UNIVERSITY OF NAIROBI

MOJOR INORGANIC NUTRIENTS IN SOIL FROM SMALL SCALE TEA FARMS AND WATER AND SEDIMENTS FROM SULAL RIVER, BURETI SUB-COUNTY, KERICHO COUNTY, KENYA

BY

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DECLARATION

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

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DEDICATION

I dedicate this work to my husband who has supported me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started. To my daughter, Chloe, who has been affected in every way possible by this program. My love for you both can never be quantified. God bless you.

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May the Almighty God bless you all.

Abstract

In a bid to increase tea yields, small scale tea growers do annual application of a blend of inorganic fertilizer containing nitrogen, phosphorous and potassium (NPK 26:5:5). The application is normally done on the onset of the short rainy seasons. These nutrients can get into the streams, rivers, lakes and oceans through surface run-off contributing greatly to water degradation and pollution problems. Thus, a study was conducted to assess the levels of chemical fertilizer nutrients in soils from small scale tea farms, water and sediments from the Sulal River. The samples were collected from an area stretching a distance of 12 Km to cover the source of nutrients application along Sulal River catchment area. Sampling was done during dry (January-February 2019) and rainy (October-November 2019) seasons. Samples were analyzed for nitrogen, phosphorous, potassium and selected physicochemical parameters of soil, water and sediments. Nitrogen, as nitrate-nitrogen (NO_3–N) and phosphorous, as phosphate-phosphorous (PO4 $^-$ P) were analyzed calorimetrically using Salicylic acid and Olsen methods, respectively. Potassium was determined using flame photometer. The levels of water and sediment quality parameters were compared with recommended levels for drinking water and likelihood for eutrophication set by Kenya Bureau of Standards, World Health Organization and Water Service Regulation Board, Kenya. Results were analyzed using IBM SPSS 20. The average levels during the dry and rainy seasons in soil samples for pH were 4.64±0.26 and 4.41±0.1, electrical conductivities were 187±45.79 and 253±23.76 µS/cm, % moisture content were 20.91±3.11and 36.38±2.20, nitrate-nitrogen were 0.68±0.20 and 0.58±0.20 mg/kg, phosphate-phosphorous were 0.14±0.08 and 0.38±0.17 mg/kg and potassium were 1.22±0.31 and 2.63±0.70 mg/kg. The average levels during dry and rainy seasons in water samples for pH were 6.72±0.00 and 6.38±0.21, dissolved oxygen levels were 6.78±0.59 and 9.58±0.64mg/L, electrical conductivities were 174±5.02 and 205±20.14 µS/cm, total dissolved solids were 92±4.59 and 120.70± 19.57 mg/L, nitrate-nitrogen were 0.58±0.21 and 1.19±0.22 mg/L, phosphate-phosphorous were 0.00±0.00 and 0.13±0.84 mg/L and potassium were 0.26±0.08 and 0.84±0.19 mg/L. The average results during the dry and rainy seasons in sediment samples for pH were 6.62±0.20 and 6.75±0.17, electrical conductivities were 67±6.66 and 52±10.19 µS /cm, % water contents were 116.96±3.95 and 129.84±5.00 %, nitrate-nitrogen were 0.70±0.35 and 0.42±0.23 mg/kg, phosphate-phosphorous were 0.49±0.25 and 1.14±0.40 mg/kg and potassium were 1.53±0.45 and 2.86±0.31 mg/kg. The levels of pH, electrical conductivity, dissolved oxygen, nitrogen and potassium in water and sediments in both seasons were within the maximum permissible limits set by KEBS, WHO and WASREB while phosphorous in water during rainy season were however, above the WHO (0.025 mg/L) and KEBS (0.030 mg/L) recommended limit for drinking and domestic use and WASREB (0.005 mg/L) level for likelihood of eutrophication. The study revealed the pollution status of Sulal River due to high levels of phosphorous of phosphorous. Availability of excess phosphorus can accelerate eutrophication in water bodies causing a reduction of dissolved oxygen, followed by death of aquatic organisms. The water from Sulal River may be used for irrigation purpose but not drinking and domestic purposes. Seasonal variation revealed significantly ($p<0.05$) higher nutrients in the rainy season than the dry season except for nitrogen and phosphorous in soil and nitrogen in sediment samples. This indicates that the seasonal changes are the major factors in the fluctuation of most of the analyzed physicochemical parameters in soil, water and sediments.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
AWWA	American Water Works Association
DO	Dissolved oxygen
EC	Electrical Conductivity
FAO	Food and Agricultural Organization
KCCRP	Kenya county climate risk profiles
KEBS	Kenya Bureau of Standards
KTDA	Kenya Tea Development Agency
LVEMP	Lake Victoria Environmental Management Project
MoFA	Ministry of Foreign Affairs
MC	Moisture Content
mt	made tea
NPK	Nitrogen, Phosphorous and Potassium
POPS	Persistent Organic Pollutants
SOM	Soil Organic Matter
SRP	Soluble Reactive Phosphorous
TDS	Total Dissolve Solids
TP	Total Phosphorous
TRFK	Tea Research Foundation of Kenya
TRI-KALRO	Tea Research Institute- Kenya Agriculture and Livestock Research Organization
USBR	United States Bureau of Reclamation
US EPA	United States Environmental Protection Agency
UV VIS	Ultraviolet–Visible spectrophotometry
WASREB	Water Service Regulation Board
WHO	World Health Organization
WPCF	Water Pollution Control Federation

CHAPTER ONE

INTRODUCTION

1.1: Background information

Nutrient pollution is a global environmental problem common to both developed and developing countries and has attracted serious attention because it is undermining human's environmental and physical health (Mateo-Sagasta *et al*., 2017). Environmental changes are accelerated by the increasing level of anthropogenic resource consumption due to the growing population (Crist *et al*., 2017). Capps *et al*., (2016) established that the growth of human population and environmental changes are closely related; the intensified land use due to food demands by the growing population has created impacts on the environment through changes to the landscape. Human beings have exploited the resource base thereby sacrificing the future to salvage the present.

Water bodies have particularly been affected by nutrients and this has become a global threat to the aquatic organisms, plants, humans and climate (Mateo-Sagasta *et al*., 2017). Sediment in water bodies is the most common pollutant because of its ability to retain and transfer nutrients to water (Guo *et al*., 2019). Nutrients in water bodies mainly come from human activities such as fertilizer runoff, discharging untreated sewages and industrial wastes. These sources can also introduce heavy metals, microorganisms, agricultural chemicals such as herbicides, pesticides, and persistent organic pollutants (POPs) into water bodies (Wu *et al*., 2020). Chemical fertilizers are the major source of nitrogen, phosphorus and potassium (Jones *et al*., 2015). According to the study conducted for Africafertilizer.Org, Kenya, about 365,373 metric tons of nitrogen, 324,200 metric tons of phosphorus and 128,340 metric tons are applied annually as chemical fertilizer in Kenya (Oseko and Dienya, 2015).

Improvement in agriculture globally have seen the increased use of nitrogen, phosphorous and potassium (NPK) fertilizers with the aim of addressing the food insecurity (Jones *et al*., 2015). Nutrient pollutants arising from fertilizer runoff and of particular concern in surface water are nitrates and phosphates. Accumulation of excess of these nutrient loads in water bodies causes eutrophication (Lewis *et al*., 2011), a situation where nutrients accelerate algae growth. Water contaminated with excess nutrients also causes chemical poisoning in humans and animals (WHO, 2013). Different water bodies have different levels of NPK, but their recommended maximum limits set by World Health Organization (WHO), Kenya Bureau of Standards (KEBS), Water Services Regulatory Board (WASREB) and National Environment Management Authority (NEMA) for various purposes are as shown in the Table 1.1.

In developing countries, the nutrient-polluted water is used for irrigation purposes (Kithiia, 2012). However, Kenya's National Environmental Management Authority (NEMA) has set out Maximum allowable levels to be reused in irrigating most crops under schedule nine of the NEMA water quality standards (Table 1.1). Sensitive crops such as carrots, grapes may be affected by nitrogen concentrations above 5 mg/L (Ribaudo, *et al*., 2011).

Table 1. 1 National standards for NPK permissible limits in water for different use in Kenya

	Domestic purpose		Likelihood of Eutrophication		Irrigation water
Nutrient (mg/L)	WHO	KEBS	WHO	WASREB	NEMA
NO_3^- N	10.00	10.00	2.5-10	5.000	30
PO4 $^-$ P	0.025	0.030	0.030	0.005	55
K^+	12.0	12.00	12.0	N/A	N/A

Source: (KEBS, 2012; WHO, 2017; WASREB, 2008; NEMA (schedule 9), 2006)

The number of people who do not access clean water in the world is estimated to be 27% and are mainly from the developing countries. It is also estimated that by the year 2025, 50% of the population in the world will be living in areas which are water-stressed as demand for water grows in the industrial and domestic sectors (WHO, 2019). The global water resources consist of 97% seawater and 3% freshwater. Approximately 97.5% of all the freshwater in the earth is accessible in ground and surface water. The rest is trapped in icecaps and glaciers or found under the surface the earth and too deep to be extracted (USBR, 2019).

Studies also reveal that surface water resources (rivers, lakes, streams, creeks and lakes) are more threatened with nutrient pollution than groundwater resources (UN/WWAP, 2019). Of the surface water resources, rivers are the most affected by nutrient pollution due to widespread human activities in developing countries. Kenyan rivers are not exception to this situation (Sutton *et al*., 2013). Many Kenyans do not have accessible clean water, especially those living in rural areas. They walk for long distances to get untreated water from rivers, boreholes and dams. The untreated water could contain nutrients more than the recommended limits, agrochemicals and bacteria capable of causing diseases. The quality of water available is further affected by the seasonal variations of rains that carry runoffs to the rivers in many parts of the country (Kithiia, 2012). Some of these rivers are in farming areas of Kenya and are therefore of concern in terms of nutrient load.

Nutrient alteration from small rivers affects downstream water bodies such as lakes, estuaries, oceans and coastal zones (Kimani *et al*., 2016). Lake Victoria, for example, is known to contain nutrients above the recommended limits given in Table 1.1 (Van *et al.*, 2019; Shayo and Limbu, 2018; Kundu *et al*., 2017). Through their studies, serious and urgent intervention is required to remedy the situation. In Kenya, major rivers that flow into Lake Victoria include Nzoia and

Nyando River. Studies in the River Nyando by Koech *et al*. (2017) and Guya (2019), Nzoia River by Achieng *et al*. (2017) and Kanda *et al*. (2017) show that these rivers contain high levels of nutrients downstream.

The Sulal River in Bureti sub-County, Kericho County, Kenya is also a victim of nutrient pollution as it flows through small scale tea farms. The river supplies water for domestic use, livestock and irrigation. However, very little is known about the quality of its waters in terms of health and well-being of the users, and also its likelihood of eutrophication. There is also no attempt that has been made to assess the effects of NPK application in tea farms might have on the quality of river waters. This concern has been addressed in the current study focused on determining the nutrient levels in soil from tea farms, water and sediments from Sulal River before and after fertilizer applications.

1.2: Statement of the Problem

Fertilizer application is a necessary for farm management practice meant to increase the yields and improve the tea quality (Zheng *et al*., 2012). Continuous application of fertilizers to soil however, degrades the soil quality status leading to soil pollution. The type and amount of fertilizers applied can affect soil pH by making the soil more basic or more acidic (Liu *et al*., 2010). Fertilizer application during the rainy seasons can result in water runoff and leachate from tea farms into rivers, streams and lakes, which could compromise the water quality. Sediment arising from deposition of soil and debris is a common pollutant in rivers, streams, lakes and reservoirs. It has the ability to retain nutrients (Guo *et al*., 2019).

