ASSESSMENT OF SELECTED PHYSICO-CHEMICAL PARAMETERS, ANIONS, AND, HEAVY METALS IN RIVER CHEMOSIT, KERICHO COUNTY, KENYA

BY

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OCTOBER, 2024

DECLARATION AND RECOMMEDATION

I affirm that this research dissertation is entirely my original work and has not been submitted for a degree at any other university.

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DEDICATION

This work is dedicated to my sons Ronny Victor, and family members for their encouragement and moral support and all those who assisted me in reaching this far.

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ABBREVIATIONS AND ACRONYMS

ANOVA	– Analysis of Variance
ASV	-Anodic stripping voltammetry
DO	- Dissolved Oxygen
EC	-Electrical conductivity
EPA	-Environmental protection agency
ETV	-Electro-thermal vaporization
GC-ICP-MS	-Gas chromatography inductively coupled mass spectrometry
GC-MS	-Gas chromatography coupled mass spectrometry
ICP-MS	-Inductively coupled plasma mass spectrometry
ICP-OES	-Inductively coupled plasma optical emission spectrometry
KEBS	-Kenya bureau of statistics
KEPHIS	-Kenya Plant Health Inspectorate Service
NEMA	-National Environmental Management Agency
PTFE	- Polytetrafluoroethylene
SE	– Standard Error
SPSS	-Statistical package for the social science
TDS	-Total dissolved solids
WASREB	-Water services and regulatory board
WHO	-World Health Organization

ABSTRACT

Clean water is fundamental for life. River Chemosit serves as a crucial water source for domestic, agricultural, and industrial purposes, thus sustaining the local livelihoods. The escalating concern regarding river pollutants poses a significant threat to public health. This study aimed to evaluate the water quality of River Chemosit to assess its current pollution status. Both upstream and downstream areas of Chemosit Centre were surveyed from August 2021 to January 2022. Water samples were systematically collected along River Chemosit from Kipkerieny, Chemosit Centre, and Kabitungu sampling points. These samples underwent comprehensive analysis for various physicochemical parameters. pH, temperature, electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS) were measured *in situ* using a calibrated portable professional series (YSI) multiparameter meter model 35 C. Additionally, a UV-VIS spectrophotometer was employed for analysing sulfates, phosphates, and nitrates, while ICP-MS was used for heavy metal analysis. The collected data was statistically analysed using SPSS version 28. Spatially, the mean values for the parameters were as follows: pH 7.0 ± 0.05, temperature 24.15 °C ± 0.18, EC 1187.94 μScm^{-1} ± 30.84, DO 8.99 mgl^{-1} ± 0.06, TDS 1460.06 mgl^{-1} ± 69.14, sulfates 0.08 mgl^{-1} ± 0.005, phosphates 0.40 mgl^{-1} ± 0.01, and nitrates 1.6 mgl^{-1} ± 0.09. Spatially, the mean values for the metals were as follows: Zn 0.07 mgl^{-1} ± 0.01, Fe 0.43 mgl^{-1} ± 0.01, Al 0.47 mgl^{-1} ± 0.03, Cu 0.02 mgl^{-1} ± 0.001. from the analysis, lead (Pb) was below the detectable limit. Seasonally, significant differences were observed in the mean values of pH, temperature, EC, TDS, sulfates, and phosphates, except for DO and nitrates. The mean values for pH, EC, DO, copper (Cu), zinc (Zn), nitrate (NO_3^-), and sulfate (SO_4^{2-}) met WHO guidelines for domestic water use both spatially and seasonally. However, mean values for aluminum (Al), iron (Fe), and phosphate (PO_4^{3-}) exceeded WHO limits, and TDS mean values surpassed WHO limits during the dry season. Correlation coefficient analysis indicated significant relationships between various physico-chemical parameters. River Chemosit's contamination with pollutants originating from anthropogenic activities and discharge from domestic and industrial sources underscores the imperative for continuous water quality monitoring to ensure compliance with NEMA and WHO standards.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Water plays a vital role in sustaining human health and well-being, serving essential functions such as drinking, cooking, and sanitation, as well as supporting industrial processes. However, access to clean water remains a challenge in growing nations due to pollution of water by harmful substances, leading to millions of deaths annually from waterborne diseases. Consequently, ensuring water quality has emerged as a paramount concern globally (Kur et al., 2019). The issue of water pollution can be from agricultural, sewage, wastewater, or oil spillage into water bodies and therefore, introduce non-metals and metals into the water system. This problem has escalated since the agricultural and industrial revolutions. Presently, a significant portion of water sources worldwide are tainted with heavy metals stemming from various human activities, including domestic and industrial processes (Rayori et al., 2021; Njue et al., 2016; Omoko et al., 2015; Srikanth et al., 2013). The environmental impact of trace metals surpasses that of other pollutants because of their non-biodegradable nature, tendency to accumulate, and extended biological half-lives. Consequently, their levels in water frequently surpass permissible thresholds. Hence, they find their way up the food pyramid, can profoundly disrupt biological processes, and could potentially lead to severe disruptions in the ecological equilibrium of natural water systems, resulting in the depletion of aquatic biodiversity (Chebet et al.,2018).

Chemical speciation indicates the diverse chemical forms of elements and their distribution in a specific sample (Mulugeta et al., 2010; Azeez et al., 2006). It is also valuable for knowing the oxidation state in which heavy metals exist in water, the type of binding ligand, and the development of definite forms of heavy metals in the location; this is because oxidation states of heavy metals can affect their toxicity and bioavailability, absorption and elimination of heavy metals, for instance, toxicity of Mn (III) species are higher than +2, +4, +6, and+7 in their oxidation states (Tangahu et al., 2011). Numerous factors, including pH, temperature, and both physical and chemical attributes, impact the solubility and accessibility of heavy metal ions. Speciation, as elucidated by Rahman and Zaim (2015) and Nsikak et al.,2013), delineates the chemical behavior of elements within water. The behavior and ultimate destiny of metals in aquatic environments are dictated by a multitude of physicochemical processes, as highlighted by Gershom et al., (2019). Within water, the specific chemical form dictates both bio-availability with other components of the system.

The availability of anions in water depends on the land usage around the river. The concentration of nitrates in water ecosystems is due to applications of inorganic fertilizers and animal manure in agricultural lands (Njue et al.,2016). Water with high levels of nitrate is not suitable for drinking because too much nitrate can affect how blood carries oxygen and can cause methemoglobinemia (blue baby syndrome). Phosphates in water are due to detergents used in washing automobiles and clothes inside the river, fertilizers, and other wastes disposed into the river. Excess phosphates in water can cause the growth of algae, which prevents the entry of sunlight required by aquatic life, reduces the amount of oxygen in the water and also removes carbon (IV)oxide, and drives the pH to higher values. High levels of sulfates in drinking water can give water a bitter or medicinal taste and can cause laxative effects, diarrhea, and dehydration (Swamy et al.,2013).

1.2 Statement of the problem

River Chemosit is a river that serves Bomet County and Kericho County, and it is mainly used for agricultural, industrial, and domestic purposes. A previous study by Ogoyi et al., (2011) reported that rivers feeding Lake Victoria contain high heavy metals with concentrations of Zn (0.050 ± 0.018) and Pb (0.83 ± 0.022). A separate study by Bett (2015) on environmental conservation indicated that embracing modern technological methods in agriculture ultimately increases productivity and reduces the cost of production, resulting in higher profits for farmers. However, farm inputs like fertilizers and agrochemicals used by farmers also pollute water bodies, and poor methods of farming destroy the soil, negatively impacting the fauna and flora. Both studies identified anthropogenic sources as the primary contributors to heavy metals and other emerging pollutants like pesticide pollution in the river. Anthropogenic activities in the vicinity of water bodies, such as agricultural practices, domestic and automotive washing, industrial discharges, bathing, and water extraction for construction and household use, are implicated. These human-induced activities surrounding the river may exacerbate the contamination of metallic and metalloid pollutants in River Chemosit. These activities and increased pollution caused by discharges from factories and shopping Centers wastes necessitate an investigation into the pollution level of metals. Despite increasing anthropogenic activities due to rapid development in counties and from past studies, it shows some gaps in these studies. The attention has been on the general pollution of water bodies. The information on pollution levels of metals and anions in the river has not been studied. The study assessed the river Chemosit's water quality upstream as well as downstream of Chemosit Centre based on selected physicochemical parameters, anions, and heavy metals.

1.3 Objectives

1.3.1 General Objectives

To assess the spatial and temporal variations of water quality of river Chemosit upstream as well as downstream of Chemosit Centre based on selected physicochemical parameters, anions, and heavy metals.

1.3.2 Specific Objectives

i. To study the spatial and temporal variations of selected physical parameters (pH, temperature, electrical conductivity, DO, and TDS) in River Chemosit.

ii. To study the spatial and temporal variations of anions (NO_3^-, SO_4^{2-}, and PO_4^{3-}) in River Chemosit.

iii. To determine the presence and concentration of Al, Fe, Cu, Zn, and Pb in River Chemosit using ICP-MS.

1.4 Hypotheses

i. There are no statistically significant variations in the spatial and temporal variations in the selected physical parameters (pH, temperature, electrical conductivity, DO, and TDS) in River Chemosit.

ii. There are no significant spatial and temporal variations in anion concentrations (NO_3^-, SO_4^{2-}, and PO_4^{3-}) in River Chemosit.

iii. Metals Al, Fe, Cu, Zn, and Pb in River Chemosit are below the recommended standard levels.

1.5 Justification of the Study

Most households and industries dispose of their waste into river Chemosit. Waste management is a great challenge due to the absence of modern facilities for proper waste disposal. Improper waste disposal reduces the quality of water, thus not suitable for use by humans, livestock and plants. The study's objective is to assess the current water quality of River Chemosit by monitoring the total concentration of specific heavy metals and anions, including physico-chemical parameters. The data analysis offers insights into the pollution level of the river.With this information, the community can use the river resources sustainably. Environmental enthusiasts and the local community can use the study findings to prevent further pollution and use the river resources sustainably.

1.6 Assumptions

i. Samples collected provided accurate information necessary to draw valid and reliable conclusions.

ii. The instrument used elicited reliable results.

iii. The methodology used addressed the problematic issues and the purpose of the study.

iv. The analysis was done, and the sample size was sufficient to detect significant differences.

1.7 Scope and Limitations

The study limited itself to pollution levels of selected metals and anions along river Chemosit in Kericho County. The study also limited itself to sampling points upstream (Kipkerieny), middle stream (Chemosit Centre), and downstream (Kabitungu), which are primarily used by the inhabitants of Kericho for industrial (Jamji and Bureti Tea factories), agricultural, and mainly domestic activities. During the study, the *in-situ* measurements were limited to pH, temperature, electrical conductivity, Dissolved Oxygen, and Total Dissolved Solids. For anions, only Nitrates, Sulphates, and Phosphates were analyzed. Metals analyzed were limited to Aluminium, iron, Copper, Zinc, and Lead.

CHAPTER TWO

LITERATURE REVIEW

This chapter covers the background information on water's physical and chemical characteristics. Moreover, the literature review also covers the heavy metals of the current study and selected methods of heavy metal analysis.

2.1 Chemical Composition of Freshwaters

River Chemosit is a freshwater river in Kenya with an area of 1023 km^2. It provides several benefits to the local community, including domestic, industrial, and agricultural water sources. It is also a source of livelihood as most of the population along the river relies on domestic activities (car washing business, water vending) as their primary source of income. The current industrial activities, particularly those of Jamji and Bureti-Kabitungu tea factories, disrupt the natural material flow and introduce new chemicals into the environment. Industrial effluents commonly contain hazardous substances, including heavy metals such as Aluminum, Lead, Iron, Copper, Manganese, and Cadmium.

The general chemical characteristics of river water are variable over time, and sampling should be done periodically in different places along the river. In the dry season, water in rivers is generally contributed by ground water, and in the rainy season is contributed by surface run-offs. Water composition in rivers changes due to pollution. The availability of calcium, silica, and hydrogen carbonates mostly comes from rocks and carbonates, while the level of potassium is low in rivers because it is mostly retained in clays. The chemical composition of water is determined by weathering, temperature, and human activities. Weathering of silicate rocks, salt deposits, sulfide deposits, and organic carbon while temperature affects the rate of dissolution and solubility of substances in water (Musungu et al.,2023). Heavy metals are categorized into essential (e.g., Nickel, Iron, and Zinc) and non-essential (e.g., Aluminium, Cadmium, Lead, Mercury, and Tin) for living organisms (Santos et al., 2014).

In aquatic ecosystems, analyzing the total concentration of heavy metals in surface water serves as a valuable tool for pinpointing pollution hotspots, identifying human-induced sources of metal contamination, and comprehending pollution patterns and interactions between metals and sediments (M. Amin,2017; Lixu & Jingli, 2015). Various metals can be present in natural water bodies due to geological sources, such as metal ores in surrounding rock formations or aquifers that supply rivers. However, industrial operations, including mining, quarrying, and metal processing, often contribute to elevated levels of heavy metals in many natural water systems. Additionally, the pH of rivers is predisposed by issues such as the geological composition of the water source, atmospheric inputs, and the presence of other chemical contaminants (Stogbauer et al., 2008). Every water body harbors a diverse array of molecules and ions resulting from soil erosion in the watershed, atmospheric deposition, and sedimentation from the river bed.

The chemical composition of a water body is tortuously linked to its climate, which influences hydrological processes and basin geology (Petrosyan & Perikhanyan, 2019). Within each water body, there exists an equilibrium of the four primary anions and three major cations. The key anions contained in natural water are; Cl^-, SO_4^{2-}, $HCO_3^{-,}$ and $CO_3^{2-,}$ and the core cations are; Ca^{2+}, $Mg^{2+,}$ and K^+. These ions are usually present at a milligram/liter parts concentration per million (ppm). In contrast, ions such as the nutrients PO_4^{3-}, $NO_3^{-,}$ and NH_4^+ are present at microgram /liter parts per billion (ppb) levels (Boyd et al.,2016, Tailling, 2006). These ions Na^+, $K^{+,}$ and Cl^- are essential minerals in regulating the internal environment of blood and tissue cells in animals, as well as in the tissues of plants.

Ca^{2+}, Mg^{2+}, Bicarbonate, and alkalinity are vital for the existence of aquatic creatures and are key factors determining water hardness and softness. Nitrates are vital plant nutrient with PO_4^{3-} and silicate for diatoms. SO_4^{2-} serves as a crucial component within certain tissue cells and is indispensable in the external environment by serving as a primary anion for maintaining charge balance, ensuring electro-neutrality,

particularly in providing a sense of balance for H^+, $Ca^{2+,}$ and Mg^{2+}. SO_4^{2-} is also essential in the acidification process distressing soils and water, though it is regularly present in more significant volumes in hard water (DHS,2023, Njuru, 2001).

Gases mainly dissolved in natural water bodies, with their composition primarily influenced by atmospheric content. Nitrogen, oxygen, argon, and carbon dioxide constitute the majority of atmospheric gases, crucial for various processes within water bodies, including biochemical reactions (Luck et al., 2008). Volcanic activity and the release of gases from the Earth's mantle introduce a variety of compounds, including carbon oxides, ammonia, hydrogen sulfide, sulfurous gases, and others, into natural water sources. Additionally, ultraviolet radiation, such as ozone and human-generated pollution, contribute to the appearance and dissolution of various gases in water (Ongeri et al., 2015; Rabajzyk & Namiesnik, 2015; Luck et al., 2008).

Sulfur and nitrogen oxides can significantly alter pH levels, potentially lowering it to as low as pH four or raising it above pH 10 in eutrophic alkaline waters, where photosynthesis can play a role. These pollutants primarily originate from human activities. The chemical composition of water is a key determinant of its quality for specific purposes, reflecting its suitability for various uses (Tailling, 2006). The concentration of substances in water varies widely, ranging from trace amounts to significant concentrations, influenced by both natural and anthropogenic activities that contribute to water pollution (Stogbauer et al., 2008).

2.2 Physical parameters of water

2.2.1 Potential of hydrogen (pH)

The potential of hydrogen(pH) measures the acidity or alkalinity of a constituent on a scale from 0 to 14 using a pH meter. It quantifies the negative common logarithm of hydrogen ion activity. Drinking water falls between pH 7 and 8.5, slightly basic due to minerals in hard water, while water with a pH below 7 is acidic. Drinking water below pH 7 causes gastrointestinal irritation, and above pH 8.5 causes eye and skin irritation. (Musungu et al.,2023). The pH of natural water offers insights into various chemical and biological processes and can indirectly indicate different impairments. Fluctuations in pH may signal the presence of industrial pollutants, photosynthesis, or algae respiration fueled by contaminants (Gershom et al., 2019).

Several factors influence water pH, including the composition of bedrock and soil through which water flows. Plant growth and organic matter within water bodies also play a role, as their decomposition releases carbon dioxide, forming carbonic acid, which can lower pH, though it's a weak acid. Industrial processes often require precise pH levels, leading to the addition of chemicals directly into water or through sewage treatment plants. Additionally, pH can be affected by the discharge of chemicals by individuals, industries, and communities into water bodies (Lofts & Tipping, 2011; Salequzzaman et al., 2008).

As pH levels rise, most metals tend to become more soluble in water. For instance, sulfur emissions from coal combustion can lead to the formation of acid rain, which, as it runs off artificial structures into water bodies, can dissolve metals. The resulting increase in dissolved metals can harm aquatic organisms and pose health risks to humans if the water is consumed (Gershom et al., 2019; Anita & Madhoolika, 2008; Agbozu et al., 2007).

The pH of water is crucial in the solubility of metals and their interactions with organic anions and marine organisms in saline environments. The solubility of metals tends to increase at a low pH, and as such, the use of pH affects the cycling and distribution of the metals in saline water. The metals that form stable complexes with chloride ions have high concentrations at higher pH values. On the contrary, the extent of formation of strong complexes with carbonates enhances the ratio of free ions at lower pH. Moreover, it shows that with decreasing pH, the adsorption of metals on organic particles is less effective since most of the particles of organic matter in saline water bear a negative charge. Metals forming strong complexes with hydroxide remain relatively unaffected by pH changes, as they do not experience significant increases in their free forms (Bielymer et al., 2012; Korfali, 2010). A study done by Oseji et al.,2019 found that the river Niger in Nigeria was slightly acidic as the pH ranged from 5.2 to 7.1. This was attributed to high turbidity, photosynthesis, and respiration. Jannat et al.,2019 obtained 7.3-7.7. This could be attributed to effluents containing alkali in river Mokeshbeel in Bangladesh. Olubanjo and Adeleke (2020) obtained 6.5-8.5. This was attributed to the large volume of water and the presence of contaminants across river Osse, Kogi state in Nigeria. All these values are in agreement with the values obtained in river Chemosit as they are within the WHO (2017). Edori O.S and Aniekan M Udongwo (2021) obtained a pH varied from 5.60 to 5.63 in Okamini River. They attributed the acidic values to the presence of dumps, abattoirs, and fish farms along the river coupled with drainage directly to the river and aerobic organisms that degrade organic wastes, producing carbon(IV)oxide, which solubilizes in water to produce carbonic acid, thus keeping the water in acidic form.

2.2.2 Temperature

Water temperature is a fundamental characteristic indicating the degree of heat or coldness of water. Turbidity, which refers to the presence of suspended solids in water, can influence water temperature. Elevated turbidity can raise water temperature as suspended particles absorb solar radiation more effectively than water alone. Consequently, heat absorbed by these particles is transferred to surrounding water molecules, leading to an upsurge in overall water temperature (Gupta et al., 2017). Various environmental factors can impact water temperature, including solar radiation, atmospheric heat transfer, stream confluence, and turbidity. Shallow and surface waters are particularly susceptible to these influences compared to deeper waters (Scannel &Jacobs, 2001).

High temperatures can increase the dissolving capacity of heavy metals, hence increasing their dangers (Banunie & Otchere, 2018; Patrick & William, 2011). Thirdly, water temperature remains an essential fact as it defines an organism's limit in tolerance to water temperatures. For instance, the mortality of zinc-sensitive organisms increases when water temperatures increase to 25°C as compared to when water temperatures are below 20°C. This trend may be a result of the permeability of body tissues, rising metabolic rate, and oxygen uptake with the increase in water temperature (Patrick & William, 2011). In addition, the dissolving ability of water depends on its temperature; for example, when water temperature decreases from typical surface temperatures of 25°C to 4°C, water increases in density (Githinji, 2019).

In a research done by Bhumika et al.,2019 in river Kharun, India, the water temperature recorded ranges between 24^0C-32^0C. They suggest that high temperatures may result from low water levels, which leads to a clear atmosphere and this is done in summer.

These values differed from the values obtained in River Chemosit as the study was done in summer only. Oseji et al.,2019 recorded high-temperature values of 22^0C to 30^0C, which could be due to low vegetation cover and degree of exposure to solar heat. This also differed from the values recorded in Chemosit River as the area is covered with vegetation. Jannat et al.,2019 stated that 23.3^0C - 30.8^0C values were found to lie within the standard limit. These values could be attributed to the fact that the number of insoluble pollutants in water also tends to increase during summer; water levels decrease and make them hot. The discharge of pollutants also increases the temperature of water in the Mokeshbeel River in Bangladesh.

2. 2. 3 Electrical conductivity

Electrical conductivity (EC) in natural waters is a standardized measure of the ability of water to conduct an electric current primarily influenced by dissolved substances. It is measured in micro Siemens per centimeter (µs/cm). EC is contingent upon the concentration of dissolved ions, often quantified as TDS (Kur et al., 2019). The origin of EC may be traced back to various sources, such as an abundance of dissolved salts resulting from inadequate irrigation management, mineral content in rainwater, runoff, or other discharge processes. At a certain threshold of salt concentration, electrical conductivity ceases to be directly correlated with salt concentration, owing to the creation of ion pairs. These pairs weaken each other's charge, meaning that advanced TDS levels do not necessarily translate to higher electrical conductivity.

Additionally, temperature influences electrical conductivity by affecting ionic concentration, as many salts exhibit greater solubility at higher temperatures. When salt dissolves, it dissociates into its constituent ions (Mobin & Bakali, 2015). Typically, freshwater sources exhibit electrical conductivity ranging between 0.001 and 0.1 µs/cm.

Elevated electrical conductivity in consumption water is linked with toxic trace elements that can potentially lead to heavy metal poisoning.

2.2.4 Ionic strength

The collective concentration of all ions within the solution estimates the ionic strength of a solution.

$$I=\frac{1}{2}\sum_i Z_i^2 C_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2.1}$$

Where C_i is the molar concentration, Z_i is the charge of ion i

Multivalent ions make significant contributions to ionic strength. Changes in ionic strength and composition can influence the structure and function of biological communities, as different taxa may have preferences for specific ionic strength ranges. Natural variations in ionic strength occur across aquatic ecosystems, and aquatic organisms tend to thrive within certain ranges of ionic strength. Alterations to these parameters can have adverse effects on aquatic biota (Lofts &Tipping et al., 2015). EC, salinity, and TDS measurements are commonly employed as indicators of water's ionic strength. Elevated salinity levels can influence the absorption of harmful substances by organisms.

