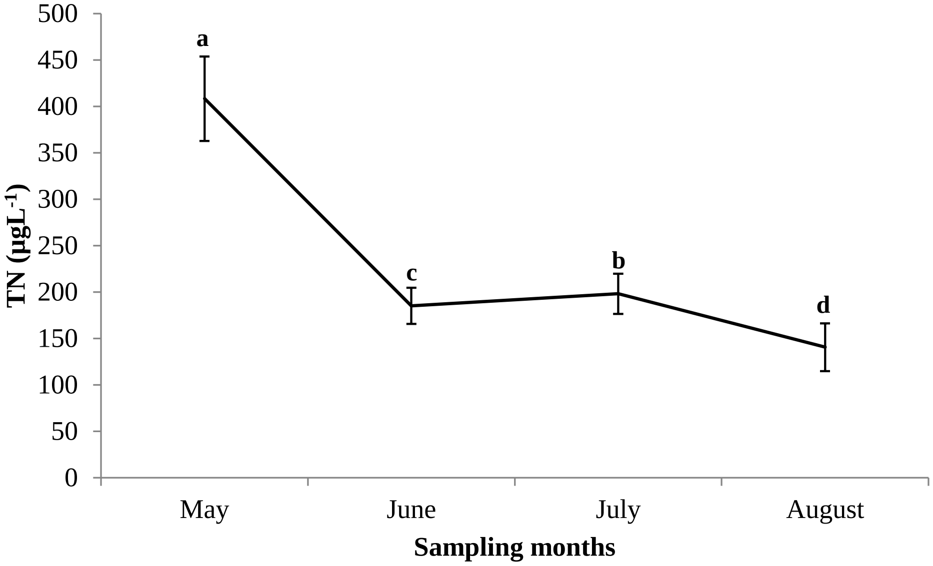

Figure 58: Monthly variations of TN (μgL^{-1}) concentrations for the current Kisii Town WWTP. Different letters (a, b, c, d) denotes that the means are significantly different ($p < 0.05$).

4.3.2.7 Total Phosphorous (TP)

The mean of TP concentration recorded was 2064 ± 114.10 μgL^{-1} with minimum and maximum values of 20.69 μgL^{-1} and 3710.20 μgL^{-1}. The anaerobic station had the highest mean TP concentration of 2742 ± 206.26 μgL^{-1} while the influent had the least mean of 801 ± 300.12 μgL^{-1} which was lower compared to the effluent station which had mean of 2557 ± 172.55 μgL^{-1}. In terms of trend, there was fluctuation in mean TP concentrations with no significant trend spatially similar to the mean trends for TSS, silicates, nitrate-nitrogen, and TN (Figure 59).

Two way ANOVA showed that TP concentrations were significantly different among the sampling stations ($F_{(8,\ 108)} = 32.23$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TP concentration of influent station (801 ± 300.12 µgL^{-1}) differed significantly with the effluent station (2557 ± 172.55 µgL^{-1}) (Figure 59).

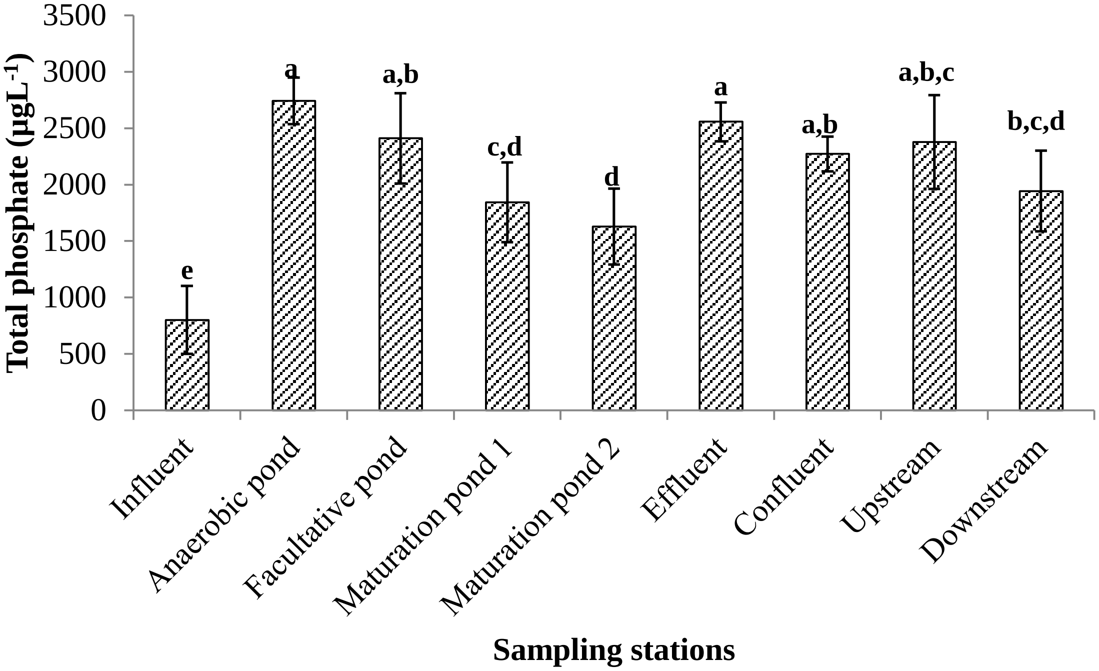

Figure 59: Spatial variations of Total phosphorous (µgL^{-1}) concentration for the current Kisii Town WWTP.
Different letters (a, b, c, d, e) signifies that the means are significantly different ($p < 0.05$).

In terms of monthly variations, the month of August had the highest mean TP concentration of 2628 ± 214.39 µgL^{-1} while May had the lowest mean of 1330 ± 214.87 µgL^{-1}. The mean TP concentration of July and August recorded were 2219 ± 211.72 µgL^{-1} and 2079 ± 208.61 µgL^{-1}. In terms of trend, there was fluctuation in mean TP concentrations during the sampling period with an increasing trend (Figure 60). Two factor ANOVA showed that mean TP concentrations were statistically significant between the sampling months ($F_{(3, 108)} = 60.5$; $p = 0.000$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean TP of May (1330.5 ± 214.87 µgL^{-1}) differed significantly with those of June (2627.5 ± 214.39 µgL^{-1}) , July (2219.3 ± 211.72 µgL^{-1}), and August (2079.0. ± 208.61 µgL^{-1}) (Figure 60).

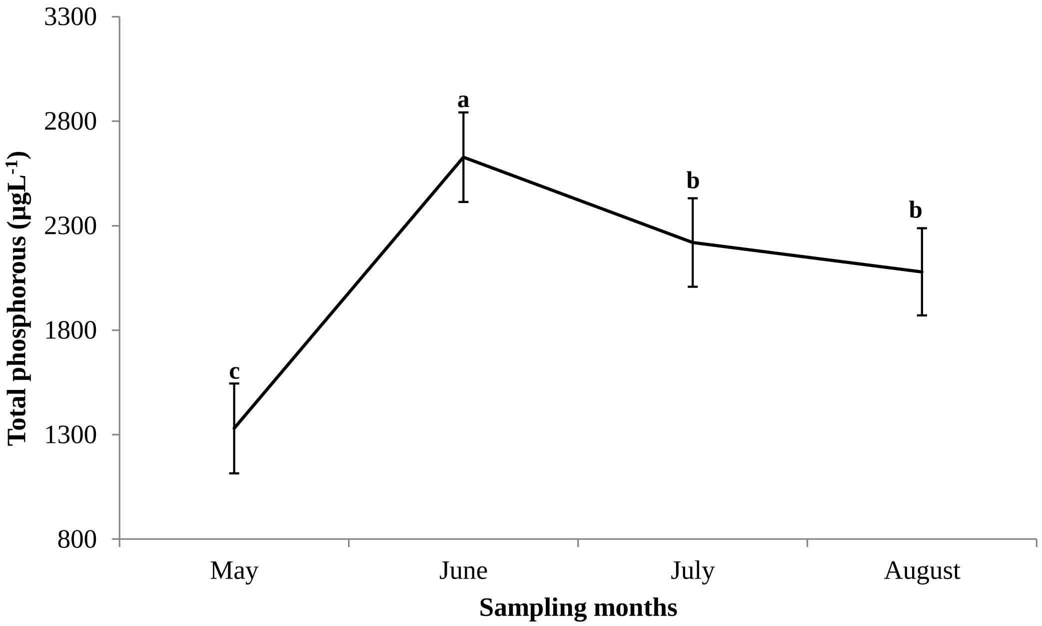

Figure 60: Monthly variations of Total phosphorous (µgL^{-1}) concentration for the current Kisii Town WWTP.
Different letters (a, b, c) signify that the means are significantly different ($p < 0.05$).

4.3.3 Heavy metal concentrations in wastewater

Results for spatial variations of heavy metal concentrations recorded for the wastewater samples collected from the Kisii Town WWTP current design are shown in Figure 61. For monthly variations are summarized in Table 22. Zn and Cd concentrations were below the detection limit both spatially and monthly.

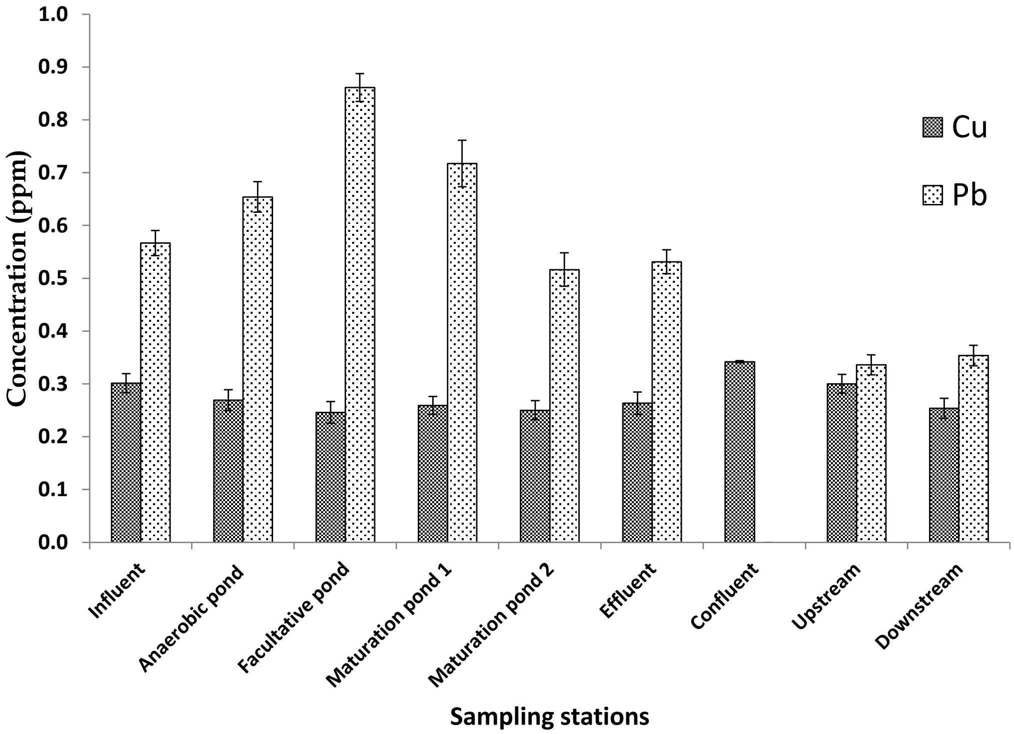

Figure 61: Spatial variations of heavy metal concentrations (in ppm) in wastewater samples from the current Kisii Town WWTP.

Table 22: Monthly variations of heavy metals concentrations (in ppm) in wastewater samples from the current Kisii Town WWTP.

Sampling months	**Heavy metal concentrations (ppm)**			
	Pb	**Zn**	**Cu**	**Cd**
May	0.60 ± 0.04	BDL	0.20 ± 0.02	BDL
July	0.53 ± 0.05	BDL	0.35 ± 0.004	BDL
***t*- value**	$t_{(30)} = 1.241$; $p = 0.274$		$t_{(34)} = 21.58$; $p = 0.000$	

The mean Pb concentration of the sampling stations ranged from 0.34 ± 0.06ppm to 0.86 ± 0.08ppm. The facultative pond had the highest mean Pb concentration of 0.86 ± 0.08ppm. In terms of trend, the mean Pb concentrations were decreasing from the influent to effluent sampling station, indicating that the WWTP is polishing the effluent received. One-way

ANOVA test showed that mean Pb concentrations were not significantly different among the sampling stations ($F_{(7, 24)} = 1.827$; $p = 0.128$) (Figure 61). Monthly, the mean Pb concentration recorded for the month of May (0.60 ± 0.04ppm) was higher than the mean concentration (0.53 ± 0.05ppm) recorded in July. The independent sample t-test showed that mean Pb concentrations were not significantly different between the sampling months ($t_{(30)} = 1.241$; $p = 0.274$) (Table 22).

The mean Cu concentration of the sampling stations ranged from 0.25 ± 0.05ppm to 0.34 ± 0.01ppm. The confluent sampling station had the highest mean concentration of 0.34 ± 0.01ppm while the maturation pond 2 sampling station had the least concentration (0.25 ± 0.05ppm). In terms of trend, the mean Cu concentrations were decreasing from the influent to effluent sampling station, indication that the WWTP is polishing the effluent received. One-way ANOVA test showed that the mean Cu concentrations were not significantly different among the sampling stations ($F_{(8, 27)} = 0.354$; $p = 0.935$) (Figure 61). In terms of monthly variations, the mean Cu concentration measured for the month of July was 0.35 ± 0.004ppm which was higher than the month of May (0.2 ± 0.02ppm). The independent sample t-test showed that mean Cu concentrations were significantly different between the sampling months ($t_{(34)} = 21.58$; $p = 0.000$). The mean concentrations for Zn and Cd were below the detection limit in both sampling months during the study period (Table 22).

4.3.4 Heavy metal concentrations in sediments

Heavy metal concentrations were analyzed in sediments from the Kisii Town wastewater stabilizing ponds including three stations along river Riana. The metals which were analyzed include Pb, Zn, Cu and Cd. Figure 62 shows mean (± SE) spatial variations while Table 23 are monthly variations of the heavy metal concentrations in sediments.

Throughout the study, mean Cd concentrations were below the detection limit (<BDL). In terms of dominance in mean concentration, Zn had the highest concentration followed by Cu then Pb.

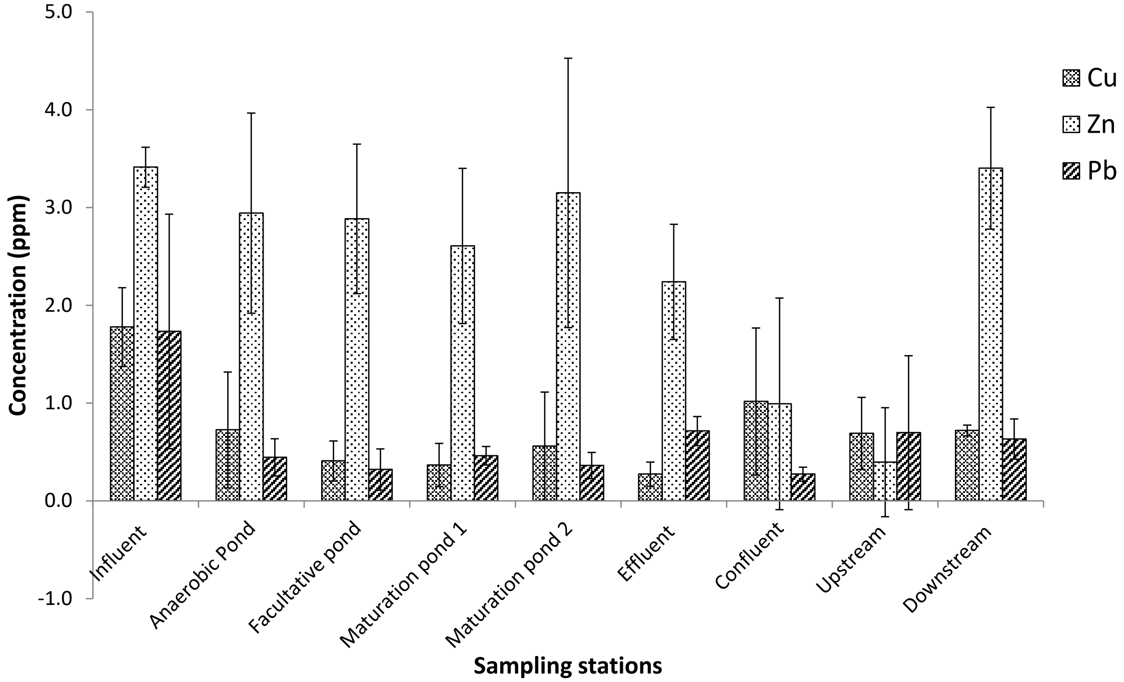

Figure 62: Spatial variation of heavy metal concentrations (in ppm) in sediments samples from the current Kisii Town WWTP.

Table 23: Monthly variations of heavy metals concentrations (in ppm) in sediments from the current Kisii Town WWTP

Sampling months	**Heavy metal concentrations (ppm)**			
	Pb	**Zn**	**Cu**	**Cd**
May	0.80 ± 0.25	1.43 ± 0.48	0.53 ± 0.18	BDL
July	0.48 ± 0.09	3.68 ± 0.67	0.90 ± 0.11	BDL
***t*- value**	$t_{(34)} = 1.87$; $p = 0.18$	$t_{(32)} = 3.357$; $p = 0.076$	$t_{(34)} = 0.006$; $p = 0.936$	

Spatially, the mean Pb concentration of the sampling stations ranged from 1.73 ± 0.98ppm to 0.27 ± 0.03ppm. The influent had the highest mean concentration of 1.73 ± 0.98ppm while the confluent had the least mean concentration (0.27 ± 0.03ppm). In terms of trend, there was a reduction in Pb concentrations in sediments from the influent to the effluent station, indication of its removal from water column during treatment process and sediments therefore acting as its sink. One-way ANOVA test showed that mean Pb concentration was not significant among the sampling stations ($F_{(8, 27)} = 0.496$; $p = 0.496$). In terms of monthly variations, Lead recorded higher mean concentration during the month of May (0.80 ± 0.25ppm) while the month of July had a mean concentration of 0.48 ± 0.09ppm. The independent sample t-test showed that means of Pb concentrations were not significantly different between the sampling months (Table 23).

The sediments mean concentration of Zn ranged from 0.79 ± 0.47ppm to 3.41 ± 1.39ppm. As shown in Figure 62, the sediments collected from influent had the highest Zn concentration while the upstream sediments samples had the least concentrations. The trend for mean Zn concentration in sediments was reducing from influent to effluent except at the maturation pond 2 in which there was a steep rise in concentration. One way ANOVA analysis showed that mean Zn concentrations were not significantly different among the sampling stations ($F_{(8, 25)} = 1.610$; $p = 0.172$) (Figure 62). In terms of monthly variations, Zn mean concentration in July (3.68 ± 0.67ppm) was higher than that of May (1.43 ± 0.48ppm). The independent sample t-test showed that means Zn concentrations were not significantly different between the sampling months (Table 23).

The mean Cu concentration in sediments from the sampling stations ranged from 0.27 ± 0.05ppm to 1.78 ± 0.59ppm. The sediments collected from the influent sampling station had the highest mean Cu concentration while the effluent had the least mean Cu concentration. Similar to the mean trend of Pb, mean Cu concentration in the sediments was reduced from the influent to that in maturation pond, indication of its removal from wastewater column during treatment process and sediments acting as there sink. One way

ANOVA test showed that mean Cu concentrations were significantly different among the sampling stations ($F_{(8, 27)} = 2.818$; $p = 0.021$) (Figure 62). In terms of monthly variations, Copper had highest mean concentration during the month of July (0.90 ± 0.11ppm) while the month of May had a mean concentration of 0.53 ± 0.18ppm. The independent sample t-test showed that mean Cu concentrations were not significantly different between the sampling months (Table 23).

4.3.5 Heavy metal concentrations in phytoplankton

Figure 63 shows the mean (± SE) spatial variation of heavy metal concentrations (in ppm) in phytoplankton samples collected from the current design of the Kisii Town WWTP including three sampling stations along river Riana.

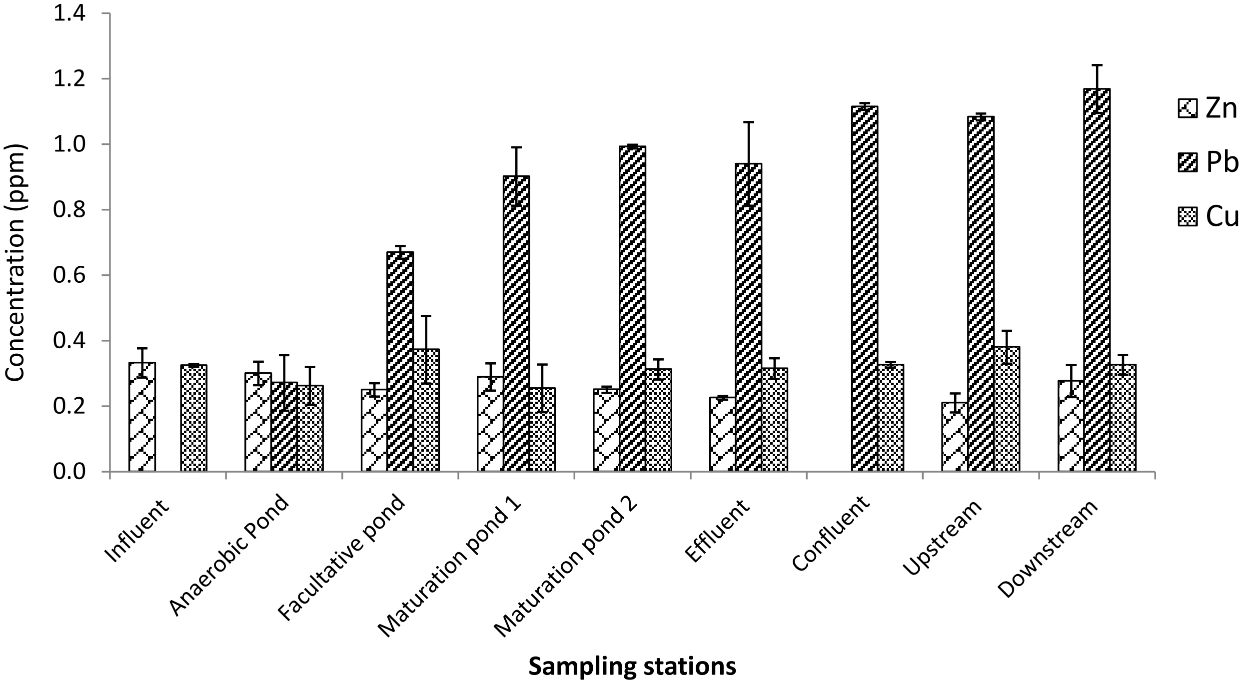

Figure 63: Spatial variation of heavy metal concentrations (in ppm) in phytoplankton samples from the current Kisii Town WWTP.