Fertilizer runoff from tea farms increases the amount of nutrients in water bodies. The availability of phosphorus and nitrogen generally promotes eutrophication; an excessive growth of phytoplankton and blue green algae (Lewis *et al*., 2011). Eutrophication would lead to oxygen loss in the water, and hence, the death of fish and other aquatic fauna (Boyd, 2019). Drinking water contaminated with excess nitrates is also harmful to human and livestock; nitrates can convert to nitrites which interfere with how oxygen is transported in the blood by oxidizing the normal Hemoglobin to methemoglobin. This condition is called Methemoglobinemia (WHO, 2018). A group which is potentially at high risk of nitrate poisoning is infants under three months of age and can be seen when babies turn “blue”. This “blue baby” condition is so serious that it can damage the brain of babies (Johnson, 2019). The diversity of cancers has been associated with drinking water containing high nitrate and phosphorous levels (WHO, 2018; Parvizishad *et al*., 2017).

1.3: Objectives

The overall objective of this study was to assess the levels of major inorganic nutrients in soil from small scale tea farms, sediments and water from Sulal River, Bureti sub-county, Kericho County.

The specific objectives of this study were to:

(i) Determine the physicochemical parameters and major inorganic nutrients in soil from the selected 10 tea farms along Sulal River catchment area in Bureti, Kericho County during dry and rainy seasons.

(ii) Determine the physicochemical parameters and major inorganic nutrients in surface water and sediments from sites adjacent to the 10 selected farms along Sulal River catchment during dry and rainy seasons.

1.4: Justification

The major source of accumulated nutrients in rivers is agricultural farms because their runoff may contain residual fertilizer nutrients (Li *et al*., 2010). The effect of fertilizers' nutrients on water quality has been reported mostly on rivers within tea estate sub-sectors that are owned by companies (Omwoma *et al*., 2011; Maghanga *et al*., 2012; Nyaboke, 2013 and Nyairo *et al*., 2015). In contrast, research on relatively small rivers within small-scale tea farms is rather limited although rivers in those areas may be affected by elevated levels of chemical nutrients from tea farms.

The assessments of nutrient levels in soil, water and sediments are important because their levels indicate the status of nutrients in soils and the pollution status of the river (Munn *et al*., 2018). Sediment indicates the quality of overlying water (Ammar *et al*., 2016) and hence its study is important in assessing environmental pollution. It is recommended to regularly monitor the levels of nutrients in farms and rivers because their high levels in drinking water are associated with health risks (Sievers, 2005). Therefore, it was imperative to determine fertilizer nutrients' levels in soil, water and sediments in the areas where small scale tea farms are close to Sulal River and then propose ways in which they can reduce the threat to lives of the consumers and protect the environment.

CHAPTER TWO

LITERATURE REVIEW

2.1: Soil Nutrients

Nutrients are chemical elements required by living organisms to grow, survive and reproduce. Plants and autotrophs synthesize their own nutrients while people and animals get them from food (Stubbs, 2016). Plant essential elements include basic elements such as carbon, hydrogen and oxygen; primary macronutrients such as nitrogen, phosphorous and potassium; secondary macronutrients which include magnesium, calcium and sulfur; and micronutrients such as nickel, manganese, iron, zinc, copper, molybdenum, boron and chlorine. Different plants have different sets of nutrient requirements and different ways of utilization (Stubbs, 2016). Various nutrients are applied at different rates and are used by plants at different times throughout the growing cycle (Fageria, 2016).

2.2: Nutritional Requirements for the Growth of Tea

The most important nutrients required by tea plant are those needed in large amounts of nitrogen, phosphorous and potassium (NPK); pure phosphorous is required during seedling transplanting, while a blend of NPK 26.5.5 or 25.5.5 is recommended for top dressing (Hajiboland, 2018). Nitrogen is majorly responsible for growth of the leaves and the production of chlorophyll and proteins while phosphorus is required in the formation of new roots and stems. The soluble phosphate is used by plants for photosynthesis (Lal and Stewart, 2016). Potassium helps the overall functions of the plant to perform correctly. The tissue requires it to maintain the optimum turgor necessary for cell division and to activate many enzymatic processes (Singh and Pathak, 2018). Studies have shown that application of fertilizers increased tea yields (Cakmakci *et al*., 2017; Mukaya, 2016).

The nutritional status of the tea plant and that of the soil largely depends on the amount of fertilizer applied (Njogu *et al*., 2015). Use of fertilizers in tea is therefore an important field management practice meant for improving crop yields and influencing quality of the final product.

2.3: Types of Fertilizers

Fertilizers applied can be organic or inorganic materials and are applied either to plant foliage or soils (Jones, 2012). Organic fertilizers are natural fertilizers obtained from plants and animals and include cow manure, compost organic materials and green crops. Inorganic fertilizers on the other hand are chemical compounds made of different formulations to suit a variety of specified functions. Inorganic fertilizers are less bulky compared to organic manures and hence easier to carry to the farm. The availability of inorganic fertilizers to the plant is relatively faster than organic fertilizers. Studies reveal that there is a higher significant crop yield with the application of inorganic fertilizers compared organic fertilizers (Kibunja *et al*., 2017; Ruto *et al*., 2019). The most widely used chemical fertilizers in Kenya since the 1960s contain nitrogen, phosphorous and potassium (Kanyanjua and Ayaga, 2006). The government of Kenya has proposed a new bill through the Food Crops Regulations 2018 which if passed by parliament will make it illegal for farmers to use animal manure in food production (GoK-MoALFI, 2019). Most farmers in Kenya use inorganic fertilizers compared to organic fertilizers with tea crops being the second user of inorganic fertilizers after maize (Oseko and Dienya, 2015).

2.4: Application of Fertilizers in Tea Farms

Tea is normally grown as a long-term monoculture; without application of fertilizers, soil available nutrients would get depleted and cannot further supply essential nutrients to the plant leading to severe reduction in yields and a degraded plantation. Tea requires moderate to high nutrient levels in soil (Table 2.1). Low levels of nutrients in tea would lower the quality and quantity of tea produced. Lack of NPK generally decreases the total content of polyphenol in tea leaves (Mosier *et al*., 2013).

Table 2. 1: Loam soil nutrient status

Nutrients	Nutrient levels (ppm)		
	Low	Moderate	High
Nitrogen	<20	20-50	>50
Phosphorous	<5	5-20	>20
Potassium	<78	78-100	>100

Source: TRI-KALRO Tea growers guide, 2019

Nutrients are lost through plucking, pruning, water run-off, leaching and decomposition to gases (Willson and Clifford, 2012). Research by Hajiboland (2017) and Sultana *et al*. (2014) showed that tea plucking removes the highest amount of nutrients from the plant hence the need to regularly apply fertilizer to tea farms. The amount of fertilizer applied may be based on results of the field tests, analyses of soil or foliage, or observing mineral deficiency symptoms; lack of nitrogen in tea shows up as overall yellow-green leaves instead of a dark green, and overall reduced plant size and slow growth while lack of phosphorus and potassium typically results in reduced growth and leaf chlorosis, respectively (Willson and Clifford, 2012).

In Kenya, small scale farmers do an annual top dressing of inorganic NPK 26:5:5 supplied by Kenya Tea Development Agency (KTDA). Farmers get different amounts of fertilizers depending on the quantity they order for and the number of tea bushes they have. On average, a 50 kg bag of NPK fertilizer is recommended for 700 bushes (50 Kgs NPK for 700 bushes). Farmers are required to apply fertilizers on the onset of short rains to reduce nutrient losses through water run-off and leaching (Kamunya *et al*., 2019).

2.5: Fertilizer Nutrients and Soil Properties

Soil characteristics are indicators of soil quality (Liu *et al*., 2010). Some of these characteristics include the pH, moisture content, electrical conductivity and extractable N-P-K. The relationship between NPK and other soil properties are discussed.

2.5.1: Soil pH

Tea does well in acidic soils. The severity of acidity is given in Table 2.2.

Table 2. 2: Degree of soil acidity

Degree of acidity	pH range
Extremely acidic	<4.5
Strongly acidic	4.5-5.0
Moderately acidic	5.0-6.0
Slightly acidic	6.0-6.5
Near neutral	6.5-7.0

Soil macronutrients (N, P, K) affect the pH more than how the soil micronutrients would, because macronutrients are added to soil in larger amounts. Nitrogen lowers the soil pH more than phosphorous because nitrogen is used in larger amounts while there is little effect of potassium on soil pH (Bhattacharyya *et al*., 2017). The research conducted by Watros *et al*. (2019) in grassland soils in Poland showed that pH and soil macronutrients exhibit a negative correlation.

Soil pH on the other hand affects nutrients availability in soil (Liu *et al*., 2010). When the pH is out of range, plants cannot absorb nutrients even when there is plenty in the soil. In highly acidic soil, base elements in the soil (potassium, magnesium and calcium) can become more available and more toxic to the plant while phosphorus is less available to the plant (Savci, 2012). Soluble phosphorous slowly gets transformed to polyphosphates as the pH changes. Phosphorous is highly available to plants in soil at pH of between 5.5 to 7 and its availability decreases at the pH below

5.5 and above 7. This is because it combines with iron hydroxides and aluminum hydroxides in very acidic soils to form compounds that are not available to plants (Bünemann *et al*., 2010).

2.5.2: Moisture Content

Soil moisture affects the availability and transformation of nutrients in soil and also the biological activities in soil. The uptake of plant nutrients in soil during the dry season is less than the uptake in the rainy season (Kiboi *et al*., 2019). Soil moisture lowers the activity of soil microorganisms which are needed to break down organic matter in soil and mineralization of organic phosphorous and nitrogen to their respective inorganic forms (Borowik and Wyszkowska, 2016). Hence, when the soil is dry, there is a reduced risk of losing it through denitrification or leaching processes. However, uptake of nitrates by plants is reduced during the dry season and suddenly rise when the rains begin. (Marschner and Rengel, 2012).

In dry soils, there is slow movement of potassium from soil to the plant roots because the soil minerals shrink, trapping potassium tightly between their layers. This form of potassium is released during rainy season (Majumdar *et al*., 2017).

2.5.3: Electrical Conductivity

Electrical conductivity (EC) of soil is its ability to transmit electrical current (Marandi *et al*., 2013). It indicates health status of soil; healthy soils have optimal electrical conductivity levels that range from 110-570 (mS/m). Having an adequate supply of electrolytes assist in nutrient delivery and plant growth. Too low electrical conductivity is an indication of low nutrients available for the plant, while too high electrical conductivity shows that there are excess available nutrients especially nitrogen in soil; nitrogen is the primary electrolyte in soil (Carter and Bentley, 2016). Mirzakhaninafchi *et al*. (2017) established a significant correlation between soil nitrogen and electrical conductivity. A linear correlation between electrical conductivity and potassium, sulfates, nitrates, chloride, sodium, and ammonia in soil was also established by Costa *et al*. (2014).