2.2.5 Total dissolved solids (TDS)

Total dissolved solids (TDS) primarily consist of inorganic salts and trace quantities of organic matter dissolved in water. The main constituents typically include cations such as Ca^{2+}, $Mg,^{2+}$ Na^{+}, and K^{+}, as well as anions like carbonate, chloride, sulfate, and nitrate. TDS in water comes from various sources, including natural processes, sewage, urban and agricultural runoff, and industrial wastewater. Water with a total dissolved solids level of about 600 mg/l is commonly considered palatable while drinking water becomes noticeably less palatable at TDS levels exceeding about 1000 mg/l (Scannel &Jacobs,2001).

Both TDS and conductivity serve as indicators of the overall inorganic mineral content in drinking water. These tests are valuable for assessing the consistency of water quality achieved through purification processes, which target the removal of inorganic contaminants. Total dissolved solids are not typically considered a primary pollutant with direct health effects; they serve as a gauge for the aesthetic qualities of water for consumption and provide a collective indication of the existence of various chemical contaminants (Kosgey et al., 2015).

In aquatic environments, TDS is crucial for maintaining cellular density balance. Increased levels of TDS in water bodies can result in cell shrinkage and alter the taste of water. This phenomenon is frequently associated with elevated levels of alkalinity or hardness. Jannat et al.,2019 obtained TDS values of river Mokeshbeel ranging from 686mg/l to 952mg/l, which surpassed the maximum allowable limit of 500mg/l of WHO but within the allowable limit of Bangladesh Environmental quality standard of 1000mg/l. This was attributed to anthropogenic activities such as washing motorcycles' clothes, bathing and runoff from the surrounding farmlands (Hogue &Deb,2017).

2.2.6 Dissolved Oxygen (DO)

Dissolved oxygen is a quantity of oxygen that is dissolved in a water sample, measured in mg/l. DO levels in water can differ due to aspects including temperature, sunlight exposure, atmospheric pressure, salinity, and the presence of aquatic vegetation. The oxygen solubility decreases with increasing temperature and water salinity. In freshwater environments at sea level, DO concentrations typically range between 15 mg/l at 0°C to 8 mg/l at 25°C. Freshwater usually maintains DO levels close to 10 mg/l. However, in waters contaminated with substances like fertilizers, suspended materials, petroleum waste, or industrial pollutants, DO levels often decline. Microorganisms responsible for breaking down contaminants rely on oxygen for their metabolic processes (Mobin et al.,2015). As these microorganisms consume oxygen to degrade pollutants, water may become anaerobic, reaching levels of dissolved oxygen (DO) too low to sustain aquatic life, including fish. Anthropogenic activities like farming and mining are primary sources of contaminants and waste entering surface water bodies. As contaminant levels rise, the biological oxygen demand of the water rises, resulting in reduced DO levels and potential mortality of aquatic life (Githinji, 2019).

2.3 Anions and their toxicity

Nitrates and phosphates are referred to as nutrient pollutants when in water bodies. These pollutants are a result of excess phosphorus and nitrogen from agricultural farms. These nutrients are mainly from animal wastes, fertilizers, pesticides, and herbicides, which are washed into the river. Water, being a universal solvent, dissolves all the substances in the river and mixes with it. They contaminate water when their concentrations are high, reducing the quality of water. These nutrients stimulate the growth of algae and plants. Neurotoxins produced by algae are harmful to aquatic animals (Chebet et al.,2018).

The allocation of a component among various inorganic complexes significantly influences its movement and accessibility in biological systems, as it impacts properties like charge, solubility, and diffusion coefficients. Complexation reactions with metals result in the formation of coordination complexes with different levels of stability. In a structure comprising of metal and ligand, the distribution of species is contingent upon aspects like as concentrations, stoichiometry, pH, and ionic strength. Metals can bind with anions to generate solution complexes (Baker et al., 2019; Rodriques et al., 2019).

The presence of sulphates in the environment is due to the oxidation of Sulphur, organic Sulphur, or sulphide. Sulfates are found in combine form in nature with some metals such as sodium, potassium, and magnesium forming various salts, and these may be leached into the water system. Fertilizers that contain sulphates can be washed into the river by rainwater.

High concentrations of sulphates can lead to acidification in rivers and streams, posing a threat to aquatic life (Edeogu, 2007). Elevated sulfate levels may indicate the existence of an acid drainage system, a significant environmental issue linked to industrial and agricultural activities.

Furthermore, high concentrations of sulfates can be harmful to cattle, causing a laxative effect due to the formation of strong acids that alter pH levels. Sulfate ions participate in complexing and precipitation reactions, influencing the solubility of trace metals and other elements. Recommended thresholds for sulfate levels in water designated for domestic use typically fall below 250 mg/l (Pillard et al., 2009).

Elevated levels of phosphates can promote algae growth, leading to eutrophication in aquatic ecosystems and subsequent declines in dissolved oxygen levels. Algae may produce toxins harmful to human and animal health (Mazzei &Piccolo, 2015). According to N. Gupta et al.,2017, high phosphate levels cause muscle damage, problems with breathing, and kidney failure.

Nitrate, occurring naturally and found in some foods at safe levels, should ideally be limited to 10 mg/l in drinking water. Consumption of water high in nitrates can cause symptoms like increased heart rate, nausea, headaches, and abdominal cramps in humans (Mielech et al., 2021). In the river, Chemosit and its streams, the presence of nitrates could be attributed to agricultural runoff and wastewater discharge. Furthermore, elevated nitrate levels can contribute to the eutrophication of water bodies. A Study carried out by Rodriques (2019) in Odessa and midland in west Texas found that high levels of nitrates were due to agriculture, septic systems, and weathering. According to Dr Eltigani and Abdallaziz (2013), in Sudan, the river Nile had higher levels of nitrate than the EPA value 10mg/l due to contamination from septic tanks, soakage pits, and animal manure. Another study carried out by Reyes Tirado (2007) in the Philippines found that the concentration of nitrates was high due to the intensive use of nitrogenous fertilizers in farming. Olubanjo and Adeleke (2020) recorded the highest mean in Odolu River Osse of 36.47mg/l.This could be due to nitrate-containing fertilizers used for the growth of crop plantations close to the river.

2.4 Analysis of anions in surface water

Different methods have been used to analyse ions like nitrates, phosphates, and sulphates, including Ion chromatography, Ultraviolet spectrophotometry, high-performance liquid chromatography, Gas chromatography, and other colourimetric methods (Kirianki et al.,2018).

2.4.1 High-performance liquid chromatography (HPLC)

A liquid sample is injected into a stream of mobile phase flowing through a column containing a stationary phase, which is a separating solvent. The components in the sample separate from one another through a process of differential migration as they flow through the column. The bands emerge from the column and the solvent flow carries to the detectors' which then deliver a voltage response as a chromatogram as the function time. The time at which each peak emerges shows the sample constituent with respect to a standard. The peak corresponds to the quantity of the analyzed ion in a sample (Oremo et al.,2020).

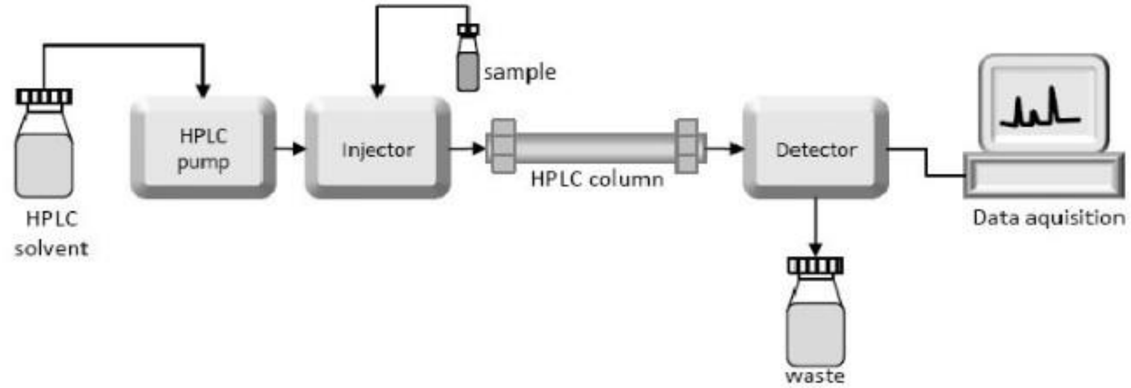


Figure 2.5.0 Schematic diagram of HPLC. Source (Czaplicki, 2013).

Solvent Reservoir-A glass reservoir holds the mobile stage component. In HPLC, the dissolvable is often a mixture of polar and non-polar liquid fractions, and specific fixations change depending on the sample arrangement.

Pump- The pump is positioned in the upper stream of the liquid chromatographic column and pumps eluent into the system from the solvent reservoir.

Injector: This device inserts the sample into the eluent flow. Sampling loops are the most extensively employed injection device.

Column- The separation is done within the column. Inside the column, silica or polymer gels are mostly used as packing materials.

Detector—The separation of samples takes place inside the column, and the separation is determined using a detector. The presence of an analyte affects the eluent's composition, and the detector quantifies these differences. This variation is measured using an electrical signal.

Data Collection- Signals from the indicator are taken via outline recorders or electronic integrators with varying degrees of multi-sided precision and the ability to examine, store, and reprocess chromatographic data. The computer coordinates the identifier's reaction with each component and displays it in a chromatograph that is to read and understand.

Advantages of HPLC

It is quick and efficient. It uses a pump and not gravity, which forces a liquid solvent through a solid adsorbent material. The different chemical components separate as they move at different rates. The experiment can be done within 10 to 30 minutes, and it provides high resolution. It is precise and highly reproducible. Because it is largely automated, basic HPLC runs can be operated with minimal training. It uses a wide range of stationary phases and has a high-pressure gradient. From the output, the identification of peaks is accurate (Czaplicki, 2013).

Disadvantages of HPLC

High cost—HPLC requires large quantities of expensive organics, such as solvents and columns, regular maintenance, and calibration. Advanced software is required for data analysis.

2.4.2 Gas Chromatography (GC)

Gas chromatography consists of a narrow tube called a column through which the vaporized sample passes as it is carried through a continuous flow through a non-reactive gas. The column is enclosed in a temperature-controlled oven. Due to their physical and chemical properties, the sample components pass through the column at different speeds, which results in interactions with the stationary phase. The chemicals exit the column and are finally detected and identified electronically (Helaluddin et al.,2016).

Advantages of gas chromatography

It is selective and, therefore, reduces interference from other ions present in the sample, hence enhancing the accuracy of the results. It allows for the simultaneous analysis of multiple ions in one analysis, therefore saving time. Minimal contamination and loss of the sample because it requires less sample preparation procedures. It can detect and quantify a variety of ions, even in complex matrices. It is easy to operate and hence can be accessed by inexperienced and experienced analysts (Boss &Fredeen,2004).

Limitations of gas chromatography

It does not have a universal detection; therefore, conductivity detection cannot give structural information about the separated species. On-ionic species or molecules that cannot interact well with ion exchange resin cannot be analyzed with Ion Chromatography.

2.5 Analysis of metals in surface water

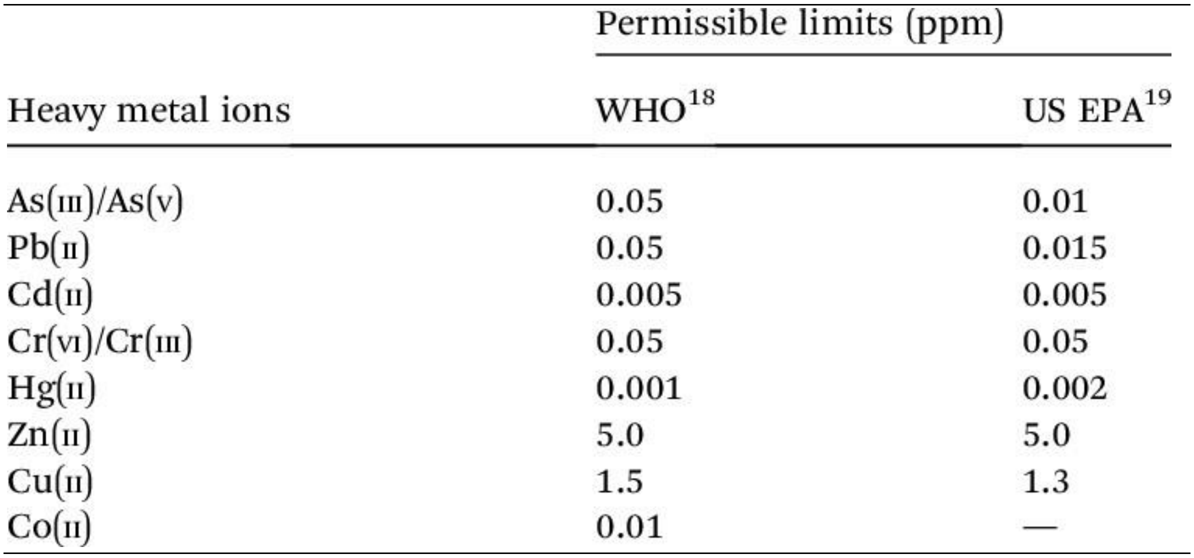
Various analytical techniques have been established for metal examination in environmental samples. These include sequential leaching methods (Helaludin et al., 2016), hyphenated techniques like GC-ICP-MS, and X-ray spectroscopic techniques (Chebet et al., 2018). These methods offer valuable insights into the chemical species present in the environment (Loska, 2012).

Regarding analysis, it's feasible to detect and measure species in environmental samples (Haruna et al., 2013). Other methods include Inductively coupled plasma atomic emission spectrometry (ICP-AES), also known as inductively coupled plasma optical emission spectrometry. Momanyi et al. 2022 used ICP-AES in the analysis of metals in river Riana in Kisii and obtained (0.192 ±0.083), Zn (0.207±0.0725). Inductively coupled plasma mass spectrometry (ICP-MS). For instance, Fan et al. (2012) utilized inductively coupled plasma optical emission spectrometry (ICP-OES) to ascertain the concentration of copper and its chemical forms in soil extracts, Tomno et al. (2020) assessed the levels of metals using ICP-OES and the concentration of trace metals were: Pb (0.0012-0.0070) and Zn (0.0232-

0.1351), Musungu et al.,2023 obtained the mean levels of lead, zinc and iron in river Yala waters as; 0.11,0.07 and 0.58 respectively by using ICP-OES. Additionally, electro-analytical techniques like anodic stripping voltammetry (ASV) and amperometry potentiometry have been employed to quantify various oxidation states of elements (Loska, 2012; Lofts & Tipping, 2011).

Heavy metals are often viewed as pollutants; it's important to recognize that they naturally exist in the environment. These metals enter surface waters through various pathways, including atmospheric deposition during heavy precipitation, leaching from bedrock or soil, and human activities. However, industrial releases often surpass permitted concentrations set by environmental regulations (Baker et al., 2019; Stogbauer et al., 2008). Environmental protection agencies have established permissible levels of heavy metals in natural water bodies, as outlined in Table 2.5.

***Table 2.5: Concentration of metals in natural water by WHO and Environmental Protection Agency* (EPA), source: (Muhammad Ekramul Mahmud et al., 2016).**



	Permissible limits (ppm)	
Heavy metal ions	WHO[18]	US EPA[19]
As(III)/As(V)	0.05	0.01
Pb(II)	0.05	0.015
Cd(II)	0.005	0.005
Cr(VI)/Cr(III)	0.05	0.05
Hg(II)	0.001	0.002
Zn(II)	5.0	5.0
Cu(II)	1.5	1.3
Co(II)	0.01	—

Human activities contribute to the transportation of various substances, like aluminum, cadmium, manganese, chromium, copper, iron, lead, and zinc. Heavy metals, being non-biodegradable, persist in the environment without breaking down into less harmful forms (Walker et al., 2005). In aquatic environments, heavy metals can manifest in diverse forms. These forms include:

i. The free ion form of an element poses the greatest toxicity to living organisms because it readily and rapidly binds to suspended particles or colloids.

ii. Elements can also exist as ions bound to various ligands, forming complex compounds.

ii. Additionally, elements may occur as precipitated molecules of compounds, either suspended in the liquid phase or adsorbed onto the surface of suspended or colloidal matter (Rabajczyk & Namiesnik, 2015; Manahan, 2003).

The specific system in which any component occurs is heavily influenced by the physical and chemical conditions of the water, which in turn affect the speciation of compounds existing within it. Factors such as water temperature, dissolved oxygen levels, biological activity, bedrock composition, and the presence of anions like hydroxides, carbonates, chlorides, and humus substances, as well as water pH, play crucial roles in determining the species of metals (Rabajczyk, 2015; Horng et al., 2009; Vicentre et al., 2009).

The evaluation of natural water quality involves assessing pertinent which include chemical parameters, physical aspects, and biological factors. The nature and extent of land usage within the watershed influence both the types and quantities of contaminants present; conversely, the frequency and strength of water flow determine the degree of exchange between substances within the deposited substances and water at the lowermost of rivers and basins (Rabajczyk &Namiesnik, 2015).

Pollutants that find their way into aquatic ecologies assume many forms, such as solution or suspension (Stogbauer et al., 2008). Water can transport these various forms over significant distances. Dust particles typically settle to the bottom of the water body, while liquid pollutants either float to the surface or settle to the lowermost alongside solid particles (Kur et al., 2019).

Heavy metals are of great concern as they are known for their persistence in nature due to their non-biodegradability. In water, they normally exhibit varying levels across different compartments of water bodies. The suspended matter contains the highest concentration, while the water column contains the lowest levels. In addition, sediments tend to accumulate metals, thus acting as their sink (Luck et al., 2008; Chapman, 1996; Nsikak et al., 2013).

2.5.1 Inductively coupled plasma optical emission spectrometry (ICP-OES)

Inductively coupled plasma–optical emission spectrometry (ICP-OES) stands as a versatile spectroscopic technique ideal for detecting trace elements across various sample types. Usually, liquid samples are introduced into the plasma directly, while solid samples require acid digestion before injection. Both gas and liquid samples can be injected directly into the instrument. The sample solution is transformed into an aerosol before entering the plasma core, where it faces a high atomization temperature of around 10,000K. This intense thermal environment facilitates the generation of plasma-free atoms in gaseous states, with sufficient energy accessible to convert these atoms into ions and then elevate them to excited states. After reaching the excited states, ionic species transition back to the ground state by emitting photons. These emitted photons carry specific wavelengths that aid in identifying the elements present, with the quantity of emitted photons directly correlating with the element's concentration in the sample. Various sample introduction techniques are employed in this method, including nebulization, hydride generation (HG) for specific elements like arsenic, selenium, and antimony, as well as electrothermal vaporization (ETV) and laser ablation (Helaluddin et al., 2016; Boss & Fredeen, 2004).

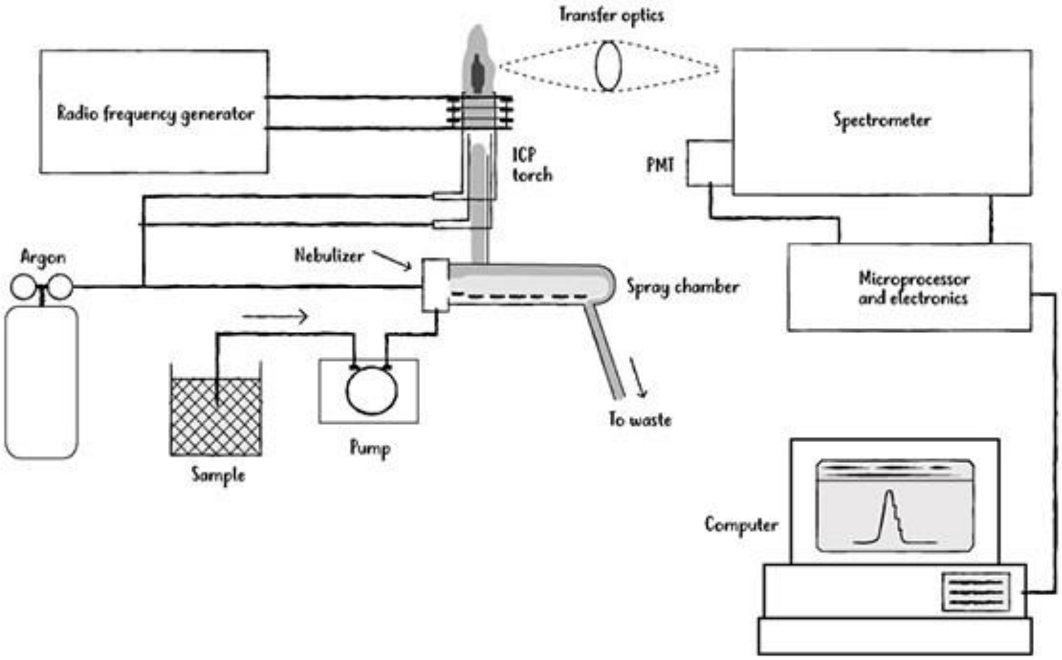


Figure 2.5.1 Block diagram of ICP-OES

(a) **High-Energy Plasma**: This type of plasma typically consists of argon, though nitrogen and mixed gases have also been utilized. It is produced by applying a high-power radio frequency signal or microwave irradiation, which ionizes the gas, creating electrons and other charged particles within the plasma.

(b) **Sample Aerosolization**: For effective analysis, the plasma matrix must interact with the sample, which necessitates aerosolizing the sample. This process is usually achieved with a nebulizer and requires a system to transport the sample from the injection port to the aerosolization point. They were once aerosolized, the high-energy plasma interacts with the sample, breaking it down into its elemental components, each emitting a unique optical signal detectable via spectroscopy.

(c) **Wavelength Separation**: Each element emits and absorbs light at specific wavelengths, but overlapping signals from multiple elements can complicate result interpretation. To resolve this, the wavelengths are typically separated using an optical grating device, allowing individual detection of each element. The system can be configured axially (viewing the plasma head-on) or radially (viewing the plasma from the side), with radial configurations generally offering better detection. However, advancements in axial configurations have also improved their detection capabilities.

(d) **Detection and Signal Processing**: A detector, often a photomultiplier tube or charge coupled device (CCD), is used to determine the sample's composition by correlating light wavelengths with specific elements. The detector is calibrated with known quantities of the target elements to enable accurate quantitation. Interfering signals that could affect the detection of the target analyte are typically removed. However, recent research has explored using these signals to gain insights into matrix effects and the overall system composition. In Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) analysis, it's essential first to determine whether and how a sample can be aerosolized. While liquid samples can be aerosolized using a nebulizer, solid samples require additional methods, such as electro thermal vaporization, electro thermal evaporation, laser ablation, or spark ablation. For gaseous samples, aerosolization is unnecessary, but mechanisms for gas capture and introduction into the detection system are required(Helalluddin,2016).

Strengths of ICP-OES

ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) offers several strengths, particularly in identifying and quantifying elements in complex samples. It has been successfully employed in analyzing the elemental composition of substances like crude oil, contaminated soil, and heavy metal mixtures—tasks that can be challenging for other analytical methods. Additionally, ICP-OES's capability to detect multiple elements simultaneously is a significant advantage, with reports indicating that up to 19 elements can be identified in a single analysis. Improvements in aerosolizing a wider range of samples have enhanced the versatility of ICP-OES, along with advancements in spectral deconvolution and calibration techniques, enabling more effective detection. Even for radioactive samples, ICP-OES can be used to determine their elemental composition, with separate measurements assessing radioactivity levels. The technique's simplicity has also made it a valuable tool in chemistry education, demonstrating its ease of use with both analytical reagent grade and spectral pure grade solvents and facilitating relatively high throughput in sample preparation and analysis (Tangahu et al.,2011).