Throughout the study period, Cd concentrations were below the detection limit (<BDL) in all phytoplankton samples analyzed.

The mean Cu concentration in phytoplankton from the sampling stations ranged from 0.25 ± 0.07ppm to 0.38 ± 0.05ppm. The phytoplankton collected from the upstream sampling station had the highest mean Cu concentration while the anaerobic pond had the least mean concentration. One way ANOVA test showed that the mean Cu concentrations in phytoplankton were not significantly different among the sampling stations ($F_{(8,\ 27)}$ = 0.648; p = 0.731). In terms of monthly variation, mean Cu concentration was higher during the month of July (0.35 ± 0.01ppm) while the month of May had a mean concentration of 0.29 ±0.03ppm. The independent sample t-test showed that mean Cu concentrations were significantly among different sampling months ($t_{(33)}$ = 8.379; p = 0.007).

For Zn, the average phytoplankton concentration range was between 0.33 ± 0.04ppm and 0.21 ± 0.03ppm. At the confluent sampling station, its concentration was below the detection limit (<BDL) in the phytoplankton samples. One way ANOVA test for Zn mean concentration difference in phytoplankton samples was not significant among the sampling stations ($F_{(7,\ 8)}$ =1.489; p = 0.293. In terms of monthly variations, Zn concentrations were below detection limits during the month of May. Therefore, the independent sample t-test was not calculated for Zn as there were fewer than two groups for the dependent variable.

The mean Pb concentration ranged from 1.17 ± 0.01ppm to 0.27 ± 0.004ppm. The downstream had the highest Pb mean concentration (1.17 ± 0.01ppm) while the influent had the least mean Pb concentration (0.27 ± 0.00ppm). Moreover, Pb mean concentration was below the detection limit in the influent sampling station. One way ANOVA test showed that mean Pb concentrations were significantly different among the sampling stations ($F_{(7,\ 8)}$ = 21.731; p = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean Pb concentration for phytoplankton samples from the anaerobic station was lower by 0.45ppm, 0.41ppm and 0.5ppm than those in the effluent, upstream and downstream sampling stations respectively. In terms of monthly variations, Pb concentrations were below detection limits during the month of July. As a result, the independent sample t-test was not calculated for Pb as there were fewer than two groups for the dependent variable consequently no calculations were done for monthly variations.

4.3.6 Heavy metals concentrations in Zooplankton

Heavy metals concentration determination was carried out for zooplankton samples which were collected from Kisii Town WWTP alongside the three sampling stations in river Riana. Figure 64 shows spatial mean concentrations of the heavy metals in zooplankton samples from the various sampling stations while Table 24 shows the monthly variations.

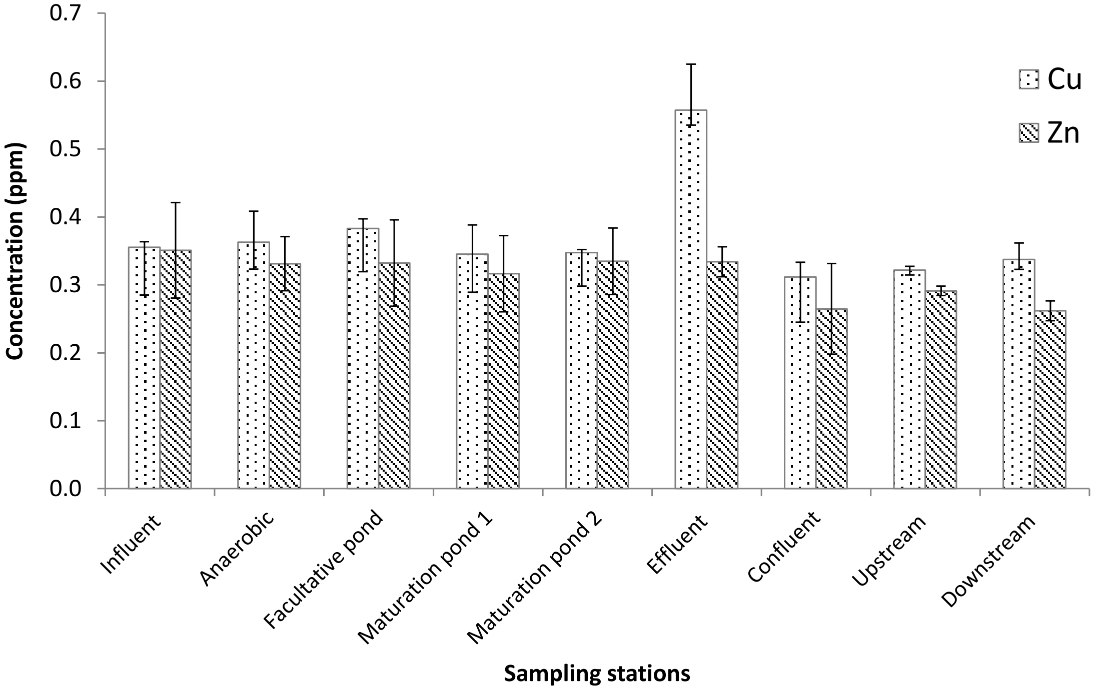

Figure 64: Spatial variation of heavy metal concentrations (in ppm) in zooplankton samples from the current Kisii Town WWTP.

Table 24: Monthly variation of heavy metal concentrations in zooplankton samples from the current Kisii Town WWTP

Sampling months	Heavy metal concentrations (in ppm)			
	Pb	Zn	Cu	Cd
May	BDL	0.34 ± 0.01	0.35 ± 0.01	BDL
July	BDL	0.29 ± 0.01	0.35 ± 0.01	BDL
***t*- value**		$t_{(34)} = 0.512$; $p = 0.479$	$t_{(34)} = 2.244$; $p = 0.143$	

The mean Cu concentration in zooplankton range was from 0.31 ± 0.01ppm to 0.38 ± 0.04ppm. For Zn, the average concentration range was between 0.26 ± 0.03ppm and 0.35 ± 0.03ppm. In general, the mean Cu concentration in zooplankton was higher compared to the mean Zn concentrations. However, one way ANOVA test for both Cu and Zn showed that their mean concentration in zooplankton samples obtained from different stations were not significantly different among the sampling stations ($F_{(8, 27)} = 1.760$; $p = 0.130$) and ($F_{(8, 27)} = 1.046$; $p = 0.428$) respectively. On the other hand, Pb and Cd concentration were below detection limit (Figure 64).

In terms of monthly variations, mean Copper concentration was relatively the same for both months while for Zn it was higher in the month May than that of July. Moreover, the independent sample t-test showed that mean Cu and Zn concentrations were not significantly different between the two sampling months. For Pb and Cd, their concentrations were below the detection limit in the two months during the study period (Table 24).

4.3.7 Comparison of heavy metal concentrations in wastewater, sediments, phytoplankton and zooplankton

4.3.7.1 Copper

A comparison of the mean Cu concentrations in wastewater, sediments, phytoplankton and zooplankton results are shown in Figure 65. The comparison revealed that mean Cu concentration in sediments was the highest with value of 0.72 ± 0.45ppm followed by zooplankton with 0.35 ± 0.02ppm then phytoplankton with 0.32 ± 0.04ppm. Copper mean concentration was lowest in the wastewater samples with a mean of 0.28 ± 0.03ppm. This shows that there is biomagnification of the CU concentration along the food chain. One way ANOVA test showed that mean Cu concentrations differences were significant among the trophic levels ($F_{(3, 32)} = 7.3563$; $p = 0.001$).

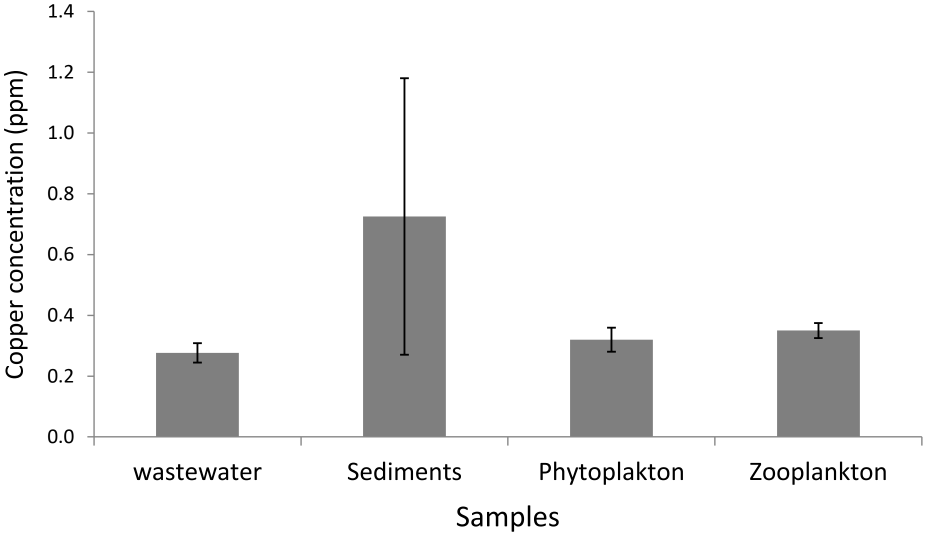

Figure 65: Comparative bar graph showing Cu concentrations (in ppm) in wastewater, sediments, phytoplankton and zooplankton samples from the current Kisii Town WWTP.

4.3.7.2 Zinc

A comparison of the mean Zn concentrations in wastewater, sediments, phytoplankton and zooplankton samples during the study period is shown Figure 66. In wastewater, Zn concentration was below detection limit. In the case of sediments, phytoplankton and zooplankton, the comparison revealed that the mean of Zn concentration was highest in sediments (2.45 ± 1.07ppm) followed by zooplankton with 0.31 ± 0.03ppm then phytoplankton least with 0.27 ± 0.04ppm. This indicates that the sediments are accumulating (sequestering) zinc while the zooplankton are biomagnifying the concentrations of the metal. It further shows that there was bioconcentration of the metal along the short food chain segment between phytoplankton and zooplankton. One way ANOVA test showed that mean Zn concentration differences were significant among the different trophic levels in the WWTP (F $_{(3, 22)}$ = 21.8136; p = 0.000).

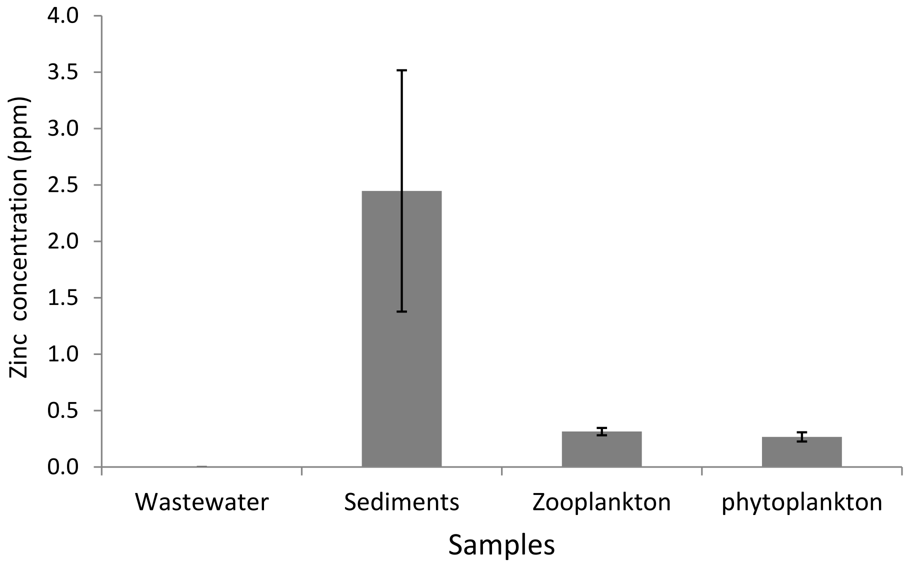

Figure 66: Comparative bar graph showing Zn concentrations (in ppm) in wastewater, sediments, phytoplankton, and zooplankton samples from the current Kisii Town WWTP.

4.3.7.3 Lead

A comparison of mean Pb concentrations in wastewater, sediments, phytoplankton and zooplankton samples during the study period is as shown in Figure 67. In zooplankton, Pb concentration was below detection limit. In the case of wastewater, sediments, and phytoplankton, the comparison revealed that the mean of Pb concentration was highest in phytoplankton with value of 0.79 ± 0.41ppm followed by sediments with 0.63 ± 0.45ppm then wastewater least (0.50 ± 0.25ppm). Therefore, the results indicate that the sediments and phytoplankton are sequestering Pb concentrations. One way ANOVA test showed that mean Pb concentration differences were not significant ($F_{(2, 24)} = 1.338$; $p = 0.2813$).

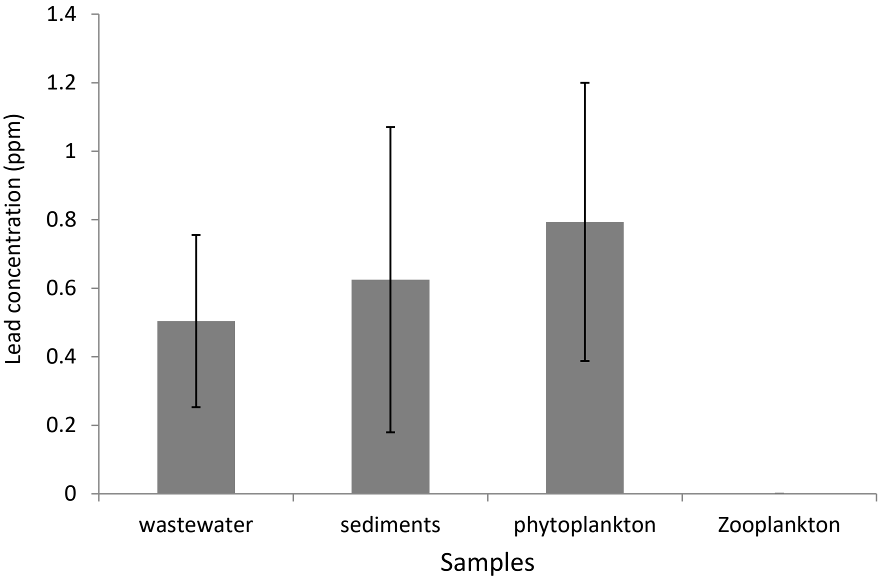

Figure 67: Comparative bar graph showing Pb concentrations (in ppm) in wastewater, sediments, phytoplankton, and zooplankton samples from the current Kisii Town WWTP.

4.3.7.4 Cadmium

A comparison of mean Cd concentration in wastewater, sediments, phytoplankton and zooplankton were not calculated as the concentrations were below detection limit throughout the study period in all samples analyzed. Further the same observation holds through for the upstream, confluent, and downstream sampling stations.

4.3.8 Pearson's Correlation between physico-chemical parameters, nutrients and heavy metals in the current Kisii Town WWTP

By carrying out Pearson's correlation analysis we determined the relationship among the different 15 parameters. Table 25, shows the correlation matrices at 5% level of significance and only those parameters with Pearson coefficients equal or higher than 0.50 (r = 0.50) were significant. It is evident there was a significant very strong positive correlation between EC with TDS and SRP, TDS and SRP, SRP and Pb, and NO_2-N and NO_3-N. There was a significant strong positive correlation between TDS and Pb, and between SiO_2 and Pb. On the other hand, there was a very strong negative correlation between EC with DO, NO_2-N and NO_3-N, temperature and NO_2-N, DO and TDS, TDS and NO_2-N, SRP and NO_2-N, and between NO_2-N and Pb. Strong negative correlation between NO_3-N with temperature, and TDS were observed.

Table 25: Pearson Correlation Coefficients (r) matrix for different physico-chemical parameters, nutrients and heavy metals for the current Kisii Town WWTP

	pH	**EC (µScm^{-1})**	**Temp (°C)**	**DO (mgL^{-1})**	**TSS (mgL^{-1})**	**TDS (mgL^{-1})**	**SiO_2 (mgL^{-1})**	**SRP (µgL^{-1})**	**NH_4-N (µgL^{-1})**	**NO2-N (µgL^{-1})**	**NO_3-N (µgL^{-1})**	**TN (µgL^{-1})**	**TP (µgL^{-1})**	**Cu (ppm)**	**Pb (ppm)**
pH	1														
EC (µScm^{-1})	-0.014	1													
Temp (°C)	0.413	0.382	1												
DO (mgL^{-1})	0.611	**-.729***	-0.002	1											
TSS (mgL^{-1})	-0.218	-0.144	-0.146	-0.048	1										
TDS (mgL^{-1})	-0.299	**.929****	0.299	**-.826****	0.022	1									
SiO_2 (mgL^{-1})	0.228	0.034	0.135	0.308	0.375	0.137	1								
SRP (mgL^{-1})	-0.284	**.721***	0.401	-0.605	0.199	**.883****	0.452	1							
NH_4-N (µgL^{-1})	0.358	-0.266	0.120	0.514	0.352	-0.161	0.647	0.099	1						
NO_2-N (µgL^{-1})	-0.177	**-.796***	**-.829****	0.456	0.062	**-.764***	-0.180	**-.771***	-0.024	1					
NO_3-N (µgL^{-1})	-0.026	**-.732***	**-.698***	0.457	0.117	**-.683***	0.046	-0.666	0.219	**.858****	1				
TN (µgL^{-1})	0.589	0.363	0.418	0.088	0.028	0.272	0.230	0.281	0.613	-0.522	-0.361	1			
TP (µgL^{-1})	-0.055	-0.434	0.229	0.411	-0.088	-0.270	0.089	-0.006	0.547	0.029	-0.045	0.218	1		
Cu (ppm)	-0.096	-0.187	-0.594	-0.077	-0.389	-0.209	-0.482	-0.465	-0.075	0.493	0.579	-0.014	-0.084	1	
Pb (ppm)	0.052	0.645	0.554	-0.251	0.125	**.699***	**.673***	**.857****	0.174	**-.753***	-0.656	0.268	-0.034	**-.717***	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

4.3.9 Current Kisii Town Wastewater Treatment Plant efficiency

The performance of the current WWTP in wastewater treatment was assessed in terms of the percentage reduction or increase of the respective physico-chemical parameter and the results are presented in Table 26.

Table 26: Water quality parameters of effluent discharge compared with national and international quality standards for the current Kisii Town WWTP

Parameter	Influent	Effluent	% Increase/ Reduction	Compliance index	NEMA	WHO	EPA
pH	7.33 ± 0.01	7.77 ± 0.06	5.7**	0.91	6.5 - 8.5	6.5 - 8.5	6-9
Temp (°C)	22.1 ± 0.34	26.1 ± 0.16	15**	0.75	25 - 35	Ambient	< 40
DO (mgL^{-1})	0.2 ± 0.04	2.7 ± 0.76	92.6**	-	*	> 4	
Conductivity (µScm^{-1})	1097.75 ± 128.92	665.58 ± 41.17	39.4	0.33	≤2000	1000	1500
TSS (mgL^{-1})	65.34 ± 7.4	77.16 ± 6.0	18**	2.57	≤30	50	50
TDS (mgL^{-1})	438.3 ± 79.5	259 ± 42.5	41	0.22	1200	500	1000
SiO2 (mgL^{-1})	20.6 ± 5.3	21.3 ± 2.1	3**	-	*		
SRP (µgL^{-1})	664.8 ± 202.46	557.0 ± 137.95	16	-	*		1000
NH4-N (µgL^{-1})	37.7 ± 14.31	276.9 ± 141.30	634**	0.003	100 ,000		1000
NO2-N (µgL^{-1})	20.2 ± 1.44	8.4 ± 0.99	58	0.0001	100 ,000		1000
NO3-N (µgL^{-1})	62.9 ± 11.81	26.4 ± 4.77	58	0.0003	100 ,000	40000	10000
TN (µgL^{-1})	236.2 ± 28.84	390.7 ± 64.88	65**	-	2 Guideline value		50000
TP (µgL^{-1})	801.0 ± 300.12	2557.0 ± 172.55	219**	1.28	≤2000	500	2000

Where: * denotes non-existence of a NEMA standard for the concentration levels of the corresponding parameter. ** denotes increase in percentage of the respective parameter between the influent and effluent. – denotes compliance index was not calculated for the corresponding parameter due to the lack of NEMA standard limit for the corresponding parameter.

The TSS removal efficiency had a slight increase at the effluent sampling point with 18% from the influent station. The TDS removal efficiency was 41% between the influent and the effluent sampling stations.

For silicates, the percentage was a minimal increase of 3% at the effluent from the influent while for SRP it was a reduction of 16%. There was an increase of 634% of ammonium-nitrogen from that of influent. The influent nitrite-nitrogen was reduced by 58% at the effluent. Similarly, nitrate-nitrogen value was reduced by 58% in wastewater during polishing by current plant design. On the other hand, there was a slight increase level of TN by 65% between the effluent and influent sampling stations at current plant design. For TP, there was a considerable increase in TP by 219%.

However, for pH, temperature and DO, efficiency of wastewater polishing was measured based on their increase between the influent and effluent sampling stations. Therefore, there was an increase in level of pH, temperature, and DO by 5.7 %, 15 %, and 92.6 % respectively, indication of the WWTP efficiency in wastewater polishing (Table 26).

Effluent discharge physico-chemical parameters compliance to national and international standards are summarized in (Table 26) for the current treatment plant. pH, electrical conductivity, temperature, TDS, and NO_3-N for the discharged effluent from the wastewater treatment plant were within the maximum allowable limits of NEMA, WHO, and EPA standards. Moreover, there compliance indices were below 1 an indication of compliance, and good polishing by WWTP. However, TSS and TP exceeded the NEMA limits and their compliance indices were above 1 an indication of non-compliance. Also, TSS was not within the WHO, and EPA set limits while TP exceeded the limits for WHO and EPA. For the other parameters, lack of NEMA standard limits for the corresponding parameters it was not possible to generalize whether the discharged effluent met the set standards. Also, their respective compliance indices were not calculated and referenced for the current WWTP. Effluent measured means for SRP, NO_2-N, NH_4-N, and TN were within the EPA set limits. On the other hand, the recorded mean for TP (2557 ± 172.55 µgL^{-1}) exceed the maximum limits set by WHO (500 µgL^{-1}), and both for NEMA, and EPA (2000 µgL^{-1}) (Table 26).

For heavy metals, the compliance indices for Cadmium and Zinc were not calculated and referenced for the treatment plant because their concentrations were generally below detection limits. The index value for Copper, 0.25 was below 1 indication compliance to NEMA, EPA, and WHO limits. However, the compliance index value for Lead was 53 which was greater than 1, indicating non-compliance to the specified NEMA, EPA, and WHO standards for heavy metals effluent discharge to the environment. The results indicate that lead and TP were problematic parameters that should be targeted by management to improve effluent standards (Table 27).