2.6: Nutrients in the Environment

Application of fertilizers in agricultural production may be regarded as nonpoint pollution source of nutrients in the environment (Jan and Esselman, 2013). Nutrients in the environment can also occur naturally when the remains of plants and animals decompose. They can also come from sewage and waste waters from homes and factories (Wu *et al*., 2020). Nutrients cycle through soil-plant-atmosphere continuum and some of them get incorporated into the soil organic matter, others absorbed by plants and the rest can be leached to groundwater, carried with soil through surface run off or volatilized into the atmosphere (Khan *et al*., 2018). Recent air and water quality concerns are attributed to excessive nutrients in the environment (US EPA, 2017).

Globally, the amount of nutrients added to crops as fertilizers are more than the nutrients removed as produce (Doughty *et al*., 2016; US EPA, 2018). This flux generates excess nutrients that can pollute the surrounding environment (Khan *et al*. 2018). The nutrients of underlying environmental concerns in agriculture are nitrogen and phosphorus. The introduction of these nutrients into the environment can make the ecosystem fertile. However, improper management of these nutrients results into nutrient pollution especially in water (Lewis *et al*., 2011).

2.6.1: Nitrogen

Nitrogen in the environment exists in many forms such as ammonia gas, nitrous oxide, nitric acid, nitrate and nitrite (Stein and Klotz, 2016). Naturally, nitrogen occurs in the soil in form of organic manures as a result of decomposing plant residues (Barker and Bryson, 2016). Nitrogen is a major nutrient applied in the largest amount for tea production. The annual recommended amounts of nitrogenous fertilizers vary from country to country, ranging from 80 kg N per hectare per year for low yielding tea in Sri Lanka to 800 kg N per hectare per year in Japan (Hasler *et al*., 2019). In Kenya, the recommended rate of nitrogenous fertilizer is 100-255 kg N per hectare per year (Kamunya, 2019). Sitienei *et al*. (2013) observed that of all the amount of nitrogenous fertilizer applied, plants can use only up to 40-70 % while the rest can be volatilized, denitrified, or carried by water together with soil through erosion and leaching.

Nitrogen is converted by bacteria present in soil to nitrate (NO_3^-) (Stein and Klotz, 2016). This form of nitrogen is the most desirable by plants. However, this form is very loosely bound to soil hence, easily washed by rain into surface water or leached into ground water through soil (Barker and Bryson, 2016). A research done by Maghanga *et al*. (2012) in different rivers passing through the tea plantations of Eastern Produce Kenya Limited found out that fertilizer application led to rise in nitrate levels in surface water.

Nitrogen in water bodies can be found in sediments and water, and contribute to eutrophication (Boyd, 2019). The primary health hazard resulting from consuming water containing high levels of nitrate, especially in infants and pregnant women, begins in the digestive system where nitrate is transformed to nitrite forms. The nitrite form of nitrogen is absorbed into the blood system and reacts with the iron component of hemoglobin to form methemoglobin creating methemoglobinemia, a condition where there is insufficient oxygen in the blood system. Drinking water containing excess nitrates may also pose the risk of cancer due to formation of highly carcinogenic compounds such as nitrites and *N*-nitroso compounds (WHO, 2018; Parvizishad, *et al*., 2017). World Health Organization (WHO, 2018) recommend nitrate-nitrogen maximum values of 10 mg/L (Table 1.1) for drinking and domestic use. Nitrate ions in water are odorless, colorless and tasteless and cannot be detected without testing. It is therefore recommended that a water analysis is done to determine the concentration levels of nitrogen compounds (WHO, 2018).

2.6.2: Phosphorous

Phosphorus exists naturally in soil, living organisms, water and minerals. Soil phosphorus occurs in organic and inorganic forms (Bünemann *et al*., 2010). The organic form of phosphorous is found in plant residues, manures and microbial tissues and is absorbed directly by plants as organic compounds. Inorganic phosphorus consists of orthophosphates (stable form usually used by plants) and polyphosphates (complexes of iron and aluminum phosphates).

Phosphate fertilizers contain the orthophosphate form of phosphorous (Boer *et al*., 2019). When fertilizer is applied to soil, phosphorus is absorbed onto to soil particles and is absorbed by the plant roots as hydrogen phosphate (HPO_4^{2-}) and dihydrogen phosphate ($H_2PO_4^{-}$) ions (Lal and Stewart, 2016).

Phosphates applied to agricultural farms as fertilizers and is not utilized by plants can be carried during rainy seasons into the surface water or migrate vertically into groundwater systems. Omwoma *et al*. (2011) established that phosphates get washed from sugarcane farms into Kuywa River in Western Kenya during the rainy seasons. Basweti *et al*. (2018) also established that the level of phosphates in River Nzoia, Kakamega fluctuates seasonally, and usually there is not a lot of ortho-phosphate in water during the dry season because it is incorporated into plants immediately after application during rainy season.

Once in water bodies, phosphates can be incorporated into sediments and chemical processes at the sediment/water interface can take place where phosphorus is released to the water surface (Dunn *et al*., 2017). Ondoo *et al*. (2019) showed that fertilizer applications and discharging domestic sewage and detergents into water bodies heavily contribute to phosphorous loading in the sediments. A review by Worsfold and Monbet, (2016) explained that phosphates in water exists in particulates and solution forms; particulate phosphorous are phosphorous in organic materials, phosphorus adsorbed to particulates and complexes of phosphorus while the dissolved phase includes soluble inorganic and organic phosphorus. The review concluded that when a water sample is tested for phosphorous without filtering, total phosphorus is obtained while the filtered fraction of the water sample gives the soluble phosphorus.

Excessive phosphorous (> 0.005 mg/L) in water bodies cause eutrophication, a situation where the water body gets enriched with mineral nutrients that favors the growth of aquatic plants (Jones *et al.,* 2015). The health hazard associated to very high levels of phosphates is the digestive problem. W.H.O, (2013) recommends 2.5 mg/L of phosphates in water (Table1.1).

2.6.3: Potassium

Depending on its availability to plants, there are three forms in which potassium exists in soil: readily available, slowly available and unavailable forms. The unavailable form exists in crystalline form and is insoluble in soil solution. The slowly available form is held in an exchangeable form by negatively charged ions in soil and plants cannot absorb much of this form during a single growing season because it is not immediately soluble in soil solution. The readily available form is soluble in soil water and is held on the soil surface, hence absorbed by plants easily (Majumdar *et al*., 2017). There is relatively little potassium dissolved in soil water at any one time and because of this, soil tests for available potassium (water-soluble) are intended to extract only K^+ ions in soil solution (Yadav and Sidhu, 2016). A report by Blanchet *et al*. (2017) showed that fertilizer is the main source of available potassium in the soil and that potassium is taken up by plants immediately after application. Available potassium is a mobile ion in soils because potassium is not attached to organic matter and so significant amounts can be washed by surface runoff or by leaching leading to low potassium level for plant growth and economic loss to farmers (Majumdar *et al*., 2017). Manohar *et al*. (2017) found out that potassium concentrations in rivers is usually less than 20 mg/L despite the level of contamination. They concluded that potassium tends to settle to the bottom, and consequently ends up in sediment mostly.

Most individuals are unlikely to experience health problems resulting from consuming water containing potassium because potassium levels in natural waters is too low to cause adverse health problems. Susceptible individuals are infants and older people, those with diabetes, hypertension, kidney dysfunction and adrenal insufficiency (WHO, 2012).

2.7: Nutrient Pollution in Rivers

Global water quality concerns include contamination by heavy metals, excess nutrients, agricultural pesticides and microbial pathogens. Nutrient pollution is the leading type of contamination in water bodies and has become a great concern to the aquatic organism, plants, humans, and climate (Mateo-Sagasta *et al*., 2017). It occurs when excess nutrients, mainly nitrogen and phosphorous, accumulate in water bodies (US EPA, 2017). Nutrient alteration from small rivers affects downstream water bodies such as lakes, estuaries, oceans and coastal zones (Kimani *et al*., 2016). Most studies in Lake Victoria, for example, showed that the levels of nutrients were above the recommended limits given in Table 1.1.

A study by Juma *et al*. (2014) showed that the levels of NO_3^- N and PO_4^- P in Lake Victoria were 10 mg/L and 4 mg/L respectively in 2012 and the levels kept increasing as a result of growing population in Kenya and Uganda. Shayo and Limbu (2018) also established that anthropogenic activities and sediments may be important sources of nutrients enrichment to the overlaying waters, thereby enhancing eutrophication of Lake Victoria. According to Lloyd *et al*., 2019 and

Githinji *et al.*, 2019, the sources of nutrients in rivers and downstream waters are widespread. Nyilitya *et al*. (2020) established that ammonium-based fertilizers and soil nitrogen were the major NO_3^- sources in tea dominated areas of Nyando, Nzoia and Sondu Miriu Rivers. Koech *et al*. (2018) also established that the effluents from a milk processing plant on the characteristics of Kipsonoi River caused profound changes in the levels of some of the physico-chemical and biological indicators. Kundu *et al*. (2017) also showed that Winam Gulf was more polluted with higher total phosphorus and nitrogen concentrations than the open lake. Nutrient pollution has been reported mostly on bigger rivers than the Sulal River, and also on rivers within tea estate sub-sectors that are owned by companies (Omwoma *et al*., 2011; Maghanga *et al*., 2012; Nyaboke, 2013 and Nyairo *et al*., 2015). Studies on relatively small rivers within small-scale tea farms are limited although rivers in those areas may be affected by elevated levels of chemical nutrients from tea farms. This study focused on agricultural primary macronutrients (nitrogen, phosphorus and potassium) as a source of nutrient pollution in water because they are applied to soils in large quantities and have a relative potential to pollute the environmental. Excess phosphorus and nitrogen in water or sediments causes faster algae growth than the ecosystems can handle, and the result is poor quality of water, decrease in oxygen levels for aquatic lives. When algae blooms, they produce high toxin levels and favors the growth of bacteria which can be harmful to humans when they drink polluted water or consume tainted fish (US EPA, 2017).

2.8: Sediment and Water and Properties

The quality of water is described by the physical, chemical and biological properties of the water and underlying sediments (WHO, 2017). A study carried out in River Kurram, Pakistan on water and sediments' parameters by Ali *et al*. (2018) showed that the levels of physicochemical parameters in sediment were a reflection of the overlying water column. Depending on the usage of water, there are different standards of water properties. W.H.O recommended limits for selected water are given in Table 2.2.

Table 2. 3: W.H.O limits for water for drinking and domestic purposes

Parameter	Recommended limit
pH	Between 6.5-8.5
DO	> 6.5 mg/L
EC	<1000 µS/cm
TDS	<500 mg/L

Source: WHO, 2008

2.8.1: pH

The pH of water is affected by sediment's composition through which the water moves (Guo *et al*., 2019). According to Boyd (2019), the pH of a water body changes when soil particles carried by rainwater enters. The soil particles could be carrying substances (heavy metals, pesticides and fertilizers) responsible for changes in pH of a water body. Water pH can also change due to carbon dioxide released from decomposing plants growing in a river. Changes in the pH value of water harms many organisms since most of them are adapted to a specific pH in water (Gensemer *et al*., 2018).

2.8.2: Dissolved Oxygen

Free oxygen enters water from air and as a waste product of photosynthesis through diffusion. (Wilson, 2010). The level of oxygen in water affects the aquatic life because it is needed for their respiration. Quality water has dissolved oxygen levels above 6.5 mg/L (WHO, 2008). Low level of dissolved oxygen is indicative of excessive bacteria infestation and biological oxygen demand.

Fertilizer runoff to water bodies also decreases the dissolved oxygen by making aquatic plants grow which then use much of the dissolved oxygen for respiration especially on cloudy weather. When these plants die, they also use much of the dissolved oxygen for decomposition (Singer, 2018). A research done by Achieng *et al*. (2017) in Sosiani River showed strong negative correlations between dissolved oxygen and NPK in water.