Limitations of ICP-OES.

The necessity for samples to be aerosolized means that solid and liquid samples cannot be analyzed in their original forms. Moreover, ICP-OES is a destructive technique, preventing the recovery of the sample after analysis, which limits its use for rare or valuable samples. The method development process for ICP-OES can also be time-consuming, involving several steps: conducting an initial analysis to identify the elements present, selecting appropriate wavelengths, optimizing signal separation to reduce overlap, comparing with an internal standard to validate the method, and addressing spectral interferences. Additionally, the cost of the required instrumentation for plasma generation, sample aerosolization, and signal analysis, while lower than some methods like ICP-MS, still poses a barrier to access (Wu et al.,2012).

Common Problems with ICP-OES

Several common issues can arise with ICP-OES, including poor precision, sample drift, suboptimal detection limits, and inaccurate identification.

Poor precision refers to inconsistent results when analyzing the same sample multiple times. This can often be traced back to problems in the sample introduction system, including the aerosolization process and the transport of the sample into the plasma matrix.

Sample drift occurs when the signal changes position over time, often due to instrument issues such as the buildup of non-aerosolized sample material in the tubing, which can slow flow rates, or degradation of the tubing due to exposure to highly acidic samples, leading to leaks.

Non-ideal detection limits imply that the sensitivity of ICP-OES may not always meet the requirements of specific applications. Although the technique can theoretically detect elements at concentrations as low as single-digit parts-per-billion (ppb), detection limits are more commonly reported in the parts-per-million (ppm) range. Improving detection limits involves optimizing sample preparation to minimize dilution and degradation and adjusting the viewing angle of the plasma-generated signal (axial, radial, or dual) for optimal signal capture (Boss &Fredeen,2004).

Inaccurate identification occurs when the ICP-OES signal mistakenly identifies one element as another. While such errors are uncommon, they can be reduced by carefully selecting wavelengths that minimize overlap from other elements. Recent advancements in multivariate spectral analysis applied to ICP-OES readouts have further helped in deconvoluting overlapping signals, thereby improving the accuracy of elemental identification (Srinkanth et al.,2013).

2.6 Selected Metals and Their Toxicity

Toxicity denotes the harmful effects exerted by a substance on living organisms, influenced by several factors, including the amount absorbed, the way of exposure, and the period of exposure. Metal toxicity, in particular, is contingent upon the chemical types formed by the metal, primarily correlating with the concentration of free metal ions, which serves as a reactivity index. Furthermore, the physiological impacts of a metal can be attributed to its interaction with various cellular anions (Nsikak et al., 2013).

2.6.1 Aluminium

The presence of aluminum in natural waters often results from leaching processes in soil and rock. The solubility of aluminum is notably influenced by water pH and temperature, increasing in solutions with a pH below 6.0 or above 8.0. Aluminium readily binds with bottom sediments in the form of metastable compounds and can become mobilized with rising water acidity. Within aquatic ecosystems, aluminum tends to accumulate throughout the food chain and is less readily absorbed by organisms in water rich in calcium, magnesium, and fluoride ions. In fish, the deposition of aluminium on gills poses significant harm (Wasike, 2019).

Aluminium salts serve as coagulants in water treatment processes. The concentration of residual aluminium in treated waters is influenced by several factors, including the initial aluminium levels in the source water, the dosage of aluminium coagulant applied, and the effectiveness of filtration in removing aluminium flocculants. In cases where residual concentrations are elevated, aluminium may accumulate within the distribution system. Over the distance from the treatment plant, a gradual decrease in aluminium concentration may be observed. Changes in flow rate can disturb these deposits, potentially leading to an increase in aluminum concentrations (Senze et al.,2015). Aluminium can get into water systems in many ways, such as cookware, industrial applications, and consumer products, i.e., cosmetics, food additives, and antiacids. High concentrations of aluminium in water can be caused by acidic or highly alkaline water. High levels of aluminium affect the ability of the body to process phosphate (Tomno et al., 2020).

2.6.2 Iron

Iron ranks occur in various forms, including salts and minerals such as oxides, hydroxides, carbonates, and sulfides, existing as reduced iron (II) or oxidized iron (III). The availability of iron depends on the natural environment in which the state of the element exists in water, either in reduced or oxidized form. For example, if the natural environment produces reduced iron, then the water will have high levels of dissolved iron (II)ions (Momanyi et al.,2022). In anaerobic surfaces, where iron is predominantly present as a ferrous ion (Fe II), concentrations may reach up to 10 mg/l, although levels below three mg/l are more common. Iron salts are employed as coagulants in drinking water treatment, while cast-iron pipes can contribute to elevated iron concentrations in drinking water (Oremo et al., 2020).

2.6.3 Copper

Copper is a reddish, soft, and flexible metal. It occurs naturally in plants and animals therefore an essential micronutrient. The Food and Nutrition Board recommends dietary intake for adults of 1.5 -3.0 milligrams per day. Taking excess copper in drinking water can cause gastrointestinal tract disturbances. It is a natural element and widely distributed in the environment. In water systems, copper is present in different states and forms different complexes. The levels of copper in drinking water can be through weathering of soil, industrial discharge, and sewage treatment. Factors that increase the concentration of copper in water are high temperature, reduced hardness, and low pH (Aras et al.,2017).

The presence of copper in water can arise from either pollution of the water source or corrosion of copper plumbing, with the latter posing the predominant concern. While copper occurrences in water are rare, potential sources of contamination include mining and smelting operations, municipal incineration, as well as various everyday items such as copper cookware, plumbing, and dental alloys. Additionally, industrial activities like fungicide and insecticide usage, swimming pool maintenance, welding, and agricultural pesticides can contribute to copper levels in water (Njuguna et al., 2021). Notably, copper exhibits toxicity to numerous aquatic plants, even at low concentrations.

2.6.4 Zinc

Zinc occurs naturally with five stable isotopes, and the most abundant is ^{64}Zn (49.17%), and its ore is zinc blende. It is a shiny grey, hard, and brittle metal but becomes malleable at 100^0C and 150^0C. Zinc has a low melting point of 419.5^0C and a boiling point of 907^0C (Tomno et al.,2020).

Zinc stands as a crucial trace element indispensable for the well-being of humans, animals, and plants alike. This vital heavy metal is ubiquitously present in all food and potable water, primarily existing in the form of organic complexes and salts. While food serves as the primary source of zinc intake, concentrations of zinc in surface water seldom surpass five mg/l as per the WHO recommended threshold (Douglas et al. 2022).

Zinc can be toxic at high concentrations because it can outcompete other vital elements like copper and calcium in biological processes, which can negatively affect reproduction in animals, plant growth, and photosynthesis in plants. In water, the toxic form of zinc is $Zn^{2+,}$ as aquatic organisms can readily absorb it. The factors that determine the availability of zinc in water are low pH(acidic) and high temperatures tend to dissolve zinc and, hence, free zinc ions. Zinc is used to prevent oxidation and rust in iron and combines with other metals to form alloys, veterinary medicine, health supplements, wood preservatives, household products, paints, and fertilizers (Kosgey et al.,2015).

2.6.5 Lead

Lead is a shiny grey, soft, and malleable metal. It has four isotopes with mass numbers of 204,206,207 and 208. Lead -208 is a stable nucleus and the heaviest isotope. These isotopes undergo decay to form isotopes of mercury. Lead, which is found in the environment at high levels, competes with other metals on plant surfaces, therefore interfering with photosynthesis. In humans, it can accumulate in soft tissues and bones and can affect the renal system, nervous system, and cardiovascular (Shock,2008).

Lead exists in two stable oxidation states (Pb (II) and Pb (IV)); However, it predominantly exists as a Pb^{2+} ion. Lead infiltrates the environment through various applications, including its use in metallic form for storage batteries, solders, ammunition, X-ray and radiation shielding systems, and tank linings. Additionally, lead inorganic salts find utility in insecticides, pigments, paints, enamels, glazes, glass, and rubber compounds (Chaitali & Jayashree, 2013). While lead does occur naturally in the environment, human activities significantly contribute to elevated lead concentrations. For instance, lead is emitted through the combustion of leaded gasoline in car engines, resulting in the generation of lead salts (Githinji, 2019).

2.7 Metals toxicity

Assessment of toxicity typically involves quantifying alterations in specific biological characteristics following contact with known concentrations of a particular element. Notably, heavy metals in water manifest in diverse chemical forms and oxidative states, leading to variations in their toxicity based on their chemical configuration (Dimitri et al., 2004). Metal toxicity is influenced by the complex interplay of water chemistry, ligand interactions, and the presence of competing ions, which regulate their bioavailability (Muhammed et al.,2020). The partitioning of metals into different chemical forms dictates their mobility and bioavailability in the environment, with the oxidation state playing a crucial role in determining toxicity. Metal speciation, therefore, significantly impacts their bioavailability and associated risks (Avila et al., 2013). The buildup of metals in various body organs may lead to adverse effects because of their non-biodegradable nature and prolonged biological half-lives. For instance, aluminum accumulation in the brain is linked to the onset of Alzheimer’s and Parkinson's diseases (Azeez et al., 2006), as well as slow growth in children, muscle weakness, and skeletal deformities. Aluminum interference with phosphorus metabolism further exacerbates symptoms such as weakness, anorexia, and bone pain (Muhammad et al., 2020). Similarly, excessive exposure or ingestion of manganese can result in conditions like Manganese, characterized by neurodegenerative effects (Manali &Kalaskar, 2013).

Lead toxicity poses significant risks to the nervous system, impacting human beings. Prolonged exposure can impair nervous system function, leading to diminished physical development and cognitive growth (Ma et al., 2020). Furthermore, chronic exposure to soluble lead salts or potent oxidants can induce nephropathy and abdominal colic-like pains (Schoeters et al., 2008). Elevated lead levels interfere with the activity of crucial enzymes essential for the synthesis of bone marrow haem, a pivotal component of hemoglobin formation (Githinji, 2019). Similarly, loosely bound copper can induce toxicity by generating responsive oxygen species like superoxide, hydrogen peroxide, and the hydroxyl radical, thereby causing harm to proteins, lipids, and DNA (Hureau & Faller, 2009; Genderen et al., 2005).

Excessive consumption of copper can aggravate irritation in the nose, mouth, and eyes, accompanied by symptoms such as headaches, diarrhea, dizziness, and vomiting. Prolonged exposure may lead to complications for individuals with Wilson’s disease, characterized by the excessive absorption and accumulation of copper (Wasike, 2019). Furthermore, elevated copper intake is associated with conditions like coronary heart disease, high blood pressure, and the risk of liver and kidney failure (Chaitali & Jayashree, 2013). Similarly, too much zinc can manifest in symptoms like impaired muscle coordination, dehydration, gastric ulcers, fatigue, and potential renal failure. In drinking water, iron exists as either Fe^{2+} or Fe^{3+} in suspended form, leading to staining of clothes and imparting a bitter taste. Excessive iron intake may elevate pulse rate, promote blood vessel coagulation, contribute to hypertension, and induce drowsiness (Lixu & Jingli,2015).

2.8 Method of Analysis

Ultra Violet-Visible Spectrophotometer is a technique used to analyze anions and metals by using advanced technique inductively coupled plasma mass spectrometry (ICP-MS)

2.8.1 Ultra Violet-Visible spectrophotometer (UV-VIS)

The ultraviolet-visible spectrophotometer was chosen for this study due to its ability to measure solution, it analyses a sample without damaging, and the analysis of data is easy. It requires less processing, and the instrument is easy to operate.

The UV-visible spectrophotometer is a tool designed to gauge the extent of light absorption in colored solutions. It evaluates the absorption spectrum of anions like sulfates, nitrates, and fluoride ions. To determine the concentrations of these anions accurately, each sample must be tinted using specific reagents. Concentrated solutions exhibit greater light absorption compared to diluted ones (Chebet et al.,2018).

Functionally, a spectrophotometer quantifies absorbance, aiding in the determination of the concentration of an absorbing molecule. It directs light emitted from a lamp through a monochromator, which segregates it into distinct wavelengths. Using an adjustable slit, light of a singular wavelength is channeled into the sample contained in a transparent cuvette. Positioned on the opposite side of the cuvette, a photoelectric tube gauges the amount of light that traverses the sample. By measuring transmitted light, the spectrophotometer deduces absorbance, a metric that correlates with concentration (Helaludin et al., 2016)

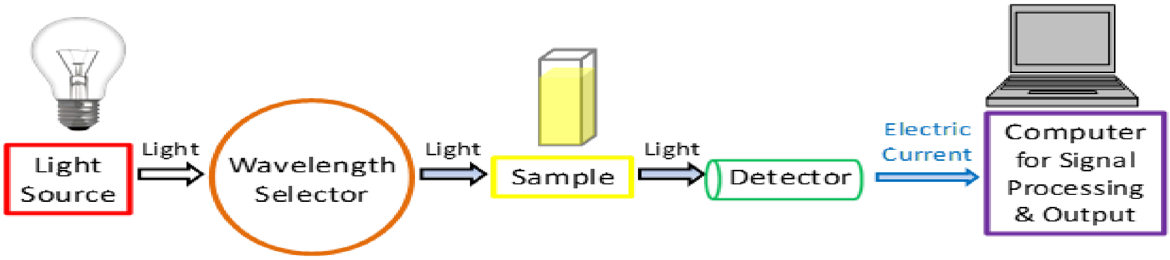


Figure 2.8.1: A schematic diagram of ultraviolet-visible spectrophotometer (Source Tom, 2021).

The functional parts of the UV-VIS spectrophotometers include;

- **Light Source**

The light source is a crucial component in a UV-Vis spectrophotometer as it provides the initial beam of light that will interact with the sample. Commonly used light sources include deuterium lamps, which emit light in the ultraviolet region (160-375 nm), and tungsten halogen lamps, which cover the visible region (375-780 nm). Some spectrophotometers combine these two lamps to cover the full UV-Vis spectrum. The stability and intensity of the light source are vital for obtaining accurate and reproducible measurements.

- **Monochromator**

The monochromator's role is to isolate a single wavelength of light from the broad spectrum emitted by the light source. This is achieved by using optical components like prisms or diffraction gratings that disperse the light into its constituent wavelengths. The monochromator then selects the desired wavelength (or a narrow band of wavelengths) by allowing it to pass through a slit while the other wavelengths are blocked. The selected wavelength is directed towards the sample, ensuring that only light of a specific wavelength interacts with the sample, which is critical for measuring its absorbance accurately (Helaluddin et al.,2016).

- **Sample Holder**

The sample holder, often a cuvette, is where the sample under investigation is placed. Cuvettes are usually made of quartz or glass, depending on the wavelength of light being used. Quartz cuvettes are required for UV measurements, while glass or plastic cuvettes may suffice for visible light measurements. The cuvette is designed to have flat, transparent sides to ensure that the light passes through the sample with minimal scattering. The absorbance of the sample is determined by measuring the intensity of light before and after it passes through the sample, with any reduction in light intensity indicating absorption by the sample.

- **Detector**

The detector is responsible for converting the light that passes through the sample into an electrical signal. Common detectors include photodiodes, which are sensitive to specific wavelengths, and photomultiplier tubes, which are highly sensitive and can amplify weak signals. The detector measures the intensity of the transmitted light and compares it to the intensity of the light before it passes through the sample. The difference between these intensities is used to calculate the absorbance, which is related to the concentration of the absorbing species in the sample according to Beer-Lambert's law(Tom,2021).

- **Readout Device**

The readout device is the final component in the system, where the data collected by the detector is processed and displayed. This device could be a computer or a digital display integrated into the spectrophotometer. It converts the electrical signals from the detector into a readable format, such as absorbance values or spectra. Advanced systems may allow for data analysis, including baseline correction, peak identification, and quantification of sample concentration. The readout provides the user with the final results, which are used to conclude the sample's properties, such as concentration, purity, and molecular structure (Boss & Fredeen 2004).

2.8.2 Inductively coupled plasma mass spectrometry (ICP-MS)

The method was chosen over ICP-OES because it has some advantages, such as; it has a lower detection limit that can extend to parts per trillion(ppt), whereas the lower limit for ICP-OES is parts per billion(ppb), greater speed, precision, and sensitivity. It also removes polyatomic spectral interferences using collision cell technology. The ICP-MS has one limitation, that is; the mass interferences (Boss &Fredeen,2004).

The sample is acidified to dissolve any metals that may be present and then diluted to a known concentration. The diluted sample is then introduced into the ICP-MS, where the liquid samples are initially converted into a fine aerosol through nebulization within the system. This aerosol is then directed into the argon plasma, where the high-energy environment atomizes and ionizes the sample. This ionization process generates ions, which are subsequently transported through the interface region and directed into a series of electrostatic lenses known as ion optics. Within the ion optics, the ion beam is focused and guided toward the quadrupole mass analyzer. This analyzer serves to separate ions based on their mass-charge ratio (M/Z), which is then measured at the detector.

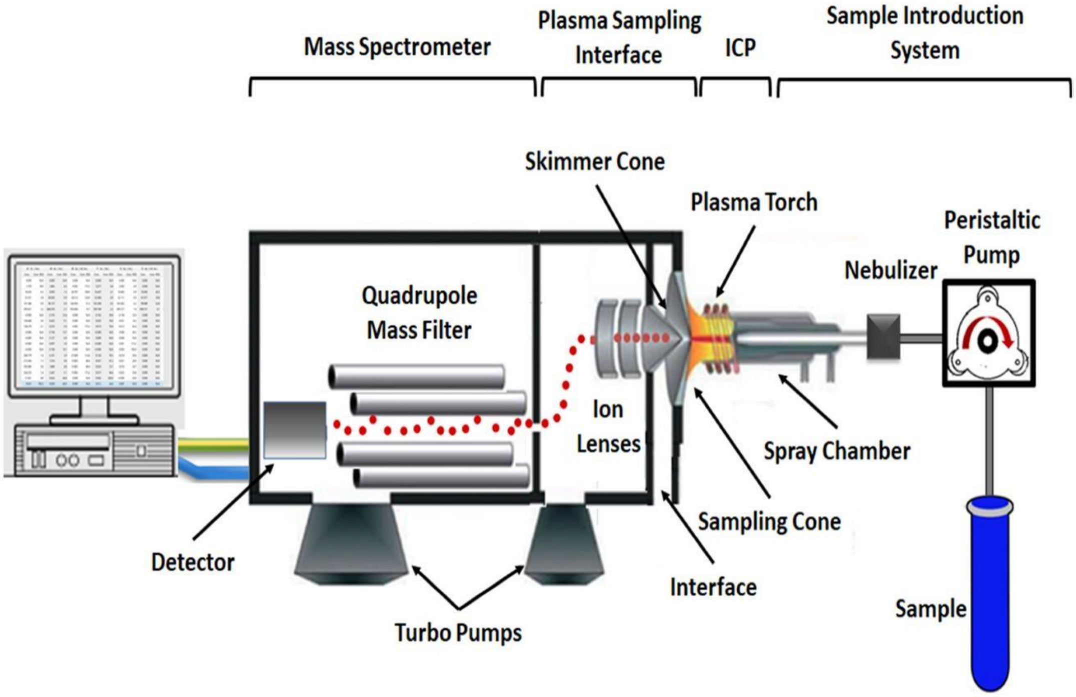


Figure 2.8.2 Schematic diagram of ICP-MS, source (Mazarakioti et al., 2022).

The working of the ICP-MS instrument

The instrument consists of sample preparation and introduction, aerosol generation, ionization by an argon plasma source, mass discrimination, and identification by the detection system, including data analysis as described below:

Sample introduction system to form a fine aerosol mist from the liquid sample which takes place at the nebulizer and the spray chamber. Plasma (Inductive Couple Plasma) converts the elements in the sample aerosol to ions in the quartz tube in the presence of a radio frequency energy through a coil wrapped around the outside of the quartz tube, which ionizes the argon gas(Bannerji,2014).

Interface to extract the ions into the vacuum system, which consists of cones that are sampling cones and skimmer cones that extract ions from the plasma and finally to the mass spectrometer.

Ion lens to focus the ions and separate them from background signals. The lens is made of several metal plates with different voltages which are used to steer and focus the ions and separates the ions from the neutral particles and photons extracted from the plasma. Collision and reaction cell to resolve the analyte ions from interfering ions. This consists of a quadrupole positioned in a cell that can address the overlapping of the isotopes.

Mass spectrometer to filter the ions by mass. A quadrupole mass filter is used to filter ions by mass and produce a mass spectrum of ions.

The electron multiplier detector generates an ion pulse or count.

Data processing. The data analysis software on the instrument control workstation computer processes the counts registered by the detector (Mazarakioti et al., 2022).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Area of Study

The research study area is located within Kericho County. Kericho County lies between longitude 35^{0}02` and $35^{0}$40` East between the equator and latitude 023^{0}. Kericho County experiences two types of seasons: wet and dry seasons. The study was conducted along Chemosit River in the southwest Mau complex forest in Kericho County and covered an area of 1023 km^{2}. It lies at 0.14^{0}-0.78^{0} South. The Chemosit River flows from the areas of Itare, Kimulot, and Nyakach and feeds Lake Victoria. Each sampling site along the river corresponds to distinct land uses prevalent in its vicinity. These sites were chosen strategically to encompass areas potentially impacted by industrial waste discharge (which includes Bureti and Jamji tea factories), sewage, and disposal practices. The main activities around the study area include livestock rearing, car washing, tea farming, road transport, and human settlement. The sampling sites were Upper stream (Kipkerieny), Middle stream (Chemosit shopping Centre) Downstream (Kabitungu) Sampling sites, as in Figure 3.1.

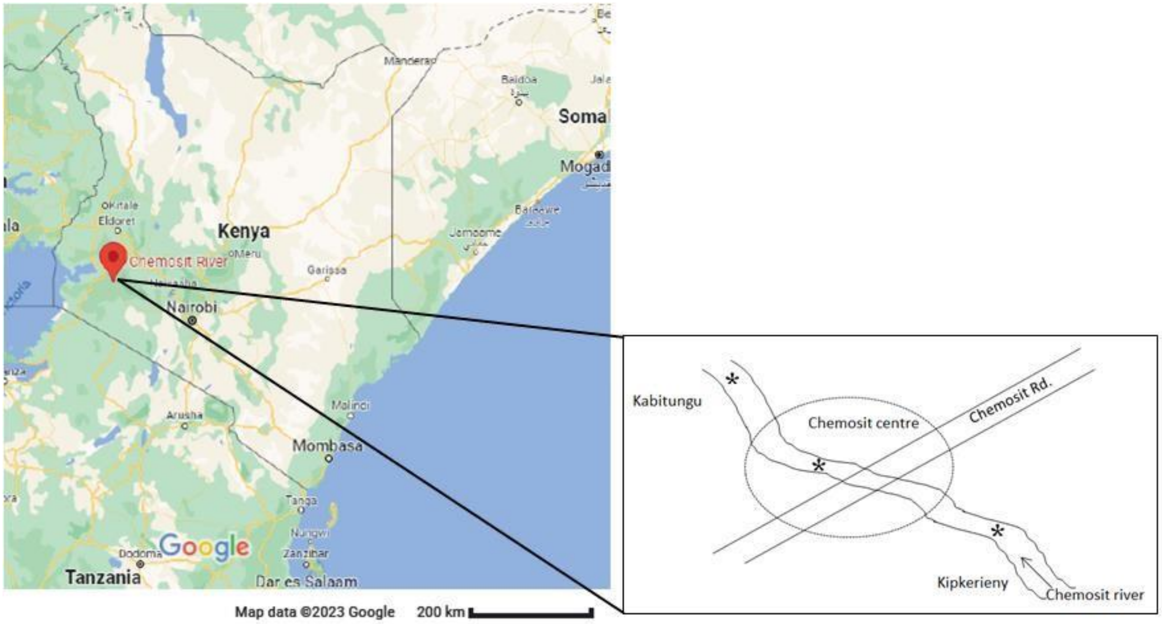


Figure 3.1: Study area map and sampling stations along River Chemosit, which are marked with Asterix (*), source: (ipfglobal, 2018).