Table 27: Heavy metal effluent discharge concentrations of the current Kisii Town WWTP compared with national and international quality standards

Metal	Influent	Effluent discharge	Compliance index value	NEMA standards	EPA	WHO
Lead (ppm)	0.57 ± 0.02	0.53 ± 0.02	53	0.01	0.006	0.01
Cadmium (ppm)	BDL	BDL	-	0.01	0.01	0.003
Zinc (ppm)	BDL	BDL	-	0.5	2	0.2
Copper (ppm)	0.6 ± 0.02	0.26 ± 0.15	0.26	1.0	0.5	1.0

4.3.10 Phytoplankton

4.3.10.1 Phytoplankton diversity and species composition

Checklist for phytoplankton species recorded in the current Kisii Town WWTP are presented in Table 28.

Table 28: A list of phytoplankton taxa found in the current Kisii Town WWTP

Chlorophyceae

Ankistrodesmus falcatus
Botryococcus braunii
Coelastrum microporum
Crucigenia sp
Dictyosphaerium reniforme
Kirchnella contorta
Kirchnella lunaris
Monoraphidium sp
Oocystis parva
Pediastrum boryanum
Pediastrum duplex
Scenedesmus curvatus
Scenedesmus acuminatus
Scenedesmus obliquus
Schroidera setigera
Tetraedron arthromisforme
Tetraedron trigonum

Dinophyceae

Ceratinium branchycerous
Glenodinium pernardii
Glenodinium pulvastitus

Euglenaphyceae

Euglena acus
Euglena virids
Euglenaphytalena acus
Euglenaphytalena virids
Phacus longicauda
Phacus sp
Strombomonas sp
Trachelomonas armata
Trachelomonas volvocina

Cyanophyceae

Anabaena flos-aquae
Anabaenopsis tanganyikae
Aphanocapsa pulchra
Aphanocapsa rivularis
Aphanothece sp
Chodatella armata
Chroococcus dispersus
Chroococcus limnetica
Chroococcus turgidus
Cylindrospermopsis africana
Merismopedia tennuissima
Microcystis aeruginosa
Microcystis wasenbergii
Oscillatoria tenuis
Plankolyngbya tallingii
Planktolyngbya circumcreta
Planktolyngbya limnetica
Planktolyngbya talingii
Romeria ankensis
Romeria elegans

Zygnematophyceae

Coelomoron merostoides
Cosmarium sp
Closterium navicula
Cosmarium menenghiana
Crucigenia menenghiana
Cosmarium connatum
Cosmarium cunningtonii
Straurastrum dickiei

Bacillariophyceae

Amphora ovaris
Amphora sp
Aulacoseira ambigua
Aulacoseira nyasensis
Aulacoseira schroidera
Chodatella subsalsa
Chodatella armata
Cyclotella kutzinghiana
Cymbella sp
Cymbella cistula
Diatoma elongatum
Diatoma hemiale
Diatoma vulgare
Navicula sp
Navicula contenta
Navicula exicilis
Nitzschia dissipata
Nitzschia lacustris
Nitzschia palea
Nitzschia recta
Nitzschia sub acicularis
Stephanodiscus astraca
Stephanodiscus sp
Surirella affins
Surirella ovalis
Surirella sp
Synedra cunningtonii
Synedra ulna

The family Bacillariophyceae had the highest number of species (37) consisting of 33 % by species composition, followed by Chlorophyceae, which was represented by 29 species consisting of 26 % by species composition. The family Cyanophyceae was represented by

22 species leading to a 20 % species composition. Other taxonomic families included Zygnemophyceae, Euglenaphyceae and Dinophyceae represented by 11 (10%), 10 (9%) and 3 (3%) species respectively.

The anaerobic pond had the highest species number of 47 (13.7%) followed by the downstream sampling station with 45 (13.1%) species while the influent station had least total number of species (28 (8.1%). Shannon-Wiener diversity index (H') ranged from 1.18 at the effluent station to 3.31 at the downstream sampling station. The maximum dominant index (D) of 0.63 was recorded at the effluent station while downstream sampling station had the least (0.05). In terms of Margalef's diversity that's species richness (d), the effluent was richer (with a value of 5.09) while the facultative pond had the least (3.96). On the other hand, Evenness (E), ranged from 0.07 to 0.61 (Table 29).

Table 29: The phytoplankton diversity indices of the current Kisii Town WWTP

	Influent	Anaerobic pond	Facultative pond	Maturation pond 1	Maturation pond 2	Effluent	Confluent	Upstream	Downstream
Taxa (s)	28	47	32	37	43	44	34	34	45
Individuals	677	1659	2497	4702	2587	4689	723	645	934
Shannon_H	2.69	2.96	1.74	2.29	2.61	1.18	3.04	3.02	3.31
Dominance_D	0.09	0.10	0.30	0.15	0.14	0.63	0.07	0.07	0.05
Margalef (Species richness)	4.14	6.21	3.96	4.26	5.35	5.09	5.01	5.10	6.43
Evenness_e^H/S	0.53	0.41	0.18	0.27	0.32	0.07	0.61	0.60	0.61

4.3.10.2 Phytoplankton abundance

The total phytoplankton biovolume for the current WWTP was 680.99 mm^3L^{-1} with a mean of 113.5 ± 127.8 mm^3L^{-1}. The family Chlorophyceae was contributing to 45.66% while Dinophyceae contributed the least with 0.38% of the total phytoplankton biovolume. The family Euglenaphyceae contributed to 33.91 % followed by Bacillariophyceae (12.86%)

then Zygnematophyceae with 4.19 % to the total biovolume of phytoplankton. The family Cyanophyceae contributed with 3.0 % of the total phytoplankton biovolume (Table 30).

Table 30: Phytoplankton biovolume of water samples from the current Kisii Town WWTP

Taxonomic group	**Phytoplankton Biovolume (mm^3L^{-1})**	**Percentage Biovolume (%)**
Bacillariophyceae	87.56	12.86
Chlorophyceae	310.96	45.66
Cyanophyceae	20.44	3.00
Dinophyceae	2.57	0.38
Euglenaphyceae	230.90	33.91
Zygnematophyceae	28.55	4.19
Grand Total	**680.99**	**100**

4.3.10.3 Spatial variation

The results obtained on the total phytoplankton biovolume depicted that there was variation between the sampling stations in the WWTP pond series. The facultative pond had the highest total phytoplankton biovolume by composition with 21.01 % followed by anaerobic pond with 8.47 %. The effluent had a slightly higher total phytoplankton biovolume with 6.12 % compared with the influent sampling station (4.33%) (Table 31). The systematic increase in the total algal biovolume from the influent to the facultative pond, it is an indication of availability of nutrients as a result of biological breakdown of nutrients which in turn promotes algal growth. Single factor ANOVA showed that the total phytoplankton biovolume variation was not statistically significant between the sampling stations ($F_{(8, 45)} = 0.6961$; $p = 0.693$).

Table 31: Spatial variations of phytoplankton biovolume of water samples from the current Kisii Town WWTP

Sampling stations	Phytoplankton Biovolume (mm^3L^{-1})	Percentage (%)
Influent	29.49	4.33
Anaerobic pond	57.71	8.47
Facultative pond	143.04	21.01
Maturation pond 1	32.25	4.74
Maturation pond 2	34.39	5.05
Effluent	41.67	6.12
Confluent	29.84	4.38
Upstream	278.09	40.84
Downstream	34.52	5.07

The results on the composition of each family in the sampling stations in the current WWTP are as shown in Figure 68. Bacillariophyceae dominated in maturation pond 1 and downstream sampling stations, indicating better water quality resulting from wastewater polishing. Chlorophyceae dominated at the upstream sampling station while Cyanophyceae recorded low total phytoplankton biovolume in most of the sampling stations. Similarly, Dinophyceae was only recorded in facultative pond, maturation pond 2, effluent, and downstream sampling stations with low total biovolume. Euglenaphyceae family recorded the highest biovolume at the facultative pond compared to other sampling stations (Figure 68).

Spatial changes in the composition of the different algal taxa in the WWTP pond series, is an evidence of progressive wastewater polishing in the WWTP pond series. Also, nutrients are available in the water column for utilization by algae for growth following degradation of organic matter and other substances in wastewater. Moreover, changes in the environmental conditions within the WWTP pond series encouraged growth and dominance of different algal taxa. In the WWTP ponds, algal blooms with different colors were observed in the water surface but were more pronounced in the facultative pond. Algal, blooms have been associated with the presence of algal toxins. Moreover, the presence of Cyanophytes especially the *Anabaena* Sp., and *Microcystis* sp. attest to this fact and they release algal toxins which are toxic to animals consequently of great concern.

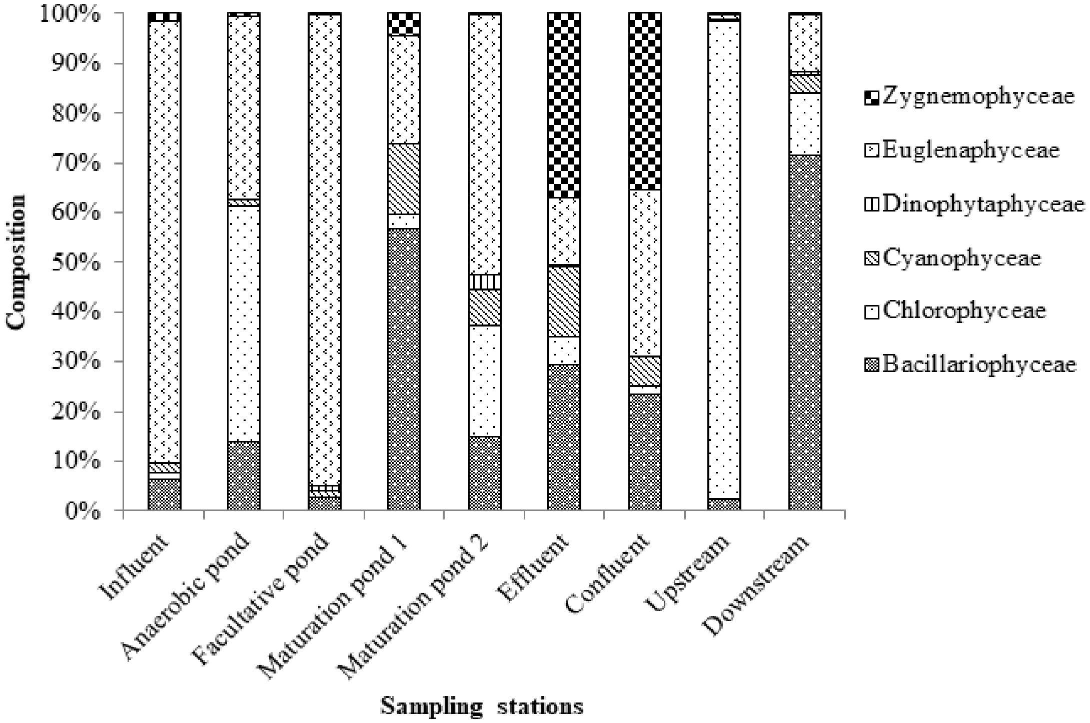

Figure 68: Relative abundance of phytoplankton taxa in sampling stations in the current Kisii Town WWTP.

4.3.10.4 Monthly variations

In terms of monthly variation, the total phytoplankton biovolume showed variation between the sampling months in the current Kisii Town WWTP, but it wasn’t significant. The month of August had the highest total biovolume of phytoplankton followed by June. The family Bacillariophyceae had the highest total biovolume in the month August. The families Cyanophyceae, Dinophyceae and Zygnematophyceae had a relatively low total phytoplankton biovolume throughout the sampling months (Figure 69). Single factor ANOVA test showed that the total phytoplankton biovolume variation was not statistically significant between the sampling months (F $_{(5, 18)}$ = 1.0151; *p* = 0.4376).

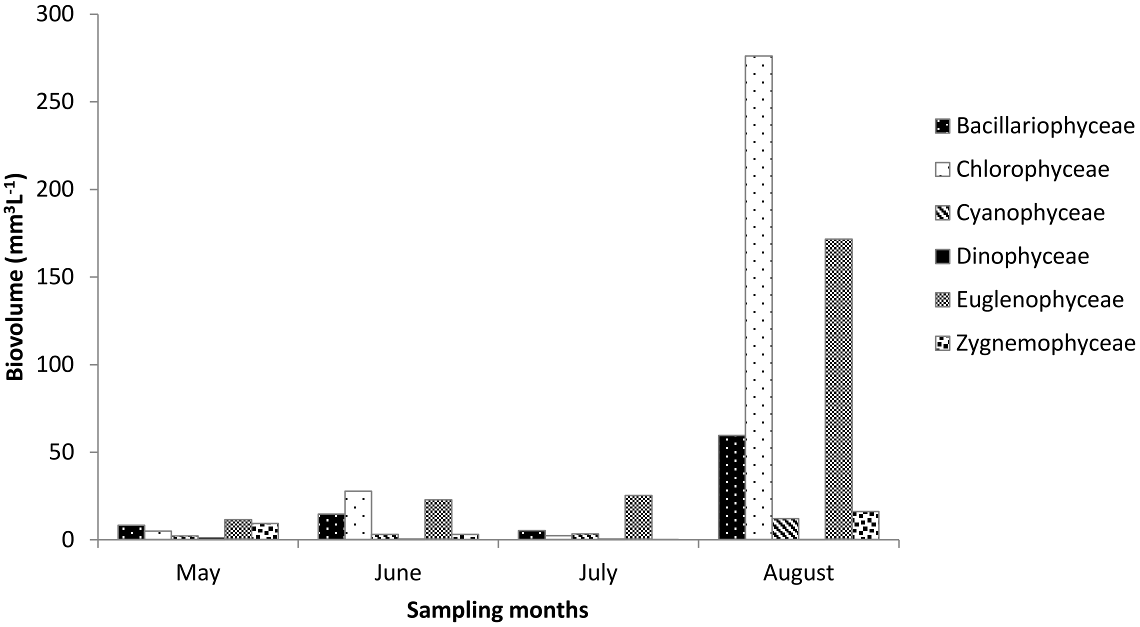

Figure 69: Monthly variations of phytoplankton biovolume in water samples from the current Kisii Town WWTP

4.3.10.5 Chlorophyll-a

The mean (± SE) of chlorophyll-a concentration calculated was 90.2 ± 17.23 mgM^{-3} with a minimum value of 0.01 mgM^{-3} and maximum value of 678.3 mgM^{-3}. The maturation pond 2 had the highest mean chlorophyll-a concentration of 175.9 ± 87.20 mgM^{-3} while the downstream station had the least mean (8.3 ± 4.04 mgM^{-3}) (Figure 70). Two-way ANOVA indicated there was a significant difference between the sampling stations (F $_{(8, 108)}$ = 1.75; *p* = 0.000). *Post hoc* Tukey Pairwise Comparisons revealed that the mean chlorophyll-a concentration of the maturation pond 2 was significantly higher compared with the other sampled stations.

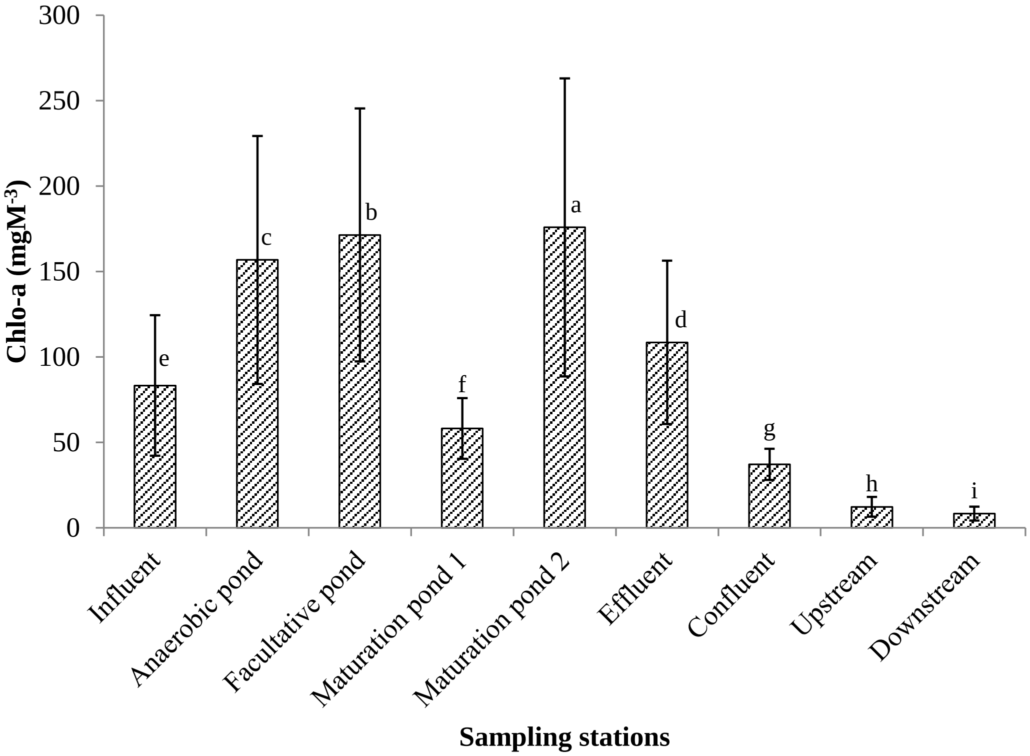

Figure 70: Spatial variation of chlorophyll-a concentration in water samples from the current Kisii Town WWTP.

Means followed by different letters (a-i) are significantly different ($p < 0.05$).

In terms of monthly variations, the month of August had the highest mean chlorophyll-a concentration of 314.7 ± 47.58 mgM^{-3} followed by the month of May with 22.4 ± 5.02 mgM^{-3}. The month of June and July had chlorophyll-a mean concentration of 12.7 ± 2.13 mgM^{-3} and 10.9 ± 1.76 mgM^{-3} respectively (Figure 71). Two factor ANOVA showed that chlorophyll-a mean concentrations were statistically significant between the sampling months ($F_{(3, 108)} = 39.08$; $p = 0.000$). Post hoc Tukey Pairwise Comparisons revealed that the mean chlorophyll-a concentration of August was significantly higher compared with the other sampling months.

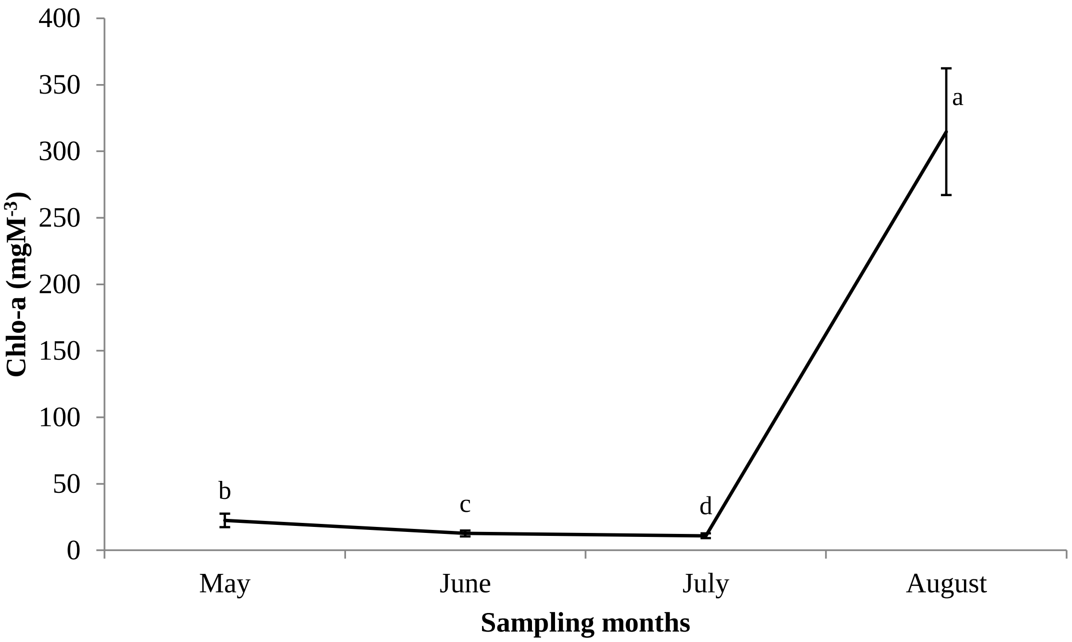

Figure 71: Monthly variation of chlorophyll-a concentrations in water samples from the current Kisii Town WWTP.
Means followed by different letters (a, b, c, d) are significantly different ($p < 0.05$).

4.3.10.6 Correlation between Physico-chemical parameters and phytoplankton abundance in Kisii Town Wastewater Treatment Plant

By carrying out correlation analysis, the relationship between the physico-chemical parameters and the phytoplankton were shown. Table 32 shows the obtained correlation matrices at 5% level of significance and only those variables with Pearson coefficients equal or higher than 0.50 ($r = 0.50$) were significant. Among the 14 variables analyzed, only some of them showed significant correlation relationship with phytoplankton.

Bacillariophyceae had a strong positive ($r = 0.55$) and strong negative ($r = -0.5$) correlation to TSS and chlorophyll-a respectively. Chlorophyceae showed a very strong negative ($r = -0.71$) correlation to SRP and strong negative correlation to conductivity ($r = -0.52$) and silicates ($r = -0.68$). For Cyanophyceae showed a very strong positive correlation to pH ($r= 0.72$) and TN ($r = 0.72$) and strong correlation to temperature ($r = 0.61$) and ammonium-nitrogen (r = 0.61) while Dinophyceae had a strong positive correlation (r = 0.68) to chlorophyll-a and Euglenaphyceae also had strong positive correlation to chlorophyll-a (r = 0.5624). Zygnematophyceae had a strong positive correlation to TN (r = 0.69) (Table 32).

Table 32: Pearson Correlation Coefficient (r) matrix of phytoplankton abundance and physico-chemical parameters in the current Kisii Town WWTP at 95 % confidence interval

	PH	Temp (°C)	DO (mgL^{-1})	Conductivity (µscm-1)	TSS (mgL^{-1})	TDS (mgL^{-1})	SiO_2 (mgL^{-1})	SRP (µgL^{-1})	NH_4-N (µgL^{-1})	NO_2-N (µgL^{-1})	NO_3-N (µgL^{-1})	TN (µgL^{-1})	TP (µgL^{-1})	Chlo-a (mgM^{-3})
Bacillariophyceae	0.0097	-0.0782	0.3850	-0.4490	**0.5504**	-0.4036	0.1694	-0.3175	0.2162	0.3477	0.2615	-0.2924	0.1321	**-0.5013**
Chlorophyceae	-0.2062	-0.2965	0.2054	**-0.5196**	0.2980	-0.4387	**-0.6836**	**-0.7066**	-0.2049	0.4663	0.3617	-0.0812	0.1709	-0.4006
Cyanophyceae	**0.7229**	**0.6077**	0.3455	0.0863	0.2572	-0.0381	0.2713	0.0290	**0.6130**	-0.4229	-0.2280	**0.7218**	0.1940	0.0650
Dinophyceae	0.4673	0.4955	0.2570	0.1714	-0.3986	0.0179	0.2388	0.1900	-0.1686	-0.3693	-0.4929	0.0816	0.0209	**0.6842**
Euglenaphyceae	0.2632	0.1695	0.1402	0.3109	-0.4568	0.2595	0.4906	0.4156	0.0769	-0.2795	-0.3840	0.1871	0.1261	**0.5624**
Zygnematophyceae	0.3871	0.1051	0.2142	-0.0713	-0.0361	-0.1141	0.2103	0.0697	0.7370	-0.0939	0.0599	**0.6854**	0.3814	-0.1059

4.3.11 Zooplankton

A total of eleven (11) zooplankton species belonging to three broad taxonomic groups were identified in the current Kisii Town WWTP. Cladocera was represented by 5 species while Rotifera family was represented by 4 species. For Copepoda, they were identified as nauplii stage and mature cyclopoida thus the family was only represented by one species (Table 33).