2.8.3: Total Dissolved Solids and Electrical Conductivity

Total dissolved solids (TDS) in water represents the total concentration of all the substances which are soluble in water; inorganic salts, minerals, metals and other compounds which can be both organic and inorganic (Shinoda *et al.*, 2016). The ability of water or sediments to transmit an electric current at any particular temperature is the electrical conductivity (EC). TDS assesses the dissolved solids in the water and encompasses both particles that conduct electricity as well as particles that do not conduct electricity (Jemily, 2019). Ganiyu *et al*. (2018) established a positive correlation between water EC and nutrients indicating that EC is directly influenced by nutrients.

Sources of dissolved solids in water can be anthropogenic such as runoff from urban areas and agricultural farms, discharge of domestic and industrial wastewaters, and road de-icing salts (Wu *et al*., 2018). A study by Uwah *et al*. (2020) in Akani Obio Uruan River, Nigeria showed that high concentrations of dissolved salts in water can result in technical problems such as salt deposits inside water pipes and boilers, and water hardness. Ondoo *et al*. (2019), in their research, noted that TDS and EC in water from Sio River, Busia County is lower during the dry season than the rainy season.

2.8.4: Water Content in Sediments

Water content is defined by the amount of water lost by sediments after oven-drying. Avimelech *et al*. (2011) established that contaminated sediments have high-water content because they contain high content of organic substance. The organic matter in sediments is made up of the organic carbon and nutrients in different forms which include carbohydrates, nucleic acids, proteins and fats derived from anthropogenic or natural sources. Determination of water content of sediments can be useful in evaluating other sediment characteristics; a research by Maloi *et al*. (2016) in Ruiru Reservoir and Talib *et al*. (2016) in Bukit Merah Reservoir, Malaysia showed that sediments' water content increase with increase in soil nutrients in sediments.

CHAPTER THREE

MATERIALS AND METHODS

3.1: Study area

The study was conducted along Sulal River catchment, located in Bureti sub county, Kericho County, Kenya (Figure 3.1). Sulal River is a permanent river which floods during the long rainy season and serves a population of approximately 4000 households (GoK, 2019). It has catchment area of 25 km^2 and total length of 12 km from its source, Kapkatet to an area where it joins Kipsonoi River. The Kipsonoi River drains southward through Bomet County into Sondu-Miriu River which enters Lake Victoria through Winam Gulf (LVEMP, 2003). It lies between Latitude 0°39'14"S and Longitude 35°10'41"E. The climate is moderately humid with an average temperature of 18°C annually. The annual rainfall has a mean of 1800mm and is bimodal where long rains occur from early March to part of June and short rains occur from October to December (KCCRP, 2018). The county has experienced adequate rainfall for a long time but for the last three decades, there has been gradual changes due to emerging changes in the weather patterns (MoFA, 2019). Rainfall is now erratic throughout the year; long rainy season occurring in July to December, excess precipitation that has resulted in flash floods destroying crops and polluting rivers, and prolonged dry season characterized by decreasing moisture that negatively affect crops like tea. In the year 2019, the driest season began from January to April while heavy rains began from July 2019 through March 2020 (KCCRP, 2020).

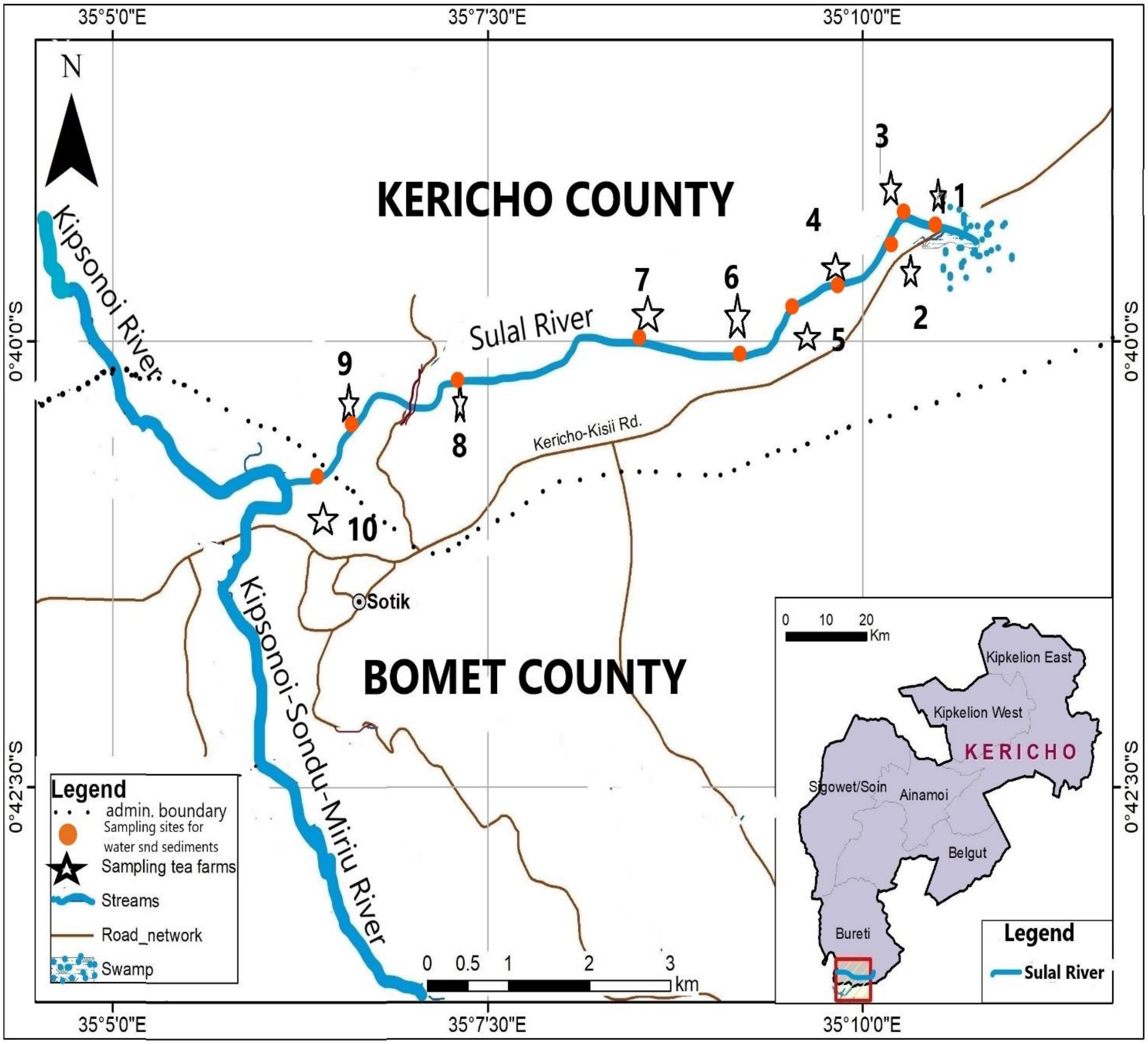

Figure 3. 1: Map of Sulal River showing sampling sites

(Source: Cherotich *et al*., 2021)

3.2: Economic Activities around the Study Area

The most important economic activity in Sulal River catchment area is agriculture. The farms are mainly covered by tea in small scale. The small-scale farm holders are concentrated in Bureti sub-county while the tea estate sub-sector is spread within the Kipkelion, Belgut and Ainamoi East sub-Counties (KCCRP, 2018). Kericho County is the largest tea producer in Kenya (World Bank, 2019). Tea leaves from the study area are taken to Kapkatet Tea Factory which is managed by Kenya Tea Development Authority (KTDA). KTDA buys fertilizers in bulk and supplies to the farmers on loan basis (Koskei, 2012), to be applied on the onset of the short rains, usually October to December. During the dry season, usually January and February, farmers prepare their tea farms for fertilizer application by weeding.

3.3: Reagents and Standards

Sodium thiosulfate (98.0 %), starch solution, alkali-iodide-azide, Manganese sulfate (98.5 %), concentrated sulfuric acid (97 %), distilled water, K_2SO_4 (99.0 %), NaOH (98.0 %), salicylic acid (99.0 %), $NaHCO_3$ (98.0 %), HCl (99.0 %), Ammonium molybdate (99.9 %), antimony potassium tartrate (98.0 %), ascorbic acid (99 %), KNO_3 (99.9 %), KH_2PO_4, (99.9 %), and KCL (99.0 %). The reagents and standards were manufactured by Sigma-Aldrich Company, USA.

3.4: Equipment and Apparatus

UV-VIS Spectrophotometer (MR Spectronic 1001 PLUS), flame photometer (EEL 100), analytical balance (C054-E032Q Shimadzu), pH-EC-TDS meter (HANNA 9812), mechanical/orbital shaker, extraction bottle with stopper, laboratory glassware and sampling bottles and bags.

3.5: Sampling Plan and Site Selection

Samples were collected in accordance with seasonal variation and farm practices that would affect residue levels of fertilizer nutrients. Collection of samples was done in February 2019 and November 2019 to capture the effects of dry season and short rainy season, respectively on the residue levels of fertilizers' nutrients in soil, sediment and water.

The selection of soil sampling sites from the tea farms was based on the site being ≤ 10m to Sulal River. Ten tea farms which are numbered 1-10 (Figure 3.1) were selected due to their closeness to the riverbank and are described in Table 3.1. The selection of water and sediment sampling sites on Sulal River was based on sites being adjacent to selected tea farms. Thus, 10 sampling sites were chosen.

Table 3. 1: The summary of the sampling sites

Local name	Sites	Latitude	Longitude	Altitude (m)	Description
Kapkatet	1	0°39'14"S	35°10'41"E	1887	This site is situated near the source of Sulal River, it is next to a swamp and covers 0.8 ha
	2	0°39'23"S	35°10'39"E	1872	It is also very close to the swamp, 1.1 km from site 1 and covers 0.45ha
	3	0°39'22"S	35°10'26"E	1894	It is 4km from site 1, covers 0.25ha
	4	0°39'26"S	35°09'59"E	1882	The site has an area of 3ha, 5km from site 1 and is connected to other several farms on its upper area
Chebongi	5	0°39'31"S	35°09'28"E	1845	Site situated at 6km from site 1 and is approx. 0.7ha
	6	0°39'40"S	35°09'11"E	1880	This site is at 7km from site 1, on the opposite side of site 5, it has an area of. 0.32 ha.
	7	0°39'53"S	35°07'13"E	1799	This site is on the same side as farm 6, situated 8km from site 1 and is approx. 0.3ha.
Sertwet	8	0°39'54"S	35°07'13"E	1796	This farm is situated approximately 9km from site 1 and is approx. 0.25 ha.
	9	0°40'19"S	35°06'57"E	1803	This farm is very close to Sulal River bridge and is approx. 0.23ha, at the administrative boundary of Bomet and Kericho Counties.
	10	0°40'44"S	35°06'15"E	1766	This farm is situated near the end of Sulal River, where it joins Kipsonoi River, the river drains through Bomet County and enters Sondu-Miriu River a tributary of Lake Victoria

3.6: Collection of Samples

Soil sampling in the selected 10 farms (Table 3.1) was done following Okalebo *et al*. (2002) procedures. 10 spots from each farm were selected for one composite sample. Soil was dug from the depth of 0-10 cm, taken using a spade and mixed. All samples from one farm were mixed to form a composite sample. Triplicate samples, 1000g each were taken from each farm, kept in a clean plastic container with a lid, labelled and kept in polyethene cooler boxes awaiting transportation to the University of Nairobi Laboratory. In the laboratory each sample was analyzed for pH, electrical conductivity (EC), percentage moisture content (MC) and major chemical nutrients (NPK).