The activities taking place along the selected sampling sites are as in Table 3.1

Table 3.1 Activities taking place in the sampling sites

Sampling station	Activities
Kipkerieny(upstream)	Agricultural activities, i.e., tea farming, livestock rearing, and residential activities
Chemosit Centre (middle stream)	Trading activities, car washing, road transport, water vending, and industrial activities (Jamji tea factory)
Kabitungu(downstream)	Agricultural activities, i.e., tea farming, livestock keeping, household activities, and industrial activities (Bureti tea factory)

3.2 Research design

Water sample was collected by using a Stratified sampling method and an experimental research design was used. Metals were examined using inductively coupled plasma mass spectrometry (ICP-MS) to determine their concentrations. Anions were analyzed using a UV-visible spectrophotometer. Physico-chemical parameters were determined *in situ*.

3.3 Sample collections

Water samples were collected from three distinct locations: Chemosit Shopping Centre, Kipkerieny, and Kabitungu. The sampling encompassed both the wet season (August to October 2021) and while dry season (November 2021 to January 2022). These sampling spots were confined to a 200-meter stretch upriver on either side of the river bank, aimed at optimizing accessibility. Sampling was executed from the central region as well as the two peripheries of the river bank, maintaining a distance of 5 meters away from the boundaries of the river. This practice was replicated thrice at intervals of 20 meters to ensure comprehensive coverage.

At every sampling point, 500 ml of water samples were collected in triplicate. Prior to collection, containers underwent cleaning by immersion in a 10% HNO_3 solution and then by rinsing with distilled water. The collected samples were then placed in sterile containers, clearly labeled with the collection location, and stored at ambient temperatures until analysis. Measurement of pH, electrical conductivity, and temperature was promptly performed by immersing portable pH and conductivity meters directly into the river water immediately after sample collection. Water sampling was done as indicated in table 3.3

Table 3.3: Number of water samples from three sampling stations

Sampling station	Wet Season			Dry Season			Total
	August	September	October	November	December	January	
Kipkerieny	3	3	3	3	3	3	18
Chemosit centre	3	3	3	3	3	3	18
Kabitungu	3	3	3	3	3	3	18

3.4 Cleaning of containers and calibration of instruments

All glassware underwent thorough cleaning with detergent, followed by rinsing with deionized water. Subsequently, these were immersed in a solution containing equal parts of nitric (V) acid for 24 hours. Afterward, the apparatus was thoroughly washed, rinsed with deionized water, and dried using an oven (Manali, 2013).

Prior to usage, calibration of the instruments (ICP-MS and UV-VIS) was conducted. The reagents utilized, including hydrochloric acid, nitric (V) acid, and hydrogen peroxide, were of analytical grade. Careful handling of samples was ensured to prevent contamination, and deionized water was consistently employed during the study. Reagent blank determinations were employed for correcting instrument readings (Tangahu et al., 2011).

3.5 Sample preservation and preparation procedure

Samples were conserved by acidification to $pH < 2$ to avert oxidation and precipitation. The acid used was HNO_3 to minimize interference by polyatomic ions, and they were stored at 6^0C to avoid adsorption losses. Water samples were filtered to remove impurities such as pebbles. Then, 9 ml of water samples were acidified with 1 ml of concentrated hydrochloric acid before being analyzed into ICP-MS and UV-VIS.

3.6 Data collection procedures

3.6.1 Determination of physicochemical parameters

a. Determination of pH

The pH was determined in situ using a calibrated pH meter through potentiometric measurement. Before and after each reading, the probes were rinsed with deionized water to ensure accuracy. The probes were then carefully lowered to a depth of 1.25 inches into the sample, allowing sufficient time for stabilization before recording the pH readings.

b. Determination of electrical conductivity and temperature

During in situ measurement, E.C. and temperature were assessed using a calibrated conductivity meter. Prior to measurement, the conductivity cells underwent calibration using known standards of potassium chloride solution with pre-determined readings. Before each measurement, the probe cells were meticulously rinsed with distilled water, and a control run was conducted. Subsequently, the conductivity cells were immersed into the samples, and standardized readings for electrical conductivity and temperature were simultaneously recorded in micro-Siemens units and degrees Celsius, respectively.

c. Determination of Dissolved oxygen

The galvanic dissolved oxygen sensor was immersed in a water sample, and oxygen that diffused across the oxygen-permeable membrane at a rate proportional to the pressure of oxygen in the water was reduced and consumed at the cathode. This reaction produced an electrical current that was directly related to the oxygen concentration. This current was carried by the ions in the electrolyte and run from the cathode to the anode and the reading was recorded in milligram per liter.

d. Total dissolved solids

A total dissolved meter is an electrical meter that calculates TDS from Siemens value and reports the TDS concentration in milligrams per liter. The total dissolved solid meter was calibrated at a temperature of 25^0C. The probes were then dipped into the beaker containing the water sample. The water sample was stirred gently so that any bubbles that might cling to the metal post were dislodged. The total dissolved solid meter was turned on to record the total dissolved reading. The reading was read from the screen for TDS.

3.6.2 Determination of Anions

i. Sulphate

The Sulfaver 4 turbidimetric method was employed for analysis. Initially, a clean sample cell was loaded with 10ml of the sample, along with the contents of one Sulfaver and four reagent powder pillows, and mixed thoroughly. A blank was prepared by filling another sample cell with 10ml of distilled water and the contents of one Sulfaver and four reagent pillows, serving as a reference for zeroing the spectrophotometer. Subsequently, the sample cells were inserted into the cell holder, and the results were read in mg/l (Chebet,2018).

ii. Phosphate

The amino acid method was used. Solutions of 2, 4, 6, and 8mg/l were set by suitable dilution of 10mg/l of standard phosphate solution. These solutions and molybdate and amino acid reagents were used to calibrate the UV-VIS spectrophotometer. The procedure began by filling a 25ml mixing cylinder with 25ml of the sample. Subsequently, 1.00ml of molybdate reagent was carefully added using a precisely calibrated dropper. Following this, 1.00ml of amino acid reagent solution was introduced, and the mixture was inverted several times to ensure thorough mixing. After allowing the solution to settle, a spectrophotometer with a wavelength of 530nm was operated for 10 minutes to stabilize. The instrument was then zeroed using the blank solution. The prepared sample was loaded into the sample cell holder, and the results were obtained and recorded in mg/l.

iii. Nitrate

The method relied on the formation of a complex between 4-phenylpyryliumperchlorate (PPP) and nitrate, followed by the extraction of this complex from the aqueous solution using microcrystalline naphthalene. The solid mass comprising the nitrate complex and naphthalene was subsequently dissolved in dimethyl formamide (DMF). The resulting solution was then measured for absorbance at 328nm.

3.6.3 Determination of metal ions

Water samples were placed in a PTFE beaker, acidified with 2mls of concentrated nitric (v) acid and HNO_3 acid, and heated to boiling for two hours in a fume extraction hood. After reaching room temperature, the samples were prudently shifted to 50 ml volumetric bottles and mixed with ultrapure water. To optimize signal intensity, each sample underwent filtration and dilution with 2% ultrapure perchloric acid ($HClO_3$) until reaching a concentration level that ensured a signal intensity below approximately 10^6 counts. Subsequently, the diluted liquid trials were presented into an argon-based, high-temperature radio frequency plasma. Within this controlled environment, metal ions moved near the detector to be accurately measured and reported by ICP-MS in terms of both counts per second and concentration.

3.7 Data analysis and presentation

A total of 54 water samples from River Chemosit underwent a thorough examination. The data were then analyzed using descriptive statistical summaries at a 95% confidence interval— statistical analyses, including ANOVA and t-tests, using SPSS version 28(Yeager,2022). Spatial and temporal variations in physico-chemical parameters were evaluated through ANOVA, with a predetermined significance level ($\alpha = 0.05$). One-way ANOVA was used in analysis when comparing the means of a single factor across three or more groups. It tests the hypothesis of equality among group means for that single factor.

In contrast, two-way ANOVA was not appropriate as it examine the effects of two factors simultaneously and their interaction on the dependent variable. Therefore, one-way ANOVA is suitable as it focuses on a single variable, such as the concentration of heavy metals in different locations. In cases where significant differences in means stood observed, post hoc examination using Tukey pairwise comparisons in SPSS helped identify specific variations between sampling stations and months. To examine seasonal differences, independent sample *t*-tests were employed to assess variations in mean values of physicochemical parameters, anions, and heavy metals between wet and dry seasons. Furthermore, Pearson correlation was utilized to calculate the coefficient of correlation between metals, physicochemical parameters, and anions, with statistical significance set at P values of 0.05

CHAPTER FOUR

RESULTS

This chapter gives the results of the study on spatial and temporal variations of selected physico-chemical parameters, Anions and heavy metals. Pearson correlations between physico-chemical parameters, Anions and metals are also presented.

4.1 Descriptive statistics

Table 4.1. Descriptive statistics summary for physicochemical parameters

Parameter	Station	N	Mean	S.E	Min	Max
pH	Kipkerieny	18	7.11	0.04	6.85	7.50
	Chemosit Centre	18	6.95	0.11	6.20	7.85
	Kabitungu	18	6.92	0.08	6.10	7.50
	Total	54	6.99	0.05	6.10	7.85
Temperature (°C)	Kipkerieny	18	24.13	0.27	22.40	25.90
	Chemosit Centre	18	24.01	0.37	22.00	26.00
	Kabitungu	18	24.31	0.29	22.50	25.80
	Total	54	24.15	0.18	22.00	26.00
EC (μs/cm)	Kipkerieny	18	1,023.89	18.83	900.00	1,200.00
	Chemosit Centre	18	1,380.17	56.24	1,090.00	1,630.00
	Kabitungu	18	1,159.78	39.69	900.00	1,450.00
	Total	54	1,187.94	30.84	900.00	1,630.00
TDS (mg/L)	Kipkerieny	18	1,244.33	153.12	517.00	1,920.00
	Chemosit Centre	18	1,760.39	46.90	1,420.00	2,010.00
	Kabitungu	18	1,375.44	102.95	900.00	1,870.00
	Total	54	1,460.06	69.14	517.00	2,010.00
DO (mg/L)	Kipkerieny	18	8.92	0.12	8.10	9.70
	Chemosit Centre	18	9.01	0.10	8.20	9.90
	Kabitungu	18	9.04	0.12	8.10	9.80
	Total	54	8.99	0.06	8.10	9.90

Kipkerieny had a PH values of 6.85 to 7.50, and Chemosit Centre (6.20 to 7.85, while the pH in Kabitungu ranged from 6.10 to 7.50. The temperature in Kipkerieny was 22.40^{0}C to 25.90^{0}C, Chemosit Centre (22.00^{0}C to 26.00^{0}C), and Kabitungu (22.50^{0}C to 25.80^{0}C). EC in Kipkerieny was 900.00 to 1200.00, Chemosit Centre (1090.00 to 1630.00), and Kabitungu (900.00 to 1450.00). TDS in Kipkerieny was 517.00 to 1920.00, Chemosit Centre (1420.00 to 2010.00), and Kabitungu (900.00 to 1.00). DO in Kipkerieny was 8.10 to 9.70, Chemosit Centre (8.20 to 9.90), and Kabitungu (8.10 to 9.80) (Table 4.1).

Table 4.2. descriptive statistics summary for Anions

Parameter	**Station**	**N**	**Mean**	**S.E**	**Min**	**Max**
SO_4^{2-} (mg/L)	Kipkerieny	18	0.07	0.01	0.03	0.11
	Chemosit Centre	12	0.07	0.01	0.03	0.10
	Kabitungu	18	0.09	0.01	0.01	0.16
	Total	48	0.08	0.01	0.01	0.16
PO_4^{3-} (mg/L)	Kipkerieny	18	0.40	0.02	0.15	0.53
	Chemosit Centre	18	0.38	0.03	0.18	0.55
	Kabitungu	18	0.42	0.03	0.16	0.56
	Total	54	0.40	0.01	0.15	0.56
$NO3^-$ (mg/L)	Kipkerieny	18	2.28	0.12	1.27	2.93
	Chemosit Centre	18	0.93	0.06	0.53	1.23
	Kabitungu	18	1.59	0.05	1.18	1.86
	Total	54	1.60	0.09	0.53	2.93

Kipkerieny had of SO_4^{2-} values of 0.03 to 0.11 and a Chemosit Centre (0.03 to 0.10), while the SO_4^{2-} in Kabitungu ranged from 0.10 to 0.16. The PO_4^{3-} in Kipkerieny was 0.15 to 0.53, Chemosit Centre (0.18 to 0.55), and Kabitungu (0.16 to 0.56). NO_3^- in Kipkerieny was 1.27 to 2.93, Chemosit Centre (0.53 to 1.23), and Kabitungu (1.18 to 1.86).

Table 4.3. descriptive statistics summary for metals

Parameter	Station	N	Mean	S.E	Min	Max
Zn (mg/L)	Kipkerieny	18	0.07	0.02	0.01	0.23
	Chemosit Centre	18	0.06	0.01	0.01	0.14
	Kabitungu	9	0.09	0.03	0.01	0.35
	Total	45	0.07	0.01	0.01	0.35
Fe (mg/L)	Kipkerieny	18	0.44	0.03	0.28	0.62
	Chemosit Centre	18	0.50	0.02	0.40	0.71
	Kabitungu	18	0.36	0.02	0.27	0.50
	Total	54	0.43	0.01	0.27	0.71
Al (mg/L)	Kipkerieny	18	0.52	0.07	0.20	1.04
	Chemosit Centre	18	0.50	0.03	0.33	0.81
	Kabitungu	18	0.40	0.02	0.25	0.56
	Total	54	0.47	0.03	0.20	1.04
Cu (mg/L)	Kipkerieny	18	0.02	0.00	0.01	0.04
	Chemosit Centre	18	0.02	0.00	0.01	0.04
	Kabitungu	18	0.02	0.00	0.01	0.05
	Total	54	0.02	0.00	0.01	0.05

Kipkerieny had values of Zn of 0.01 to 0.23 and a Chemosit Centre (0.01 to 0.14), while the Zn in Kabitungu ranged from 0.10 to 0.35. The Fe in Kipkerieny was 0.28 to 0.62, Chemosit Centre (0.40 to 0.71), and Kabitungu (0.27 to 0.50). Al in Kipkerieny was 0.20 to 1.04, Chemosit Centre (0.33 to 0.81), and Kabitungu (0.25 to 0.56).

4.2 Spatial variations

The spatial variation analysis of the physicochemical parameter, anions, and metals for the stations, i.e., Kipkerieny, Chemosit Centre, and Kabitungu, are presented in Table 4.1.1, and Figure 4.1.2

4.1.1 Spatial Variations of the physicochemical parameters and anions

Table 4.1.1 indicates the descriptive summary of the mean, standard error (±S. E), and ANOVA comparisons of the measured parameters of the different sampling stations along River Chemosit in Kericho County during the study period.

Table 4.1.1: Mean (± SE) spatial variations in the measured physico-chemical and anions

	Sampling station			**p-values**
Parameter	**Kipkerieny**	**Chemosit Centre**	**Kabitungu**	
PH	7.11 ± 0.04^a	6.95 ± 0.11^a	6.92 ± 0.08^a	0.22
Temperature (°C)	24.13 ± 0.27^a	24.01 ± 0.37^a	24.31 ± 0.29^a	0.79
DO (mg/l)	8.92 ± 0.12^a	9.01 ± 0.10^a	9.04 ± 0.12^a	0.75
EC (µs/cm)	1023.89 ± 18.83^b	1380.17 ± 56.24^a	1159.78 ± 39.69^b	0.00
TDS (mg/l)	1244.33 ± 153.12^b	1760.39 ± 46.90^a	1375.44 ± 102.95^b	0.01
SO_4^{2}- (mg/l)	0.07 ± 0.01^a	0.07 ± 0.01^a	0.09 ± 0.01^a	0.07
PO_4^{3-} (mg/l)	0.40 ± 0.02^a	0.38 ± 0.03^a	0.42 ± 0.03^a	0.61
NO_3^- (mg/l)	2.30 ± 0.12^a	0.93 ± 0.06^c	1.59 ± 0.05^b	0.00

Means within a row followed by different letters (a, b, c) are significantly different (*p* < 0.05) concerning the measured parameter and stations.

The mean (± SE) pH value recorded was 7.0 ± 0.05, and the values ranged from 6.1 to 7.85(Table 4.1.1). The pH value recorded in Kabitungu was lower compared with the mean pH of Kipkerieny. The tested ANOVA shows results indicating that there were no statistically substantial differences in pH among the various sampling stations ($p = 0.22$). The mean temperature value recorded was 24.15 ^{0}C ± 0.18, with a smallest value of 22 ^{0}C and an extreme value of 26 ^{0}C (Table 4.1.1). The temperature difference investigated was not statistically different across the sampling stations at the 5% Significant level($p=0.79$).

The dissolved oxygen (DO) recorded mean was 8.99 mgl^{-1} ± 0.06 with a minimum value of 8.1 mgl^{-1} and a maximum value of 9.9 mgl^{-1} (Table 4.1.1). The least amount of dissolved oxygen was recorded at Kipkerieny (8.92 ± 0.12) station. One-way ANOVA showed that dissolved oxygen concentrations were not statistically significant between the stations ($p = 0.75$).

The mean (± SE) electrical conductivity value recorded was 1187.94 µScm^{-1} ± 30.84, and the recorded values ranged between 900 µScm^{-1} and 1630 µScm^{-1} (Table 4.1.1), with the Chemosit Centre sampling station recording the highest mean value of 1380.17 µScm^{-1} ± 56.24. The results from the single-factor ANOVA indicated a statistically significant difference in conductivity between the sampling stations ($p = 0.00$). Subsequent post-hoc tests further elucidated that the mean conductivity at the Chemosit Centre station was notably higher compared to that of the Kipkerieny station. However, the Kipkerieny station fails to exhibit a substantial variance in mean conductivity when compared with the Kabitungu station. The total dissolved solids (TDS) recorded mean was 1460.06 mgl^{-1} ± 69.14 with a minimum value of

517 mgl^{-1} and a maximum value of 2010 mgl^{-1} (Table 4.1.1). The least amount of total dissolved solids was recorded at Kipkerieny (1244.33 mgl^{-1} ± 153.12) station. Results from ANOVA showed that the TDS concentrations were statistically significant between the sampling stations (p=0.01). *Post hoc* tests exposed that the Chemosit Centre station's mean TDS was significantly higher, equated with the average conductivity of the Kipkerieny station, which was the least. Still, the latter station did not differ significantly from Kabitungu.

The mean (± SE) level of sulfate concentration that was recorded was 0.08 mgl^{-1} ± 0.005, having minimum and a maximum of 0.01 mgl^{-1} and 0.16 mgl^{-1} (Table 4.1.1) with Chemosit Centre recording the least value of 0.0696 mgl^{-1} ± 0.01. The mean sulfate values across the sampled stations were not different statistically measured at a 5% significance level (p = 0.07). For phosphates, the mean value recorded was 0.40 mgl^{-1} ± 0.01, with the lowest and the highest mean values of 0.15 mgl^{-1} and 0.56 mgl^{-1} (Table 4.1.1). Results from the ANOVA analysis demonstrated that phosphate levels do not exhibit a significant change across the sampled stations at the 5% significant level (p=0.61).

The mean (± SE) value of nitrates concentration recorded was 1.6 mgl^{-1} ± 0.09 with a minimum value of 0.52 mgl^{-1} and a maximum value of 2.93 mgl^{-1} (Table 4.1.1). A single-factor ANOVA showed that the mean nitrate values were significantly different among the sampled stations(p=0.00). *Post hoc* test showed that Kipkerieny station mean nitrates were significantly higher compared with Chemosit Centre, which recorded the lowest nitrate concentrations.

4.1.2 Spatial variations of heavy metals

Figure 4.1.2 summarizes the mean and standard error (±S. E) and ANOVA comparisons of the measured heavy metals concentrations from the different sampling stations along the River Chemosit during the study period (Figure 4.1.2).

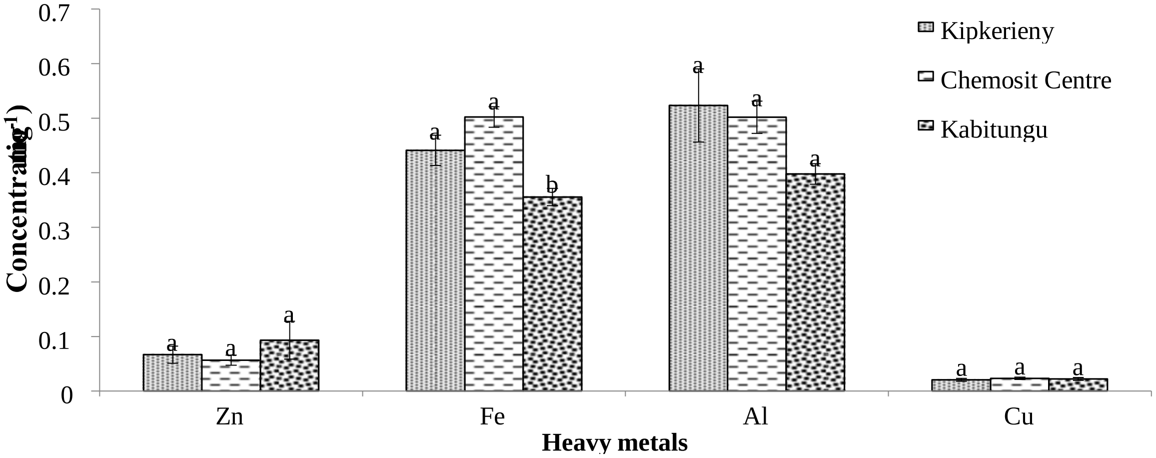


Figure 4.1.2: Mean ± SE spatial variations for heavy metals (mgl-1) concentrations from the different sampling stations. Means followed by different letters (a and b) are significantly different (p< 0.05) with respect to heavy metals and stations.