Table 33: A list of zooplankton species in water samples from the current Kisii Town WWTP

Cladocera	**Rotifera**
Bosmina longirostris	*Asplanchna* sp
Ceriodaphnia sp	*Brachionus angularis*
Ceriodaphnia cornuta	*Euchlanis* sp
Diaphanosoma excisum	*Trichocerca* sp
Moina micrura	
Copepoda	
Nauplii	
Cyclopoida	

4.2.11.1 Zooplankton Diversity

Zooplankton diversity indices recorded during the study period for the current wastewater treatment plant are summarized in Table 34. Total number of zooplankton species recorded at different sampling stations ranged between 1 and 11. The highest numbers of zooplankton species were recorded in maturation pond 1 with 11 species while the facultative pond had the least number of species of 1. The highest Shannon-Wiener diversity index (H') was at the influent (H'=2.17) followed by maturation pond 2 with 2.017. Facultative pond had the least diversity index (H'=0) with one taxonomic group dominating. The dominant index (D) had a maximum value of 1 which was recorded at the facultative pond while the influent station had the least value of 0.1282. Along river Riana, the dominant index values were between 0.2013 and 0.2305 at downstream and upstream sampling stations respectively. In terms of species richness (d), the influent was richer with a value of 2.457 while the facultative pond had the least (0). Evenness (E), it ranged from 0.3354 at the maturation pond 1 to 1 at the facultative pond sampling station.

Table 34: Zooplankton diversity indices of water samples from the current Kisii Town WWTP

	Influent	**Anaerobic pond**	**Facultative pond**	**Maturation pond 1**	**Maturation pond 2**	**Effluent**	**Confluent**	**Upstream**	**Downstream**
Taxa (s)	9	7	1	11	9	7	8	6	8
Shannon-Weiner (*H'*)	2.17	2.011	0	1.306	2.017	1.979	1.784	1.667	1.862
Dominance (D)	0.1282	0.1436	1	0.4325	0.1758	0.1493	0.2011	0.2305	0.2013
Margalef	2.457	1.985	0	1.82	2.14	2.233	2.015	1.731	1.931
Evenness e^H/S	0.8762	0.934	1	0.3354	0.7515	0.9047	0.6616	0.7567	0.7148

4.2.11.2 Zooplankton abundance and spatial variations

In the current Kisii Town WWTP, maturation pond 1 sampling station had the highest zooplankton total abundance followed by maturation pond 2 while the facultative pond had the least total zooplankton abundance (Table 35). Cladocera recorded the highest abundance at maturation pond 1 and upstream sampling stations. *Diaphanosoma excisum* was the most dominant in abundance and peaked in Maturation pond 1 sampling station (153 IndL^{-1}). *Moina micrura* dominated in maturation pond 1 with abundance of 42 IndL^{-1} while the effluent had the least (1 IndL^{-1}). *Bosmina longirostris* was only recorded in the influent and maturation pond 1 with abundance of 2 IndL^{-1} and 3 IndL^{-1} respectively.

Ceriodaphnia cornuta was recorded only in maturation ponds 1 and 2 with abundances of 3 IndL^{-1} and 2 IndL^{-1} respectively. *Ceriodaphnia* sp. was only recorded in the maturation pond 1 sampling station with an abundance of 1 IndL^{-1} (Table 35).

For Copepoda taxonomic group, the highest abundance was recorded at downstream station while the lowest at effluent sampling station. Copepoda, nauplii, and Cyclopoida were recorded in all sampling stations except at the facultative pond. Nauplii abundance ranged between 2 IndL^{-1} and 23 IndL^{-1} while Cyclopoida ranged from 2 IndL^{-1} to 10 IndL^{-1} (Table 35).

For Rotifera, the highest abundance was recorded in maturation pond 1 and closely followed by maturation pond 2. The least abundance for Rotifera was recorded at facultative pond. *Asplanchna* sp. abundance ranged between 1 – 7 IndL^{-1}. *Brachionus angularis* was recorded in all sampling stations except in the facultative pond and the abundance ranged between 1 - 10 IndL^{-1}. *Trichocerca* sp. abundance was recorded in all sampling stations and ranged between 2 – 8 IndL^{-1} with maturation pond 2 having the highest abundance. On the other hand, *Euchlanis* sp. was recorded in all sampling stations except in the facultative pond and its relative abundance ranged between 1 – 8 IndL^{-1} (Table 35).

Table 35: Spatial distribution of zooplankton taxonomic groups in water samples from different sampling sites in current Kisii Town WWTP

	Abundance (IndL^{-1})								
Taxa	**Influent**	**Anaerobic pond**	**Facultative pond**	**Maturation pond 1**	**Maturation pond 2**	**Effluent**	**Upstream**	**Confluent**	**Downstream**
Rotifera									
Asphlanchna sp	1			7	6			1	2
Brachionus angularis	3	3		10	3	2	2	1	5
Trichocerca sp	5	3	2	3	8	2	2	2	3
Euchlanis sp	5	4		8	3	4	1	2	1
Total	**13**	**10**	**2**	**28**	**21**	**7**	**4**	**5**	**11**
Copepoda									
Nauplii	9	4		10	3	2	12	16	23
Cyclopoida	4	3		2	7	3	5	3	10
Total	**13**	**7**	**0**	**12**	**10**	**5**	**17**	**20**	**33**
Cladocera									
Bosmina longirostris	2			3					
Ceriodaphnia cornuta				3	2				
Ceriodaphnia sp				1					
Diaphanosoma excisum	6	7		153	23	4	3	14	9
Moina micrura	3	3		42	8	1		5	5
Total	**9**	**10**	**0**	**202**	**33**	**5**	**3**	**19**	**14**
Total zooplankton abundance	**36**	**27**	**2**	**242**	**64**	**17**	**24**	**44**	**59**

4.2.11.3 Monthly variations

For the current WWTP, as shown in Table 36, there were variations in the recorded total zooplankton abundance during the study period with the month of May recording the least total zooplankton abundance.

Table 36: Monthly variation of zooplankton abundance in water samples from the current Kisii Town WWTP

Month	**No. of species**	**Abundance (IndL^{-1})**	**Percentage (%)**
May	8	115.8	22.5
July	10	212.5	41.3
August	9	186.7	36.3

Figure 72 shows monthly distribution of zooplankton total abundance for each taxonomic group for the current wastewater treatment plant. Cladocera recorded the highest total abundance during the month of July with *Diaphanosoma excisum* recording the highest abundance. Similarly, Copepoda taxonomic group recorded the highest total abundance in the month of July with Nauplii dominating. For Rotifera, the highest total abundance was recorded in August and the dominant species were *Brachionus angularis, Euchlanis* sp., and *Trichocerca* sp.

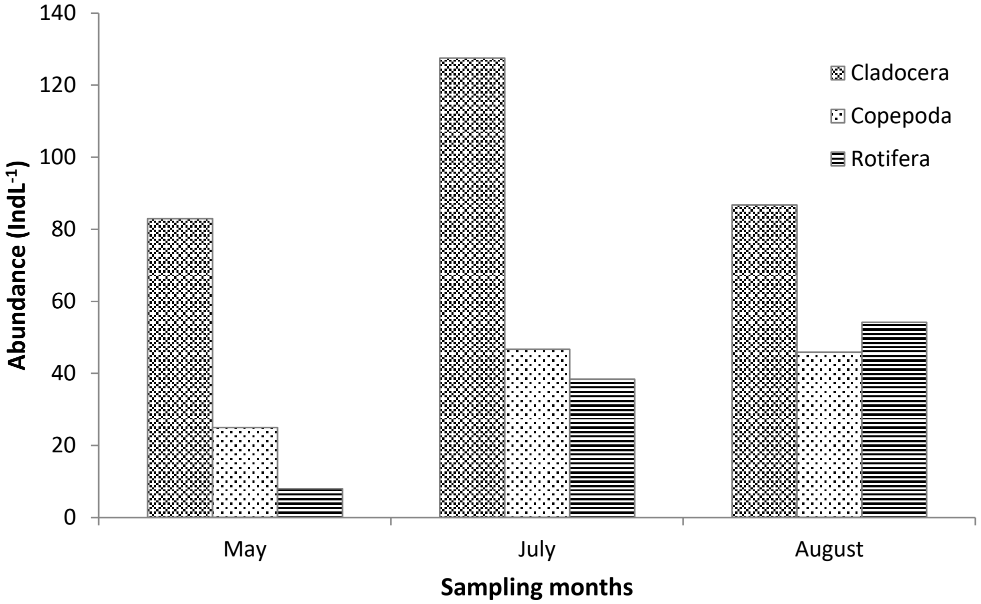

Figure 72: Monthly distribution of zooplankton taxa in water samples from the current Kisii Town WWTP.

4.2.11.4 Correlation between Physico-chemical parameters and Zooplankton abundance and distribution in the current design of the Kisii Town Wastewater Treatment Plant

By carrying out correlation analysis the relationship between the physico-chemical parameters and the zooplankton were shown. Table 37 shows the obtained correlation matrices at 5% level of significance and only those variables with Pearson coefficients equal or higher than 0.50 (r = 0.50) were significant. Among the 14 variables analyzed, only some of them showed significant correlation relationship with zooplankton. Copepoda showed a very strong positive correlation (r= 0.83) to nitrite-nitrogen and to nitrate-nitrogen (r = 0.73). On the other hand, Copepoda showed a strong negative correlation to temperature (r = - 0.69), conductivity (r = -0.63), TDS (r = -0.61), SRP (r = -0.63) and TN (r = -0.68) (Table 37).

Table 37: Pearson Correlation Coefficient (r) matrix of zooplankton abundance and physico-chemical parameters for the current Kisii Town WWTP at 95 % confidence interval

	PH	Temp (°C)	DO (mgL^{-1})	Conductivity (µScm^{-1})	TSS (mgL^{-1})	TDS (mgL^{-1})	SiO_2 (mgL^{-1})	SRP (µgL^{-1})	NH_4-N (µgL^{-1})	NO2-N (µgL^{-1})	NO_3-N (µgL^{-1})	TN (µgL^{-1})	TP (µgL^{-1})
Cladocera	0.3511	0.3541	0.1477	0.1179	0.0522	0.0583	0.4043	0.0307	0.2709	-0.2085	0.1467	0.0156	-0.1831
Copepoda	-0.3000	**-0.6873**	0.2199	**-0.6349**	0.3174	**-0.6081**	-0.1786	**-0.6280**	-0.2019	**0.8325**	**0.7261**	**-0.6833**	-0.2529
Rotifera	0.1504	0.4400	-0.2285	0.3241	0.1631	0.2376	0.0734	0.1219	-0.2119	-0.3758	-0.1275	-0.1697	-0.4982

4.3.12 Total and Fecal coliforms

The total and fecal coliforms (TC and FC) counts of wastewater samples obtained from the current Kisii Town WWTP are presented in Table 38.

Table 38: Spatial variations of Total and Fecal coliforms counts in water samples from the current Kisii Town WWTP

	TC (counts/100ml)	FC (counts/100ml)
Influent	57.00 ± 14.8	34.25 ± 12.2
Anaerobic pond	46.50 ± 8.1	31.00 ± 5.4
Facultative pond	34.50 ± 8.5	18.50 ± 2.7
Maturation pond 1	27.75 ± 4.9	10.50 ± 4.2
Maturation pond 2	39.50 ± 10.7	8.25 ± 4.6
Effluent	35.00 ± 8.5	10.50 ± 2.6
Confluent	36.75 ± 14.6	20.75 ± 9.9
Upstream	25.00 ± 8.5	10.50 ± 1.8
Downstream	36.75 ± 8.3	17.25 ± 2.1
Percentage reduction	38.6	69.3
NEMA	≤30	Nil

From the results, they were present in all wastewater samples collected from the WWTP pond series including the sampling points along Riana river. The mean of TC recorded was 37.64 ± 3.3 counts/100ml with minimum and maximum values of 11 and 85 counts/100ml. The influent station had the highest mean of 57.0 ± 14.8 counts/100ml compared with the effluent (35.0 ± 8.5 counts/100ml). The upstream sampling station had lower mean for TC counts compared with the downstream station. In terms of trend, the mean TC counts generally showed a decline in total coliform counts between the influent and effluent sampling stations, indication that there numbers were being reduced as the wastewater underwent polishing. One-way ANOVA showed that mean TC counts were not significantly different among the sampling stations ($F_{(8, 27)} = 0.9$; $p = 0.534$).

The mean for fecal coliforms counts recorded was 17.94 ± 2.3 counts/100ml with minimum and maximum values of 0 and 60 counts/100ml. The influent station had the highest mean value of 34.25 ± 12.2 counts/100ml while maturation pond 2 had the least count of 8.25 ± 4.6 counts/100ml. The upstream sampling station had a lower FC mean (10.5 ± 1.8 counts/100ml) compared with the downstream station (17.25 ± 2.1 counts/100ml). In terms of trend, there was a decline in fecal coliform counts between the influent and effluent sampling stations, indication that there numbers were being reduced as the wastewater underwent polishing in the WWTP system. One-way ANOVA showed that TC counts were not significantly different among the sampling stations ($F_{(8, 27)} = 2.37$; $p = 0.05$) (Table 38). The efficiency of the current WWTP in total and fecal coliform removal was assessed in terms of their percentage reduction. The TC removal efficiency was 38.6 % while for FC was 69.3 % between the influent and the effluent sampling stations, indication that there numbers were being reduced as the wastewater underwent polishing as it passed through the WWTP pond series. However, in terms of effluent discharge TC and FC compliance to national standards, they were not within the allowable limits by NEMA standards as shown in Table 38.

In terms of monthly variations, the total and fecal coliform counts results are presented in Table 39. The mean value for TC recorded was 37.64 ± 3.33 Counts/100ml with minimum and maximum values of 11 and 85 Counts/100ml. The highest TC mean was recorded in the month of May with 46.33 ± 7.68 Counts/100ml followed by the month of August with 44.89 ± 8.3 Counts/100ml. The month of July had the least mean value of 34.11 ± 4.3 Counts/100ml. In terms of trend, the mean TC counts fluctuated with no trend. One-way ANOVA showed that mean TC counts were not significantly different among the sampling months ($F_{(3, 32)} = 2.5$; $p = 0.077$).

The mean for FC count recorded was 17.94 ± 2.33 Counts/100ml with minimum and maximum values of 0 and 60 Counts/100ml. The month of May had the highest counts with 24.11 ± 6.65 Counts/100ml while June with the least counts of 11.44 ± 1.17 Counts/100ml. In terms of trend, the mean FC counts fluctuated with no trend. One-way ANOVA showed that FC counts were not significantly different among the sampling months ($F_{(3, 32)} = 1.96$; $p = 0.14$) (Table 39).

Table 39: Monthly variations of total and fecal coliform counts in water samples from the current Kisii Town WWTP

Months	TC (Counts/100ml)	FC (Counts/100ml)
May	46.33 ± 7.676	24.11 ± 6.653
June	25.22 ± 3.386	11.44 ± 1.168
July	34.11 ± 4.312	13.78 ± 3.054
August	44.89 ± 8.272	22.44 ± 5.039

4.4 Comparison between the initial and current Kisii Town Wastewater Treatment Plant

The means of physico-chemical parameters measured at the influent and effluent from the initial and current Kisii Town WWTPs were compared to reveal whether there was a significant difference between the plants following renovation. The calculated independent sample *t*-test showed that the influent means of DO, TSS, NO_2-N, SRP, TP, TN, and NH_4-N values were significantly different between the two wastewater treatment plant designs. For the effluent, the calculated independent sample *t*-test showed that means of DO, TSS, NO_2-N, NO_3-N, TP, TN, and NH_4-N values were significantly different between the two wastewater treatment plant designs (Table 40). On the other hand, six (6) out of fourteen (14) of the measured physico-chemical parameters in the effluent discharged from both designs were within the NEMA standards. These parameters include: pH, temperature, TDS, NH_4-N, NO_2-N, and NO_3-N.

Table 40: A Comparison of physico-chemical and biological parameters between the initial and current Kisii Town WWTPs

Parameter	**Design**	**Influent (mean ± SE)**	***t*-value**	**Effluent (mean ± SE)**	***t*-value**
pH	Initial	6.54 ± 0.61	$t_{(22)} = 1.287$;	7.14 ± 0.45	$t_{(22)} = 1.391$;
	Current	7.33 ± 0.08	$p = 0.211$	7.77 ± 0.06	$p = 0.178$
Temperature (°C)	Initial	22.27 ± 0.21	$t_{(22)} = 0.454$;	25.93 ± 0.38	$t_{(22)} = 0.388$;
	Current	22.08 ± 0.34	$p = 0.655$	26.09 ± 0.16	$p = 0.702$
DO (mgL^{-1})	Initial	2.00 ± 0.73	$t_{(22)} = 2.426$;	5.57 ± 1.08	$t_{(22)} = 2.192$;
	Current	0.23 ± 0.04	$p = 0.024$	2.67 ± 0.76	$p = 0.039$
Conductivity (μScm^{-1})	Initial	1403.97 ± 325.71	$t_{(22)} = 0.874$;	616.07 ± 37.11	$t_{(22)} = 0.893$;
	Current	1097.75 ± 128.92	$p = 0.391$	665.58 ± 41.17	$p = 0.381$
TSS (mgL^{-1})	Initial	172.55 ± 39.78	$t_{(22)} = 2.649$;	30.02 ± 2.36	$t_{(22)} = 7.322$;
	Current	65.34 ± 7.41	$p = 0.015$	77.16 ± 5.99	$p = 0.0000$
TDS (mgL^{-1})	Initial	572.16 ± 90.97	$t_{(22)} = 1.016$;	293.22 ± 28.57	$t_{(22)} = 0.668$;
	Current	438.32 ± 95.27	$p = 0.321$	259.04 ± 42.46	$p = 0.511$
NO_2-N (μgL^{-1})	Initial	43.31 ± 9.12	$t_{(22)} = 2.502$;	35.45 ± 7.12	$t_{(22)} = 3.760$;
	Current	20.21 ± 1.44	$p = 0.02$	8.42 ± 0.99	$p = 0.001$
NO_3-N (μgL^{-1})	Initial	67.08 ± 11.98	$t_{(22)} = 0.25$;	45.73 ± 7.25	$t_{(22)} = 2.229$;
	Current	62.88 ± 11.81	$p = 0.805$	26.38 ± 4.77	$p = 0.036$
SRP (μgL^{-1})	Initial	1120.96 ± 82.49	$t_{(22)} = 2.086$;	479.91 ± 88.99	$t_{(22)} = 0.470$;
	Current	664.85 ± 202.46	$p = 0.049$	557.03 ± 137.95	$p = 0.643$
TP (μgL^{-1})	Initial	1604.23 ± 213.36	$t_{(22)} = 2.181$;	1443.38 ± 243.97	$t_{(22)} = 3.726$;
	Current	800.99 ± 300. 12	$p = 0.04$	2556.85 ± 172.55	$p = 0.001$
TN (μgL^{-1})	Initial	800.12 ± 201.64	$t_{(22)} = 2.768$;	1080.45 ± 248.68	$t_{(22)} = 2.684$;
	Current	236.24 ± 28.84	$p = 0.011$	390.69 ± 64.88	$p = 0.014$
NH_4-N (μgL^{-1})	Initial	464.14 ± 147.93	$t_{(22)} = 2.869$;	776.11 ± 109.47	$t_{(22)} = 2.793$;
	Current	37.71 ± 14.31	$p = 0.009$	276.86 ± 141.30	$p = 0.011$
SiO_2 (mgL^{-1})	Initial	33.61 ± 5.78	$t_{(22)} = 1.649$;	30.42 ± 5.70	$t_{(22)} = 1.509$;
	Current	20.63 ± 5.34	$p = 0.113$	21.25 ± 2.11	$p = 0.146$
Chlo-a (mgM^3)	Initial	39.8 ± 15.52	$t_{(22)} = 0.988$;	88.91 ± 21.41	$t_{(22)} = 0.375$;
	Current	83.26 ± 41.14	$p = 0.334$	108.53 ± 47.79	$p = 0.713$

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Introduction

This chapter presents the discussions on the results obtained of the five study objectives (Chapter 1). The first part discusses changes in the physico-chemical parameters and whether the discharged effluent met the national and international effluent standards guidelines. The second part focuses on the variation of the plankton in the treatment plant and how it was influenced by physico-chemical parameters. Thirdly, heavy metals results are discussed in terms of concentrations in wastewater, sediments, and their accumulation in plankton. Moreover, total and fecal coliforms counts are discussed including whether the discharged effluent met the national and international standard guidelines for them. Lastly, results for the initial and current Kisii Town WWTPs are discussed.

5.2 Wastewater treatment and stabilization ponds

Wastewater is rich with pollutants grouped into physical, chemical, heavy metals, oil and grease, and biological (UNESCO, 2017). Disposal of untreated or partially treated wastewater into water bodies has been associated with eutrophication, affecting aquatic species composition and dominance (Kumar, 2015) including posing health hazards to human and animals. Therefore, there is need for wastewater treatment before disposal or reuse. On the other hand, population increase has led to increased demand for clean water and put pressure on the available wastewater treatment facilities resulting in discharge of semi-treated wastewater oblivious of its consequences (UNESCO, 2017).

In the Tropics, wastewater stabilization ponds are common in domestic and municipal wastewater treatment due to their low cost of operation, favourable climate, low-maintenance, and sustainability (Amoatey & Bani, 2011). Moreover, to an extent they are efficient in wastewater treatment but with inefficiencies and therefore do not meet local, national, and international required effluent standards in relation to TN, TP, heavy metals, and coliforms (Atwebembeire et al., 2019; Nikuze *et al*., 2020; Omondi, 2019; Ronoh, 2017; Wanjohi et al., 2019). Causes of inefficiencies of the WWTPs include: land size, increased sewage wastewater loading, capital, and energy among others. Nevertheless, WWTPs need to polish the effluent so as to meet quality standards. The means by which pollutants are removed are through physical, chemical, and biological processes. Physical processes include filtration, sedimentation, vitalization and adsorption while chemical processes include hydrolysis, precipitation, and redox reactions. The biological processes of pollutant removal include: microbial and algal metabolism (Thamke and Khan, 2021). Kisii Town WWTP was renovated during the year 2019-2021 following inefficiencies of the previous design in wastewater polishing. In the current study, wastewater polishing efficiencies of the Kisii Town WWTPs were assessed.