Samples of water from the 10 selected sites were collected following the APHA/AWWA/WPCF (2005) method. Samples were taken from Sulal River in triplicates and kept in a one-liter clean plastic sampling containers, labeled as per the site and kept in polyurethane cooler-boxes awaiting transportation to the University of Nairobi Laboratory where each sample was analyzed for pH, dissolved oxygen, total dissolved solids, electrical conductivity and major nutrients (NPK).

Sediment sampling in the 10 selected sites was also done according to Okalebo *et al*. (2002). Samples were taken using a stainless-steel spade from the depth of 0–10 cm and mixed on a sterilized aluminum foil to form a composite sample. At each sampling site, sediment samples were taken from three points which were close to each other and approximately 1kg of each triplicate was kept in a clean plastic container with a lid, labeled according to the site and kept in polyurethane cooler boxes containing dry ice. Samples were taken to the University of Nairobi Laboratory where each sample was analyzed for pH, electrical conductivity (EC), water content (WC) and major nutrients (NPK).

3.7: Determination of Soil, Sediment and Water Samples' Parameters

Soil and sediment parameters were determined as per Okalebo *et al*. (2002) and Estefan *et al*. (2013) while the water parameters were determined as per APHA/AWWA/WPCF (2005) procedures.

In the laboratory, samples of soil and sediment were dried using an oven at 105°C for 24 hours. External objects were removed, and a roller was used to break down the large masses of the particles. Samples were then sieved using a 2.0 mm mesh and kept for subsequent analysis in a refrigerator using labeled plastic bags.

Samples of water were filtered using No. 42 Whatman paper and stored in a refrigerator using clean plastic bottles to be used in subsequent analysis.

3.7.1: Determination of pH

The pH was determined using HANNA 9812 pH meter calibrated using buffer solutions of pH 4, 7 and 10. All the readings were taken at room temperature (Okalebo *et al*., 2002).

The soil and sediment pH were determined by taking 20 g of each homogenized sieved samples in a 100 mL beaker then adding 50 mL of deionized water to form a 2:5 soil/ sediment-water suspension. The mixture was mechanically shaken at 15 rpm for 15 minutes using an orbital shaker before the electrode was immersed into the suspension to determine the pH. The reading was taken after 30 minutes.

Water pH was determined by taking 40 mL of each triplicate water samples into 100 mL glass beakers. The electrode was immersed to determine the pH as was done with the soil samples.

3.7.2: Determination of Moisture Content

Dry clean crucibles were first weighed (Wt_1). 5 g (Wt_2) of each soil and sediment samples were then placed on the crucibles and oven-dried at 105°C for 15 hours, then cooled in a desiccator to room temperature and re-weighed (Wt_3) to obtain the moisture contents. Percentage moisture content was calculated using Equation 3.1.

$$\text{Moisture/water content (\%)} = \frac{\text{Wt2} - \text{Wt3}}{\text{Wt2} - \text{Wt1}} \text{ x } 100 \qquad (3.1)$$

where, wt1 = weight of dry clean crucibles; wt2 = weight of dry crucibles containing samples before drying; and wt3 = weight of dry clean crucibles and sample after drying.

3.7.3: Determination of Electrical Conductivity

The electrical conductivity (EC) for each soil, water and sediment samples were determined using HANNA 9812 conductivity meter calibrated using distilled water and potassium chloride (0.01 N and 0.10 N).

20 g of each homogenized sieved soil and sediment samples were weighed into a beaker. 100 mL of deionized distilled water was added to form a 1:5 soil/sediment: water suspension and then mechanically shaken at 15 revolutions per minute for one hour. The cell of the conductivity meter was then rinsed thoroughly with distilled water before it was immersed into the sample solutions.

The EC for each triplicate water samples was determined by taking 50 mL water samples and swirled for one minute to dissolve all soluble salts before the cell of the conductivity was immersed into the suspension to determine the EC.

3.7.4: Determination of Total Dissolved Solid

Total dissolved solids were determined using HANNA 9812 TDS meter calibrated using distilled water and potassium chloride (0.01 N and 0.10 N).

50 mL of each filtered sample of water was taken in a 100 mL beaker and swirled for one minute. Using distilled deionized water, the meter tip was rinsed thoroughly before immersing into the sample to record the reading at room temperature.

3.7.5: Dissolved Oxygen Determination

Determination of dissolved oxygen was done following the Winkler Method (Ward, 2016).

Filtered water samples were each poured carefully into a 300 mL glass bottle so that no air got trapped inside. 2 mL of manganese sulphate and 2 mL alkali-iodide-azide were added consecutively using calibrated pipette, slowly so as not to introduce bubbles via pipette. The bottle was then stoppered and then inverted several times while observing air bubbles. A precipitate was formed which was dissolved by adding 2 mL of concentrated sulfuric acid. A 201 mL sample solution was pipetted into a 250-mL Erlenmeyer flask and 2 mL of starch solution indicator was added. The sample solution (blue) was then titrated with sodium thiosulfate while swirling continuously until the endpoint where the color disappeared. Each mL of sodium thiosulfate equals 1 mg/L dissolved oxygen. The amount of sodium thiosulfate used as titrant was used to obtain the concentration in mg/L of the dissolved oxygen in the sample from Equation 3.2.

$$\text{Dissolved oxygen (mL/g)} = \text{volume of sodium thiosulfate used} \qquad (3.2)$$

3.8: Determination of Nutrients

Stock solution of nitrate-nitrogen was prepared by weighing 7.223 g of potassium nitrate dried at 105 °C into 100 mL beaker and then transferred to a one-liter volumetric flask. The flask was made to the mark using deionized distilled water to make 1000 µg N /mL. Standard solution was made by diluting 25 mL of the stock solution in a 500 mL volumetric flask using deionized distilled water to make 50 µg N /mL. A series of standards of 0, 2, 4, 6, 8 and 10 µg N /mL were made by transferring 0, 2, 4, 6, 8, and 10 mL of the standard solution into a clean, labelled set of 100 mL volumetric flasks and topped to the mark using distilled water. Absorbance of the working standards were measured at wavelength of 419 nm using UV-VIS spectrophotometer. The absorbance and standard concentrations were used to make the calibration curves for nitrate that was used during nitrogen-nitrate determinations in soil, sediments and water samples analysis.

Stock solution of phosphate-phosphorous was prepared by weighing 2.197 g of potassium dihydrogen phosphate dried at 100 °C for two hours into 100 mL beaker and then transferred to a one-liter volumetric flask. The flask was made to the mark using deionized distilled water to make 500 µg P /mL. A standard solution was made by diluting 50 mL of the stock solution in a 250 mL volumetric flask using deionized distilled water to make 100 µg P /mL. A series of standards of 0, 1, 2, 3, 4, and 5 µg P /mL were made by transferring 0, 5, 10, 15, 20 and 25 mL of the standard solution into a clean, labelled set of 500 mL volumetric flasks and topped to the mark using distilled water. Absorbances were read at wavelength of 882 nm using UV-VIS spectrophotometer. The absorbance and standard concentrations were used to make the calibration curves for phosphorous and was used during phosphorous analysis in soil, sediment and water samples.

Stock solution of potassium was prepared by weighing 1.907 g of potassium chloride dried at 100 °C for two hours into 100 mL beaker and then transferred to a one-liter volumetric flask. 10 mL of dilute HCl was added solution and the flask made to the mark using deionized distilled water to make 1000 µg K/mL. Standard solution was made by diluting 10 mL of the stock solution in a 100 mL volumetric flask using deionized distilled water to make 100 µg K /mL. Five solutions of 0, 1, 2, 3, and 4µg K /mL were made by transferring 0, 1, 2, 3 and 4 mL of the standard solution into a clean, labelled set of 100 mL volumetric flasks and topped to the mark using distilled water. The concentrations were analyzed using a Flame Photometer at 767-nm wavelength. The emissions and standard concentrations were used to make the calibration curve for potassium and was used during potassium analysis in soil, sediment and water samples.

3.8:1: Determination of Nitrogen

Nitrogen was determined calorimetrically as nitrate-nitrogen by using salicylic acid method (Okalebo *et al*., 2002; Estefan *et al*., 2013).

Nitrogen was extracted in form of nitrate from 5.0 g of previously prepared soil and sediment samples using 50 mL solution of 0.5 M potassium sulphate (87.1g in 1-L DI) in 100 mL plastic bottles. Each bottle was capped and shaken using an orbital shaker at 200 rpm for one hour before filtering into 100 mL Erlenmeyer flasks using No. 42 Whatman filter paper.

Colorimetric measurement was done by pipetting 0.5 mL of the standard solutions, sample extracts and a reagent blank into suitably labeled test tubes followed by 1 mL of 5 % (w/v) salicylic acid (5 g salicylic acid in 95 mL Sulphuric acid) and then mixed thoroughly by hand shaking. The mixtures were left to settle at room temperature for 30 minutes before slowly adding 10 mL solution of 4 M sodium hydroxide (160 g in 1-L DI water). The mixture was again shaken and left for 1 hour. The UV-VIS spectrophotometer was used to measure the absorbance at wavelength of 419 nm. The level of total nitrogen in soil/sediment samples expressed in N mg/kg were obtained from equations 3.3 and 3.4 (section 3.8.1.1).

Water samples were directly measured calorimetrically by taking 10 mL of prepared water samples in a 50 mL volumetric flask. 10 mL of 5 % salicylic acid was added and then mixed thoroughly by hand shaking. The mixtures were left to settle at room temperature for 30 minutes before slowly adding 100 mL solution of 4 M sodium hydroxide. The mixture was again shaken and left for 1 hour. The absorbance was measured on a UV-VIS spectrophotometer at wavelength of 419 nm. The level of total nitrogen in water samples expressed in N mg/L was calculated using Equation 3.5 (section 3.8.1.1).

3.8.1.1: Calculation of Nitrogen Levels

For soil and sediments samples: nitrogen (mg/kg) = $\frac{(c2-c1)\times ve\times MCF}{wt}$ (3.3)

Where c_2 = nitrate concentration reading from the calibration graph, c_1 = blank concentration, v_e = volume of the sample extract, wt = weight of the prepared soil/sediment sample and MCF = moisture correction factor, given as: MCF= $\frac{100-\%\ M}{100}$ (3.4)

Where M is moisture content of the soil/sediment samples.

For water samples, nitrogen (ml/L) $=$ $\frac{(a-b)\times v}{vf}$ (3.5)

where a = concentration of NO_3^- N in the solution, b = concentration of NO_3^- N in the blank, v= volume of the extract and v_f = volume of the volumetric flask.

3.8.2: Determination of Phosphorous

Extractable phosphorous (as phosphate-phosphorous) was determined calorimetrically using Olsen method (Okalebo *et al*., 2002; Estefan *et al*., 2013).

Phosphorous was extracted as phosphates from 5 g of each of the homogenized soils and sediment samples using 100 mL of Mehlic 1 solution in 250 mL Erlenmeyer flasks. The flasks were stoppered and shaken at 200 - 300 rpm using orbital shaker for 30 minutes before filtering through a Whatman filter paper No. 42.