The mean concentration of zinc in the sampling stations fluctuated from 0.01 mgl^{-1} to 0.35 mgl^{-1} (Figure 4.1.2). Kabitungu station had the highest zinc mean concentration with 0.09 mgl^{1} ± 0.03. The mean concentration of zinc was not important among the sampling stations (*p* = 0.41). The average concentration of iron in the sampling stations fluctuated from 0.27 mgl^{1} to 0.71 mgl^{-1}(Figure 4.1.2). The Chemosit Centre sampling station had the highest iron concentration with 0.5022 mg^{-1}± 0.02 (Figure 4.1.2). It was significant (p = 0.01) among the sampling stations. At the same time, p*ost hoc* analysis showed that the iron means in the Kabitungu station was significantly lower compared with Chemosit Centre, which recorded the highest iron concentrations. The mean absorption of Aluminium in the sampling stations fluctuated from 0.2 mgl^{-1} to 1.04 mgl^{-1}(Figure 4.1.2). The Kipkerieny sampling station had the highest concentration of Aluminium with 0.5233 ml^{-1}± 0.07 (Figure 4.1.2). Its mean concentration was not substantial (p = 0.11) among the sampling stations at 5% Significance level.

The concentration of copper in the sampling stations also averaged from 0.01 mgl^{-1} to 0.05 mgl^{-1}. Kipkerieny sampling station had the lowest concentration of copper (Figure 4.1.2). ANOVA test indicated that the mean concentration of copper was insignificant among the sampling stations ($p = 0.728$). The concentration of lead in the sampling stations averaged 0.00 mgl^{-1} in all the stations. Therefore, no ANOVA tests were carried out to investigate the significance.

4.2 Temporal variations

The temporal variation analysis of the physicochemical parameter, anions, and metals for the months; August 2021, September 2021, October 2021, November 2021, December 2021, and January 2022, are presented in Table 4.2.1, and Figure 4.2.2

Table 4.2.1 The summary of the mean, standard error (±S. E), and ANOVA comparisons of the measured physico-chemical parameters of the different sampling months along river Chemosit.

Parameter	Sampling months						
	August, 2021	September, 2021	October, 2021	November, 2021	December 2021	January, 2022	p-values
pH	6.53 ± 0.11^{b}	6.93 ± 0.07^{a}	6.95 ± 0.09^{a}	7.29 ± 0.11^{a}	7.15 ± 0.06^{a}	7.10 ± 0.13^{a}	0.00
Temperature (°C)	25.59 ± 0.11^{a}	$25.41 \pm 0.16^{a, b}$	24.86 ± 0.16^{b}	23.37 ± 0.27^{c}	$23.17 \pm 0.16^{c, d}$	22.50 ± 0.10^{d}	0.00
DO (mg/l)	$9.06 \pm 0.08^{a, b}$	$9.18 \pm 0.18^{a, b}$	8.67 ± 0.19^{b}	$8.91 \pm 0.12^{a, b}$	$8.78 \pm 0.15^{a, b}$	9.34 ± 0.11^{a}	0.02
EC (µs/cm)	$1282.33 \pm 93.50^{a, b}$	$1280.78 \pm 86.19^{a, b}$	1370.22 ± 76.10^{a}	1015.44 ± 27.39^{b}	1053.33 ± 32.87^{b}	$1125.56 \pm 34.69^{a, b}$	0.00
TDS (mg/l)	1032.89 ± 157.40^{b}	1057.56 ± 131.06^{b}	1053.00 ± 136.50^{b}	1879.22 ± 22.99^{a}	1874.89 ± 25.41^{a}	1862.78 ± 27.17^{a}	0.00
SO_4^{2}- (mg/l)	0.09 ± 0.01^{a}	0.08 ± 0.02^{a}	0.08 ± 0.01^{a}	0.09 ± 0.01^{a}	0.09 ± 0.01^{a}	0.05 ± 0.01^{a}	0.11
PO_4^{3-} (mg/l)	0.36 ± 0.05^{a}	0.39 ± 0.03^{a}	0.45 ± 0.02^{a}	0.38 ± 0.05^{a}	0.44 ± 0.03^{a}	0.37 ± 0.01^{a}	0.37
NO_3^{-} (mg/l)	1.83 ± 0.23^{a}	1.85 ± 0.21^{a}	1.86 ± 0.25^{a}	1.39 ± 0.23^{a}	1.45 ± 0.21^{a}	1.21 ± 0.14^{a}	0.13

Means within a row followed by different letters (a, b, c) are significantly different (*p* < 0.05) with respect to the measured parameter and months.

4.2.1 Temporal variations of physicochemical parameters and anions

Temporally, the mean pH value recorded was 6.99 ± 0.05 with a minimum value of 6.1 and a maximum value of 7.85 (Table 4.2.1), with November having the uppermost average (± SE) pH of 7.29 ± 0.11, followed by December, which noted a mean of 7.15 ± 0.06 while August had the lowest mean of 6.53 ± 0.11. The results obtained indicate a steady increase in the mean pH from August to November, then a decline from December to January. pH was significantly diverse between the test groups for months having a *p* of less than 0.05. *Post hoc* showed that the average pH of August (6.53 ± 0.11) was significantly lower compared with the other months, which in turn did not differ significantly from each other (Table 4.2.1). For temperature, the mean (± SE) value recorded was 24.15 ^{0}C ± 0.18 with between 22 ^{0}C and 26 ^{0}C (Table 4.2.1), with August having the highest mean temperature of 25.59 ^{0}C ± 0.11 and January having the low average of 22.50 ^{0}C ± 0.100. Temperature was significantly diverse between the selected months at $p< 0.05$. *Post hoc* Tukey Pairwise Comparisons revealed four groups of months in which their mean temperatures did not differ significantly from each other (Table 4. 2.1).

The dissolved oxygen (DO) recorded mean was 8.99 mgl^{-1} ± 0.06, with 8.1 mgl^{-1} and 9.9 mgl^{-1} being the two boundaries (Table 4.2.1). The least amount of DO was recorded during October (8.67 ± 0.19). One-way ANOVA showed that dissolved oxygen concentrations were statistically significant between the sampling months with $p< 0.05$. *Post hoc* shows two groups of months in which their mean DO did not differ significantly from each other. The first group comprises the months of August to December, while the second group is the months of September to January (Table 4.2.1).

The mean (± SE) electrical conductivity value recorded was 1187.94 μScm^{-1} ± 30.84, and the recorded values ranged between 900 μScm^{-1} and 1630 μScm^{-1} (Table 4.2.1), with the October recording the uppermost mean of 1370.22 μScm^{-1} ± 76.1. E.C. was significantly varying between the sampling stations, given a $p < 0.05$. *Post hoc* showed two groups of months in which their mean electrical conductivity did not differ significantly from each other (Table 4. 2.1).

The recorded mean TDS was 1460.06 mgl^{-1} ± 69.14, with 517 mgl^{-1} and 2010 mgl^{-1} as the two limiting values (Table 4.2.1). The least amount of TDS was recorded during August (1032.89 ± 157.4), followed by September. TDS concentrations were statistically substantial between the sampling stations ($p < 0.05$). *Post hoc* was done, and it indicates that the two groups of months in which their mean TDS did not differ significantly from each other. The first group comprises the months of August to October, while the second group comprises the months of November to January (Table 4. 2.1).

For anions, the mean (± SE) level of sulphate concentration that was recorded was 0.08 mgl^{1} ± 0.005 with values of 0.01 mgl^{-1} and 0.16 mgl^{-1} being the boundaries (Table5.2), with January recording the least value of 0.05 mgl^{-1} ± 0.01. An ANOVA showed that the mean sulphate values were not significantly diverse among the sampled months at $p > 0.05$. contrarily, the mean (± SE) value of nitrates concentration noted was 1.6 mgl^{-1} ± 0.09 with a minimum 52 mgl^{-1} and a maximum of 2.93 mgl^{-1}(Table 4.2.1). A single-factor ANOVA showed that the mean nitrate values were not suggestively diverse among the sampled months ($p > 0.05$). For phosphates, the mean value recorded was 0.40 mgl^{-1} ± 0.01, with the smallest and supreme mean values of 0.15 mgl^{-1} and 0.56 mgl^{-1}(Table 4.2.1). Results of phosphate were insignificant midst the sampled months ($p > 0.05$) (Table 4.2.1).

4.2.2 Temporal variations of heavy metals.

Figure 4.2.2 shows the temporal variations of the mean, standard error (±S. E), and ANOVA comparisons of the measured heavy metals concentrations along river Chemosit during the study period.

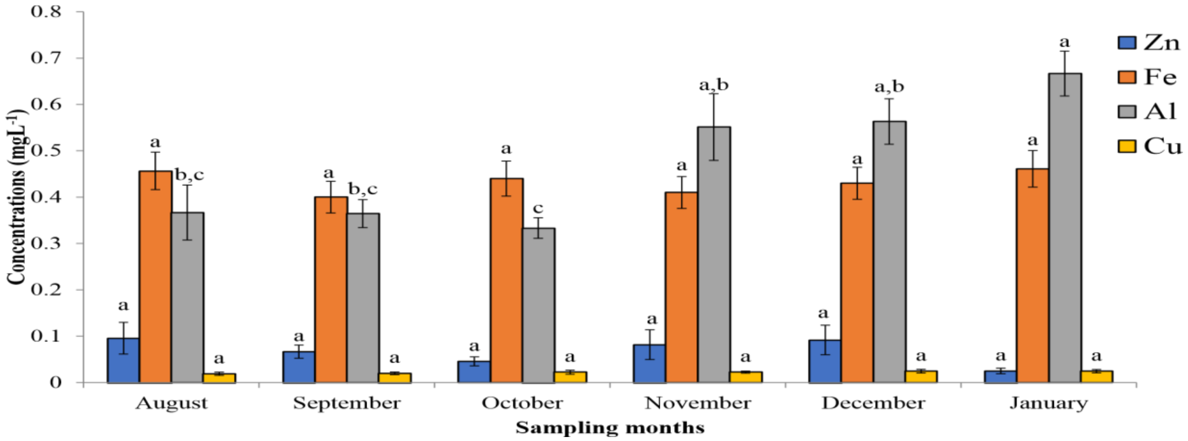


Figure 4.2.2: Mean (± SE) temporal variations for heavy metals (mgl-1) concentrations from the different sampling months along river Chemosit. Means followed by different letters (a, b, and c) are significantly different (p < 0.05) with respect to heavy metals.

The average concentration of zinc in the sampling stations fluctuated from 0.01 mgl^{-1} to 0.35 mgl^{-1}. In January, they recorded the lowest mean concentration with 0.03 mgl^{-1} ± 0.01. results show zinc was insignificantly dissimilar among the sampling stations (*p* =0.31) (Figure 4.2.2). The results came with Iron having values between 0.27 mgl^{-1} and 0.71 mgl^{-1}. September had the lowest concentration of iron, followed by November. Hypothesis tests showed that the mean iron concentration was not significantly different among the months (*p* = 0.82) (Figure 4.2.2). The mean concentration of Aluminium in the sampling stations was between 0.2 mgl^{1} to 1.04 mgl^{-1}. These results were significant at a 5% significant level (p =0.00). The *Post* *hoc* was done, and it showed that the three groups of months in which their mean concentrations of Aluminium did not differ significantly from each other (Figure 4.2.2). The mean concentration of copper in the sampling stations ranged from 0.01 mgl^{-1} to 0.05 mgl^{-1}. In August they had the least concentration of copper. The mean concentration of copper was insignificant during the sampling months ($p > 0.84$) (Figure 4.2.2). The concentration of lead in the sampling stations averaged from 0.00 mgl^{-1} in all six months. Therefore, no ANOVA tests were carried out to investigate the significance.

4.3 Seasonal variations

The mean (±SE) of seasonal variations of the physicochemical parameters, anions, and heavy metals along river Chemosit during the study period are summarized in Table 4.3.1. The means of physicochemical parameters measured were compared to reveal whether there was a significant difference between the dry and wet seasons. The calculated independent sample *t*-test showed that the means of pH, temperature, EC, and TDS values were significantly different between the two seasons except for DO ($t_{(52)} = -0.344$; $p = 0.73$). For anions, the calculated independent sample *t*-test showed that the means of Sulphates and Phosphates values were insignificantly different between the two seasons except for Nitrates ($t_{(52)} = 0.13$; $p = 0.004$). For heavy metals, the independent sample *t*-test showed that the means of zinc, iron, and copper concentration were insignificantly different between the two seasons except for Aluminium ($t_{(52)} = -5.91$; $p = 0.0$) (Table 4. 3.1).

Table 4.3.1: Seasonal variations of the physico-chemical parameters, anions, and heavy metals.

Parameter	Season	Mean ± SE	*t*- value
PH	Wet	6.8 ± 0.06	$t_{(52)} = -4.424$; $p = 0.0$
	Dry	7.2 ± 0.06	
Temperature (°C)	Wet	25.3 ± 0.1	$t_{(52)} = 13.89$; $p = 0.0$
	Dry	23.0 ± 0.1	
EC (μScm^{-1})	Wet	1311.1 ± 48.2	$t_{(52)} = 4.731$; $p = 0.0$
	Dry	1064.6 ± 19.8	
TDS (mgl^{-1})	Wet	1047.8 ± 78.9	$t_{(52)} = -10.29$; $p = 0.0$
	Dry	1872.3 ± 14.1	
DO (mgl^{-1})	Wet	9.0 ± 0.1	$t_{(52)} = -0.344$; $p = 0.73$
	Dry	9.0 ± 0.1	
SO_4^{2}- (mgl^{-1})	Wet	0.08 ± 0.01	$t_{(46)} = 0.72$; $p = 0.48$
	Dry	0.08 ± 0.01	
PO_4^{3-} (mgl^{-1})	Wet	0.40 ± 0.02	$t_{(52)} = 0.13$; $p = 0.9$
	Dry	0.40 ± 0.02	
NO_3^- (mgl^{-1})	Wet	1.85 ± 0.13	$t_{(52)} = 2.983$; $p = 0.004$
	Dry	1.35 ± 0.11	
Zn (mgl^{-1})	Wet	0.07 ± 0.01	$t_{(43)} = 0.15$; $p = 0.88$
	Dry	0.07 ± 0.02	
Fe (mgl^{-1})	Wet	0.43 ± 0.02	$t_{(52)} = -0.05$; $p = 0.96$
	Dry	0.43 ± 0.02	
Al (mgl^{-1})	Wet	0.35 ± 0.02	$t_{(52)} = -5.91$; $p = 0.0$
	Dry	0.59 ± 0.03	
Cu (mgl^{-1})	Wet	0.02 ± 0.002	$t_{(52)} = -1.19$; $p = 0.24$
	Dry	0.02± 0.002	

4.4 Pearson Correlation analysis for physicochemical parameters, anions, and metals.

Pearson correlation measures the strength and the direction of the linear relationship between the two variables. The correlation coefficient ranges from -1 to +1, with -1 explaining a perfect negative correlation, +1 a perfect positive correlation, and 0 means that there is no correlation at all. A negative sign shows that an increase in the first variable will possibly lead to a decrease in the second variable. A positive sign shows a positive correlation, which means that an increase in the first variable causes an increase in the second variable.

By carrying out Pearson's correlation analysis, a linear relationship between the 12 different parameters along River Chemosit in Kericho County was determined. Table 4.4.1 shows the obtained linear correlation matrices at a 5% significance level, and only those parameters with Pearson coefficients equal to or higher than 0.05 ($r = 0.05$) were significant. There was an important, very strong negative link between temperature and TDS ($r_{(54)} = -.712$, $p< 0$) and TDS with nitrate ($r_{(54)} = -.715$, $p< 0$). Here a significant strong positive connection between temperature and EC ($r_{(54)} = .449$, $p = .001$). In contrast, there was a suggestively strong negative association between pH with temperature ($r_{(54)} = -.47$, $p< 0$), EC ($r_{(54)} = .521$, $p< 0$), and EC with nitrate ($r_{(54)} = -.413$, $p = .002$). Lastly, there was a moderate positive association between temperature and nitrate ($r_{(54)} = .37$, $p = .006$). For metals, a strong negative relationship between temperature and Aluminium ($r_{(54)} =-.583$, $p<0$) and Iron with nitrates ($r_{(54)} =-.342$, $p=0.011$). A substantial, strong positive association between iron and electrical conductivity ($r_{(54)} =0.473$, $p<0$) and

Aluminium with total dissolved solids ($r_{(54)}$ =.679, $p<0$). In contrast, there is a significant negative relationship between aluminum and nitrates ($r_{(54)}$ =-.317, $p=0.02$, and a substantial, strong positive association with iron ($r_{(54)}$ =.579, $p<0$).

Table 4.4 1: Pearson Correlation Coefficient (r) matrix for different physicochemical parameters, anions, and heavy metals

	pH	Temp. (°C)	EC (µScm^{-1})	TDS (mgL^{-1})	DO (mgL^{-1})	SO$_4^{2-}$ (mgL^{-1})	PO$_4^{3-}$ (mgL^{-1})	NO$_3^-$ (mgL^{-1})	Zn (mgL^{-1})	Fe (mgL^{-1})	Al (mgL^{-1})	Cu (mgL^{-1})
pH		-.470**	-.521**	0.25	-0.18	0.04	0.01	-0.01	-0.22	-0.26	0.20	0.01
Temp. (°C)	-.470**		.449**	-.712**	-0.08	0.22	-0.05	.370**	0.16	-0.05	-.583**	-0.14
EC (µScm^{-1})	-.521**	.449**		-0.02	-0.03	0.06	0.02	-.413**	0.05	.473**	-0.13	0.10
TDS (mgL^{-1})	0.25	-.712**	-0.02		0.04	-0.02	-0.06	-.715**	0.09	.357**	.679**	0.26
DO (mgL^{-1})	-0.18	-0.08	-0.03	0.04		-0.20	0.02	-0.12	-0.12	0.05	-0.01	0.02
SO$_4^{2-}$ (mgL^{-1})	0.04	0.22	0.06	-0.02	-0.20		-0.07	-0.09	0.06	-0.17	-0.16	-0.01
PO$_4^{3-}$ (mgL^{-1})	0.01	-0.05	0.02	-0.06	0.02	-0.07		0.09	0.08	0.05	-0.07	0.17
NO$_3^-$ (mgL^{-1})	-0.01	.370**	-.413**	-.715**	-0.12	-0.09	0.09		0.10	-.342*	-.317*	-0.21
Zn (mgL^{-1})	-0.22	0.16	0.05	0.09	-0.12	0.06	0.08	0.10		.302*	0.25	0.14
Fe (mgL^{-1})	-0.26	-0.05	.473**	.357**	0.05	-0.17	0.05	-.342*	.302*		.579**	0.11
Al (mgL^{-1})	0.20	-.583**	-0.13	.679**	-0.01	-0.16	-0.07	-.317*	0.25	.579**		0.21
Cu (mgL^{-1})	0.01	-0.14	0.10	0.26	0.02	-0.01	0.17	-0.21	0.14	0.11	0.21	

* 0.05 C.L (two-tailed)

**0.01 C.L (two-tailed)

The Pearson correlation indicates that a change in pH negatively affects Zinc and iron while it is positive on Aluminum and Copper. Also, a temperature change is negatively related to iron, Aluminum, and copper however, it is positive with zinc. EC has a positive effect on zinc, iron, and copper, though its negative with Aluminum (Douglas et al., 2022). TDS showed that a surge in its concentration marks a rise in the concentration of all the studied metals (Petrosyan et al., 2019). DO indicates that it has a negative relationship with zinc and Aluminum, while it is positive with iron and copper. The relation between the anions and the metals was presented in that sulfates have a positive association with zinc while negative with other metals (Edori & Udongwo, 2021; Mazzei & Piccolo, 2015). Phosphates correlate negatively with zinc and Aluminium while positive with iron and copper. Nitrates, on the other hand, have a negative relationship with other metals except for zinc.

4.5 Compliance with National and International Standards

As shown in Table 4.5.1, the measured water quality standards of river Chemosit in Kericho County during the study period TDS exceeded NEMA during a dry period, while PO_4^{3-}, Aluminium, and iron exceeded the NEMA and WHO standards during wet and dry seasons, while all the other limits were within the satisfactory limits.

Table 4.5.1: Physico-chemical parameters, anions, and metals compliance to NEMA and WHO standards

Parameter	Season	Mean ± SE	NEMA standards for domestic water sources	NEMA standards for irrigation	WHO Standards for Domestic water
pH	Wet	6.8 ± 0.06	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
	Dry	7.2 ± 0.06			
Temperature (°C)	Wet	25.3 ± 0.1	±3^{0}C of the ambient temperature of the water body		
	Dry	23.0 ± 0.1			
EC (µScm^{-1})	Wet	1311.1 ± 48.2	*	*	2500
	Dry	1064.6 ± 19.8			
TDS (mgl^{-1})	Wet	1047.8 ± 78.9	1200	1200	1000
	Dry	1872.3 ± 14.1			
DO (mgl^{-1})	Wet	9.0 ± 0.1	*	*	*
	Dry	9.0 ± 0.1			
SO_4^{2}- (mgl^{-1})	Wet	0.08 ± 0.01	400	*	400
	Dry	0.08 ± 0.01			
PO_4^{3-} (mgl^{-1})	Wet	0.40 ± 0.02	30	*	0.05
	Dry	0.40 ± 0.02			
NO_3^- (mgl^{-1})	Wet	1.85 ± 0.13	10	*	10
	Dry	1.35 ± 0.11			
Zn (mgl^{-1})	Wet	0.07 ± 0.01	1.5	2	5
	Dry	0.07 ± 0.02			
Fe (mgl^{-1})	Wet	0.43 ± 0.02	0.3	1	0.3
	Dry	0.43 ± 0.02			
Al (mgl^{-1})	Wet	0.35 ± 0.02	0.1	5	0.2
	Dry	0.59 ± 0.03			
Cu (mgl^{-1})	Wet	0.02 ± 0.002	0.05	0.05	0.1
	Dry	0.02 ± 0.002			

Where: * denotes the non-existence of a NEMA standard for the concentration levels of the corresponding parameter.

CHAPTER FIVE

DISCUSSION

5.1 Physical-chemical parameters

The mean pH value ranged from between (6.915±0.08) to (7.113±0.04). High pH values recorded in Kipkerieny might be due to large volumes of water. Low pH values at Chemosit shopping Centre could be attributed to detergents used in washing automobiles, washing clothes, bedrock and soil composition of the area, decomposing organic materials from plants and animal wastes, releasing carbon (IV)oxide, which dissolved to form carbonic acid, dumping of chemicals into water by the community, effluents from the shops and effluents containing acid from the car wash and high temperatures.

The low pH values in Kabitungu could be attributed to the discharge from the Bureti tea factory. Pesticides and fertilizers from nearby tea farms and other agricultural farms were washed down the river during rainy seasons, resulting in slightly acidic water across the stations, months, and seasons (Atobatele &Ugwumba,2010). At each sampling point, the pH values (6.1-7.85) were within the acceptable WHO, KEBS, NEMA, and WASREB (2018) limits for surface water (6.5-8.5).

Aquatic organisms thrive within a pH range of 6.1–7.85, fostering diverse ecosystems. However, when the pH exceeds this range, physiological stresses may arise, leading to a decline in aquatic biodiversity. In general, lower pH levels increase the solubility of Aluminium and iron, as in table 4.3.1, during the wet season, making them more available for uptake by aquatic organisms (Boyd et al., 2016; Bhumika et al., 2019).