5.3 Physico-chemical parameters

5.3.1 pH

For both Kisii Town WWTPs, the recorded mean pH values of the effluent were significantly higher than that of the influent that’s the influent pH was more acidic than that of effluent which was more alkaline. The low pH value was attributed to high organic load in the sewage wastewater and the process of bio-treatment led to pH increase in the effluent. For instance, dense algal growth results in pH increase due to assimilation of nitrates, and carbon dioxide. This holds as during the study, there was increase in algal biomass in the lagoons. These findings are in agreement by observations by Ronoh (2017) in a study conducted in Moi University WWTP and Wanjohi et al., (2019) in his study conducted in University of Eldoret WWTP where they both observed an increase in pH between the influent and the effluent. The mean pH values of the effluent discharged from the treatment plant into river Riana were within the permissible limits by NEMA, WHO and EPA standards of 6 - 9 during the study period. Effluent discharge with extreme pH ranges can be harmful to aquatic organisms as most biochemical reactions are catalyzed by enzymes which act within small pH ranges.

The month of May, for the current design, and December, for initial design, had the lowest mean pH values. This was attributed to higher concentrations of organic and inorganic loads in the ponds following water evaporation during the short rains and drier seasons resulting in lower wastewater levels. The low water levels in the WWTP implied that the high organic and inorganic loading were concentrated in a smaller volume of water thus making the discharge effluent to be of poor quality. In addition, effluent discharges from domestic, and institutions among others within the municipality can also result in change of pH. The high pH values recorded during the sampling period in the other months were attributed to dilution effect from rainfall which characterized the sampling months. Similar results were obtained in the study conducted in Gacuriro wastewater treatment plant, Rwanda where pH temporal variation was linked to seasonality (Nikuze, Niyomukiza, Nshimiyimana, & Kwizera, 2020).

5.3.2 Conductivity

The mean EC of Effluent discharged into river Riana, was within WHO and EPA discharge standards. The mean conductivity values for the influent were higher than those of the effluent; that is it depicted a general declining trend from the influent point to the discharge point. This was attributed to decline in dissolved salts and heavy metals concentrations responsible for conductance as the wastewater underwent treatment. Also, the higher conductivity value recorded in the influent can be attributed to high inorganic load as the water enters the ponds. On the other hand, the low conductivity value recorded at the effluent can be attributed to the utilization of dissolved nutrients by phytoplankton found in the lagoons. This is evidenced by the increasing trends of algal biovolume from the inlet to maturation ponds. This findings corroborates well with those obtained from the University of Eldoret WWTP (Wanjohi, Mwasi, Mwamburi & Isaboke, 2019). During the entire sampling period, the upstream sampling point on river Riana recorded a lower mean conductivity value than the downstream sampling point. This can be attributed to minimal human activity in upstream while the downstream can be attributed to the treatment plant which act as a point source of pollution. This corroborates well to the studies done by Omondi (2019) and Babu et al. (2021) in L. Naivasha, and L. Victoria, respectively whereby, they observed polluted sampling sites in the respective lakes recorded higher conductivity.

Previous studies have shown that changes in seasons results in temporal conductivity variations (Atwebembeire et al., 2019; Omondi, 2019). In the current study, both treatment plant designs showed monthly variation in mean conductivity. The low mean conductivity that was recorded in the month of May (in the current WWTP) and December (in the initial WWTP) were linked to increased rainfall during the sampling months which led to dilution of the effluent in the WWTP. On the other hand, high conductivity during the dry season was associated with increasing concentrations of chemical compounds responsible for conductance in the wastewater concentrated by evaporation this implied that the concentrations of ions (cations and anions) per unit volume of water was high thereby increasing effluents’ EC. Moreover, strong winds can also re-suspend sediments including chemicals in the lagoons due to their shallow depth hence increase electrical conductivity.

5.3.3 Temperature

The recorded mean temperature of discharged effluent into Riana river was within the allowable limits by NEMA, WHO and EPA. Moreover, the ranges were suitable for wastewater treatment as it was within the optimal ranges of microbial activities responsible for organic and inorganic substances breakdown. In addition, the recorded temperature ranges were optimal for algal growth hence lagoons had diverse communities of algae. In turn, the algae converted the nutrients into biomass thus polishing the wastewater in the lagoons. The temperature recorded for both treatment plant designs, showed a slight increase in the mean temperature from the influent to effluent sampling stations. These changes were attributed to harsh environmental conditions (in the anaerobic ponds), sampling time, and the dimensions of the stabilization ponds with shallow mean depth of the ponds. Moreover, the increasing trends of algal biovolume in the lagoons contributed to increase in suspended solids which absorb solar energy and retain its heat for longer periods.

The increase in temperature in wastewater in the sampling stations also influenced the solubility of compounds which was evidenced by spatial variation of heavy metals concentrations in wastewater during the study. Ronoh (2017) in his study at Moi University wastewater treatment plant, and Wanjohi et al. (2019) in the University of Eldoret wastewater treatment plant both observed decline in mean temperature between the influent and the effluent sampling points. The high temperatures were attributed to exothermic reactions during breakdown of organic and inorganic matter in the wastewater.

In this study, there were changes in mean temperature between the sampling months for both designs. These changes were attributed to seasonality. Studies have shown that water temperature tend to vary with seasons. High temperatures recorded during the dry season have been attributed to water depth, solar radiation, and suspended particles absorbing solar energy. Also, domestic wastewater has a higher temperature than that of maturation and tertiary ponds because of large institution within Kisii such as hospitals, schools and polytechniques could be discharging effluents with high temperature due to their cooking ventures. Also domestic households with domestic hot water instant showers contribute with effluent with high temperature at influent at the WWTP. High temperature is suitable for organic matter decomposition in the ponds as they are shallow. During wet seasons, lower temperatures have been reported and associated with clouds which cover solar energy from reaching the water surface. Also, the storm water, and rainfall cooled the lagoon surface water. Moreover, there is increasing sewage wastewater that flows to the WWTPs during the wet season (Omondi, 2019; Otieno, 2015; Ronoh, 2017; Waithaka, 2017; Zobeidi, Ammar & Bebba, 2015).

5.3.4 Dissolved oxygen (DO)

Dissolved oxygen percentage increase in wastewater was 180 % for the initial wastewater treatment plant design, while it increased by 1250 % for the current design. This indicated that the quality of wastewater improved as it underwent polishing through the lagoons before being discharged as expected. Anaerobic ponds had least mean DO. The significantly low levels of DO in the influent and anaerobic pond were attributed to the decomposition of sewage rich in organic matter by microbes that required oxygen. The increase of DO concentrations in the facultative pond was linked to photosynthetic algal activities. The high level of DO in the effluent was linked to the reduction of organic matter in the maturation ponds and exposure of wastewater in the ponds to atmospheric oxygen resulting from mixing brought about by strong winds blowing above the ponds. With reference to Riana river, for both initial and current designs, higher DO mean levels recorded at the upstream sampling station can be attributed to lower temperature levels, and lower organic matter while the lower levels at the downstream stations can be attributed to higher organic loads from the treatment plant, and higher sediments; thus absorbing solar radiation leading to higher temperature resulting low DO concentrations. The current findings corroborates study findings by Ronoh (2017) in the Moi University sewage treatment plant and other similar studies (Babu et al., 2021; Zobeidi, Ammar & Bebba, 2015). Monthly, the mean DO showed a significant difference between the sampling months for both wastewater treatment plant designs. These differences were attributed to seasonality, where water temperature plays a role in DO solubility (Omondi, 2019; Otieno, 2015; Waithaka, 2017). Also, low DO concentrations can be attributed to variable levels of organic matter and differential flow rates of sewage water from the municipality.

5.3.5 Total Suspended Solids (TSS)

The recorded mean TSS concentrations for the influent were relatively higher than the effluent for both treatment plant designs. The reduction was attributed to removal of suspended solids in wastewater column by algae and microorganisms and also through the process of sedimentation of settleable solids forming sludge. On the other hand, the availability of nutrients in the lagoons promoted the growth of algae, in turn contributing to increase of suspended solids in the lagoons including the effluent discharged. The effluent discharged TSS concentration from the initial plant design was within the maximum permissible limits by NEMA, WHO, and EPA standards. For the current design, it was above the permissible limits by NEMA which is 30 mgL^{-1} but it was within WHO set standards and not EPA limits, resulting from presence of algal cells in the effluent. The upstream sampling station had lower mean TSS concentrations than the downstream sampling station and this was attributed to lower suspended particulate matter. However, the higher mean TSS concentrations at the downstream sampling station can be attributed to the treatment plant's organic load discharge into the river. The study findings corroborate well with findings by Ronoh (2017), who noted in their study that there was a significant difference in mean TSS values of samples collected from influent compared with effluent from the sewage treatment plant, and the outlet didn't meet NEMA and Moi University effluent discharge standards.

In terms of monthly variations, from these results, there was a considerable significant mean TSS concentrations difference between the sampling months for both wastewater treatment plant designs, and this was attributed to the increased amount of suspended solids in the wastewater column due to surface runoff leading to increase inorganic and organic matter and this is in agreement with other similar studies (Nikuze et al., 2020).

5.3.6 Total Dissolved Solids (TDS)

Total dissolved solids had a steady decline in mean concentration between the influent and effluent station in the WWTPs with reduction efficiency between 41-49%. This reduction indicates significant polishing of wastewater by the WWTP. Subsequently, effluent discharged mean TDS concentrations were within the permissible limits of NEMA (1200 mgL^{-1}), EPA (1000 mgL^{-1}), and WHO (500 mgL^{-1}) standards for both WWTPs designs. High mean TDS concentrations recorded at the influent sampling stations were linked to higher organic and inorganic materials load from municipal wastes. In the anaerobic pond, there was progressive decomposition of organic and inorganic matter in wastewater resulting in simpler harmless soluble substances (TDS). Reduction in the mean TDS levels through the WWTP pond series towards the effluent sampling station was associated with phytoplankton nutrient uptake and utilization, settlement of both organic and inorganic particulate matter forming sludge. This is in line with previous studies which have shown that settling of the inorganic and organic substances in the stabilization ponds results in TDS concentrations reduction while the substances forms part of sludge (Ronoh, 2017).

In terms of monthly variation, the month of September in the initial WWTP and July for the current WWTP had the lowest mean TDS concentrations and this was attributed to dilution effect attributed to high prevailing rainfall, and algal uptake of nutrients. Coincidentally, during this period, the phytoplankton biovolume was relatively high together with nutrients concentrations. June and December for the current and initial WWTP, respectively had the highest mean TDS and this was associated with reduction in wastewater levels in the WWTPs’ ponds due to higher evaporation rates, and reduction in municipal sewage flow into the lagoons, coinciding with the dry season. The higher rates of evaporation reduced the volume of water in the WWTP thus concentrating dissolved solids in wastewater into a smaller volume. This study's findings are consistent with other findings (Otieno, 2015).

5.3.7 Nutrient concentrations

5.3.7.1 Silicates

The mean silicates concentrations reduced minimally (with 9% reduction) between the influent and effluent sampling stations, indicating the WWTP had poor efficiency in its removal. This could be due to a low demand of silicates by algae or phytoplankton in the WWTP. Therefore, the WWTP acts as a point source of pollution of silicate into river

Riana. This is evidenced by the increase in silicate concentration between the upstream (14.60 ± 4.21 $\mathrm{mgL^{-1}}$) and downstream (21.28 ± 3.33 $\mathrm{mgL^{-1}}$) sampling stations along river Riana before and after the effluent discharge point respectively. The poor performance of the WWTP in silicates removal was associated with lot of dissolved solids, inorganic matter and organic materials from the municipal wastewater. In terms of monthly variations, there was a significant mean difference in silicate concentrations among the sampling months for both treatment plant designs. These differences were generally attributed to seasonality of wastewater load during the sampling period.

5.3.7.2 Soluble Reactive Phosphorous (SRP)

The mean SRP levels for both WWTPs showed a significant decline from the influent to effluent sampling stations. Subsequently, effluent discharged mean SRP concentrations were within the permissible limits of EPA (1000 $\mathrm{\mu gL^{-1}}$) standards for both WWTPs designs. The higher mean SRP levels at the influent stations can be attributed to increased sediment loads, organic matter, and inorganic particulate matter from the municipal wastewater. While, the lower SRP levels recorded at the effluent station can be attributed to nutrient removal and efficiency of the ponds by phytoplankton uptake and utilization by microbes. The higher concentrations of SRP in the lagoons supported algal growth in the lagoons. Further, the microbes and algal cells die off and settle in the lagoons as sludge. These findings are similar to the studies carried out by Omondi (2019) and Wanjohi et al. (2019). Consequently, the reduction in SRP levels along river Riana based on the upstream and downstream observations can be attributed to R. Riana’s self-purification capacity. Monthly, Two-factor ANOVA test showed that the mean SRP values were significantly different among the sampling months for the initial and current design and these differences were attributed to seasonality of wastewater flow into the WWTP (Omondi, 2019).

5.3.7.3 Nitrite-Nitrogen

There was a decline in mean nitrite-nitrogen concentrations as the wastewater passed through the WWTP. The higher mean nitrite-nitrogen levels at the influent stations can be attributed to increased organic matter rich in nitrogenous compounds in the municipal wastewater. Utilization of nutrients by algae can be the reason for the low levels of nitrite-nitrogen in the effluent sampling station. Also, the reduction in nitrite-nitrogen concentration was linked to the process of nitrification that’s being oxidized to nitrate by the nitrobacter bacteria. The nutrient rich organic matter in the WWTP, therefore created a favorable environment for nitrification by the bacteria (Curtin, Duerre, Fitzpatrick, & Meyer, 2011). In terms of compliance, the concentration of nitrite-nitrogen in the discharged effluent from the initial and current wastewater treatment plant designs were within the maximum allowable limits by NEMA, WHO and EPA standards. In addition, these results show that both designs of the treatment plants acted as point source of pollution to river Riana based on the upstream-downstream increasing trend. This findings agree with other studies that have shown that sewage treatment plants act as point source of pollution if they are not efficient in nitrite-nitrogen removal (Musungu et al., 2013; Ronoh, 2017).

5.3.7.4 Nitrate-Nitrogen

Monthly, there was a significant difference in nitrate-nitrogen levels between the sampling months for both wastewater treatment plants. This variation was attributed to seasonality. Spatially, for both wastewater treatment plants, the discharged effluent means values for nitrate-nitrogen were within the maximum allowable limits by NEMA, WHO, and EPA standards. Nevertheless, discharge of nitrates to rivers leads to eutrophication negatively impacting aquatic ecosystems. Higher level of nitrate-nitrogen in the upstream station was an indication that river Riana had other sources of nitrate apart from the treatment plant such as runoffs from agricultural fields. The reduction of nitrate-nitrogen concentration for both designs from influent to effluent was attributed to denitrification by Pseudomonas bacteria which reduced nitrate to nitric oxide, nitrous oxide, then finally nitrogen gas (Curtin et al., 2011). Also, algal assimilation of nitrates into biomass also led to nitrate concentration reduction in the pond series. This coincides with algal total biovolume increase between the influent and the facultative pond then decline towards the effluent due to depletion of nutrients in the ponds. This is in agreement with study findings of Vendramelli et.al., (2017) that algae in lagoons assimilate ammonia and nitrate into biomass. For the initial design, the sewage treatment plant was a point source of nitrate-nitrogen enrichment to river Riana. The current study findings corroborate other similar studies (Atwebembeire et al., 2019; Ronoh, 2017).

5.3.7.5 Ammonium-Nitrogen

In terms of monthly variations, for both designs, there was a significant difference in ammonium-nitrogen concentration between the sampling months. These differences in concentration were mainly attributed to change in seasons, and sewage wastewater pollutant composition. For instance, during the long rains, there was dilution of ammonium-nitrogen concentration in wastewater due to its high solubility in water. The low levels on ammonium-nitrogen in the influent indicated that nitrogen was in the organic form yet to be assimilated into ammonia through ammonification. The increase of ammonium-nitrogen as the wastewater underwent polishing was attributed to ammonification (conversion of organic matter to ammonium-nitrogen), and denitrification (Curtin et al., 2011). This study finding do not agree with that of Ronoh (2017) where they observed a reduction in ammonium-nitrogen concentration between the influent and effluent and vice versa to the study findings by Musungu et al., (2013). The inefficiency in ammonium-nitrogen removal can be attributed to wastewater retention time in the lagoons, lower nitrification, poor volatilization of ammonia resulting from lower temperatures, pH, and interferences from other exogenous source of nitrogen like nitrogen fixation from the atmosphere by phytoplankton especially cyanobacteria, and other reactions involving breakdown of proteins. In water, ammonia is highly soluble and it exists in the equilibrium, that’s in the ionized and unionized forms. When pH is high, it exists in unionized state (ammonia state), which is highly soluble and toxic to aquatic fauna and flora. However, in this state, coupled with higher temperatures it can be lost to the atmosphere through volatilization (Griffiths, E. W, 2009; Vendramelli et.al., 2017). The upstream sampling station had a higher mean concentration of ammonium-nitrogen than the downstream indicating that the sources of ammonium-nitrogen into river Riana was diffuse in addition to the Kisii town wastewater treatment plant.

5.3.7.6 Total Nitrogen (TN)

For the initial and current WWTPs, the influent had a lower mean TN concentrations compared to the effluent and these study findings were contrary to findings of Ronoh *et al.*, (2017) in Moi University WWTP. The low levels of TN in the influent were attributed to raw sewage rich in lodged nitrogen compounds in organic material yet to be broken down. The initial design from the results obtained it was a point source of pollution to river Riana for TN as the Upstream station had a lower TN mean compared with the downstream station. This finding agree with previous studies that have indicated that sewage treatment plants act as point sources of pollution contributing to surface waters eutrophication (Atwebembeire et al., 2019; Babu et al., 2021; Musungu et al., 2013; Omondi, 2019; Ronoh, 2017). The current design, the upstream sampling station recorded a higher mean TN (223.3 ± 39.70 μgL^{-1}) than that of the downstream sampling station (110.1 ± 21.93 μgL^{-1}) an indication that the river had other sources of TN. In terms of monthly variations, Two factor ANOVA analysis showed that mean of TN did vary significantly among the sampling months for the initial and current WWTPs. These variations were attributed to changes in seasonality, that's, during the rainy season, the levels of TN dropped due to the dilution effect (Omondi, 2019). Therefore, the Kisii Town WWTP did not attenuate TN between the influent and the effluent. The discharged effluent means for TN concentrations did not exceed the allowable limits by EPA standards. Therefore, improvement should be geared towards increasing the number of ponds for the WWTP to be effective in TN removal. TN is important in eutrophication and water quality assessment.

5.3.7.7 Total Phosphorous (TP)

In terms of monthly variations, Two-factor ANOVA test showed that the mean differences in TP concentrations were statistically significant between the sampling months for the initial and current WWTPs. This variation was attributed to changes in seasonality and anthropogenic activities within the municipality during sampling months. For instance, wide use of detergents rich with phosphates during cleaning in institutions, businesses, and homes in the municipality then discharging their effluents into the WWTP.

Spatially, the mean value of the influent (1604.2 ± 213.4 µgL^{-1}) was higher than that of the effluent (1443.4 ± 244.0 µgL^{-1}) with 10% reduction indicating minimal removal of TP during wastewater treatment for the initial design. Reduction can be linked to algal uptake, and sedimentation and precipitation processes. In the sediments, the TP can be organic form that's the algal biomass, and inorganic form. On the other hand, for the current design, the mean value of the effluent (2557.0 ± 172.55 µgL^{-1}) was higher than that of the influent (801.0 ± 300.12 µgL^{-1}) recording a 219% increase in mean TP concentration and this implied inefficiency of TP removal from wastewater during treatment. Consequently, the discharged effluent mean TP concentrations exceeded NEMA maximum set standards. Increase in TP concentrations in the WWTP pond series can be associated with conversion of the organic and inorganic phosphorous in the sediment through biogeochemical processes.

In general, from these results, they indicate that the wastewater treatment plant was a point source of nutrient enrichment (eutrophication) to river Riana for TP due to its incomplete removal. The continued discharge of TP into river Riana will lead to eutrophication, and eventually affecting species diversity, and water quality of the river (Musungu et al., 2013; Ronoh, 2017). To improve TP removal efficiency, algal cells harvesting can be done, water retention period increased to enhance sedimentation similar to the study recommendations by Griffiths, E. W (2009) focusing on the role of algae in wastewater nutrients removal in turn the algal biomass utilized for biofuel or fertilizer production or other products which are useful.

5.4 Heavy metals in wastewater, sediments and plankton

The aim of wastewater treatment is removing pollutants including heavy metals. Heavy metals pose great danger to health and environment, due to their persistence in nature as they are non-biodegradable thus bioconcentrate, bioaccumulate, and get biomagnified in the food chain. Therefore, heavy metal concentrations in effluents and sludge from WWTPs including in portable water are regulated worldwide (Hargreaves et. al., 2017). To meet the specified requirements, regular monitoring and optimization of WWTPs is carried out to improve their efficiency in wastewater polishing. Previous studies have shown that WWTPs have varied capacities in heavy metals removal with the conventional treatment plants being the least (Cantinho et. al., 2016; Hargreaves et. al., 2017). Their poor performance in heavy metal removal has been associated with their engineering design, incapacity to mitigate effects of certain physico-chemical and environmental parameters such as TN, TP, and TSS. Heavy metals have the properties of bioaccumulation, bioconcentration and biomagnification, in sediments, water, and plankton. For instance, heavy metals from wastewater column accumulate in sludge eventually ending up in the environment during dumping, and when sludge is used as fertilizer (Cantinho et. al., 2016). Plankton bioconcentrate and bioaccumulate heavy metals resulting in their biomagnification in the food web (Cantinho et. al., 2016; Hargreaves et. al., 2017).

The heavy metals assessed in this study (Cd, Cu, Pb and Zn) were determined in wastewater, sediments, and plankton (phytoplankton and zooplankton). The analyzed samples were obtained from the Kisii Town WWTP, including three stations along river Riana at the effluent discharge point. This study revealed the presence of Cu, Pb, and Zn but Cd was not recorded throughout the study period. Moreover, the study revealed accumulation of heavy metals in plankton which might result in biomagnification of heavy metals in the food web, posing health hazards.

Lead recorded the highest concentration in the wastewater samples compared to Cu, while Zn and Cd concentrations were not recorded in the wastewater. Monthly, Pb levels were higher in the month of May than July and vice versa for Cu and this could be attributed to higher influx of wastewater and surface runoffs into the plant. Sources of lead within the municipality could be garage and car wash effluent, and paints used in the construction industry among others. Contrary to the observation made on wastewater, the order in terms of concentrations was that Zn had the highest concentration followed by Cu, and then Pb. Monthly, Zn and Cu concentrations were higher in July than May while for Pb, its concentration was higher in May than July in sediments samples. Therefore, the concentrations of heavy metals in the Kisii Town WWTP depicted monthly variation which could be attributed to changes in the amount of wastewater received, quantity of rainfall, and human activities within.