Colorimetric measurement was done by taking 10 ml of each standard, 10ml of each the sample extract and a reagent blank into separate 50 mL volumetric flasks. 10 mL of Olsen solution (42 g of $NaHCO_3$ in a 1-L of distilled water and 1 M sodium hydroxide solution to adjust pH to 8.5) followed by 20 mL distilled deionized water then 8 mL of Murphy Riley Solution (mixture of 12 g Ammonium Molybdate in 250 mL of warm distilled water, 0.291 g antimony potassium tartrate in 100 mL of distilled water and 1litre 5 N H_2SO_4, all diluted to 2 liters with distilled water) were added to each solution in the flasks. The solution was then made to the mark (50 mL) using deionized distilled water and analyzed on a UV-VIS spectrophotometer at 882 nm wavelength. The level of total phosphorous in soil/sediment samples expressed in P mg/kg were calculated using Equation 3.6 (section 3.8.2.1).

Water samples were colorimetrically measured by taking 10 mL of each of the filtered water samples in 50 mL volumetric flasks. 10 mL of Olsen solution followed by 20 mL distilled deionized water then 8 mL of Murphy Riley Solution were added to each water samples in the flasks. The solution was then made to the mark (50 mL) using deionized distilled water and analyzed on a UV-VIS spectrophotometer at 882 nm wavelength. The level of total phosphorous in water samples expressed in mg/L was calculated using equation 3.7 (section 3.8.2.1).

3.8.2.1: Calculation of Phosphorous Levels

For soil and sediments sample, phosphorous (mg/kg) = $\frac{(a-b)\times v}{w}$ (3.6)

For water samples, phosphorous (mg/l) =$\frac{\text{graph reading}\times v}{vf}$ (3.7)

where a = concentration of P in elute, b = concentration of P in the blanks, v = volume of the sample, w = weight of the soil/sediment samples and vf= volume of flask used for measurement

3.8.3: Determination of Potassium

Potassium was extracted from 5 g of each of the prepared samples of soil and sediment in 50 mL centrifuge tubes using 5 mL Mehlic I solution (. The tubes were stoppered with clean rubber and shaken on a shaker until supernatant liquid became clear and then filtered into a 50 mL volumetric flask using Whatman filter paper No. 42. Emissions were measured at 767-nm wavelength using a Flame Photometer. The level of potassium in soil and sediment samples expressed in mg/kg was calculated using equation 3.8 (section 3.8.3.1).

10 mL of filtered water samples were directly taken into a 100 mL flask and aspirated into Flame photometer and the emission measured at 767 nm. The level of potassium in water samples expressed in mg/L was calculated using equation 3.9 (section 3.8.3.1).

3.8.3.1: Calculation of Potassium Levels

For soil and sediment samples: K (mg/kg) = $\frac{\text{conc.reading from calibration curve} \times v}{wt}$ (3.8)

For water samples: K (mg/l) = concentration reading from the calibration graph ×v (3.9)

Where wt, is the weight of the soil/sediment samples and v is volume of the extracted sample.

3.9: Statistical Data Analysis

Statistical program for social scientists (IBM SPSS Version 20) was used to perform the analyses; descriptive statistics were used to obtain the mean and standard deviation of the sample triplicates of each parameter, Bivariate Pearson’s correlation (r) value was used to show the degree of association between the selected physicochemical parameters (pH, EC, MC, TDS and DO) and the major nutrients (NPK), and the paired sample test was used to compare the means in the levels of NPK between dry and wet seasons. Differences were regarded to be significant at 95% confidence limit.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1: Physicochemical Characteristics and Nutrients in Soil.

The physicochemical parameters (pH, moisture content (MC), electrical conductivity (EC)) and major inorganic nutrients (nitrogen (N), phosphorous (P) and potassium (K)) in soil samples were analyzed in triplicates (n=3). The mean in each site and each parameter in 10 different sites were computed in the dry and rainy seasons. The results are presented in Table 4.1 and the calibration curves for inorganic nutrients are presented in Figures 4a-c in appendix.

Table 4. 1: The physicochemical parameters and major nutrient levels in the soil samples

	Dry season					
Parameter/ site	**pH**	**MC (%)**	**EC (**µS /cm)	**NO_3^- N** (mg/kg)	**PO_4^- P** (mg/kg)	**K** (mg/kg)
1	4.80±0.12	14.78±0.37	150±5.29	0.56±0.06	0.10±0.04	1.12±0.15
2	4.57±0.08	14.93±0.20	190±5.24	0.60±0.02	0.15±0.03	1.29±0.28
3	4.45±0.02	18.46±0.39	187±3.89	0.87±0.01	0.22±0.08	1.14±0.14
4	4.80±0.01	16.96±0.26	182±4.20	0.51±0.06	0.17±0.03	1.09±0.19
5	4.62±0.05	21.76±0.52	245±6.50	0.24±0.04	0.32±0.04	2.05±0.28
6	4.07±0.03	14.17±0.36	133±3.87	0.67±0.02	0.09±0.08	1.09±0.29
7	4.55±0.10	16.87±038	175±5.30	0.79±0.02	0.18±0.02	1.11±0.10
8	4.86±0.01	14.71±0.18	140±5.50	0.84±0.08	0.08±0.05	1.04±0.27
9	4.71±0.02	21.63±0.41	220±5.25	0.14±0.03	0.23±0.04	1.24±0.18
10	4.98±0.08	12.58±0.53	85±7.85	0.58±0.03	0.06±0.03	0.98±0.36
M± SD, n=10	**4.64±0.26**	**20.91±3.11**	**187±45.79**	**0.68±0.20**	**0.14±0.08**	**1.22±0.31**
	Rainy season					
1	4.38±0.06	30.92±0.56	242±4.20	0.43±0.04	0.38±0.07	2.56±0.11
2	4.47±0.01	33.95±0.35	250±6.01	0.54±0.07	0.47±0.04	3.39±0.21
3	4.32±0.06	37.36±0.45	289±7.29	0.79±0.03	0.68±0.04	3.48±0.15
4	4.42±0.09	32.82±0.34	248±4.85	0.63±0.03	0.31±0.06	2.06±0.22
5	4.25±0.08	32.12±0.20	221±8.47	0.90±0.07	0.12±0.07	1.65±0.35
6	4.18±0.03	36.45±0.41	259±4.98	0.37±0.09	0.42±0.08	2.87±0.16
7	4.45±0.01	35.56±0.37	260±3.45	0.61±0.05	0.27±0.03	1.85±0.20
8	4.80±0.12	37.12±0.29	287±6.71	0.38±0.08	0.56±0.06	3.44±0.14
9	4.24±0.09	30.13±0.48	216±3.72	0.81±0.09	0.08±0.07	2.02±0.31
10	4.58±0.02	34.40±0,34	253±4.80	0.33±0.04	0.46±0.07	2.98±0.25
M ±SD, n=10	**4.41±0.18**	**36.38±2.20**	**253±23.76**	**0.58±0.20**	**0.38±0.17**	**2.63±0.70**

4.1.1: Soil pH

The results of soil pH analyses on samples collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.1.

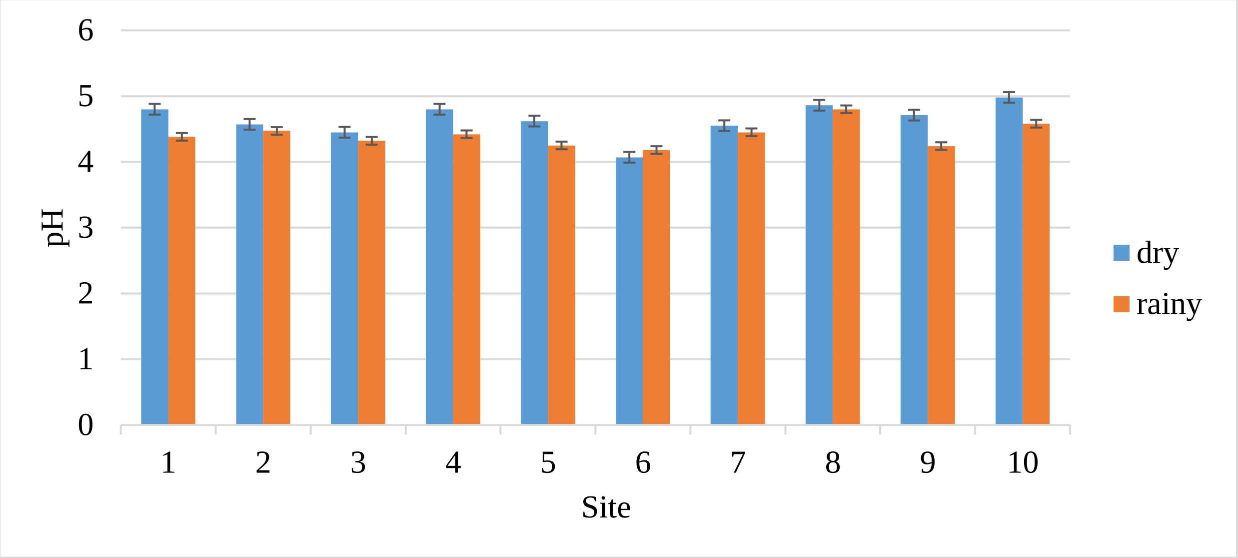

Figure 4. 1: The pH in soil samples

The results in Figure 4.1 show that during the dry season, the highest soil pH was recorded in Site 10 (4.98±0.08) and the lowest in Site 6 (4.07±0.03). Similarly, during the rainy season, the highest soil pH was in Site 8 (4.80±0.12) and the lowest in Site 6 (4.18±0.03). Seasonal variation shows that except Site 6, the pH levels of soil in other sites were lower during the rainy season than in dry season (Figure 4.1). The pH range in both seasons indicate moderate acidic pH levels and fell within the range for tea soils (4.0-5.0) (Willson and Clifford, 2012). A previous study carried out by Watros *et al*. (2019) in a similar environment demonstrated the same trend with the values of pH varying from 4.1 to 4.8 and 3.9 to 4.5 during the dry and rainy seasons respectively. According to Watros *et al*. 2019, the different levels of nitrates and phosphates observed in this study could probably be attributed to the different levels of pH in each farm. Soil pH affects nutrient availability especially phosphorous and potassium; phosphorous is unavailable to plants at pH of

<5.5 and >7 while potassium is replaced by more oxidizing cations such as Al^+, H^+ and Mn^+ in low soil pH. (Bünemann *et al*., 2010)

Bivariate Pearson correlation values in Table 4.2 were obtained by correlating the pH and nitrogen, phosphorous and potassium (NPK) values from Table 4.1.

Table 4. 2: Bivariate Pearson correlation between soil pH and NPK in dry and wet seasons

	Nutrients	**r**	**Sig. (2-tailed)**
Dry season	**N**	-.260	.468
	P	-.338	.339
	K	.282	.431
Rainy season	**N**	-0.528	.120
	P	.120	-.412
	K	.525	.236

The results in Table 4.2 show that the pH and soil nutrients in both seasons had a non-significant (p>0.05) correlation. The NPK levels had no effect on the pH in both seasons.

4.1.2: Soil Moisture Content

The results of soil moisture content analyses on samples collected from 10 different sites during the dry and rainy seasons are presented in Figure 4. 2.