The average temperature ranged from 24.006±0.37°C to 24.306±0.29°C across the sampled locations. The fluctuations in water temperature observed in this study may be linked to climatic variables, such as rainfall, which can influence temperature variations. Despite these fluctuations, the average water temperature fell within the World Health Organization's recommended standards of 25°C to 32°C. The elevated water temperatures can be attributed to various aspects, including manufacturing discharge, agricultural runoff, and domestic wastewater. Temperature affects the rate of chemical reactions and the solubility of metals (Raimi et al., 2018). As presented in the results chapter, high concentrations of iron and aluminium during the wet season could be due to high temperatures (25.3^0C) (Jannat & Mottalib,2019; Julius et al.,2018) and high TDS.

The mean electrical conductivity values ranged between (1023.89±18.83 µS/cm) to (1380.17±56.24 µS/cm). The electrical conductivity levels exceeded the WHO's recommended limits of 600 µS/cm for natural water. This may be attributed to various factors, such as domestic effluent discharges from Chemosit Centre and industrial effluents from Kabitungu. Additionally, agricultural surface runoff might have contributed to the increased concentration of ions. The presence of dissolved metals in water can be influenced by higher electrical conductivity levels, potentially leading to elevated concentrations of dissolved metal (Hoque & Deb, 2017; Nyabaro et al., 2013). WHO recommends that EC beyond 3000 µs/cm may cause acute diarrhea, while one between 1000 and 2900 µs/cm results in mild diarrhea, and below 1000 µs/cm is recommended for drinking.

Research carried out in the rivers of Chesogon, Murunyi in Sigor division West Pokot County by Gershom et al.,2019 observed that the E.C values were high during dry season(221.83µS/cm.75µS/cm) compared to wet season (163µS/cm-194µS/cm). These could be attributed to high temperature and turbidity. High temperature increases the ionization of compounds in water, leading to higher E.C. During the dry season, there is less precipitation and movement of water. The ions in rivers thus have a higher concentration and are still enabling to be detected, thus leading to higher E.C values. It was also attributed to the low volume of water in the region resulting from its arid nature and more influx of agrochemicals and detergents from the residents. These values differed from the values of the Chemosit River because it passes through nutrient-rich agricultural lands of tea plantations.

The average values for TDS fluctuated between (1244.33±153.12mg/l) to (1760.39±46.90 mg/) Table 4.1.1. The highest concentration of TDS was observed at Chemosit shopping Centre, and Low TDS values were recorded in Kipkerieny. The TDS levels exceeded both the acceptable limits set by the National Environmental Management Authority (NEMA) in Kenya, which is 1200 mg/l, and the WHO's permissible limit of 1000 mg/l. This elevation in TDS levels could be attributed to numerous factors as well as surface runoff, weathering of rocks, agricultural runoff, discharge of domestic waste, and animal waste. High TDS concentrations have implications for water quality, affecting its taste, odor, color, and hardness. Conversely, excessively low TDS levels may compromise the taste of drinking water. Exceeding the TDS of 1000mg/l would compromise drinking water quality and is considered by WHO as not good for human consumption, beyond the limits, resulting in physiological process impairments, including gastrointestinal irritations in people suffering from kidney problems.

The DO mean concentration ranged from 8.922 to 9.039 mg/land was within the acceptable values of WHO standards (Olubanjo & Adeleke, 2020). The dissolved oxygen concentrations were found to be higher during the wet season as compared to the dry season. This could be due to the increased volume of water during the wet season, hence high aeration, and low in the dry season due to low volume of water, hence minimal aeration.

World Health Organization recommends the pH for drinking water should be between 6.5 to 8.5, Temperature 24^0C-25^0C, EC<1500µs/cm, TDS 1000mg/l, DO 9mg/l. From these estimates, the study found that River Chemosit had mean values as pH 6.99± 0.05, temperature 24.15^0C±0.18, EC 1187.94µs/cm±30.84, TDS 1460.06 mg/l±69.14, DO 8.99mg/l±0.06, falling within the range provided, recommended for human consumption and the aquatic ecosystem but TDS was above the recommended level (Raimi et al., 2018).

5.2 Anions

The study found that NO_3^-, SO_4^{2-}, and PO_4^{3-} were present and their concentrations in the three stations varied; NO_3^-1.601mg/l± 0.09, SO_4^{2-},0.08mg/l ±0.01 and PO_4^{3-}0.40mg/l± 0.01in river Chemosit, according to WHO recommended limits, NO_3^- 10mg/l, SO_4^{2-} 400mg/l PO_4^{3-} 0.3mg/l. Nitrates and sulphates were within the recommended limits, while Phosphates were above the recommended limits, and household and industrial wastes could cause these. The residents engage in various activities along the river, including washing clothes directly in the water and using detergents during car washing, which results in the discharge of phosphates into the river. Furthermore, agricultural practices such as grazing and tea cultivation, as well as activities in market centers, also contribute to phosphate accumulation. Additionally, natural processes such as erosion from rocks, soils, and sediments further contribute to the phosphate increase in the river. Their presence in excess concentrations can lead to eutrophication, resulting in algal blooms and depletion of oxygen in water (Chebet et al., 2018; Nyabaro et al., 2013). The findings showed that phosphates mean concentration was high and nitrates below recommended limits fell within the same other study in River Isiukhu and River Muruny (Oremo et al.,2020), Gershom et al.,2019 obtained a mean value which was higher than the WHO value in rivers of Sigor division in west Pokot County. This was attributed to fecal pollution and fertilizers from agricultural lands. Kirianki et al.,2018 obtained 27.90±0.29 nitrates in rivers in Mauche and Njoro River 9.23±1.38, which was above the KEBS and WHO limits. This was attributed to agricultural activities due to nitrogenous fertilizers. This study differed from Chemosit's results as the mean of nitrates was below the set standard limits. Swamy et al., 2013 in Nandi County, found that the concentration of phosphates was high due to the use of fertilizers and industrial wastes. Monitoring the concentration of Phosphates can help identify potential sources of eutrophication, such as agricultural and urban runoff. (Kosgey et al., 2015; Bannerji, S. 2014, Kumar &Asolekar ,2014). The range of Nitrates was within WHO recommended levels.

5.3 Presence and concentration of metals

The study found that Al, Fe, Cu, and Zn were present, but Pb was below the detectable limit. The natural level of lead in water is low since its salts, that is, phosphates, carbonates, and sulfates are poorly soluble in water because of their poor solubility and pH ≥6. Lead is completely adsorbed on the sediment; hence, lead is least found in water. The concentration of metals which was confirmed to be present were: Al 0.47mg/l±0.03, Fe 0.43mg/l±0.01, Cu 0.02mg/l± 0.001and Zn 0.07mg/l±0.01 in river Chemosit waters, according to WHO recommended limits, Al 0.2mg/l, Fe 0.3mg/l, Cu 0.1mg/l and Zn 5mg/l.

From the study, the concentration of zinc was very low, and its concentration in river Chemosit could be due to mineralogy and weathering. The weathering of zinc-containing bedrock gives rise to zinc ions in water. It could be attributed to a fairly neutral pH where zinc is insoluble in water. It is also an essential trace element required by most organisms for their growth and development. Since zinc compounds are present in fungicides and insecticides, which are emitted from the farms along the river, Chemosit could be taken up by the aquatic plants and animals.

Copper was relatively low in all sampling points; it could be due to mineralogy and weathering. Copper has various uses; therefore, its low concentration in water might be due to its interactions with various functional groups such as organic matter particulate organic carbon, which form strong bonds with them. The solubility of copper in water is low because Copper forms highly insoluble sulphides, carbonates, oxides, and hydroxides.

High concentrations of iron in all these sampling points could be attributed to high temperatures, agricultural surface runoff from the farms and household wastewater in Kipkerieny, industrial effluents from Bureti tea factory in Kabitungu, car washing and automobiles, household wastewater in Chemosit shopping Centre. Iron is profuse in the earth's crust and has many uses industrially, which is probably the reason why it was present in relatively high quantities in all sampling points. This study is in agreement with the study done by Kirianki et al.,2018 in Mauche and Njoro rivers, where the mean values were 0.87±0.23 and 0.89±0.05, respectively. The mean concentration was above KEBS and WHO limits and was due to the infiltration of iron from soils.

Aluminum is the most abundant metallic element in Earth's crust and the most widely used metal in food packaging, paints, rubber, and ceramics, and contained in some fertilizers. High concentrations in these sampling points might be due to high temperatures, which increased the solubility of aluminum and aluminum compounds released into the river as wastewater effluents, surface runoff from the farms, hence fertilizers, weathering of rocks, pesticides, and herbicides end up into the river. High concentrations of Aluminium ions are toxic to plants as they reduce the intake of phosphate and are strong neurotoxicants in human beings. Aluminum and iron were above the recommended limits, while zinc and copper were within acceptable limits. The findings showed that Aluminium and iron concentrations were high and fell within the same other study in Ewaso Nyiro River (Njuguna et al.,2021)

Human Health: These metals can carry a significant threat to human well-being if they are present in high concentrations in drinking water (Hoque & Deb, 2017). For example, copper can cause gastrointestinal distress and liver damage at high levels. Aquatic Ecosystems can be affected by elevated concentrations of metals (Ma et al., 2020). For example, Fe is also restricted to reduce the instances of staining cloths and plumbing materials; Aluminium beyond 0.2 mg/l results in human memory loss, dementia, and severe trembling can interfere with aquatic plant growth (Cholewińska et al., 2018). Water quality has a link to the presence of metals in river Chemosit waters. It can indicate poor water quality and may be indicative of anthropogenic activities such as industrial activities and agricultural runoff.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

River Chemosit is a vital natural resource for the residents of Chemosit town and the surrounding areas, including communities living along the riparian zones. The river not only provides water for domestic use but also supports agriculture, industry, and aquatic life, making it an essential component of the local ecosystem. Given its significance, this study aimed to evaluate the current pollution status of River Chemosit by analyzing selected physicochemical parameters, anions, and metals. The insights gained from this study provide a detailed understanding of the river's water quality and its suitability for various uses, particularly in the context of human consumption and the sustainability of the aquatic ecosystem.

6.1.1 Physico-chemical Parameters

The study revealed that the levels of physicochemical parameters along River Chemosit varied both spatially and seasonally. These variations can be directly linked to pollutant loading from the river's surroundings, largely due to anthropogenic activities such as agricultural runoff, industrial discharges, and domestic effluents. The spatial variation was evident across the three sampling stations: Kipkerieny, Chemosit Centre, and Kabitungu each of which is influenced by different environmental and human factors.

For instance, the pH values recorded across the three sampling sites ranged from 6.10 to 7.85, which generally fall within the acceptable limits set by the World Health Organization (WHO), the Kenya Bureau of Standards (KEBS), the National Environment

Management Authority (NEMA), and the Water Services Regulatory Board (WASREB) for surface water (6.5-8.5). However, the relatively lower pH values observed at Chemosit Centre and Kabitungu suggest a localized impact from industrial effluents, agricultural runoff, and other anthropogenic activities. These findings underscore the potential influence of human activities on the river's water quality, particularly in areas closer to urban centers and industrial zones.

Temperature values, which ranged from 22.00°C to 26.00°C with an overall mean of 24.15°C, were found to be within WHO's recommended range of 24°C to 32°C. However, temperature fluctuations were observed, which can be attributed to both natural climatic conditions and local human activities, such as manufacturing processes and agricultural practices. Elevated temperatures can accelerate chemical reactions and affect the solubility of metals, which may lead to increased concentrations of dissolved elements such as iron and aluminum an effect particularly noted during the wet season when water volumes and runoff are higher.

Electrical conductivity (EC) levels in River Chemosit exceeded WHO's recommended limit of 600 µS/cm for natural water, with recorded values ranging from 1,023.89 µS/cm to 1,380.17 µS/cm across the sampling stations. The elevated EC levels indicate a higher concentration of dissolved ions in the water, which is likely due to domestic effluent discharges, industrial waste, and agricultural surface runoff. High EC levels are a clear indication of potential contamination by dissolved metals and salts, posing risks to both human health and the aquatic ecosystem.

Similarly, Total Dissolved Solids (TDS) levels exceeded the permissible limits set by WHO and NEMA, with values ranging from 517.00 mg/L to 2,010.00 mg/L. The highest TDS concentrations were observed at Chemosit Centre, likely due to the combined effects of agricultural runoff, weathering of rocks, and discharge of domestic waste. Elevated TDS levels can negatively impact water taste, odor, and hardness, making it unsuitable for human consumption. Moreover, high TDS levels can also affect the health of aquatic organisms by altering the water's chemical balance.

Dissolved Oxygen (DO) levels, which ranged from 8.10 mg/L to 9.90 mg/L, were within the acceptable range set by WHO. Higher DO concentrations were observed during the wet season, indicating better water quality and higher aeration levels due to increased water volumes. Adequate DO levels are crucial for maintaining healthy aquatic ecosystems, as they support the survival of fish and other aquatic organisms.

6.1.2 Anions and Metals

The study also focused on the analysis of anions, specifically anions such as nitrates ($NO_3^{-)}$, sulfates (SO_4^{2-}), and phosphates (PO_4^{3-}). The presence and concentration of these anions were confirmed across different stations, months, and seasons. Notably, nitrate levels varied significantly across the three stations and two seasons, reflecting the influence of agricultural activities and effluent discharge on water quality. Sulfate and phosphate levels, however, did not show significant spatial or seasonal differences. Despite this, phosphate levels were consistently above the WHO and NEMA limits for domestic water, posing a significant risk of eutrophication. Excessive phosphate levels can lead to algal blooms and subsequent oxygen depletion, which can severely disrupt aquatic ecosystems and harm aquatic life. The presence and concentration of metals, including aluminum (Al), iron (Fe), copper (Cu), and zinc (Zn), were also confirmed in River Chemosit. Among these, iron showed significant spatial variation, indicating localized sources of contamination. Aluminum, zinc, and copper levels did not vary significantly across the stations, months, or seasons. However, the concentrations of aluminum and iron were found to be above the

NEMA and WHO limits, raising concerns about their potential impact on both human health and aquatic life. Elevated levels of these metals can have toxic effects, particularly on the nervous and reproductive systems, and can also disrupt the ecological balance of aquatic environments. Lead, on the other hand, was below detectable limits, which is a positive finding, given the harmful effects of lead on human health and the environment. The absence of detectable lead levels suggests that there may be effective control measures in place to limit lead pollution in the river. In conclusion, the study's findings indicate that while River Chemosit maintains certain physicochemical parameters within acceptable limits, the elevated levels of TDS, EC, phosphates, aluminum, and iron highlight potential risks to water quality and the overall health of the river ecosystem. Human activities, particularly agricultural practices, industrial discharges, and domestic waste management, have a significant impact on the river's water quality. These activities contribute to the elevated levels of key parameters, posing risks not only to the environment but also to public health.

To safeguard River Chemosit and ensure its continued viability as a resource for human consumption and aquatic life, it is essential to implement continuous monitoring and stringent pollution control measures. These measures should focus on reducing the input of pollutants from agricultural, industrial, and domestic sources. Additionally, raising awareness among the local population about the importance of protecting the river and adopting sustainable practices is crucial for the long-term preservation of this vital water resource.

Finally, further research is recommended to explore the long-term trends in water quality in River Chemosit and to assess the effectiveness of implemented pollution control measures.

Such research will provide valuable insights into the sustainability of the river's ecosystem and its capacity to support the needs of the local population.

6.2 Recommendations

The collected data from this study serves as a crucial baseline for future research and monitoring efforts aimed at preserving the water quality of River Chemosit. The findings highlight several areas where improvements can be made to protect this vital resource. Based on the current study's findings and the identified gaps, the following expanded recommendations are proposed:

There is an urgent need for stricter enforcement of environmental regulations to control the discharge of pollutants into River Chemosit. Regulatory bodies, such as the National Environment Management Authority (NEMA), should ensure that industries and agricultural activities along the river, particularly those from Jamji, Bureti tea factories, and local farmers, comply with environmental standards. This includes implementing best practices for waste management and pollution control to minimize the release of heavy metals, anions, and other contaminants into the river. Regular inspections and penalties for non-compliance should be enforced to deter practices that degrade water quality.

Continuous monitoring of River Chemosit's water quality is essential to detect changes in pollution levels and assess the effectiveness of regulatory measures. NEMA, in collaboration with local authorities and environmental organizations, should establish a comprehensive water quality monitoring program. This program should include regular sampling and analysis of key physicochemical parameters, anions, and metals at multiple points along the river. The data collected will not only help in tracking pollution trends but also in identifying new sources of contamination. Additionally, the establishment of a centralized database accessible to researchers, policymakers, and the public will facilitate transparency and informed decision-making.

Raising awareness among local communities and schools about the importance of protecting River Chemosit and its ecosystems is crucial for fostering a culture of environmental stewardship. Educational programs should be developed to inform residents, farmers, and industries about the impact of their activities on the river's health and the long-term consequences of pollution. These programs could include workshops, seminars, and hands on activities that teach best practices for waste management, sustainable agriculture, and water conservation. Integrating environmental education into school curriculums will help instill a sense of responsibility in the younger generation, ensuring that they grow up with a strong commitment to preserving natural resources.

Agriculture is a significant contributor to the pollution of River Chemosit, particularly through runoff containing fertilizers, pesticides, and other chemicals. To mitigate this, there is a need to promote sustainable agricultural practices among farmers along the river. These practices could include the use of organic fertilizers, integrated pest management (IPM), and conservation tillage, which reduce the amount of harmful substances entering the water. Training and support should be provided to farmers to help them adopt these practices, which can enhance crop yields while protecting the river’s water quality.

The riparian zones along River Chemosit play a critical role in maintaining the river's ecological health by filtering pollutants, stabilizing banks, and providing habitat for wildlife. However, these areas are often degraded due to deforestation, overgrazing, and construction activities. It is recommended that efforts be made to restore and protect these riparian zones through reforestation, controlled grazing, and the establishment of buffer zones where no agricultural or industrial activities are allowed. Such measures will help reduce the amount of pollutants entering the river and improve its overall health.

Further research is needed to develop innovative solutions for pollution control in River Chemosit. This could include the exploration of natural and engineered wetlands, bioremediation techniques, and the use of eco-friendly materials to treat industrial and agricultural effluents before they enter the river. Collaborations between academic institutions, environmental organizations, and the private sector can drive the development and implementation of these solutions. Additionally, research into the long-term effects of current pollution levels on both human health and aquatic life is crucial to inform future regulations and mitigation strategies.

A comprehensive River Basin Management Plan (RBMP) for River Chemosit should be developed to coordinate the efforts of various stakeholders in managing the river's resources. The RBMP would provide a framework for sustainable water use, pollution control, and habitat conservation, ensuring that all activities within the river basin are aligned to maintain water quality and ecological integrity. This plan should involve the participation of local communities, government agencies, industries, and non-governmental organizations to ensure that all perspectives are considered and that the plan is effectively implemented.

By implementing these recommendations, it is possible to preserve the water quality of River Chemosit, protect the health of the local population, and sustain the river's ecological functions for future generations. Continuous efforts and collaboration among all stakeholders will be essential in achieving these goals.

6.3 Further study

Further research could be conducted to investigate the sources and transport mechanisms of pollutants in River Chemosit, as well as their potential impacts on human health and aquatic biota. Such studies would provide a more comprehensive understanding of the dynamics of pollution in the river and help identify the most critical areas for intervention.

- **Identification of Pollution Sources**

A detailed investigation into the specific sources of pollutants entering River Chemosit is essential for effective management and remediation. This research should focus on pinpointing the exact origins of contaminants, whether they are from agricultural runoff, industrial effluents, domestic waste, or other anthropogenic activities. Advanced techniques such as isotope tracing, chemical fingerprinting, and remote sensing could be employed to accurately identify and differentiate between point and non-point sources of pollution. Understanding the contribution of each source would enable more targeted and effective regulatory actions.

- **Understanding Pollutant Transport Mechanisms**

Various factors, including hydrological conditions, river morphology, and climatic events, influence the movement and distribution of pollutants within River Chemosit. Research into the transport mechanisms of these pollutants—such as how they are carried downstream, how they interact with sediments, and how they are affected by seasonal changes—would provide valuable insights into the processes that exacerbate pollution levels. Hydrodynamic modeling and field studies could be used to simulate and observe the behavior of pollutants under different environmental conditions, helping to predict potential hotspots of contamination and areas at greater risk.

- **Assessment of Human Health Impacts**

  The presence of heavy metals, anions, and other contaminants in River Chemosit poses potential risks to the health of the local population, particularly those who rely on the river for drinking water, irrigation, and other domestic uses. Further research should investigate the pathways through which these pollutants enter the human body, whether through direct ingestion, dermal contact, or consumption of contaminated food. Epidemiological studies could be conducted to examine the prevalence of health issues such as gastrointestinal diseases, neurological disorders, and other conditions that may be linked to exposure to river pollutants. Additionally, toxicological assessments of the detected contaminants could provide a clearer picture of their potential health risks.

- **Impact on Aquatic Biota**

  The presence and concentration of pollutants directly influence the health of aquatic ecosystems in River Chemosit. Further research should focus on assessing the impacts of contaminants on the river's aquatic biota, including fish, invertebrates, and plant species. This could involve studies on bioaccumulation, where pollutants concentrate in the tissues of organisms, potentially leading to toxic effects as they move up the food chain. Research into the reproductive, developmental, and behavioral impacts of these pollutants on aquatic species would provide crucial information on the ecological consequences of pollution. Additionally, biomonitoring using indicator species could help assess the overall health of the river ecosystem.

- **Long-term Environmental Monitoring**

  Understanding the long-term trends in pollution levels and their effects on both human health and aquatic ecosystems is essential for developing sustainable management strategies. Establishing a long-term environmental monitoring program for River Chemosit, which regularly collects and analyzes data on water quality, pollutant concentrations, and ecological health, would provide valuable baseline information for future research. Such a program could also help in detecting early warning signs of environmental degradation and in evaluating the effectiveness of pollution control measures over time.

- **Socioeconomic Impacts of Pollution**

  The socioeconomic implications of pollution in River Chemosit should also be explored, particularly in relation to its impact on livelihoods, food security, and local economies. Research could investigate how declining water quality affects agriculture, fisheries, and tourism in the region, as well as the costs associated with water treatment and healthcare. Understanding these socioeconomic impacts would highlight the broader consequences of pollution and reinforce the importance of protecting the river for the well-being of local communities.

- **Integration of Research Findings into Policy and Management**

  Finally, the findings from these research efforts must be effectively integrated into policy and management practices. Collaboration between researchers, policymakers, and local stakeholders should be strengthened to ensure that scientific insights are translated into practical actions that protect and restore River Chemosit. The development of evidence-based policies, informed by rigorous research, will be key to achieving long-term sustainability and safeguarding the river for future generations.

In summary, further research into the sources, transport mechanisms, and impacts of pollutants in River Chemosit is vital for developing a deeper understanding of the challenges facing this critical water resource. Such studies would provide the scientific foundation needed to implement effective interventions, protect human health, preserve aquatic ecosystems, and ensure the sustainable use of the river.