In phytoplankton samples, the order of dominance of the assessed heavy metals was : it followed the order Pb>Cu>Zn. Cu accumulation was higher in July then May while Zn and Pb were only recorded during May and July respectively. This could be associated to preferential uptake and utilization of the respective constituents by the phytoplankton. For zooplankton samples, monthly, Cu and Zn concentrations were higher in the month of May than July and it followed the order Cu>Zn. This findings are similar to other studies that have shown significant variations in metal levels in water column, sediments, and plankton (Chinnaraja, Santhanam, Balaji, Dinesh & Jothiraj, 2011).

Cu metal concentration was found in wastewater, sediment, phytoplankton and zooplankton. The confluent sampling station had the highest concentration of Cu and this was attributed to anthropogenic activities and institutional effluents within the town and its catchment. On the other hand, the downstream sampling station had the least Cu concentration and this can be attributed to phytoremediation (Andresen, 2010), increased water volume resulting in copper concentration dilution.

Zn concentration was variable during the sampling period. In wastewater, it was below the detection limit. The low concentration was attributed to low concentration of Zn in wastewater, and increased rainfall in the region might have led to the dilution of the concentrations of the heavy metals in the sewage wastewater, leading to low concentrations. Also, plankton (phytoplankton and zooplankton) in the treatment plant bio-accumulated heavy metal hence reducing the heavy metal concentration in wastewater as shown in other studies (Tessema, Lemma, Fetahi, & Kebede, 2020). In addition, sediments might have also acted as potential heavy metal sinks reducing Zn concentrations in the wastewater column. The declining trend of Zn concentration levels followed the order sediments>Zooplankton>phytoplankton>wastewater. Agoro et al. (2020) showed variations in heavy metals concentrations in wastewater and sewage sludge from municipal treatment plants in Eastern Cape Province, South Africa as well as the study by Tessema et al. (2020) in Lake Koka in Ethiopia. They showed that heavy metal concentration in the bottom sediments was higher compared to that in the water column at the same sites during sampling. The retention period of wastewater in treatment plant respective ponds might be short; therefore, some of the metals might have been transported out of the plant resulting in their low concentrations in the treatment plant (Muiruri, 2009).

Pb was recorded in wastewater, sediments, and phytoplankton but not in zooplankton samples following the order phytoplankton>sediments>wastewater. The low level of Pb in wastewater was linked to the metal uptake by planktons and settling in the sewage sediments/sludge, thus acting as sink. The presence of Pb in wastewater should be of public health concern in terms of wastewater reuse and discharge into water bodies. The presence of Pb in wastewater was attributed to greater solubility characteristics and effluents from institutions (that's higher learning and research institutions), hospitals and industries within the town. Some studies have also shown that Pb has dominated most of the metal products, paints, pesticides, pipelines, and cables, and this can be the reason for the presence of Pb in the wastewater sample (Tyagi, 2014).

5.5 Wastewater treatment efficiency and compliance

Wastewater is rich with pollutants thus need treatment. Disposal of partially or untreated wastewater has been associated with adverse effects on the environment and outbreak of diseases. Due to the scarcity of clean water, treated wastewater is a potential alternative water source for domestic, agricultural and industrial uses, including wastewater safe disposal (UNESCO, 2017). The wastewater in the Kisii Town WWTP is treated by biological means in a single series of stabilization ponds. The WWTP has been recently renovated to improve its efficiency in wastewater polishing and the effluent discharged to be within the maximum allowable limits by NEMA and international standards (Kisii Couty Government, 2013).

The Kisii Town WWTPs pollutant removal was generally low for most of the parameters with their percentage reduction being below 60% contrary to the findings in the studies conducted in Moi University (Ronoh, 2017), University of Eldoret (Wanjohi et al., 2019), and Gacuriro Vision City, Rwanda (Nikuze et al., 2020) WWTPs whereby the majority of the pollutant reduction percentages were above 60%. Nevertheless, for both designs, the pollutant reduction, however small, indicates that the quality of wastewater improved as it underwent polishing through the lagoons before being discharged into river Riana as expected. The low levels of pollutant removal in the Kisii Town WWTP even after renovation was attributed to the increased sewage wastewater volume rich with organic and organic pollutants linked to increased human population in the town, large number of institutions that's medical, research, teaching, and poor operation and maintenances of the ponds for example delayed sludge removal (Kilingo, Bernard, & Hong-bin, 2021).

In terms of compliance to the NEMA, WHO, and EPA standards for effluent disposal to the environment, the effluent values of pH, temperature, TDS, NH_4-N, NO_2-N and NO_3-N discharged from the initial and current plant designs were within the maximum allowable limits, there compliance indices being below 1 (< 1). For the other parameters both for the initial and current wastewater plant design, due to the lack of NEMA standard limits for the corresponding parameters, we could not generalize whether the discharged effluent met the set standards. Also, their respective compliance indices were not calculated and referenced for the plant. These findings are similar to other studies (Kilingo et al., 2021; Ronoh, 2017; Wanjohi et al., 2019).

For heavy metals, the compliance indexes for Cd and Zn were not calculated and referenced for the current treatment plant because their concentrations were generally below detection limits. The compliance index value for Cu, 0.25 was below 1, indicating compliance. However, the compliance index value for Pb was 53, this value being more than 1, indicates non-compliance to the specified NEMA, WHO, and EPA standards for effluent discharge to the environment. Other study findings have similarly indicated differential heavy metals removal in WWTPs (Miruka, Kariuki, Yusuf, & Onyatta, 2018; Wanjohi et al., 2019).

5.6 Phytoplankton

5.6.1 Phytoplankton diversity and species composition

Phytoplankton are aquatic plants, and they are primary producers providing food to other aquatic organisms (Emmanuel & Onyema, 2007). However, their community structure is affected by water quality; as a result, they have been used as bio-indicators in water quality monitoring. The cyanobacteria *Microcystis* sp. and the Diatom *Nitzchia* sp. are good indicators of polluted water. *Chlamydomonas, Euglena, Scenedesmus,* and *Microcystis* are good indicators of eutrophic waters (Sakset, A, and Chankaew, W. 2013). Wastewater is of poor quality as it is rich in pollutants and phytoplankton do play an important role in wastewater treatment through utilization of nutrients and converting them into biomass (Gani, ALfassane & Khondker, 2011; Pastich et al., 2016; UNESCO, 2017). In addition, they bioconcentrate, and bioaccumulate heavy metals thus contributing to their removal from water column (Tessema, Lemma, Fetahi, & Kebede, 2020). In the current study, there was a considerable spatial and monthly variation in the phytoplankton abundance and diversity between the sampling stations. These variations were linked to changes in physical, chemical, and biological environmental conditions as the wastewater underwent treatment.

During this study, the initial wastewater treatment design had a total of 124 phytoplankton species compared to the current design with 112 species. The identified species belonged to six taxonomic groups: Euglenaphyceae, Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae, and Zygnematophyceae. The families Bacillariophyceae, Chlorophyceae, and Cyanophyceae generally dominated the phytoplankton species by composition in both treatment plant designs. Differences in the total number of species recorded between the WWTP designs were attributed to the difference in the wastewater treatment plant designs, environmental conditions, and seasonality. Also, human activities during renovation disturbed establishment of phytoplankton species in the latter design. These findings corroborate the findings obtained by Babu et al. (2021) in L. Victoria and Omondi (2019) in L. Naivasha where both showed that algal community structures are affected by varying physico-chemical parameters.

The Euglenaphyceae was dominant in the influent, facultative, and the effluent while the Bacillariophyceae dominated in the anaerobic pond. The dominance of Euglenaphyceae can be attributed to organic load from the municipal wastewater. On the other hand, the cyanophytes were moderate in all stations and this could be attributed to their tolerance to variable changes in the environmental conditions. For instance, this was seen in *Microcystis aeruginosa* and *Anabaena* spp. which were found in the sampling stations. The low diversity was attributed to extreme environmental conditions observed in the sampling stations, in line with other similar studies carried out in polluted aquatic environments (Babu et al., 2021; Islam & Huda, 2016).

The different sampling stations recorded variation in phytoplankton diversity indices for the initial and current wastewater treatment plant designs. However, Shannon-Wiener diversity index for the current plant design was higher than the initial plant design which indicates an improvement in biodiversity. The low diversity of species in the initial design can be associated with the fact that the well establishment species out competed other species leading to dominance of some as depicted by the dominance indices. The phytoplankton species diversity index (H') during this study in the initial design of the treatment plant was generally low, indicating low diversity but with a few taxa dominating as a result. This indicates that the initial design had a much lower capacity for treating wastewater compared with the current. Species Evenness (E), values ranged between 0.04952 - 0.1161 for the previous treatment plant design. The current design, species Evenness (E) ranged from 0.07 - 0.61, depicting a significant difference and an improvement of the species evenness in the WWTP. Generally, the low evenness values recorded in both designs indicated that a few species dominated in the sampling stations, which was linked to harsh conditions in the wastewater treatment lagoons; hence the species were not evenly distributed in the sampling stations.

5.6.2 Phytoplankton biomass and distribution

During this study, the total phytoplankton biovolume recorded for the initial WWTP was lower than the new WWTP design. In terms of total biovolume percentage, the Euglenaphyceae, and Dinophyceae were dominant in the initial WWTP while Chlorophyceae, and Euglenaphyceae dominated in the current WWTP. Therefore, it appears that phytoflagellate and zooflagellates were the most dominant taxa in the initial and current WWTP design. These are indicators of poor quality water. This dominance can be attributed to favorable environmental conditions favoring optimum survival of the two taxa. This seemingly led to competitive exclusion of other species. Moreover, there were changes in the composition of different algal taxa in the lagoon pond series, indication of progressive wastewater polishing in the WWTPs. Evidence that the WWTPs polished the effluent was discerned by comparing the algal composition within the WWTP pond series with that of upstream sampling station along river Riana which in this case served as the control and indicated that Bacillariophyceae were the dominate taxa there. Bacillariophyceae are indicators of good water quality. The increasing representativeness of Bacillariophyceae along the pond treatment series towards the effluent attests to the fact that ponds were treating the wastewater. This also indicates there is progressive degradation of organic matter in wastewater thus releasing nutrients into the water column which together with other breakdown of organic substances lead to variation in the environmental conditions within the water treatment pond series. The environmental variation encourages dominance of different algal taxa in the different ponds that's from anaerobic, facultative, and maturation ponds.

For the initial Kisii Town WWTP, the anaerobic pond had the highest total phytoplankton biovolume by composition of Dinophyceae with the dominant species being *Ceratium branchyceros*. This was attributed to extended mixing periods and resident time in the anaerobic pond. In the facultative pond, Euglenaphyceae and Dinophyceae groups had a higher biovolume. For Euglenaphyceae, *Euglena Virids* and *Euglenaphyta lena acus* recorded the highest biovolume while for Dinophyceae it was only *Ceratium branchyceros* species that was recorded. This could be attributed to availability of nutrients that were dislodged from the organic load hence available for utilization, and reduced turbidity which enhance transparency; hence a higher photosynthetic activity in the pond. The least phytoplankton total biovolume was recorded in the downstream sampling station and this can be attributed to washing down of the species by water currents, increased turbidity leading to elevated temperature, and also an aspect of competition leading to mutual exclusion. This could further be due to dilution effect by the large volume of water in River Riana which changed the physical and chemical parameters such as nutrient concentrations and transparency, which therefore could encourage a change in species composition.

For the Kisii Town WWTP, the highest phytoplankton total biovolume was recorded in the facultative pond sampling station. The algal composition was dominated by Euglenaphyceae by biovolume among other groups of which *Euglena acus* species was the most abundant. Moreover, Euglenaphyceae dominated in the influent, anaerobic pond, and maturation pond 2 of which *Euglena acus* species accounted for the highest biovolume. The dominance of Euglenaphyceae (*Euglena acus*) can be attributed to higher organic and inorganic load in the sampling ponds. The differences in the total phytoplankton biomass and species distribution in the sampling stations were attributed to the variable unfavorable conditions in the lagoons, operational and design differences of the WWTP (Babu et al., 2021; Islam & Huda, 2016; Omondi, 2019).

In terms of monthly variation for both treatment plant designs, there was variation between the sampling months for the total phytoplankton biovolume but these differences were not statistically significant. Though in this study there has been an attempt to account for temporal effects on the treatment of wastewater this could be mitigated by the fact that the variation in the volume of wastewater entering the WWTP is at all times dependent on the quantity of water received by the households in the municipality from domestic portable water supply system. This supply is independent of season, that’s it could be more during the dry or wet season depending on existing operational water management system used by the portable water supply system. By and large the physical and chemical environment in the WWTP is controlled by variation of the wastewater supply.

In the initial WWTP, Euglenaphyceae dominated monthly in terms of biovolume during the month of August and September where *Euglena acus* and *Euglena Virids* were the most abundant due to favorable climatic and environmental conditions. In November, the

Dinophacean, *Ceratium branchyceros* dominated the algal composition of the WWTP. During the entire study period, the biovolume for Chlorophyceae and Zygnematophyceae were relatively low an indication of poor adaptation to polluted and harsh environmental conditions. For the Cyanophyceae taxa, *Microcystis aeruginosa* species was the most abundant among other species. For the current design, Dinophyceae biovolume was generally low throughout the study period while higher biovolume was recorded for Euglenaphyceae, Chlorophyceae and Bacillariophyceae. The apparent increase in the dominance of the latter two taxa is evidence for improvement of the wastewater treatment capacity by the current WWTP because these algal groups normally are indicators of good water quality.

The differences in the phytoplankton biovolume and changes in families between the sampling months were attributed mainly to differences in volume of wastewater supplied to the WWTP and to a lesser extent to seasonal changes, nutrients availability and biological activities (Omondi, 2019). Moreover, the higher biovolume of Euglenaphyta during the study period was an indication of the polluted nature of the wastewater. This corroborates the study findings by Babu et al. (2021) which showed significant levels of Euglenaphyta in Kisumu Bay in which receives a large volume of semi-treated sewage wastewater from both the traditional wastewater treatment trickling filter plant adjacent to Kasat river, and the WWTP at Nyalenda. Due to this, the water quality in Kisumu bay has rapidly declined in the last three decades, that’s between 1990 and the present, and the physical and chemical environment there is very close to that existing in the WWTPs. The algal composition in the inner Kisumu bay is dominated by Cyanophyceae mainly by *Anabaena* sp., and *Microcystis aeruginosa* species, and presently Euglenaphyceae have started to appear there. In general, the results obtained from this study indicate that the phytoplankton community structure was influenced by the variation in the physico-chemical parameters in line with findings in other studies (Adelakun, Mu’azu, Amali, & Omotayo, 2016; Babu et al., 2021; Islam & Huda, 2016; Omondi, 2019).

During the study, algal blooms with different colors throughout the ponds on the water surface were observed. These algal blooms are an indicator of presence of algal toxins in the WWTP. The predominant algae species observed in this study such as *Microcystis aeruginosa* and *Anabaena* sp. together with other species from other taxa are known to produce potent algal toxins known as microcystins. The produced algal toxins can cause serious illness or death to humans, wildlife, and livestock and other forms of life in aquatic ecosystems. Babu et. al., (2021), in his study at Kisumu bay in Lake Victoria, observed algal toxins were in high concentration where algal blooms were present. Therefore, there is need for other studies to be conducted in the Kisii municipality WWTP to assess the presence, concentrations, and types of algal toxins.

5.7 Zooplankton

Zooplankton are free-floating microscopic aquatic organisms. They play a key role in the aquatic food webs. However, they are sensitive to the environmental conditions, thus affecting their community structure, rendering them suitable as water quality bio-indicators (Adhikari, Goswami & Mukhopadhyay, 2017; Deksne, 2011; Khune & Parwate, 2017). In the current study, a total of 15 and 11 zooplankton species were recorded in the initial and current wastewater treatment plant design respectively. The identified species belonged to three taxonomic groups: Rotifera, Cladocera, and Copepoda. The zooplankton community structure observed was largely due to variations of physico-chemical parameters in different functional ponds within the wastewater lagoons. The changes in the dynamics of functional ponds have largely been attributed to changes in water quality. This corroborates well with the findings by Dejen, Vijverberg, Nagelkerke & Sibbing (2004) on the temporal and spatial distribution of microcrustacean zooplankton in relation to turbidity and other environmental/limnological factors in a large tropical lake. Favorable environmental factors within the functional ponds have enhanced high primary productivity resulting in the availability of high algal biomass that eventually supports high zooplankton production. The relatively high abundance found in the present study for the larger zooplankton (copepods and cladocerans) community might be explained by favorable conditions such as food source (phytoplankton), good light penetration, temperature, and nutrients availability. Notably, the scarcity of bigger cladocerans such as the *Daphnia* species is not clear but the study suggests stressful conditions represented by effluent water and consequently high nutrient load in the functional ponds. Further investigation need to be carried out to establish why Cladocera are not present in the WWTP. This has an important bearing on wastewater treatment process.

The low species diversity of Cladocera and Rotifera in both treatment WWTP designs in this study was attributed to extreme environmental and eutrophic conditions associated with temperature, predominant decomposing organic matter, and nutrient availability. The low abundance and diversity of Copepoda found in this study might be explained by unfavorable conditions such as the low penetration of light due to the high turbidity of water. This corroborates well with the findings by Omondi et al., (2011) on spatial and temporal variations of zooplankton in relation to environmental factors in Lake Baringo.

The higher abundance and richness depicted at maturation Pond 1, Pond 2 and Influent in the current design can be attributed to these stations' high temperature, eutrophic conditions, and operational wastewater management plan and upgrading the initial design to the current design with additional ponds. In addition, the higher abundance at these stations can be linked with higher chlorophyll-a levels as far as phytoplankton productivity is concerned. On the other hand, the low abundance recorded at the upstream point and facultative ponds in the current design can be attributed to limited nutrient conditions and low chlorophyll-a concentrations. This corroborates well with Omondi et al., (2011) study on zooplankton variation in Lake Baringo amid environmental parameters such as chlorophyll-a levels. Unlike the low abundance recorded by Rotifera, the high abundance recorded by Cladocera and Copepoda can be attributed to the ponds' eutrophic conditions due to nutrient inflow and retention rate.

The different sampling stations had different zooplankton species' total abundance. Moreover, the species diversity index (H') was generally low an indication of low diversity this as already mentioned is due to harsh environmental conditions in the WWTP. The low zooplankton abundance and diversity in the sampling stations might be attributed to variation in limnological parameters in the sampling stations. Based on the findings of this study, it is worth noting that zooplankton abundance and diversity contributes significantly to R. Riana's riverine fisheries through discharge at the confluent point. This study finding agrees with other previous studies which focused on plankton in similar environments (phytoplankton or zooplankton) abundance, diversity and spatial-temporal variation (Goździejewska & Tucholski, 2011; Hassan et al., 2019; Kumar, Dahms, Won, Lee, & Shin, 2015; Omondi, Yasindi, & Magana, 2011; Were-Kogogo, Adhiambo, 2017). On the other hand, the zooplankton contributes in wastewater polishing by indirectly removing heavy metals from the water column by feeding on phytoplankton which as shown in this study bioconcentrate heavy metals in their cells. The current study findings further show that the zooplankton bioconcentrate, and bioaccumulate heavy metals in the Kisii Town WWTP. Moreover, they biomagnified the heavy metal concentrations in the short food chain within the lagoon thus posing a health risk. Zooplankton uptake of heavy metals is an indication that they require them for various metabolic processes in their cells. Removing the zooplankton before effluent discharge into Riana river will contribute to better quality effluent with lower heavy metal concentrations from the WWTP. This can be done by introducing planktivorous fish which can later be harvested thus preventing the heavy metals entering the receiving water in river Riana.

5.8 Total and fecal coliforms

For both Kisii Town WWTP designs, the recorded mean TC and FC counts of the effluent were significantly lower than that of the influent, indication that their numbers were being reduced as the wastewater underwent polishing. However, the final discharge with TC and FC counts were above the permissible NEMA limits, that’s TC of ≤30 and for FC being zero counts/100ml. Therefore, discharge of the effluent from the plant into Riana river poses a great health hazard especially on the outbreak of water-borne diseases.

Total and fecal coliforms concentration reduction in the WWTP pond series can be attributed to extreme pH, high temperatures, and solar radiation especially the UV component which is toxic to bacteria and other pathogens. Moreover, the decreasing liquid depth in the pond series could have resulted in high temperature and high DO concentrations. The elevated levels of DO are associated with diverse photosynthetic algal community structure. During photosynthesis, the algae take up carbon dioxide obtained from breakdown of carbonate and bicarbonates by resident bacteria, and released hydroxyl ions from the carbonates contributes to increase in pH. The micro-algae in turn produce oxygen required by the pond bacteria and other microbes in the microbial food web to breakdown inorganic and organic substances and nutrients in wastewater releasing nutrients into the water column thus promoting algal growth. Coliforms die-off in extreme environmental conditions thus their decline in concentrations in the pond series. This finding corroborates well with the study by Khasisi et. al., (2021) conducted at Egerton University WWTP where they observed that coliforms declined between the inlet and outlet.

5.9 Comparison between the initial and current Kisii Town Wastewater Treatment Plants

Wastewater treatment plants are designed such that pollutants are removed efficiently during wastewater polishing. The initial Kisii Town Wastewater Treatment Plant had a capacity of 8,000m^3/day. However, the design was not optimal in sewage wastewater polishing due to the increased volume of wastewater it receives as a result of increased population and connectivity to the sewage distribution network. The discharge of partially or untreated wastewater to the environment is of great concern for the risk they pose thus necessitated the renovation of the treatment plant up to a capacity of 15,000 m^3/day of wastewater. Despite this capacity is still inadequate in addressing the wastewater treatment of the Kisii Municipality because the sewage distribution network is limited to a smaller area and a larger number of households are still not connected to the sewage distribution network. Most of the households either use septic tanks and latrines to manage their wastewater.

From the results obtained, they indicate that some of the influent physico-chemical parameters significantly varied between the two treatment plant designs. These differences were attributed to slight changes in the Kisii Town population and changes with seasonality to a limited extent. This study's findings are consistent with others (Nikuze et al., 2020; Otieno, 2015; Ronoh, 2017; Wanjohi et al., 2019).

The variations of the physico-chemical parameters that were measured in the effluent between the two designs were attributed to the changes in the WWTP design which included changes in the ponds' dimensions and additional ponds in the current design, and current wastewater management system. The fact that the Kisii Town WWTP did not improve on the removal of TN, and TP was due to the fact that the resultant plankton and invertebrate biomass in the WWTP wasn't harvested as the effluent containing this organisms was used to estimate the concentrations of the nutrients. Removal of the biological biomass component of the wastewater will lead to a reduction in the concentration of heavy metals thus improving tis quality. Therefore, experiments need to be conducted to find out the optimal methods of removing the biological component of the wastewater effluent so as to improve its quality. Once such study would be to test the efficacy of using macrophytes to remove the heavy metals and other pollutants from wastewater, and then harvest the resultant biomass for other uses by humans.