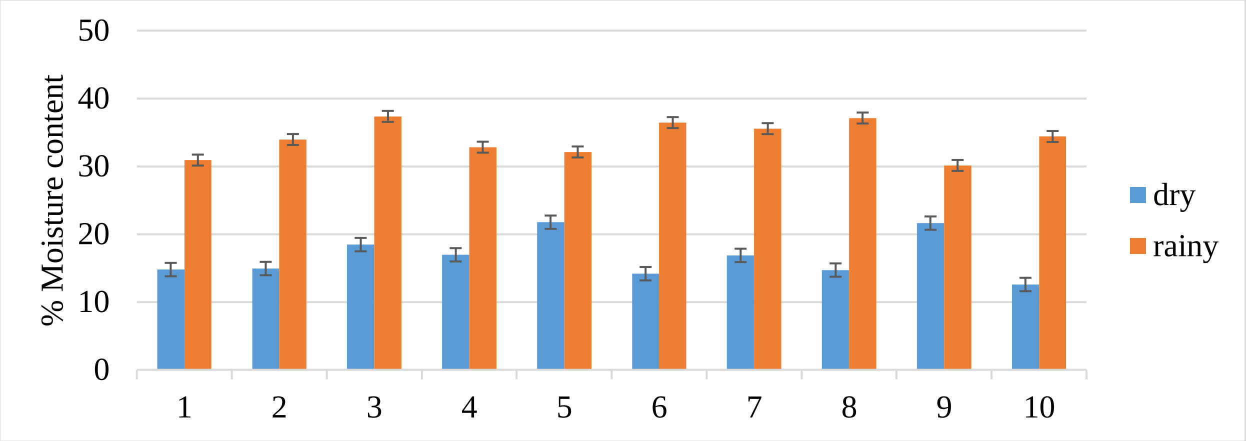

Figure 4. 2: Moisture content in soil samples

The soil moisture content during the dry season ranged from 12.58±0.53 % in Site 10 to 21.76±0.52 % in Site 5. Similarly, soil moisture content during the rainy season ranged from 30.13±0.48 % recorded in Site 9 to 37.36±0.45 % in Site 3. All soil samples had higher moisture content during the rainy season due to the effect of rainfall. The variation of moisture content in different sites is influenced by vegetation cover, organic materials and topography (Jacobs *et al*., 2017). Reduction in soil moisture greatly affects absorption of soil nutrients because the activity of soil microorganisms which play an important role in breaking down organic matter and mineralization of organic phosphorous and nitrogen to their respective inorganic form is favored in moist soils (Borowik and Wyszkowska 2016).

Bivariate Pearson correlation values in Table 4.3 were obtained by correlating the percentage moisture content to nitrogen, phosphorous and potassium (NPK) levels from Table 4.1.

Table 4. 3: Bivariate Pearson correlation between soil MC and NPK

	Nutrients	r	Sig. (2-tailed)
Dry season	**N**	.556	.123
	P	.937**	.000
	K	.681*	.030
Rainy season	**N**	.953**	.000
	P	.897**	.000
	K	.731*	.016

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

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

The results show that soil moisture content and soil nutrients in both seasons exhibit significant ($p<0.05$) positive correlations except for nitrogen during the dry season ($p=0.123$) (Table 4.3). Positive correlation indicates soil nutrients increase with increasing soil moisture content.

4.1.3: Soil Electrical Conductivity

The results of soil electrical conductivity analyses on samples collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.3.

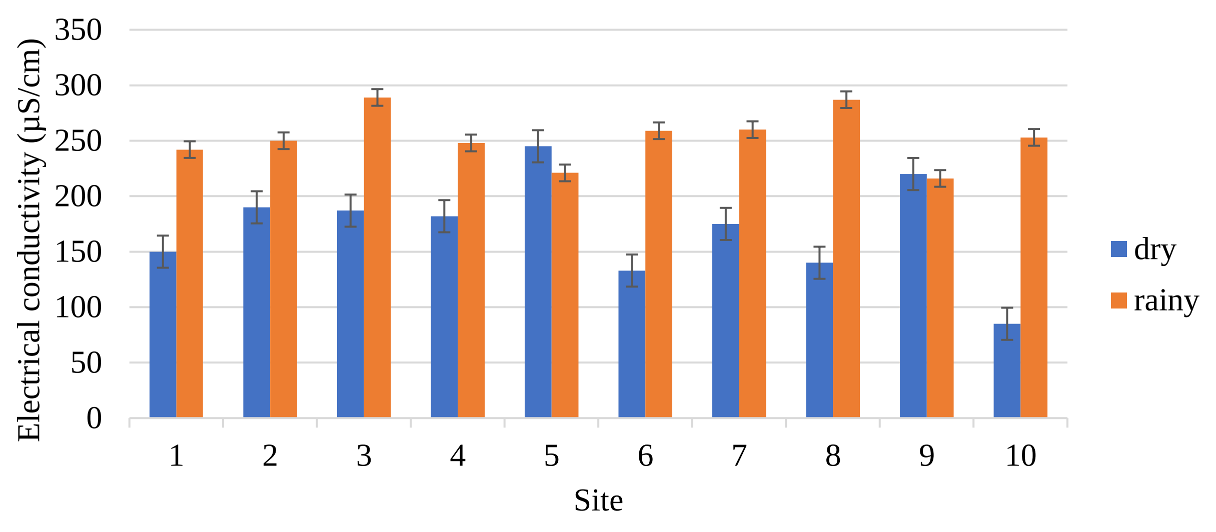

Figure 4. 3: Electrical conductivity in soil samples

Electrical conductivity (EC) of soil ranged from 85±7.85 µS/cm in Site 10 to 245±6.50 µS/cm in Site 5 and 216±3.72 µS/cm in Site 9 to 289±7.29 µS/cm in Site 3 during dry and rainy seasons, respectively (Table 4.1). Sites 5 and 9 had higher levels of electrical conductivity (EC) in the dry season, while soil samples from other sites had higher levels during rainy season than dry season. Soil nutrients affects the electrical conductivity of soil (Watros *et al*. 2019) and the variation in different sites is possibly due to different nutrient levels in each tea farm. Correlations of soil EC and soil nutrients are shown in Table 4.4. Higher EC during rainy season is possibly due to presence of water-soluble nutrients from application of fertilizers (Costa *et al*., 2014). These results agree with a study done by Nyaboke, (2013) in tea farms in Kisii that also attributed different values of electrical conductivity in soil to different levels of soil nutrients.

Bivariate Pearson correlation values in Table 4.4 were obtained by correlating the electrical conductivity to nitrogen, phosphorous and potassium (NPK) values from Table 4.1.

Table 4. 4: Bivariate Pearson correlation between soil EC and NPK

	Nutrients	**r**	**Sig. (2-tailed)**
Dry season	N	.918**	.000
	P	.930**	.000
	K	.742*	.014
Rainy season	N	.871**	.001
	P	.759*	.011
	K	.617	.057

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

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

Results of Pearson correlation in both seasons indicate that the electrical conductivity (EC) had significant positive correlations with all nutrients except potassium in the rainy season. Significant positive correlations of soil electrical conductivity (EC) with soil nutrients indicate that soil electrical conductivity (EC) increase with an increase in soil nutrients.

4.1.4: Soil Nitrogen

The results of nitrogen analyses on soil samples collected from 10 different sites during dry and rainy seasons are shown in Figure 4.4.

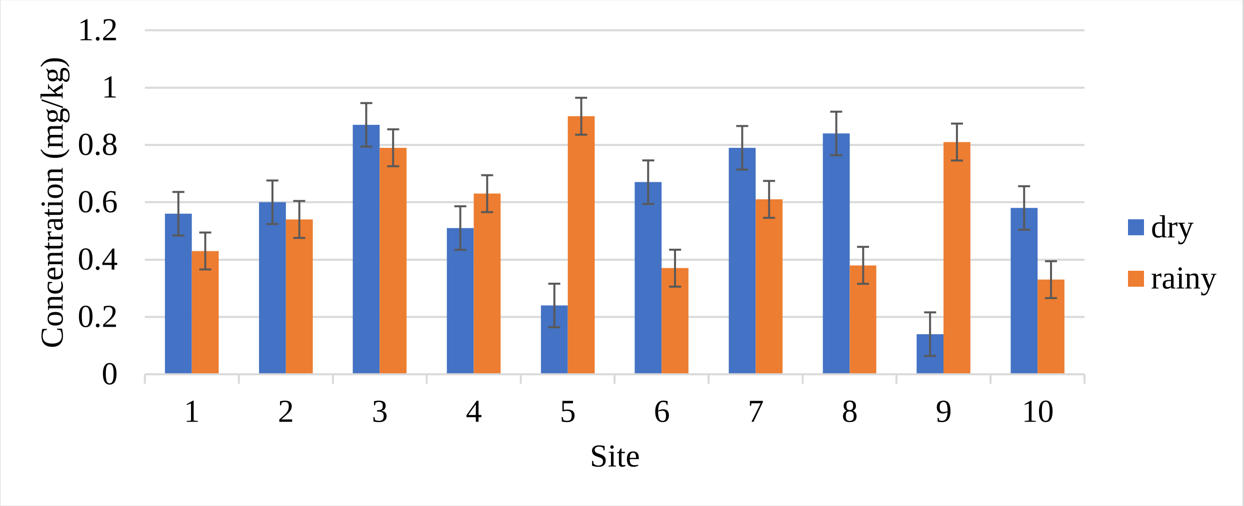

Figure 4. 4: Soil samples nitrogen levels

Nitrogen levels ranged from 0.14±0.03 mg/kg in Site 9 to 0.87±0.01 mg/kg in Site 3 and 0.33±0.04 mg/kg in Site 10 to 0.90±0.07 mg/kg in Site 5 during the dry and rainy seasons, respectively (Table 4.1). The tea farm with high-quality soils usually has available nitrogen content of >2 mg/kg (Table 2.1). The low nitrogen level in soil is possibly due to immediate absorption of nitrogen by tea plants after fertilizer application (Ma and Ruan 2019) or loss through surface runoff, volatilization, denitrification, or leaching. A similar observation was made by Ruto *et al*. (2019) in soils from Kericho who attributed low levels of nitrogen in soil to leaching. The variation of nitrogen levels in each farm is attributed to different application rates in each tea farm; different farmers apply different amounts of fertilizers despite the recommended rate of 100-255 kg N per hectare per year (Mucheru-Muna *et al*., 2013). The results also showed that all sites except 4, 5 and 9 had lower nitrogen levels during the rainy season than the dry season (Figure 4.4). The paired t-tests values in Table 4.5 were obtained by comparing the mean levels of nitrogen between two seasons from Table 4.1.

Table 4. 5: Paired soil sample tests for difference in means of nitrogen between two seasons.

	Nitrogen		Paired differences			
	Means (mg/kg)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	0.68	0.20	Dry-rainy	9	.008	.994
Rainy season	0.48	0.20				

The mean level of nitrogen in the dry season was higher than the rainy season but their difference was not significant. The low level of nitrogen during the rainy season is possibly because nitrates dissolve immediately after the onset of rainfall and are taken up by the tea plant, leached or carried away by water run-off. During the dry season, nitrates are usually built up through decomposition of proteins and nucleic acids from dropped tea leaves and other nitrogenous organic substances in soil releasing NH_3 which is converted to nitrates (Maqsood *et al*., 2016). The seasonal variation of nitrate-nitrogen observed in this study agrees with the results of Jacobs *et al.* (2016). According to Jacobs *et al.* (2016), the nitrate concentrations rose steadily after the onset of the rains and decreased drastically as rain continued because the rains can carry nitrates flushed out by the initial rains.