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APPENDICES

I. Research permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **694035**

Date of Issue: **27/September/2021**

RESEARCH LICENSE

This is to Certify that Miss.. Cherotich Emily of Kisii University, has been licensed to conduct research in Kericho on the topic: DETERMINATION OF POLLUTANT LEVELS AND INORGANIC LIGANDS ALONG RIVER CHEMOSIT, kERICHO-KENYA for the period ending : 27/September/2022.

License No: **NACOSTI/P/21/13283**

694035

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

Verification QR Code

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KISII UNIVERSITY

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OFFICE OF THE REGISTRAR RESEARCH AND EXTENSION

REF: KSU/R&E/ 03/5/ 548 DATES: 9th September, 2021

The Head, Research Coordination
National Council for Science, Technology and Innovation
(NACOSTI) Utalii House, 8th Floor, Uhuru
Highway P. O. Box 30623- 00100 NAIROBI -
KENYA.

Dear Sir/ Madam

RE: EMILY CHEROTICH LANGAT MPS13/70092/15

The above mentioned is a student of Kisii University currently pursuing a Degree of Master of Science in Physical Chemistry. The topic of her research is, ""Determination of pollutants levels and inorganic ligands along River Chemosit, Kericho County, Kenya".

We are kindly requesting for assistance in acquiring a research permit to enable her carry out the research.

Thank you.

(crProf. Akalo Shitandi, PhD
Registrar, Research and Extension

KISII UNIVERSITY
09 SEP 2021
REGISTRAR RESEARCH & EXTENSION

cc: DVC (ASA)Registrar
(ASA)Director SPGS

II.Spatial variations

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
pH	Kipkerieny	18	7.1133	0.18166	0.04	7.023	7.2037	6.85	7.5
	Chemosit Centre	18	6.9494	0.4756	0.11	6.7129	7.186	6.2	7.85
	Kabitungu	18	6.9150	0.35585	0.08	6.738	7.092	6.1	7.5
	Total	54	6.9926	0.36247	0.04933	6.8937	7.0915	6.1	7.85
Temperature (°C)	Kipkerieny	18	24.1330	1.1402	0.2687	23.566	24.7	22.4	25.9
	Chemosit Centre	18	24.0060	1.5498	0.3653	23.235	24.776	22	26
	Kabitungu	18	24.3060	1.21	0.2852	23.704	24.907	22.5	25.8
	Total	54	24.1480	1.2932	0.176	23.795	24.501	22	26
EC (µs/cm)	Kipkerieny	18	1023.8900	79.901	18.833	984.16	1063.62	900	1200
	Chemosit Centre	18	1380.17	238.619	56.243	1261.5	1498.83	1090	1630
	Kabitungu	18	1159.78	168.374	39.686	1076.05	1243.51	900	1450
	Total	54	1187.94	226.635	30.841	1126.08	1249.8	900	1630

TDS (mg/l)	Kipkerieny	18	1244.33	649.649	153.124	921.27	1567.4	517	1920
	Chemosit Centre	18	1760.39	198.968	46.897	1661.44	1859.33	1420	2010
	Kabitungu	18	1375.44	436.782	102.951	1158.24	1592.65	900	1870
	Total	54	1460.06	508.069	69.139	1321.38	1598.73	517	2010
DO (mg/l)	Kipkerieny	18	8.922	0.4953	0.1168	8.676	9.169	8.1	9.7
	Chemosit Centre	18	9.006	0.4051	0.0955	8.804	9.207	8.2	9.9
	Kabitungu	18	9.039	0.5226	0.1232	8.779	9.299	8.1	9.8
	Total	54	8.989	0.4705	0.064	8.86	9.117	8.1	9.9
SO_4^{2-} (mg/l)	Kipkerieny	18	0.070944	0.021251	0.005009	0.060377	0.081512	0.031	0.11
	Chemosit Centre	12	0.069583	0.024322	0.007021	0.05413	0.085037	0.031	0.098
	Kabitungu	18	0.094172	0.046268	0.010906	0.071164	0.117181	0.0116	0.163
	Total	48	0.079315	0.034809	0.005024	0.069207	0.089422	0.0116	0.163
PO_4^{3-} (mg/l)	Kipkerieny	18	0.398583	0.104811	0.024704	0.346462	0.450704	0.1489	0.5328
	Chemosit Centre	18	0.381828	0.109601	0.025833	0.327325	0.436331	0.1828	0.5533

	Kabitungu	18	0.417939	0.111264	0.026225	0.362608	0.473269	0.1597	0.5611
	Total	54	0.39945	0.107561	0.014637	0.370092	0.428808	0.1489	0.5611
NO_3^- (mg/l)	Kipkerieny	18	2.282778	0.518012	0.122097	2.025177	2.540379	1.267	2.932
	Chemosit Centre	18	0.930111	0.243453	0.057382	0.809045	1.051177	0.525	1.231

	Kabitungu	18	1.588889	0.206832	0.048751	1.486034	1.691744	1.18	1.86
	Total	54	1.600593	0.655422	0.089192	1.421697	1.779488	0.525	2.932
Zn (mg/l)	Kipkerieny	18	0.0667	0.06607	0.01557	0.0338	0.0995	0.01	0.23
	Chemosit Centre	18	0.0567	0.03926	0.00925	0.0371	0.0762	0.01	0.14
	Kabitungu	9	0.0933	0.10416	0.03472	0.0133	0.1734	0.01	0.35
	Total	45	0.068	0.06663	0.00993	0.048	0.088	0.01	0.35
Fe (mg/l)	Kipkerieny	18	0.4411	0.11777	0.02776	0.3825	0.4997	0.28	0.62
	Chemosit Centre	18	0.5022	0.08004	0.01887	0.4624	0.542	0.4	0.71
	Kabitungu	18	0.3556	0.06706	0.01581	0.3222	0.3889	0.27	0.5
	Total	54	0.433	0.10785	0.01468	0.4035	0.4624	0.27	0.71
Al (mg/l)	Kipkerieny	18	0.5233	0.28479	0.06713	0.3817	0.665	0.2	1.04
	Chemosit	18	0.5017	0.12529	0.02953	0.4394	0.564	0.33	0.81

	Centre								
	Kabitungu	18	0.3978	0.08033	0.01893	0.3578	0.4377	0.25	0.56
	Total	54	0.4743	0.19021	0.02588	0.4223	0.5262	0.2	1.04
Cu (mg/l)	Kipkerieny	18	0.0206	0.01056	0.00249	0.0153	0.0258	0.01	0.04
	Chemosit Centre	18	0.0233	0.00907	0.00214	0.0188	0.0278	0.01	0.04
	Kabitungu	18	0.0222	0.01166	0.00275	0.0164	0.028	0.01	0.05
	Total	54	0.022	0.01035	0.00141	0.0192	0.0249	0.01	0.05
ANOVA									
		Sum of Squares	Df	Mean Square	F	Sig.			
pH	Between Groups	0.404	2	0.202	1.572	0.218			
	Within Groups	6.559	51	0.129					
	Total	6.963	53						
Temperature (°C)	Between Groups	0.816	2	0.408	0.237	0.79			
	Within Groups	87.819	51	1.722					
	Total	88.635	53						
EC (µs/cm)	Between Groups	1163825	2	581912.7	19.043	0			
	Within Groups	1558443	51	30557.71					

	Total	2722269	53						
TDS (mg/l)	Between Groups	2590114	2	1295057	5.955	0.005			
	Within Groups	11090977	51	217470.1					
	Total	13681091	53						
DO (mg/l)	Between Groups	0.13	2	0.065	0.286	0.753			
	Within Groups	11.603	51	0.228					
	Total	11.733	53						
SO_4^{2}- (mg/l)	Between Groups	0.006	2	0.003	2.834	0.069			
	Within Groups	0.051	45	0.001					
	Total	0.057	47						
PO_4^{3-} (mg/l)	Between Groups	0.012	2	0.006	0.498	0.61			
	Within Groups	0.601	51	0.012					
	Total	0.613	53						
NO_3^- (mg/l)	Between Groups	16.471	2	8.236	66.705	0			
	Within Groups	6.297	51	0.123					
	Total	22.768	53						
Zn (mg/l)	Between Groups	0.008	2	0.004	0.911	0.41			
	Within Groups	0.187	42	0.004					
	Total	0.195	44						

Fe (mg/l)	Between Groups	0.195	2	0.098	11.831	0			
	Within Groups	0.421	51	0.008					
	Total	0.617	53						
Al (mg/l)	Between Groups	0.162	2	0.081	2.356	0.105			
	Within Groups	1.755	51	0.034					
	Total	1.918	53						
Cu (mg/l)	Between Groups	0	2	0	0.32	0.728			
	Within Groups	0.006	51	0					
	Total	0.006	53						

III. Statistical Variations

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	0.404	2	0.202	1.572	0.218
	Within Groups	6.559	51	0.129		
	Total	6.963	53			
Temperature (°C)	Between Groups	0.816	2	0.408	0.237	0.79
	Within Groups	87.819	51	1.722		
	Total	88.635	53			
EC (µs/cm)	Between Groups	1163825	2	581912.7	19.043	0
	Within Groups	1558443	51	30557.71		
	Total	2722269	53			
TDS (mg/l)	Between Groups	2590114	2	1295057	5.955	0.005
	Within Groups	11090977	51	217470.1		
	Total	13681091	53			
DO (mg/l)	Between Groups	0.13	2	0.065	0.286	0.753
	Within Groups	11.603	51	0.228		
	Total	11.733	53			
SO_4^{2-} (mg/l)	Between Groups	0.006	2	0.003	2.834	0.069
	Within Groups	0.051	45	0.001		
	Total	0.057	47			
$PO4^{3-}$ (mg/l)	Between Groups	0.012	2	0.006	0.498	0.61
	Within Groups	0.601	51	0.012		
	Total	0.613	53			
NO_3^-(mg/l)	Between Groups	16.471	2	8.236	66.705	0
	Within Groups	6.297	51	0.123		
	Total	22.768	53			
Zn (mg/l)	Between Groups	0.008	2	0.004	0.911	0.41
	Within Groups	0.187	42	0.004		
	Total	0.195	44			
Fe (mg/l)	Between Groups	0.195	2	0.098	11.831	0
	Within Groups	0.421	51	0.008		
	Total	0.617	53			

Al (mg/l)	Between Groups	0.162	2	0.081	2.356	0.105
	Within Groups	1.755	51	0.034		
	Total	1.918	53			
Cu (mg/l)	Between Groups	0	2	0	0.32	0.728
	Within Groups	0.006	51	0		
	Total	0.006	53			

Homogeneous Subsets						
pH						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1				
Kabitungu	18	6.915				
Chemosit Centre	18	6.9494				
Kipkerieny	18	7.1133				
Sig.		0.231				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
Temperature (°C)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1				
Chemosit Centre	18	24.006				
Kipkerieny	18	24.133				

Kabitungu	18	24.306				
Sig.		0.773				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
EC (µs/cm)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1	2			
Kipkerieny	18	1023.89				
Kabitungu	18	1159.78				
Chemosit Centre	18		1380.17			
Sig.		0.06	1			
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
TDS (mg/l)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1	2			

Kipkerieny	18	1244.33				
Kabitungu	18	1375.44				
Chemosit Centre	18		1760.39			
Sig.		0.678	1			
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
DO (mg/l)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1				
Kipkerieny	18	8.922				
Chemosit Centre	18	9.006				
Kabitungu	18	9.039				
Sig.		0.745				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
SO_4^{2-} (mg/l)						
Tukey HSD a,b						

Sampling station	N	Subset for alpha = 0.05				
		1				
Chemosit Centre	12	0.069583				
Kipkerieny	18	0.070944				
Kabitungu	18	0.094172				
Sig.		0.115				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 15.429.						
bthe group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.						
PO_4^{3-}(mg/l)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1				
Chemosit Centre	18	0.381828				
Kipkerieny	18	0.398583				
Kabitungu	18	0.417939				
Sig.		0.582				
Means for groups in homogeneous subsets are displayed.						

a Uses Harmonic Mean Sample Size = 18.000.						

NO_3^- (mg/l)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1	2	3		
Chemosit Centre	18	0.930111				
Kabitungu	18		1.588889			
Kipkerieny	18			2.282778		
Sig.		1	1	1		
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
Zn (mg/l)						
Tukey HSD a,b						
Sampling station	N	Subset for alpha = 0.05				
		1				
Chemosit Centre	18	0.0567				
Kipkerieny	18	0.0667				
Kabitungu	9	0.0933				

Sig.		0.337				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 13.500.						
But the group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.						
Fe (mg/l)						

Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1	2			
Kabitungu	18	0.3556				
Kipkerieny	18		0.4411			
Chemosit Centre	18		0.5022			
Sig.		1	0.118			
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						

Al (mg/l)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1				
Kabitungu	18	0.3978				
Chemosit Centre	18	0.5017				
Kipkerieny	18	0.5233				
Sig.		0.115				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						
Cu (mg/l)						
Tukey HSD a						
Sampling station	N	Subset for alpha = 0.05				
		1				
Kipkerieny	18	0.0206				
Kabitungu	18	0.0222				
Chemosit Centre	18	0.0233				
Sig.		0.708				
Means for groups in homogeneous subsets are displayed.						
a Uses Harmonic Mean Sample Size = 18.000.						

IV Temporal variations

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
pH	August	9	6.53	0.31828	0.106	6.2898	6.7791	6.1	7
	September	9	6.93	0.20501	0.068	6.7769	7.092	6.5	7.25
	October	9	6.95	0.26154	0.087	6.7445	7.1466	6.55	7.5
	November	9	7.29	0.31988	0.107	7.0441	7.5359	6.9	7.8
	December	9	7.15	0.1719	0.057	7.0212	7.2855	6.86	7.42
	January	9	7.10	0.37861	0.126	6.8068	7.3888	6.51	7.85
	Total	54	6.99	0.36247	0.049	6.8937	7.0915	6.1	7.85
Temperature (°C)	August	9	25.59	0.3371	0.112	25.33	25.848	24.8	25.9
	September	9	25.41	0.491	0.164	25.034	25.789	24.5	26
	October	9	24.86	0.4773	0.159	24.489	25.222	24.2	25.7
	November	9	23.37	0.8078	0.269	22.746	23.988	22	24.6
	December	9	23.17	0.4848	0.162	22.794	23.539	22.3	23.9
	January	9	22.50	0.3	0.100	22.269	22.731	22	22.9
	Total	54	24.15	1.2932	0.176	23.795	24.501	22	26
EC (µs/cm)	August	9	1282.33	280.489	93.496	1066.73	1497.94	900	1629
	September	9	1280.78	258.555	86.185	1082.03	1479.52	981	1620
	October	9	1370.22	228.299	76.100	1194.74	1545.71	1050	1630
	November	9	1015.44	82.169	27.390	952.28	1078.61	900	1130
	December	9	1053.33	98.601	32.867	977.54	1129.13	950	1210
	January	9	1125.56	104.057	34.686	1045.57	1205.54	970	1260
	Total	54	1187.94	226.635	30.841	1126.08	1249.8	900	1630

TDS (mg/l)	August	9	1032.89	472.199	157.400	669.92	1395.85	517	1664
	September	9	1057.56	393.179	131.060	755.33	1359.78	542	1618
	October	9	1053.00	409.51	136.503	738.22	1367.78	587	1600
	November	9	1879.22	68.978	22.993	1826.2	1932.24	1800	2000
	December	9	1874.89	76.232	25.411	1816.29	1933.49	1780	2010
	January	9	1862.78	81.513	27.171	1800.12	1925.43	1710	1930
	Total	54	1460.06	508.069	69.139	1321.38	1598.73	517	2010
DO (mg/l)	August	9	9.06	0.2404	0.080	8.871	9.24	8.5	9.3
	September	9	9.18	0.5403	0.180	8.762	9.593	8.4	9.9
	October	9	8.67	0.5701	0.190	8.228	9.105	8.1	9.6
	November	9	8.91	0.348	0.116	8.644	9.179	8.5	9.6
	December	9	8.78	0.4381	0.146	8.441	9.115	8.1	9.5
	January	9	9.34	0.3432	0.114	9.081	9.608	8.9	9.8
	Total	54	8.99	0.4705	0.064	8.86	9.117	8.1	9.9
SO_4^{2-} (mg/l)	August	7	0.09	0.028463	0.011	0.062533	0.115181	0.052	0.137
	September	8	0.08	0.053074	0.019	0.039629	0.128371	0.031	0.163
	October	8	0.08	0.024139	0.009	0.056944	0.097306	0.045	0.125
	November	9	0.09	0.021477	0.007	0.075935	0.108953	0.057	0.118
	December	7	0.09	0.03153	0.012	0.058697	0.117018	0.031	0.119
	January	9	0.05	0.031492	0.010	0.025693	0.074107	0.0116	0.094
	Total	48	0.08	0.034809	0.005	0.069207	0.089422	0.0116	0.163
PO_4^{3-} (mg/l)	August	9	0.36	0.152829	0.051	0.245726	0.480674	0.1489	0.5469

	September	9	0.39	0.102879	0.034	0.310398	0.468557	0.1958	0.5328
	October	9	0.45	0.06365	0.021	0.402308	0.500159	0.3461	0.5349
	November	9	0.38	0.151357	0.050	0.264546	0.497232	0.1597	0.5533
	December	9	0.44	0.083361	0.028	0.377412	0.505566	0.3145	0.5611
	January	9	0.37	0.029416	0.010	0.3478	0.393022	0.3214	0.4091
	Total	54	0.40	0.107561	0.015	0.370092	0.428808	0.1489	0.5611
NO_3(mg/l)	August	9	1.83	0.679789	0.227	1.312024	2.357087	1.108	2.871
	September	9	1.85	0.622705	0.208	1.371236	2.328542	1.135	2.655
	October	9	1.86	0.73467	0.245	1.297171	2.426606	1.114	2.932
	November	9	1.39	0.674464	0.225	0.874561	1.911439	0.525	2.335
	December	9	1.45	0.620086	0.207	0.976582	1.929863	0.65	2.26
	January	9	1.21	0.406141	0.135	0.898812	1.523188	0.695	1.821
	Total	54	1.60	0.655422	0.089	1.421697	1.779488	0.525	2.932
Zn (mg/l)	August	9	0.10	0.10285	0.034	0.0165	0.1746	0.03	0.35
	September	9	0.07	0.04272	0.014	0.0338	0.0995	0.02	0.14
	October	9	0.05	0.02877	0.010	0.0234	0.0677	0.01	0.09
	November	6	0.08	0.07834	0.032	-0.0005	0.1639	0.01	0.22
	December	6	0.09	0.07834	0.032	0.0095	0.1739	0.02	0.23
	January	6	0.03	0.01517	0.006	0.0091	0.0409	0.01	0.05
	Total	45	0.07	0.06663	0.010	0.048	0.088	0.01	0.35
Fe (mg/l)	August	9	0.46	0.12145	0.040	0.3633	0.55	0.3	0.71
	September	9	0.40	0.10223	0.034	0.3214	0.4786	0.29	0.57
	October	9	0.44	0.1138	0.038	0.3525	0.5275	0.28	0.65
	November	9	0.41	0.10344	0.034	0.3305	0.4895	0.29	0.59
	December	9	0.43	0.10404	0.035	0.35	0.51	0.27	0.55

	January	9	0.46	0.11826	0.039	0.3702	0.552	0.28	0.62
	Total	54	0.43	0.10785	0.015	0.4035	0.4624	0.27	0.71
Al (mg/l)	August	9	0.37	0.17797	0.059	0.2299	0.5035	0.23	0.81
	September	9	0.36	0.09043	0.030	0.2949	0.434	0.25	0.51
	October	9	0.33	0.0669	0.022	0.2819	0.3848	0.2	0.41
	November	9	0.55	0.21578	0.072	0.3852	0.717	0.33	1.04
	December	9	0.56	0.14697	0.049	0.4504	0.6763	0.4	0.82
	January	9	0.67	0.14509	0.048	0.5551	0.7782	0.52	0.9
	Total	54	0.47	0.19021	0.026	0.4223	0.5262	0.2	1.04
Cu (mg/l)	August	9	0.019	0.01054	0.004	0.0108	0.027	0.01	0.04
	September	9	0.020	0.00866	0.003	0.0133	0.0267	0.01	0.03
	October	9	0.022	0.01302	0.004	0.0122	0.0322	0.01	0.04
	November	9	0.022	0.00667	0.002	0.0171	0.0273	0.01	0.03
	December	9	0.024	0.01236	0.004	0.0149	0.0339	0.01	0.05
	January	9	0.024	0.0113	0.004	0.0158	0.0331	0.01	0.04
	Total	54	0.02	0.01035	0.001	0.0192	0.0249	0.01	0.05

ANOVA		Sum of Squares	df	Mean Square	F	Sig.			
pH	Between Groups	3.068	5	0.614	7.56	0			
	Within Groups	3.896	48	0.081					
	Total	6.963	53						
Temperature (°C)	Between Groups	76.155	5	15.231	58.581	0			
	Within Groups	12.48	48	0.26					
	Total	88.635	53						
EC (µs/cm)	Between Groups	922691.3	5	184538.3	4.922	0.001			
	Within Groups	1799578	48	37491.2					
	Total	2722269	53						
TDS (mg/l)	Between Groups	9181300	5	1836260	19.588	0			
	Within Groups	4499791	48	93745.65					
	Total	13681091	53						
DO (mg/l)	Between Groups	2.889	5	0.578	3.136	0.016			
	Within Groups	8.844	48	0.184					
	Total	11.733	53						
SO_4^{2-} (mg/l)	Between Groups	0.011	5	0.002	1.944	0.107			
	Within Groups	0.046	42	0.001					
	Total	0.057	47						
PO_4^{3-} (mg/l)	Between Groups	0.063	5	0.013	1.108	0.369			

	Within Groups	0.55	48	0.011					
	Total	0.613	53						
NO_3^- (mg/l)	Between Groups	3.616	5	0.723	1.812	0.128			
	Within Groups	19.152	48	0.399					
	Total	22.768	53						
Zn (mg/l)	Between Groups	0.027	5	0.005	1.249	0.305			
	Within Groups	0.168	39	0.004					
	Total	0.195	44						
Fe (mg/l)	Between Groups	0.027	5	0.005	0.444	0.816			
	Within Groups	0.589	48	0.012					
	Total	0.617	53						
Al (mg/l)	Between Groups	0.849	5	0.17	7.631	0			
	Within Groups	1.068	48	0.022					
	Total	1.918	53						
Cu (mg/l)	Between Groups	0	5	0	0.408	0.841			
	Within Groups	0.005	48	0					
	Total	0.006	53						
		N	**Mean**	Std. Deviation	**Std. Error**	95% Confidence Interval for Mean		**Minimum**	**Maximum**
						Lower Bound	Upper Bound		
pH	August	9	6.53	0.31828	0.106	6.2898	6.7791	6.1	7
	September	9	6.93	0.20501	0.068	6.7769	7.092	6.5	7.25