In terms of compliance to national and international set standards for effluent discharge into the environment, pH, temperature, TDS, and NO_3-N for the discharged effluent during the entire study period were within the allowable limits by NEMA, WHO, and EPA standards. The recorded mean of electrical conductivity for effluent was within the WHO, and EPA standards. On the other hand, the recorded mean for TP exceed the maximum limits set by

WHO (500 μgL^{-1}). For heavy metals, copper and zinc concentrations were within the NEMA, EPA, and WHO limits but lead exceeded NEMA, EPA, and WHO standards.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Kisii Town Wastewater Treatment Plant plays a crucial role in polishing wastewater from Kisii municipality and its environs. This study aimed at assessing whether the Kisii Town Wastewater Treatment Plant efficiently polished wastewater it receives based on physical, chemical and biological parameters including heavy metals analysis.

Based on the results obtained from the current study, the following conclusions have been drawn:

1. There was improvement on the levels of selected physico-chemical parameters namely pH, DO, TDS, SRP, NO_2^--N, and NO_3^--N and coliforms that's TC and FC after wastewater treatment by Kisii Town Wastewater Treatment Plant, indication of wastewater polishing.
2. For phytoplankton and zooplankton community structure, this study revealed that there was spatial and monthly variation in terms of diversity and distribution before and after the WWTP was renovated. In terms of taxonomic groups, the phytoplankton species which were identified belonged to six broad taxonomic groups which include: Bacillariophyceae, Chlorophyceae, Cyanophyceae Euglenaphyceae, Zygnematophyceae, and Dinophyceae while for zooplankton they belonged to three taxa namely Cladocera, Rotifera, and Copepoda. Moreover, the plankton contributed in wastewater polishing through conversion of nutrients into their biomass. The species diversity of phytoplankton and zooplankton were low and there was absence of large bodied Cladocera among the zooplankton.

3. The population densities and species composition of the plankton communities in the lagoon were influenced by the physico-chemical parameters.
4. The Kisii Town WWTP plays a critical role in heavy metal removal from the wastewater during polishing. The sediments acted as sink for heavy metals. Also, plankton played a significant role in heavy metals removal from the wastewater column through bioconcentration, bioaccumulation, and biomagnification (that’s in the short food chain in the WWTP ponds: decomposing organic matter→bacterial decomposers→microinvertebrates eg. Ciliates; Sediments→algae→zooplankton)
5. The Kisii Town WWTP was generally efficient in wastewater treatment as most of the physico-chemical parameters and heavy metals which were measured in the effluent discharged were within the maximum allowable limits of NEMA, WHO, and EPA and there compliance indices were below 1 despite their respective pollutant reduction percentages being low.
6. The renovation of the Kisii Town Wastewater Treatment Plant and improvement on its management must have contributed to improvement of its efficiency in wastewater polishing but the design still has challenges dealing with removal of nutrients (especially TN and TP), and also coliforms.

6.2 RECOMMENDATIONS AND FUTURE STUDIES

The objective of this study was to assess the efficiency of Kisii Town Wastewater Treatment Plant in wastewater polishing it receives using selected physico-chemical and biological parameters. The collected data forms a baseline for future studies. Gaps were identified based on the current study findings for further research. Therefore, the following recommendations have been drawn:

1. The Kisii Town WWTP should be improved in its wastewater treatment capacity to mitigate the increased volume of wastewater received from the municipality resulting from ever increasing population and additional new homes being connected to the sewer line geared towards improving its efficacy in wastewater polishing.
2. There is need for further research in the Kisii Town WWTP to identify plankton community structures using other methods like molecular techniques in addition to microscopic techniques using standard identification keys. Moreover, algal toxins found in the WWTP need to be identified and characterized following the observation on the existence of cyanobacteria blooms which are known to produce toxins.
3. During this study only four heavy metals were analyzed. Moreover, the method used for analysis was only detecting one element at a time. Therefore, this study recommends more studies to be conducted to include other heavy metals not covered during this study. Further, more recent techniques i.e Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) can be employed in heavy metals analysis which allow bulk heavy metals per in a single sample analysis in particular there should be emphasis on the analysis on concentration of heavy metal with potent poisoning such as mercury which have potent poisoning in aquatic environment.
4. To address the issue of nutrient enrichment and heavy metals pollution in the effluent receiving waters, this study proposes construction of a wetland with appropriate macrophytes for further polishing of effluent. Moreover, the plants will

also contribute in heavy metals removal through phytoremediation but the extent to which it is able to mitigate the pollutants needs to be determined.

5. Currently, there is increasing concern over emergent pollutants resulting from the use of certain chemical compounds in households such as body care products, pharmaceutical, and pesticides which previously were not considered to be harmful to aquatic organisms. Initial research has indicated that metabolites of these compounds have got deleterious impacts on aquatic organisms such as sex reversal in fish, and carcinogenic problems. There is therefore need to assess the efficiency of the Kisii Town WWTP in mitigating problems associated with these compounds and to further identify and characterize them.
6. There is need also to conduct research on the most efficient method of harvesting and removing biological biomass that builds up in the Kisii Town WWTP and investigate on its uses and whether there are possible challenges when using that biomass.
7. There is need to include fish within the Kisii Town WWTP system to assist in cropping up the algal biomass so as to improve the efficiency on wastewater treatment. There is therefore further need to conduct research on optimal stocking density and fish species types that can be used to improve wastewater treatment since the fish are capable of removing plankton and retaining them in their bodies.

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APPENDICES

Appendix 1: NEMA Standards for effluent discharge into the environment

Parameter	Maximum Allowable (Limits)
Biological Oxygen Demand (BOD 5 days at 20°C) (mgL^{-1})	30
Total Suspended Solids (mgL^{-1})	≤30
Conductivity	≤2000
Total Dissolved Solids (mgL^{-1})	1200
Total Coliforms (counts/ 100 ml)	30
pH (Hydrogen ion activity, marine)	6.5-8.5
Oil and Grease (mgL^{-1})	Nil
Temperature (in degrees Celsius) based on ambient temperature.	Ambient Temperature ±3
Chemical Oxygen Demand (mgL^{-1})	50
Colour in Hazen Units (HU)	15
Total phosphorus (mgL^{-1})	≤2
Total Nitrogen (mgL^{-1})	2 Guideline value
Ammonia, ammonia compounds, nitrate compounds and nitrite compounds (mgL^{-1})	100
Chromium VI (mgL^{-1})	0.05
Lead (mgL^{-1})	0.01
Cadmium (mgL^{-1})	0.01
Zinc (mgL^{-1})	0.5

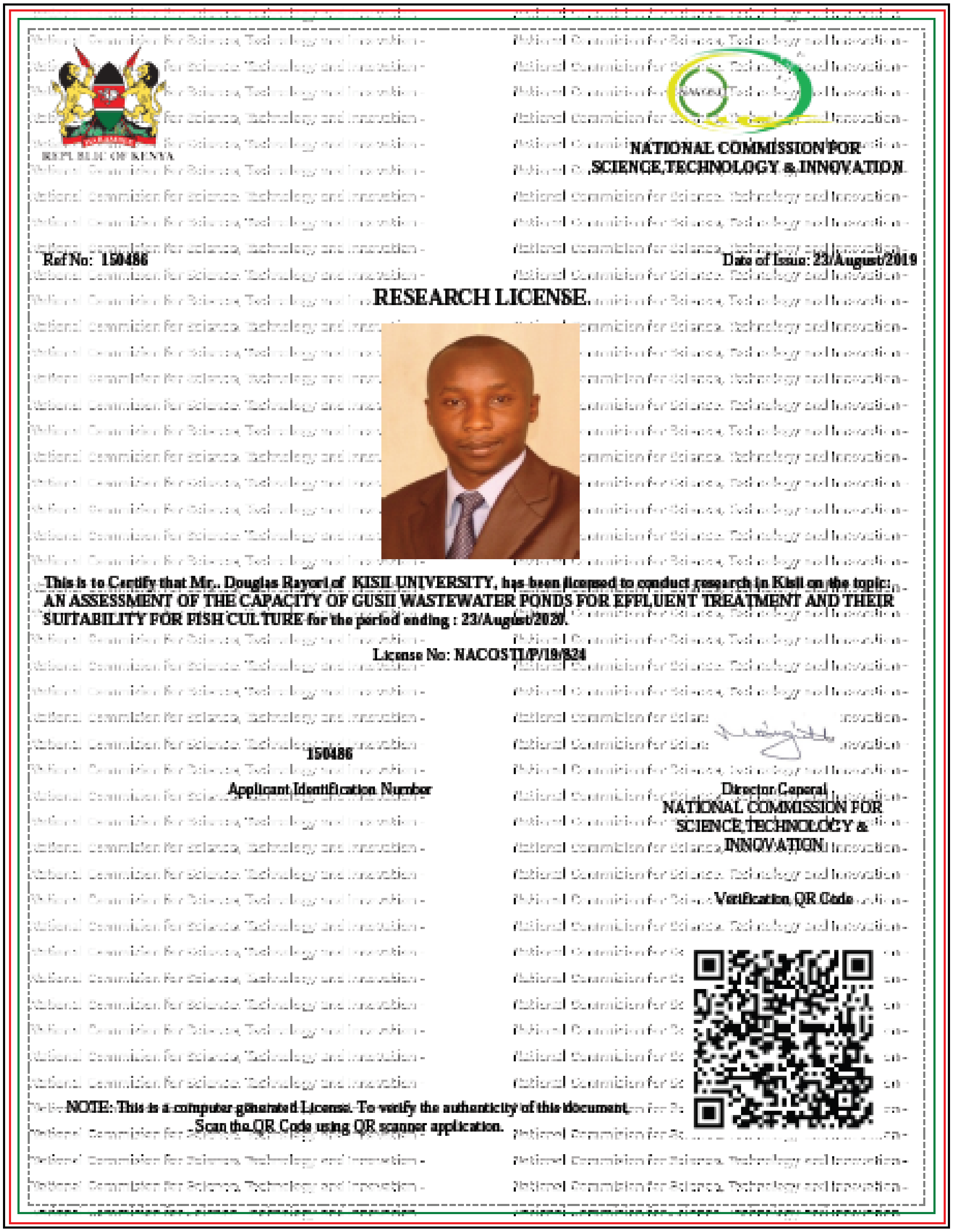
Appendix 2: Effluent wastewater quality parameter from Kisii town initial design of the wastewater treatment plant in 2015

Parameter	**Treatment plant effluent**	**NEMA standards (Maximum)**
pH	7.65	6.5 – 8.5
TDS (mgL-1)	361	1200
COD (mgL-1)	130	50
BOD5 (mgL-1)	78	30
TSS (mgL-1)	96	30
Temperature (°C)	25.23	25 - 35
TN (mgL-1)	61.32	2
TP (mgL-1)	15.64	2

Source: Gusii wastewater and sanitation company (GWASCO, 2015).

Appendix 3: Pictorial Representation of the Field and Laboratory Analysis

Appendix 4: NACOSTI Research Permit



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This is to Certify that Mr.. Douglas Rayori of KISII UNIVERSITY, has been licensed to conduct research in Kisii on the topic: AN ASSESSMENT OF THE CAPACITY OF GUSII WASTEWATER PONDS FOR EFFLUENT TREATMENT AND THEIR SUITABILITY FOR FISH CULTURE for the period ending : 23/August/2020.

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Appendix 5: Questionnaire

Dear respondent,
I am a postgraduate student in Kisii University, School of Agriculture and Natural Resources Management (FANRM), Department of Natural resources, Aquatic Sciences and Fisheries. I am conducting a study on “AN ASSESSMENT OF THE CAPACITY OF GUSII WASTEWATER PONDS FOR EFFLUENT TREATMENT AND THEIR SUITABILITY FOR FISH CULTURE. The study findings will provide information on the quality of the treated wastewater and the public opinion on the water reuse for aquaculture and other options. I therefore request for your honest opinion. The information provided will not be used for any other purpose other than the one stated above. Your maximum co-operation will be highly appreciated. Thank you.
Yours sincerely,
RAYORI DOUGLAS MOSOTI
INSTRUCTIONS: TICK AS APPROPRIATE
PART A: Personal information

1. What is your gender?
   ○ Male ○ Female
2. What is your age year category?
   ○ 10-20 ○ 21-30 ○ 31-40 ○ 41-50 ● 51 and above
3. What is your level of education?
   ○ Primary ○ High School ○ College or technical institute ○ University
4. Do you have knowledge on aquaculture?
   a. Not at all
   b. Some idea
   c. Sufficient knowledge
5. What is your source of information?
   ○ Google ○ Television or Radio ○ A friend ○ Other sources
6. Have you ever used any of the aquaculture products i.e fish, oil..?
   a. Not at all
   b. Some

PART 2: Information on public perceptions on Suneka treated wastewater reuse

7. Have you ever heard of Suneka wastewater treatment plant or Suneka sewage?
   ○ Yes ○ No
8. Do you have knowledge on the role of Suneka wastewater treatment plant?
   a) sufficient information
   b) some idea
   c) no idea at all
9. Do you have any knowledge on the process of wastewater treatment?
   a. Not at all
   b. Some idea
   c. Sufficient knowledge
10. Do you have any information/knowledge on wastewater reuse?
    a. Not at all
    b. Some idea
    c. Sufficient knowledge

11. Are you willing to use treated wastewater?
    ○ Yes ○ No ○ May be
12. If yes, you can use the treated wastewater for:
    a. Domestic uses
    b. Agricultural
    c. Others
13. If for agricultural purposes, you can use the treated wastewater for:
    a. Aquaculture
    b. Irrigation and other related roles i.e cleaning farm tools
    c. Others
14. If for aquaculture, can you use the treated wastewater for fish culture?
    ○ Yes ○ No
15. With the fish cultured in the treated wastewater, will you be willing to use it as:
    a. Food
    b. Source of income
    c. Ornamental
16. If you are not willing, what are your concerns?
    a. Health concerns
    b. Doubts on the quality of the treated wastewater due to the process of treatment
    c. Reject because of psychological or religious reasons
    d. Others
17. Based on your experience, can you encourage other people to use the treated wastewater
    ○ Yes ○ No

THANK YOU FOR YOUR TIME

Appendix 6: Publications

1. **Douglas, R.**, Albert, G. ., Reuben, O., Paul, O., Hellen, N., Boniface, G., Obed, N., Omondi, A., & Job, O. (2022). Assessment of Heavy Metal Concentrations (Cu, Cd, Pb, and Zn) in Wastewater from Gusii Treatment Plant in Kisii County, Kenya. *Pan Africa Science Journal*, *1*(02), 122–138. https://doi.org/10.47787/pasj.v1i02.12

2. **Rayori, D.**; Getabu, A.; Omondi, R.; Orina, P.; Gisacho, B.; Omondi, A. Phytoplankton diversity in Gusii wastewater treatment plant in Kisii County, Kenya. *International Journal Fisheries and Aquatic Studies* 2021; 9(3):299-306. DOI: https://doi.org/10.22271/fish.2021.v9.i3d.2505

Manuscript:

Assessment of spatial- temporal variations in Zooplankton diversity in relation to selected limnological parameters: A case of Kisii town wastewater treatment, Kenya

Appendix 7: ANOVA tables for physical-chemical parameters

A. Initial WWTP: Physical-chemical parameters

1. Months

Dependent Variable: Temp

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	25.231	.258	24.715	25.747
September	24.757	.258	24.241	25.273
November	23.826	.258	23.310	24.342
December	23.443	.258	22.927	23.959

2. Station

Dependent Variable: Temp

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	22.265	.341	21.582	22.948
Anaerobic	23.956	.341	23.273	24.638
Facultative	26.525	.341	25.842	27.208
Tertiary	26.233	.341	25.551	26.916
Effluent	25.931	.341	25.248	26.613
Upstream	22.612	.341	21.930	23.295
Downstream	22.678	.341	21.995	23.360

Temp

Tukey HSD[a,b]

Months	N	Subset		
		1	2	3
December	21	23.4429		
November	21	23.8262	23.8262	
September	21		24.7571	24.7571
August	21			25.2310
Sig.		.720	.062	.566

Temp

Tukey HSD[a,b]

Station	N	Subset		
		1	2	3
Influent	12	22.2650		
Upstream	12	22.6125	22.6125	
Downstream	12	22.6775	22.6775	
Anaerobic	12		23.9558	
Effluent	12			25.9308
Tertiary	12			26.2333
Facultative	12			26.5250
Sig.		.977	.096	.878

1. Months

Dependent Variable: pH

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	7.488	.095	7.298	7.678
September	7.949	.095	7.759	8.139
November	8.097	.095	7.907	8.286
December	4.435	.095	4.245	4.624

2. Station

Dependent Variable: pH

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	6.543	.125	6.292	6.793
Anaerobic	6.042	.125	5.791	6.293
Facultative	6.783	.125	6.532	7.034
Tertiary	7.204	.125	6.953	7.455
Effluent	7.138	.125	6.887	7.388
Upstream	7.728	.125	7.477	7.979
Downstream	7.507	.125	7.257	7.758

1. Months

Dependent Variable: DO(mg/L)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	6.195	.155	5.884	6.506
September	1.171	.155	.860	1.483
November	4.730	.155	4.419	5.041
December	4.053	.155	3.742	4.364

2. Station

Dependent Variable: DO(mg/L)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	2.004	.205	1.593	2.416
Anaerobic	.414	.205	.003	.826
Facultative	4.450	.205	4.038	4.862
Tertiary	3.071	.205	2.659	3.482
Effluent	5.569	.205	5.158	5.981
Upstream	5.643	.205	5.231	6.054
Downstream	7.110	.205	6.698	7.522

DO(mg/L)

Tukey HSD^{a,b}

Months	N	Subset			
		1	2	3	4
September	21	1.1714			
December	21		4.0529		
November	21			4.7300	
August	21				6.1948
Sig.		1.000	1.000	1.000	1.000

DO(mg/L)

Tukey HSD^{a,b}

Station	N	Subset					
		1	2	3	4	5	6
Anaerobic	12	.4142					
Influent	12		2.0042				
Tertiary	12			3.0708			
Facultative	12				4.4500		
Effluent	12					5.5692	
Upstream	12					5.6425	
Downstream	12						7.1100
Sig.		1.000	1.000	1.000	1.000	1.000	1.000

1. Months

Dependent Variable: Conductivity (µscm-1)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	1125.846	17.939	1089.910	1161.782
September	774.038	17.939	738.102	809.974
November	565.317	17.939	529.381	601.252
December	438.508	17.939	402.572	474.444

2. Station

Dependent Variable: Conductivity (µscm-1)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	1403.972	23.731	1356.434	1451.511
Anaerobic	878.917	23.731	831.378	926.455
Facultative	887.956	23.731	840.417	935.494
Tertiary	926.138	23.731	878.600	973.677
Effluent	616.069	23.731	568.531	663.608
Upstream	128.168	23.731	80.630	175.707
Downstream	240.269	23.731	192.731	287.808

Conductivity (µscm-1)

Tukey HSD^{a,b}

Months	N	Subset			
		1	2	3	4
December	21	438.508			
November	21		565.317		
September	21			774.038	
August	21				1125.846
Sig.		1.000	1.000	1.000	1.000

Conductivity (µscm-1)

Tukey HSD[a,b]

Station	N	Subset				
		1	2	3	4	5
Upstream	12	128.168				
Downstream	12		240.269			
Effluent	12			616.069		
Anaerobic	12				878.917	
Facultative	12				887.956	
Tertiary	12				926.138	
Influent	12					1403.973
Sig.		1.000	1.000	1.000	.796	1.000

1. Months

Dependent Variable: TSS (mg/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	115.748	5.411	104.907	126.588
September	61.390	5.411	50.549	72.230
November	166.513	5.411	155.673	177.354
December	166.513	5.411	155.673	177.354

2. Station

Dependent Variable: TSS (mg/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	172.553	7.159	158.213	186.894
Anaerobic	137.000	7.159	122.659	151.341
Facultative	205.308	7.159	190.968	219.649
Tertiary	63.000	7.159	48.659	77.341
Effluent	30.015	7.159	15.674	44.356
Upstream	137.410	7.159	123.069	151.751
Downstream	147.500	7.159	133.159	161.841

TSS (mg/l)

Tukey HSD[a,b]

Months	N	Subset		
		1	2	3
September	21	61.3895		
August	21		115.7476	
November	21			166.5133
December	21			166.5133
Sig.		1.000	1.000	1.000

TSS (mg/l)

Tukey HSD[a,b]

Station	N	Subset				
		1	2	3	4	5
Effluent	12	30.0150				
Tertiary	12		63.0000			
Anaerobic	12			137.0000		
Upstream	12			137.4100		
Downstream	12			147.5000	147.5000	
Influent	12				172.5533	
Facultative	12					205.3083
Sig.		1.000	1.000	.943	.188	1.000

1. Months

Dependent Variable: TDS(mg/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	323.675	8.624	306.400	340.951
September	166.952	8.624	149.676	184.227
November	439.571	8.624	422.295	456.846
December	439.571	8.624	422.295	456.846

2. Station

Dependent Variable: TDS(mg/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	572.158	11.408	549.305	595.011
Anaerobic	318.657	11.408	295.803	341.510
Facultative	316.397	11.408	293.543	339.250
Tertiary	289.249	11.408	266.396	312.103
Effluent	293.218	11.408	270.365	316.071
Upstream	315.770	11.408	292.917	338.624
Downstream	291.647	11.408	268.793	314.500

TDS(mg/l)

Tukey HSD^{a,b}

Months	N	Subset		
		1	2	3
September	21	166.9519		
August	21		323.6751	
November	21			439.5710
December	21			439.5710
Sig.		1.000	1.000	1.000

TDS(mg/l)

Tukey HSD^{a,b}

Station	N	Subset	
		1	2
Tertiary	12	289.2493	
Downstream	12	291.6467	
Effluent	12	293.2181	
Upstream	12	315.7704	
Facultative	12	316.3967	
Anaerobic	12	318.6567	
Influent	12		572.1578
Sig.		.539	1.000

1. Months

Dependent Variable: NO2-N (ug/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	20.450	1.097	18.252	22.648
September	47.160	1.097	44.962	49.358
November	17.501	1.097	15.303	19.699
December	35.328	1.097	33.130	37.526

2. Station

Dependent Variable: NO2-N (ug/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	43.310	1.451	40.403	46.217
Anaerobic	19.183	1.451	16.276	22.091
Facultative	19.338	1.451	16.431	22.246
Tertiary	30.508	1.451	27.601	33.415
Effluent	35.453	1.451	32.546	38.361
Upstream	24.549	1.451	21.642	27.457
Downstream	38.425	1.451	35.518	41.333

NO2-N (ug/l)

Tukey HSD^{a,b}

Months	N	Subset		
		1	2	3
November	21	17.5011		
August	21	20.4498		
December	21		35.3278	
September	21			47.1600
Sig.		.240	1.000	1.000

NO2-N (ug/l)

Tukey HSD^{a,b}

Station	N	Subset				
		1	2	3	4	5
Anaerobic	12	19.1834				
Facultative	12	19.3383				
Upstream	12	24.5492	24.5492			
Tertiary	12		30.5080	30.5080		
Effluent	12			35.4535	35.4535	
Downstream	12				38.4253	38.4253
Influent	12					43.3099
Sig.		.141	.073	.214	.773	.226

1. Months

Dependent Variable: NO3-N (ug/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	27.188	1.493	24.197	30.178
September	78.511	1.493	75.521	81.501
November	43.588	1.493	40.598	46.579
December	60.583	1.493	57.592	63.573

2. Station

Dependent Variable: NO3-N (ug/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	67.083	1.975	63.127	71.039
Anaerobic	58.080	1.975	54.125	62.036
Facultative	31.105	1.975	27.150	35.061
Tertiary	44.719	1.975	40.763	48.675
Effluent	45.729	1.975	41.773	49.684
Upstream	58.274	1.975	54.318	62.229
Downstream	62.281	1.975	58.326	66.237

NO3-N (ug/l)

Tukey HSD[a,b]

Months	N	Subset			
		1	2	3	4
August	21	27.1876			
November	21		43.5885		
December	21			60.5825	
September	21				78.5108
Sig.		1.000	1.000	1.000	1.000

NO3-N (ug/l)

Tukey HSD[a,b]

Station	N	Subset			
		1	2	3	4
Facultative	12	31.1054			
Tertiary	12		44.7192		
Effluent	12		45.7285		
Anaerobic	12			58.0805	
Upstream	12			58.2737	
Downstream	12			62.2813	62.2813
Influent	12				67.0830
Sig.		1.000	1.000	.741	.606

1. Months

Dependent Variable: NH4-N (ug/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	750.764	36.715	677.216	824.313
September	781.534	36.715	707.986	855.083
November	811.223	36.715	737.674	884.772
December	748.149	36.715	674.601	821.698

2. Station

Dependent Variable: NH4-N (ug/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	464.137	48.569	366.842	561.433
Anaerobic	674.038	48.569	576.742	771.334
Facultative	1089.951	48.569	992.656	1187.247
Tertiary	987.138	48.569	889.842	1084.434
Effluent	776.113	48.569	678.817	873.409
Upstream	813.925	48.569	716.629	911.221
Downstream	605.122	48.569	507.826	702.417

NH4-N (ug/l)

Tukey HSD[a,b]

Station	N	Subset			
		1	2	3	4
Influent	12	464.1373			
Downstream	12	605.1216	605.1216		
Anaerobic	12	674.0380	674.0380		
Effluent	12		776.1127		
Upstream	12		813.9249	813.9249	
Tertiary	12			987.1380	987.1380
Facultative	12				1089.9513
Sig.		.050	.052	.171	.745

1. Months

Dependent Variable: TN (ug/l)

Months	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
August	1623.524	55.069	1513.209	1733.840
September	354.052	55.069	243.737	464.368
November	459.146	55.069	348.831	569.462
December	1233.266	55.069	1122.951	1343.582

2. Station

Dependent Variable: TN (ug/l)

Station	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Influent	800.115	72.849	654.182	946.049
Anaerobic	409.002	72.849	263.069	554.936
Facultative	1280.701	72.849	1134.767	1426.634
Tertiary	1231.410	72.849	1085.476	1377.344
Effluent	1080.450	72.849	934.517	1226.384
Upstream	764.675	72.849	618.742	910.609
Downstream	856.127	72.849	710.193	1002.060

TN (ug/l)

Tukey HSD[a,b]

Months	N	Subset 1	Subset 2	Subset 3
September	21	354.0522		
November	21	459.1461		
December	21		1233.2662	
August	21			1623.5245
Sig.		.536	1.000	1.000

TN (ug/l)

Tukey HSD[a,b]

Station	N	Subset 1	Subset 2	Subset 3	Subset 4
Anaerobic	12	409.0023			
Upstream	12		764.6755		
Influent	12		800.1152	800.1152	
Downstream	12		856.1266	856.1266	
Effluent	12			1080.4503	1080.4503
Tertiary	12				1231.4100
Facultative	12				1280.7007
Sig.		1.000	.973	.112	.461

1. Months

Dependent Variable: TP (ug/l)

Months	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
August	1866.275	89.940	1686.103	2046.447
September	1407.513	89.940	1227.341	1587.685
November	883.658	89.940	703.486	1063.830
December	1308.962	89.940	1128.790	1489.134

2. Station

Dependent Variable: TP (ug/l)

Station	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Influent	1604.226	118.980	1365.881	1842.571
Anaerobic	1272.282	118.980	1033.937	1510.627
Facultative	1824.905	118.980	1586.560	2063.250
Tertiary	1542.229	118.980	1303.884	1780.574
Effluent	1443.384	118.980	1205.039	1681.729
Upstream	859.657	118.980	621.312	1098.003
Downstream	1019.531	118.980	781.186	1257.876

TP (ug/l)

Tukey HSD[a,b]

Months	N	Subset 1	Subset 2	Subset 3
November	21	883.6578		
December	21		1308.9622	
September	21		1407.5133	
August	21			1866.2748
Sig.		1.000	.866	1.000

TP (ug/l)

Tukey HSD^{a,b}

Station	N	Subset			
		1	2	3	4
Upstream	12	859.6575			
Downstream	12	1019.5308	1019.5308		
Anaerobic	12	1272.2823	1272.2823	1272.2823	
Effluent	12		1443.3837	1443.3837	1443.3837
Tertiary	12			1542.2287	1542.2287
Influent	12			1604.2263	1604.2263
Facultative	12				1824.9049
Sig.		.197	.172	.443	.278

1. Months

Dependent Variable: Sio2 (Mg/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	37.811	1.025	35.759	39.864
September	28.731	1.025	26.679	30.784
November	63.263	1.025	61.210	65.316
December	1.896	1.025	-.156	3.949

2. Station

Dependent Variable: Sio2 (Mg/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	33.612	1.355	30.897	36.328
Anaerobic	35.322	1.355	32.606	38.037
Facultative	33.991	1.355	31.276	36.706
Tertiary	32.582	1.355	29.866	35.297
Effluent	30.424	1.355	27.709	33.140
Upstream	32.504	1.355	29.789	35.220
Downstream	32.042	1.355	29.327	34.758

Sio2 (Mg/l)

Tukey HSD^{a,b}

Months	N	Subset			
		1	2	3	4
December	21	1.8962			
September	21		28.7313		
August	21			37.8111	
November	21				63.2629
Sig.		1.000	1.000	1.000	1.000

1. Months

Dependent Variable: SRP (ug/l)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	1032.459	32.578	967.197	1097.722
September	436.967	32.578	371.705	502.230
November	596.143	32.578	530.880	661.405
December	644.722	32.578	579.460	709.985

2. Station

Dependent Variable: SRP (ug/l)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	1120.958	43.097	1034.624	1207.292
Anaerobic	725.423	43.097	639.089	811.757
Facultative	1002.123	43.097	915.789	1088.457
Tertiary	803.582	43.097	717.247	889.916
Effluent	479.914	43.097	393.580	566.248
Upstream	401.970	43.097	315.636	488.304
Downstream	209.041	43.097	122.707	295.375

SRP (ug/l)

Tukey HSD^{a,b}

Months	N	Subset		
		1	2	3
September	21	436.9671		
November	21		596.1427	
December	21		644.7224	
August	21			1032.4592
Sig.		1.000	.718	1.000

SRP (ug/l)

Tukey HSD[a,b]

Station	N	Subset			
		1	2	3	4
Downstream	12	209.0408			
Upstream	12		401.9696		
Effluent	12		479.9144		
Anaerobic	12			725.4229	
Tertiary	12			803.5815	
Facultative	12				1002.1229
Influent	12				1120.9577
Sig.		1.000	.859	.857	.457

1. Months

Dependent Variable: CHLO(a) (Mg/m3)

Months	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
August	18.430	.751	16.926	19.935
September	29.135	.751	27.631	30.639
November	169.331	.751	167.827	170.835
December	28.657	.751	27.153	30.161

2. Station

Dependent Variable: CHLO(a) (Mg/m3)

Station	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Influent	39.801	.993	37.811	41.791
Anaerobic	81.204	.993	79.215	83.194
Facultative	88.949	.993	86.959	90.939
Tertiary	49.993	.993	48.004	51.983
Effluent	88.911	.993	86.921	90.901
Upstream	31.130	.993	29.140	33.120
Downstream	49.729	.993	47.739	51.719

CHLO(a) (Mg/m3)

Tukey HSD[a,b]

Months	N	Subset		
		1	2	3
August	21	18.4304		
December	21		28.6567	
September	21		29.1350	
November	21			169.3310
Sig.		1.000	.969	1.000

CHLO(a) (Mg/m3)

Tukey HSD[a,b]

Station	N	Subset				
		1	2	3	4	5
Upstream	12	31.1298				
Influent	12		39.8012			
Downstream	12			49.7293		
Tertiary	12			49.9935		
Anaerobic	12				81.2044	
Effluent	12					88.9107
Facultative	12					88.9491
Sig.		1.000	1.000	1.000	1.000	1.000

B) Current WWTP: Physical-chemical parameters

pH

Tukey HSD[a,b]

Date	N	Subset	
		1	2
May	27	7.1874	
July	27		7.5781
August	27		7.6048
June	27		7.6689
Sig.		1.000	.302

Conductivity (µscm-1)

Tukey HSD[a,b]

Station	N	Subset			
		1	2	3	4
Upstream	12	115.7500			
Downstream	12	146.6667			
Confluent	12		295.6667		
Maturation pond 2	12			658.2500	
Effluent	12			665.5833	
Maturation pond 1	12			676.8333	

Facultative pond	12			704.9167	
Anaerobic pond	12			752.7500	
Influent	12				1097.7500
Sig.		.986	1.000	.078	1.000

Conductivity (µscm-1)

Tukey HSD[a,b]

Date	N	Subset		
		1	2	3
May	27	335.1111		
July	27		611.6296	
August	27		659.7778	659.7778
June	27			666.4444
Sig.		1.000	.104	.989

Temp

Tukey HSD[a,b]

Station	N	Subset		
		1	2	3
Downstream	12	21.9250		
Influent	12	22.0833		
Upstream	12	22.5750		
Confluent	12	22.6333		
Anaerobic pond	12		25.2250	
Facultative pond	12		25.2417	
Effluent	12		26.0917	
Maturation pond 1	12		26.1000	
Maturation pond 2	12			27.3583
Sig.		.492	.216	1.000

Temp

Tukey HSD[a,b]

Date	N	Subset	
		1	2
July	27	23.9481	
June	27	24.2074	
August	27	24.2407	
May	27		25.0407
Sig.		.571	1.000

DO(mg/L)

Tukey HSD[a,b]

Station	N	Subset					
		1	2	3	4	5	6
Influent	12	.2333					
Anaerobic pond	12		.6167				
Maturation pond 2	12			2.1917			
Effluent	12				2.6667		
Maturation pond 1	12				2.9500	2.9500	
Confluent	12					3.2500	3.2500
Downstream	12					3.2583	3.2583
Upstream	12						3.3333
Facultative pond	12						3.5250
Sig.		1.000	1.000	1.000	.258	.166	.295

DO(mg/L)

Tukey HSD[a,b]

Date	N	Subset		
		1	2	3
May	27	.6222		
July	27		1.7370	
June	27		1.7630	
August	27			5.6667
Sig.		1.000	.986	1.000

TSS (mg/l)

Tukey HSD[a,b]

Station	N	Subset						
		1	2	3	4	5	6	7
Confluent	12	35.2203						
Facultative pond	12		45.7757					
Maturation pond 2	12			53.1922				

Anaerobic pond	12				57.8800			
Influent	12					65.3394		
Maturation pond 1	12					65.3799		
Upstream	12						73.3282	
Effluent	12							77.1578
Downstream	12							79.7788
Sig.		1.000	1.000	1.000	1.000	1.000	1.000	.100

TSS (mg/l)

Tukey HSD[a,b]

Date	N	Subset 1	2	3	4
August	27	24.1822			
May	27		70.2711		
July	27			74.7415	
June	27				76.6063
Sig.		1.000	1.000	1.000	1.000

TDS(mg/l)

Tukey HSD[a,b]

Station	N	Subset 1	2	3	4
Upstream	12	59.8600			
Downstream	12	67.0725			
Confluent	12	107.4750			
Maturation pond 2	12		212.1183		
Effluent	12		259.0367		
Maturation pond 1	12		260.2500		
Facultative pond	12		267.9167	267.9167	
Influent	12			358.2167	358.2167
Anaerobic pond	12				400.3500
Sig.		.815	.653	.086	.897

TDS(mg/l)

Tukey HSD[a,b]

Date	N	Subset 1	2	3
July	27	49.1778		
May	27		198.4056	
June	27			307.9185
August	27			329.9630
Sig.		1.000	1.000	.695

Sio2 (Mg/l)

Tukey HSD[a,b]

Station	N	Subset 1	2	3	4	5	6
Upstream	12	14.6037					
Maturation pond 2	12		18.2756				
Anaerobic pond	12			19.4067			
Influent	12				20.6302		
Effluent	12				21.2536		
Downstream	12				21.2843		
Confluent	12					25.3389	
Maturation pond 1	12					26.1995	
Facultative pond	12						27.1041
Sig.		1.000	1.000	1.000	.307	.058	1.000

Sio2 (Mg/l)

Tukey HSD[a,b]

Date	N	Subset 1	2	3	4
July	27	12.7784			
June	27		13.9434		
May	27			26.1434	
August	27				33.4001
Sig.		1.000	1.000	1.000	1.000

Soluble reactive phosphorous (SRP) (ug/l)

Tukey HSD^{a,b}

Station	N	Subset							
		1	2	3	4	5	6	7	8
Upstream	12	61.8774							
Downstream	12		270.4558						
Confluent	12			452.3142					
Maturation pond 2	12				469.4936				
Maturation pond 1	12					513.7534			
Effluent	12						557.0234		
Facultative pond	12							654.9058	
Influent	12							664.8490	
Anaerobic pond	12								777.3033
Sig.		1.000	1.000	1.000	1.000	1.000	1.000	.141	1.000

Soluble reactive phosphorous (SRP) (ug/l)

Tukey HSD^{a,b}

Date	N	Subset		
		1	2	3
July	27	95.3730		
June	27	101.5952		
May	27		653.5037	
August	27			1114.8507
Sig.		.053	1.000	1.000

NO2-N (ug/l)

Tukey HSD^{a,b}

Station	N	Subset						
		1	2	3	4	5	6	7
Maturation pond 2	12	7.0043						
Effluent	12	8.4230						
Anaerobic pond	12		10.7623					
Maturation pond 1	12			15.2408				
Facultative pond	12			16.1134				
Influent	12				20.2065			
Confluent	12					43.8101		
Upstream	12						50.5863	
Downstream	12							55.9750
Sig.		.569	1.000	.951	1.000	1.000	1.000	1.000

NO2-N (ug/l)

Tukey HSD^{a,b}

Date	N	Subset			
		1	2	3	4
August	27	8.9907			
May	27		20.9842		
July	27			32.8356	
June	27				38.5769
Sig.		1.000	1.000	1.000	1.000

NO3-N (ug/l)

Tukey HSD[a,b]

Station	N	Subset						
		1	2	3	4	5	6	7
Effluent	12	26.3831						
Anaerobic pond	12	27.1795						
Maturation pond 2	12	29.6000	29.6000					
Facultative pond	12		35.3334					
Influent	12			62.8779				
Maturation pond 1	12				88.4190			
Downstream	12					104.5030		
Upstream	12						119.7943	
Confluent	12							146.9914
Sig.		.775	.097	1.000	1.000	1.000	1.000	1.000

NO3-N (ug/l)

Tukey HSD[a,b]

Date	N	Subset			
		1	2	3	4
May	27	31.5335			
August	27		40.5358		
July	27			96.1198	
June	27				116.7361
Sig.		1.000	1.000	1.000	1.000

NH4-N (ug/l)

Tukey HSD[a,b]

Station	N	Subset							
		1	2	3	4	5	6	7	8
Maturation pond 2	12	4.3120							
Influent	12		37.7115						
Downstream	12			87.8376					
Anaerobic pond	12				97.8005				
Upstream	12				98.1391				
Facultative pond	12					193.9045			
Maturation pond 1	12						234.5820		
Confluent	12							271.7630	
Effluent	12								276.8619
Sig.		1.000	1.000	1.000	.981	1.000	1.000	1.000	1.000

NH4-N (ug/l)

Tukey HSD[a,b]

Date	N	Subset			
		1	2	3	4
July	27	3.4982			
June	27		4.2170		
August	27			12.5201	
May	27				558.8368
Sig.		1.000	1.000	1.000	1.000

TN (ug/l)

Tukey HSD[a,b]

Station	N	Subset					
		1	2	3	4	5	6
Downstream	12	110.1245					
Anaerobic pond	12		185.0670				
Maturation pond 2	12		199.4790				
Upstream	12			223.2529			

Confluent	12			226.6453			
Influent	12			236.2434	236.2434		
Maturation pond 1	12				249.6057		
Facultative pond	12					276.3959	
Effluent	12						390.6855
Sig.		1.000	.248	.382	.344	1.000	1.000

TN (ug/l)

Tukey HSD^{a,b}

Date	N	Subset			
		1	2	3	4
August	27	140.5448			
June	27		185.2361		
July	27			198.1078	
May	27				408.3331
Sig.		1.000	1.000	1.000	1.000

TP (ug/l)

Tukey HSD^{a,b}

Station	N	Subset				
		1	2	3	4	5
Influent	12	800.9906				
Maturation pond 2	12		1628.4167			
Maturation pond 1	12		1844.4598	1844.4598		
Downstream	12		1942.5514	1942.5514	1942.5514	
Upstream	12			2272.4730	2272.4730	2272.4730
Confluent	12				2378.1933	2378.1933
Facultative pond	12				2410.7238	2410.7238
Effluent	12					2556.8545
Anaerobic pond	12					2741.9207
Sig.		1.000	.464	.106	.054	.053

TP (ug/l)

Tukey HSD^{a,b}

Date	N	Subset		
		1	2	3
May	27	1330.4580		
August	27		2078.9849	
July	27		2219.2740	
June	27			2627.5425
Sig.		1.000	.488	1.000

CHLO(a) (Mg/m3)

Tukey HSD^{a,b}

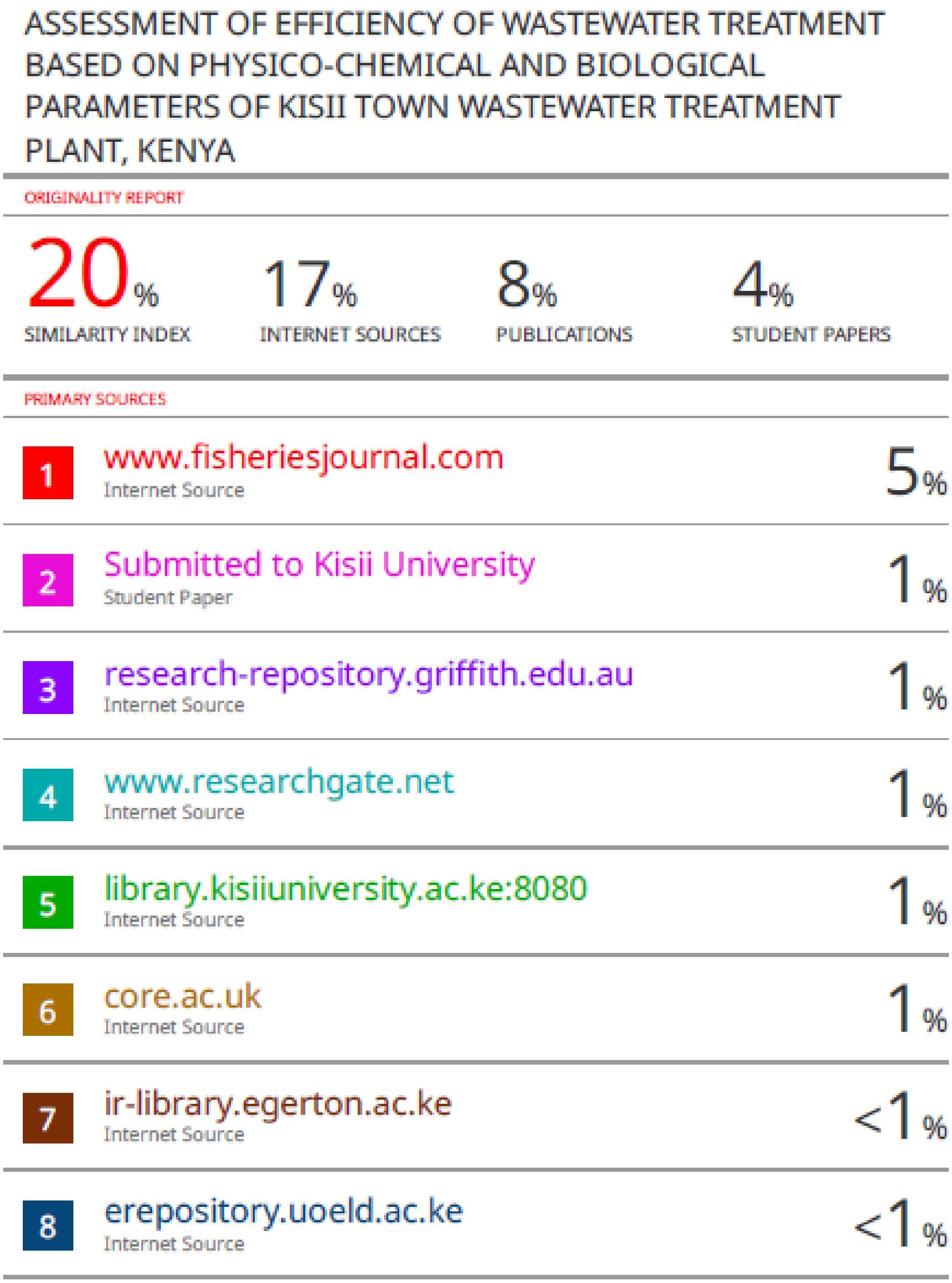
Station	N	Subset								
		1	2	3	4	5	6	7	8	9
Downstream	12	8.2835								
Upstream	12		12.2723							
Confluent	12			37.1466						
Maturation pond 1	12				58.0963					
Influent	12					83.2560				
Effluent	12						108.5297			
Anaerobic pond	12							156.7768		
Facultative pond	12								171.4070	
Maturation pond 2	12									175.8806
Sig.		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

CHLO(a) (Mg/m3)

Tukey HSD[a,b]

Date	N	Subset			
		1	2	3	4
July	27	10.9044			
June	27		12.6533		
May	27			22.4344	
August	27				314.7406
Sig.		1.000	1.000	1.000	1.000

Appendix 8: Turnit In Plagiarism Report



ASSESSMENT OF EFFICIENCY OF WASTEWATER TREATMENT BASED ON PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS OF KISII TOWN WASTEWATER TREATMENT PLANT, KENYA

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