	October	9	6.95	0.26154	0.087	6.7445	7.1466	6.55	7.5
	November	9	7.29	0.31988	0.107	7.0441	7.5359	6.9	7.8
	December	9	7.15	0.1719	0.057	7.0212	7.2855	6.86	7.42
	January	9	7.10	0.37861	0.126	6.8068	7.3888	6.51	7.85
	Total	54	6.99	0.36247	0.049	6.8937	7.0915	6.1	7.85
Temperature (°C)	August	9	25.59	0.3371	0.112	25.33	25.848	24.8	25.9
	September	9	25.41	0.491	0.164	25.034	25.789	24.5	26
	October	9	24.86	0.4773	0.159	24.489	25.222	24.2	25.7
	November	9	23.37	0.8078	0.269	22.746	23.988	22	24.6
	December	9	23.17	0.4848	0.162	22.794	23.539	22.3	23.9
	January	9	22.50	0.3	0.100	22.269	22.731	22	22.9
	Total	54	24.15	1.2932	0.176	23.795	24.501	22	26
EC (µs/cm)	August	9	1282.33	280.489	93.496	1066.73	1497.94	900	1629
	September	9	1280.78	258.555	86.185	1082.03	1479.52	981	1620
	October	9	1370.22	228.299	76.100	1194.74	1545.71	1050	1630
	November	9	1015.44	82.169	27.390	952.28	1078.61	900	1130
	December	9	1053.33	98.601	32.867	977.54	1129.13	950	1210
	January	9	1125.56	104.057	34.686	1045.57	1205.54	970	1260
	Total	54	1187.94	226.635	30.841	1126.08	1249.8	900	1630
TDS (mg/l)	August	9	1032.89	472.199	157.400	669.92	1395.85	517	1664
	September	9	1057.56	393.179	131.060	755.33	1359.78	542	1618
	October	9	1053.00	409.51	136.503	738.22	1367.78	587	1600
	November	9	1879.22	68.978	22.993	1826.2	1932.24	1800	2000
	December	9	1874.89	76.232	25.411	1816.29	1933.49	1780	2010
	January	9	1862.78	81.513	27.171	1800.12	1925.43	1710	1930

	Total	54	1460.06	508.069	69.139	1321.38	1598.73	517	2010
DO (mg/l)	August	9	9.06	0.2404	0.080	8.871	9.24	8.5	9.3
	September	9	9.18	0.5403	0.180	8.762	9.593	8.4	9.9
	October	9	8.67	0.5701	0.190	8.228	9.105	8.1	9.6
	November	9	8.91	0.348	0.116	8.644	9.179	8.5	9.6
	December	9	8.78	0.4381	0.146	8.441	9.115	8.1	9.5
	January	9	9.34	0.3432	0.114	9.081	9.608	8.9	9.8
	Total	54	8.99	0.4705	0.064	8.86	9.117	8.1	9.9
SO_4^{2-} (mg/l)	August	7	0.09	0.028463	0.011	0.062533	0.115181	0.052	0.137
	September	8	0.08	0.053074	0.019	0.039629	0.128371	0.031	0.163
	October	8	0.08	0.024139	0.009	0.056944	0.097306	0.045	0.125
	November	9	0.09	0.021477	0.007	0.075935	0.108953	0.057	0.118
	December	7	0.09	0.03153	0.012	0.058697	0.117018	0.031	0.119
	January	9	0.05	0.031492	0.010	0.025693	0.074107	0.0116	0.094
	Total	48	0.08	0.034809	0.005	0.069207	0.089422	0.0116	0.163
PO_4^{3-} (mg/l)	August	9	0.36	0.152829	0.051	0.245726	0.480674	0.1489	0.5469
	September	9	0.39	0.102879	0.034	0.310398	0.468557	0.1958	0.5328
	October	9	0.45	0.06365	0.021	0.402308	0.500159	0.3461	0.5349
	November	9	0.38	0.151357	0.050	0.264546	0.497232	0.1597	0.5533
	December	9	0.44	0.083361	0.028	0.377412	0.505566	0.3145	0.5611
	January	9	0.37	0.029416	0.010	0.3478	0.393022	0.3214	0.4091
	Total	54	0.40	0.107561	0.015	0.370092	0.428808	0.1489	0.5611

NO_3^- (mg/l)	August	9	1.83	0.679789	0.227	1.312024	2.357087	1.108	2.871
	September	9	1.85	0.622705	0.208	1.371236	2.328542	1.135	2.655
	October	9	1.86	0.73467	0.245	1.297171	2.426606	1.114	2.932
	November	9	1.39	0.674464	0.225	0.874561	1.911439	0.525	2.335
	December	9	1.45	0.620086	0.207	0.976582	1.929863	0.65	2.26
	January	9	1.21	0.406141	0.135	0.898812	1.523188	0.695	1.821
	Total	54	1.60	0.655422	0.089	1.421697	1.779488	0.525	2.932
Zn (mg/l)	August	9	0.10	0.10285	0.034	0.0165	0.1746	0.03	0.35
	September	9	0.07	0.04272	0.014	0.0338	0.0995	0.02	0.14
	October	9	0.05	0.02877	0.010	0.0234	0.0677	0.01	0.09
	November	6	0.08	0.07834	0.032	-0.0005	0.1639	0.01	0.22
	December	6	0.09	0.07834	0.032	0.0095	0.1739	0.02	0.23
	January	6	0.03	0.01517	0.006	0.0091	0.0409	0.01	0.05
	Total	45	0.07	0.06663	0.010	0.048	0.088	0.01	0.35
Fe (mg/l)	August	9	0.46	0.12145	0.040	0.3633	0.55	0.3	0.71
	September	9	0.40	0.10223	0.034	0.3214	0.4786	0.29	0.57
	October	9	0.44	0.1138	0.038	0.3525	0.5275	0.28	0.65
	November	9	0.41	0.10344	0.034	0.3305	0.4895	0.29	0.59
	December	9	0.43	0.10404	0.035	0.35	0.51	0.27	0.55
	January	9	0.46	0.11826	0.039	0.3702	0.552	0.28	0.62
	Total	54	0.43	0.10785	0.015	0.4035	0.4624	0.27	0.71
Al (mg/l)	August	9	0.37	0.17797	0.059	0.2299	0.5035	0.23	0.81
	September	9	0.36	0.09043	0.030	0.2949	0.434	0.25	0.51
	October	9	0.33	0.0669	0.022	0.2819	0.3848	0.2	0.41
	November	9	0.55	0.21578	0.072	0.3852	0.717	0.33	1.04
	December	9	0.56	0.14697	0.049	0.4504	0.6763	0.4	0.82
	January	9	0.67	0.14509	0.048	0.5551	0.7782	0.52	0.9
	Total	54	0.47	0.19021	0.026	0.4223	0.5262	0.2	1.04

Cu (mg/l)	August	9	0.019	0.01054	0.004	0.0108	0.027	0.01	0.04
	September	9	0.020	0.00866	0.003	0.0133	0.0267	0.01	0.03
	October	9	0.022	0.01302	0.004	0.0122	0.0322	0.01	0.04
	November	9	0.022	0.00667	0.002	0.0171	0.0273	0.01	0.03
	December	9	0.024	0.01236	0.004	0.0149	0.0339	0.01	0.05
	January	9	0.024	0.0113	0.004	0.0158	0.0331	0.01	0.04
	Total	54	0.02	0.01035	0.001	0.0192	0.0249	0.01	0.05
ANOVA									
		Sum of Squares	df	Mean Square	F	Sig.			
pH	Between Groups	3.068	5	0.614	7.56	0			
	Within Groups	3.896	48	0.081					
	Total	6.963	53						
Temperature (°C)	Between Groups	76.155	5	15.231	58.581	0			
	Within Groups	12.48	48	0.26					
	Total	88.635	53						
EC (µs/cm)	Between Groups	922691.3	5	184538.3	4.922	0.001			
	Within Groups	1799578	48	37491.2					
	Total	2722269	53						
TDS (mg/l)	Between Groups	9181300	5	1836260	19.588	0			
	Within Groups	4499791	48	93745.65					
	Total	13681091	53						
DO (mg/l)	Between Groups	2.889	5	0.578	3.136	0.016			
	Within Groups	8.844	48	0.184					
	Total	11.733	53						

SO_4^{2-} (mg/l)	Between Groups	0.011	5	0.002	1.944	0.107			
	Within Groups	0.046	42	0.001					
	Total	0.057	47						
PO_4^{3-} (mg/l)	Between Groups	0.063	5	0.013	1.108	0.369			
	Within Groups	0.55	48	0.011					
	Total	0.613	53						
NO_3^- (mg/l)	Between Groups	3.616	5	0.723	1.812	0.128			
	Within Groups	19.152	48	0.399					
	Total	22.768	53						
Zn (mg/l)	Between Groups	0.027	5	0.005	1.249	0.305			
	Within Groups	0.168	39	0.004					
	Total	0.195	44						
Fe (mg/l)	Between Groups	0.027	5	0.005	0.444	0.816			
	Within Groups	0.589	48	0.012					
	Total	0.617	53						
Al (mg/l)	Between Groups	0.849	5	0.17	7.631	0			
	Within Groups	1.068	48	0.022					
	Total	1.918	53						
Cu (mg/l)	Between Groups	0	5	0	0.408	0.841			
	Within Groups	0.005	48	0					
	Total	0.006	53						

Homogeneous Subsets					
pH					
Tukey HSD a					

Months	N	Subset for alpha = 0.05			
		1	2		
August	9	6.5344			
September	9		6.9344		
October	9		6.9456		
January	9		7.0978		
December	9		7.1533		
November	9		7.29		
Sig.		1	0.105		
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
Temperature (°C)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1	2	3	4
January	9	22.5			
December	9	23.167	23.167		
November	9		23.367		
October	9			24.856	
September	9			25.411	25.411
August	9				25.589
Sig.		0.079	0.96	0.21	0.976
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
EC (µs/cm)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1	2		
November	9	1015.44			

December	9	1053.33			
January	9	1125.56	1125.56		
September	9	1280.78	1280.78		
August	9	1282.33	1282.33		
October	9		1370.22		
Sig.		0.056	0.098		
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
TDS (mg/l)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1	2		
August	9	1032.89			
October	9	1053			
September	9	1057.56			
January	9		1862.78		
December	9		1874.89		
November	9		1879.22		
Sig.		1	1		
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
DO (mg/l)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1	2		
October	9	8.667			
December	9	8.778	8.778		
November	9	8.911	8.911		
August	9	9.056	9.056		
September	9	9.178	9.178		

January	9		9.344		
Sig.		0.137	0.075		
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					

SO_4^{2-} (mg/l)					
Tukey HSD a,b					
Months	N	Subset for alpha = 0.05			
		1			
January	9	0.0499			
October	8	0.077125			
September	8	0.084			
December	7	0.087857			
August	7	0.088857			
November	9	0.092444			
Sig.		0.133			
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 7.916.					
bthe group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.					
PO_4^{3-}(mg/l)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1			
August	9	0.3632			
January	9	0.370411			
November	9	0.380889			
September	9	0.389478			
December	9	0.441489			
October	9	0.451233			

Sig.		0.51			
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
NO_3^- (mg/l)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1			
January	9	1.211			
November	9	1.393			
December	9	1.453222			
August	9	1.834556			
September	9	1.849889			
October	9	1.861889			
Sig.		0.263			
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
Zn (mg/l)					
Tukey HSD a,b					
Months	N	Subset for alpha = 0.05			
		1			
January	6	0.025			
October	9	0.0456			
September	9	0.0667			
November	6	0.0817			
December	6	0.0917			
August	9	0.0956			
Sig.		0.341			
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 7.200.					

bthe group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.					
Fe (mg/l)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1			
September	9	0.4			
November	9	0.41			
December	9	0.43			
October	9	0.44			
August	9	0.4567			
January	9	0.4611			
Sig.		0.849			
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
Al (mg/l)					
Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1	2	3	
October	9	0.3333			
September	9	0.3644	0.3644		
August	9	0.3667	0.3667		
November	9		0.5511	0.5511	
December	9		0.5633	0.5633	
January	9			0.6667	
Sig.		0.997	0.07	0.575	
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					
Cu (mg/l)					

Tukey HSD a					
Months	N	Subset for alpha = 0.05			
		1			
August	9	0.0189			
September	9	0.02			
November	9	0.0222			
October	9	0.0222			
December	9	0.0244			
January	9	0.0244			
Sig.		0.876			
Means for groups in homogeneous subsets are displayed.					
a Uses Harmonic Mean Sample Size = 9.000.					

V. Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2 tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
pH	Equal variances assumed	0.094	0.761	-4.424	52	0	-0.37556	0.08489	-0.54591	-0.20521
	Equal variances not assumed			-4.424	52	0	-0.37556	0.08489	-0.54592	-0.20519
Temperature (°C)	Equal variances assumed	0.586	0.448	13.888	52	0	2.2741	0.1637	1.9455	2.6026
	Equal variances not assumed			13.888	49	0	2.2741	0.1637	1.9451	2.603
EC (µs/cm)	Equal variances assumed	28.954	0	4.731	52	0	246.333	52.067	141.854	350.813
	Equal variances not assumed			4.731	35	0	246.333	52.067	140.581	352.086

TDS (mg/l)	Equal variances assumed	55.486	0	-10.293	52	0	-824.481	80.101	-985.217	-663.746
	Equal variances not assumed			-10.293	28	0	-824.481	80.101	-988.654	-660.309
DO (mg/l)	Equal variances assumed	0.795	0.377	-0.344	52	0.732	-0.0444	0.1291	-0.3036	0.2147
	Equal variances not assumed			-0.344	51	0.732	-0.0444	0.1291	-0.3037	0.2148
SO_4^{2-} (mg/l)	Equal variances assumed	0.014	0.906	0.716	46	0.477	0.007243	0.01011	-0.01311	0.027593
	Equal variances not assumed			0.714	45	0.479	0.007243	0.010144	-0.01319	0.027677
PO_4^{3-} (mg/l)	Equal variances assumed	0.587	0.447	0.125	52	0.901	0.003707	0.02955	-0.05559	0.063004
	Equal variances not assumed			0.125	51	0.901	0.003707	0.02955	-0.05561	0.063021
NO_3^- (mg/l)	Equal variances assumed	1.284	0.262	2.983	52	0.004	0.49637	0.166416	0.162432	0.830309
	Equal variances not assumed			2.983	51	0.004	0.49637	0.166416	0.162267	0.830474

Zn (mg/l)	Equal variances assumed	0.313	0.579	0.154	43	0.879	0.00315	0.0205	-0.0382	0.0445
	Equal variances not assumed			0.153	36	0.879	0.00315	0.02054	-0.0385	0.04479
Fe (mg/l)	Equal variances assumed	0	0.997	-0.05	52	0.96	-0.00148	0.02963	-0.06095	0.05798
	Equal variances not assumed			-0.05	52	0.96	-0.00148	0.02963	-0.06095	0.05799
Al (mg/l)	Equal variances assumed	4.988	0.03	-5.91	52	0	-0.23889	0.04042	-0.32	-0.15777
	Equal variances not assumed.			-5.91	46	0	-0.23889	0.04042	-0.32027	-0.15751
Cu (mg/l)	Equal variances assumed	0.121	0.729	-1.188	52	0.24	-0.00333	0.00281	-0.00896	0.0023
	Equal variances not assumed			-1.188	52	0.24	-0.00333	0.00281	-0.00896	0.0023

VI. Pearson Correlation analysis

Correlations													
		pH	Temperature (°C)	EC (μs/cm)	TDS (mg/l)	DO (mg/l)	$SO_4{}^{2-}$ (mg/l)	$PO_4{}^{3-}$ (mg/l)	$NO_3{}^{-}$ (mg/l)	Zn (mg/l)	Fe (mg/l)	Al (mg/l)	Cu (mg/l)
pH	Pearson Correlation	1	-.470**	-.521**	0.254	-0.182	0.042	0.01	-0.005	-0.222	-0.256	0.196	0.011
l	Sig. (2tailed)		0	0	0.063	0.189	0.779	0.943	0.97	0.144	0.062	0.156	0.936
	N	54	54	54	54	54	48	54	54	45	54	54	54
Temperature (°C)	Pearson Correlation	.470**	1	.449**	-.712**	-0.075	0.22	-0.052	.370**	0.161	-0.047	.583**	-0.139
	Sig. (2tailed)	0		0.001	0	0.59	0.132	0.708	0.006	0.292	0.734	0	0.318
	N	54	54	54	54	54	48	54	54	45	54	54	54
EC (μs/cm)	Pearson Correlation	.521**	.449**	1	-0.017	-0.033	0.062	0.023	-.413**	0.05	.473**	-0.131	0.102
	Sig. (2tailed)	0	0.001		0.901	0.814	0.676	0.869	0.002	0.742	0	0.347	0.463
	N	54	54	54	54	54	48	54	54	45	54	54	54
TDS (mg/l)	Pearson Correlation	0.254	-.712**	-0.017	1	0.041	-0.022	-0.064	-.715**	0.092	.357**	.679**	0.257
	Sig. (2tailed)	0.063	0	0.901		0.766	0.883	0.648	0	0.548	0.008	0	0.061

	N	54	54	54	54	54	48	54	54	45	54	54	54
DO (mg/l)	Pearson Correlation	-0.182	-0.075	-0.033	0.041	1	-0.2	0.016	-0.123	-0.116	0.049	-0.011	0.016
	Sig. (2tailed)	0.189	0.59	0.814	0.766		0.173	0.91	0.374	0.448	0.727	0.937	0.907
	N	54	54	54	54	54	48	54	54	45	54	54	54
SO_4^{2}- (mg/l)	Pearson Correlation	0.042	0.22	0.062	-0.022	-0.2	1	-0.067	-0.086	0.055	-0.166	-0.157	-0.009
	Sig. (2tailed)	0.779	0.132	0.676	0.883	0.173		0.65	0.561	0.741	0.26	0.286	0.952
	N	48	48	48	48	48	48	48	48	39	48	48	48
PO_4^{3-} (mg/l)	Pearson Correlation	0.01	-0.052	0.023	-0.064	0.016	-0.067	1	0.089	0.079	0.047	-0.07	0.171
	Sig. (2tailed)	0.943	0.708	0.869	0.648	0.91	0.65		0.52	0.608	0.737	0.613	0.218
	N	54	54	54	54	54	48	54	54	45	54	54	54
NO_3^- (mg/l)	Pearson Correlation	-0.005	.370**	-.413**	-.715**	-0.123	-0.086	0.089	1	0.101	-.342*	-.317*	-0.205
	Sig. (2tailed)	0.97	0.006	0.002	0	0.374	0.561	0.52		0.51	0.011	0.02	0.137
	N	54	54	54	54	54	48	54	54	45	54	54	54
Zn (mg/l)	Pearson	0.	0.161	0.05	0.092	-0.116	0.055	0.079	0.101	1	.302*	0.251	0.139
	Correlation	222											
	Sig. (2tailed)	0.144	0.292	0.742	0.548	0.448	0.741	0.608	0.51		0.044	0.097	0.363

	N	45	45	45	45	45	39	45	45	45	45	45	45
Fe (mg/l)	Pearson Correlation	-0.256	-0.047	.473**	.357**	0.049	-0.166	0.047	-.342*	.302*	1	.579**	0.108
	Sig. (2tailed)	0.062	0.734	0	0.008	0.727	0.26	0.737	0.011	0.044		0	0.438
	N	54	54	54	54	54	48	54	54	45	54	54	54
Al (mg/l)	Pearson Correlation	0.196	-.583**	-0.131	.679**	-0.011	-0.157	-0.07	-.317*	0.251	.579**	1	0.207
	Sig. (2tailed)	0.156	0	0.347	0	0.937	0.286	0.613	0.02	0.097	0		0.132
	N	54	54	54	54	54	48	54	54	45	54	54	54
Cu (mg/l)	Pearson Correlation	0.011	-0.139	0.102	0.257	0.016	-0.009	0.171	-0.205	0.139	0.108	0.207	1
	Sig. (2tailed)	0.936	0.318	0.463	0.061	0.907	0.952	0.218	0.137	0.363	0.438	0.132	
	N	54	54	54	54	54	48	54	54	45	54	54	54

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

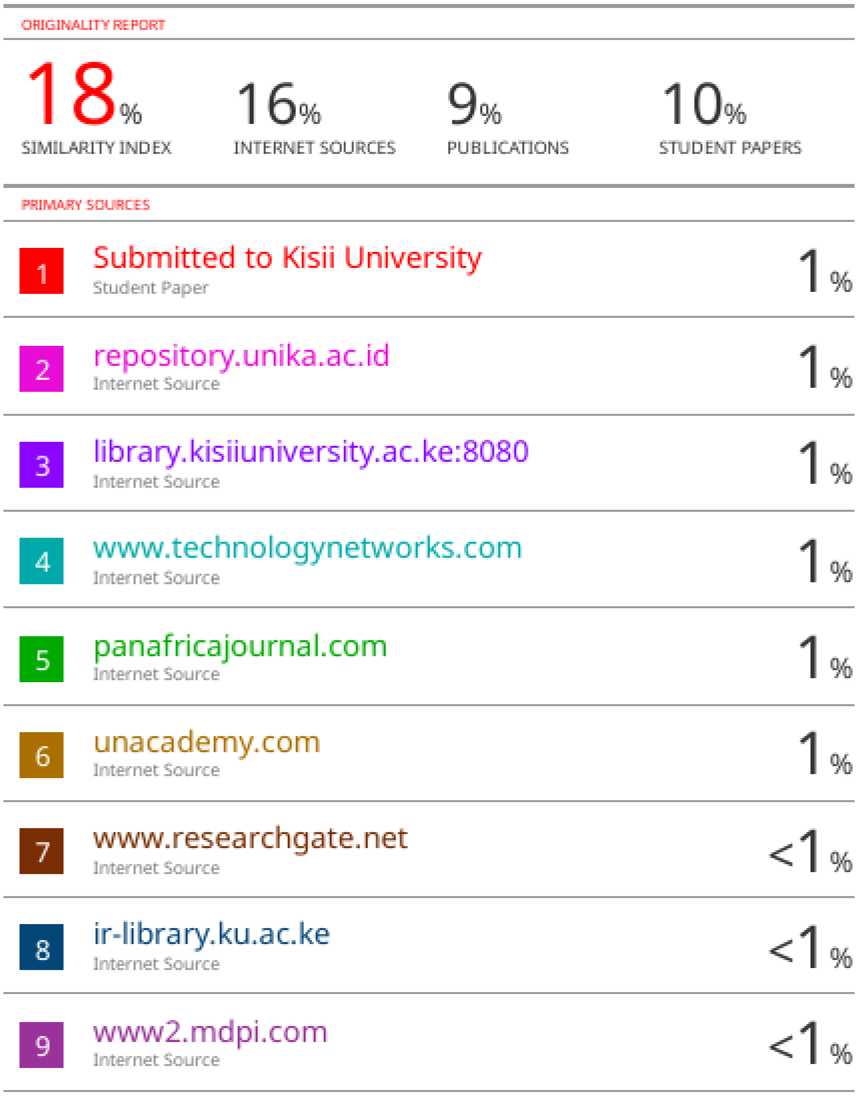
* Correlation is significant at the 0.05 level (2-tailed).

VII. Water sample collections in Kipkerieny, Chemosit Centre and Kabitungu

VIII. Water sample testing in the laboratory

IX. Plagiarism Report

ASSESSMENT OF SELECTED PHYSICO-CHEMICAL PARAMETERS, ANIONS, AND HEAVY METALS IN RIVER CHEMOSIT, KERICHO COUNTY, KENYA.



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