4.1.5: Soil Phosphorous

The results of phosphorous analyses on samples collected from 10 different sites during dry and rainy seasons are shown in Figure 4.5.

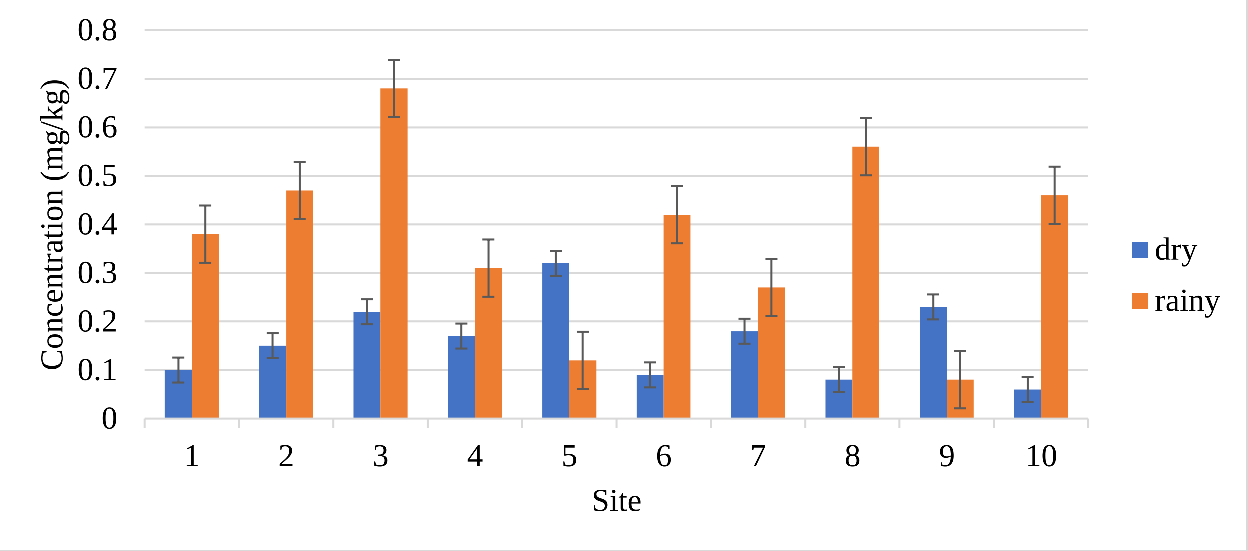

Figure 4. 5: Phosphorous in soil samples

The highest PO_4^- P level during the dry season was recorded in Site 5 with 0.32 ±0.04 mg/kg and lowest in Site 10 with 0.06 ± 0.03 mg/kg. During the rainy season, the highest PO_4^- P level was in Site 3 (0.68±0.04 mg/kg) and the lowest level was in Site 9 (0.08±0.07 mg/kg) (Table 4.1). The mean concentrations for both seasons were lower than the recommended level of 5 mg/kg (Table 2.1) for tea and this is the reason for annual application of fertilizers. Low levels of phosphorous in soils is possibly because majority of phosphorous in soils is fixed, and hence, plant available phosphorous is scarcely available despite the abundance of both inorganic and organic phosphorous in soils (Kunwar *et al*., 2018). Mucheru-Muna *et al*. (2013) also recorded low phosphorous levels in soil, and they attributed it to inadequate application of fertilizers by poor-resource farmers who consider fertilizer application a luxury, leading to poor crop performance. The results also showed that except Sites 5 and 9, the rest of the sites recorded higher PO_4^- P in rainy season than in dry season (Figure 4.5). The paired t-tests values in Table 4.6 were obtained by comparing the mean values of phosphorous between two seasons from Table 4.1.

Table 4. 6: Paired t-tests for difference in means of phosphorous between two seasons.

	Phosphorous		Paired differences			
	Means (mg/kg)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	0.16	0.24	Dry-rainy	9	-2.840	.19
Rainy season	0.38	0.20				

Phosphorous mean level was higher in the rainy than dry season, but their means do not vary significantly (Table 4.6).

4.1.6: Soil Potassium

The results of potassium analyses on soil samples collected from 10 different sites during dry and rainy seasons are shown in Figure 4.6.

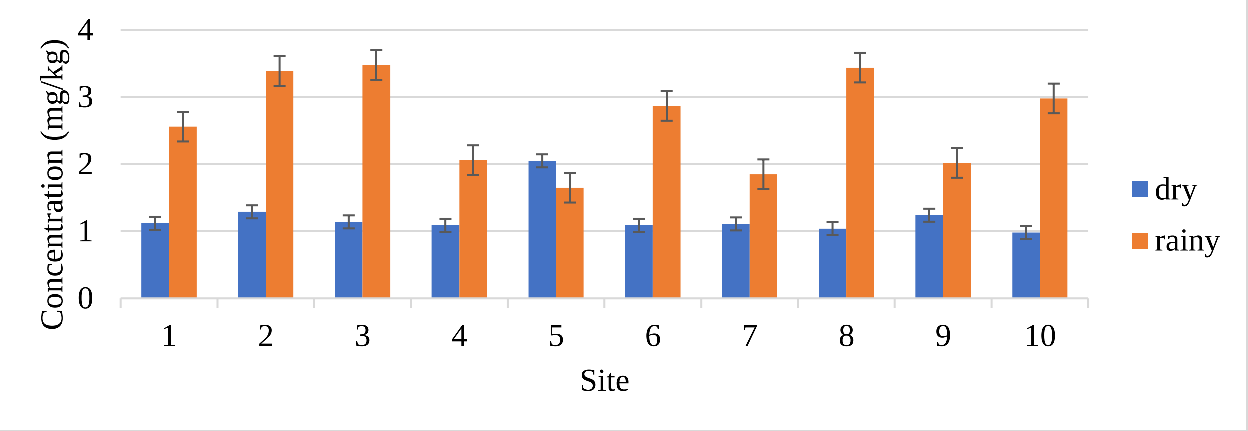

Figure 4. 6: Potassium in soil samples

Available potassium content during the dry season ranged from 0.98 ±0.36 mg/kg to 2.05 ±0.28 mg/kg recorded in Sites 10 and 5, respectively. Similarly, in the rainy season, a range of 1.65±0.35 mg/kg to 3.48 ±0.15 mg/kg were recorded in Sites 5 and 3, respectively (Table 4.1). The lower than the recommended level of potassium (>78 mg/kg) in both seasons is because potassium is loosely attached to the soil organic matter and it can directly be washed from the soil during the rainy season (Majumdar *et al*., 2017). The low potassium levels recorded in this study is similar to Ruto *et al.* (2019) who concluded that the low levels of soil potassium in dry and rainy seasons following application of NPK fertilizers is attributed to low soil pH leading to replacement of potassium ions by more oxidizing cations such as Al^+, H^+ and Mn^+. Potassium levels in all sites except Site 5 were higher during the rainy season than during dry season (Figure 4.6). The paired t-tests values in Table 4.7 were obtained by comparing the mean values of potassium between two seasons from Table 4.1.

Table 4. 7: Paired soil sample tests for difference in means of potassium between two seasons

	Potassium		Paired differences			
	Means (mg/kg)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	1.21	0.24	Dry-rainy	9	-5.030	.001
Rainy season	2.63	0.20				

The mean level of available potassium in soil was significantly higher in the rainy season than the dry season (Table 4.7). This variation can be due to addition of fertilizers containing potassium during the rainy season. In addition, rain helps the shift of potassium from slowly available forms to readily available forms, hence during the rainy season the potassium level in soil is higher than in the dry season (Majumdar *et al*., 2017). Similar variation was made by Blanchet *et al*. (2017) that fertilizers are the main source of available potassium in soils during the wet season.

4.2: Physicochemical Characteristics and Nutrients in Water Samples

The levels of physicochemical parameters (dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS)) and major nutrients (nitrogen (N), phosphorous (P) and potassium (K)) in water samples in 10 different sites were computed in dry and rainy seasons. The mean levels are shown in Table 4.8.

Table 4. 8: Physicochemical parameters and major nutrients levels in water samples

	Dry Season						
Parameter/ Site	**pH**	**DO** (mg/l)	**EC** (µS /cm)	**TDS** (mg/l)	**NO_3^- N** (mg/l)	**PO4$^-$ P** (mg/l)	**K** (mg/l)
1	6.80±0.14	7.2±0.06	170±5.20	95±7.61	0.48±0.36	<0.012	0.33±0.14
2	6.70±0.12	6.8±0.06	172±2.20	92±10.01	0.63±0.21	<0.012	0.41±0.09
3	6.67±0.08	8.4±0.13	181±10.20	91±3.45	0.84±0.72	<0.012	0.27±0.08
4	6.81±0.03	8.7±0.11	167±3.64	85±5.50	0.42±0.09	<0.012	0.21±0.01
5	6.69±0.07	7.6±0.04	178±5.20	97±10.21	0.64±0.85	<0.012	0.14±0.02
6	6.68±0.09	7.5±0.07	180±9.08	95±5.92	0.71±0.08	<0.012	0.29±0.02
7	6.68±0.02	7.8±0.09	169±3.08	97±2.80	0.79±0.03	<0.012	0.30±0.24
8	6.70±0.14	8.4±0.12	177±0.00	84±6.27	0.60±0.10	<0.012	0.28±0.09
9	6.72±0.13	7.8±0.13	171±7.09	94±6.90	0.53±0.36	<0.012	0.19±0.05
10	6.75±0.08	8.1±0.14	170±7.90	90±10.20	0.50±0.15	<0.012	0.15±0.03
M± SD, n=10	**6.72±0.0**	**6.78±0.59**	**174±5.02**	**92±4.59**	**0.58±0.21**	**-**	**0.26±0.08**
LOD					0.08	0.012	0.03
	Rainy season						
1	6.43±0.09	9.2±0.09	195±10.34	108±4.80	0.98±0.45	0.05±0.02	0.64±0.32
2	6.64±0.08	9.8±0.11	180±6.25	106±6.78	0.90±0.09	0.08±0.06	0.73±0.14
3	6.49±0.11	10.0±0.07	197±3.45	105±2.50	1.04±0.45	0.03±0.01	1.01±0.42
4	6.54±0.05	10.4±0.03	200±10.50	106±5.54	0.95±0.22	0.01±0.02	0.64±0.15
5	6.23±0.12	8.8±0.14	192±3.24	112±2.90	1.10±0.56	0.08±0.03	0.92±0.23
6	6.60±0.15	9.3±0.07	202±3.95	120±3.48	1.37±0.91	0.03±0.02	0.73±0.11
7	6.21±0.11	8.7±0.09	208±6.71	118±9.45	1.28±0.65	0.24±0.11	1.10±0.48
8	6.32±0.15	10.3±0.12	210±1.00	152±4.89	1.40±0.67	0.23±0.09	0.92±0.32
9	6.18±0.06	9.1±1.03	210±2.31	120±5.53	1.49±0.30	0.25±0.14	1.10±0.20
10	6.08±0.01	10.2±0.10	256±9.21	160±2.09	1.38±0.18	0.27±0.01	0.64±0.21
M± SD, n=10	**6.38±0.21**	**9.58±0.64**	**205±20.14**	**121±19.6**	**1.19±0.22**	**0.13±0.84**	**0.84±0.19**

BDL-Below detectable limit

4.2.1: Water Samples pH

The results of pH analyses on water samples collected from 10 different sites during dry and rainy seasons are presented in Figure 4.7.

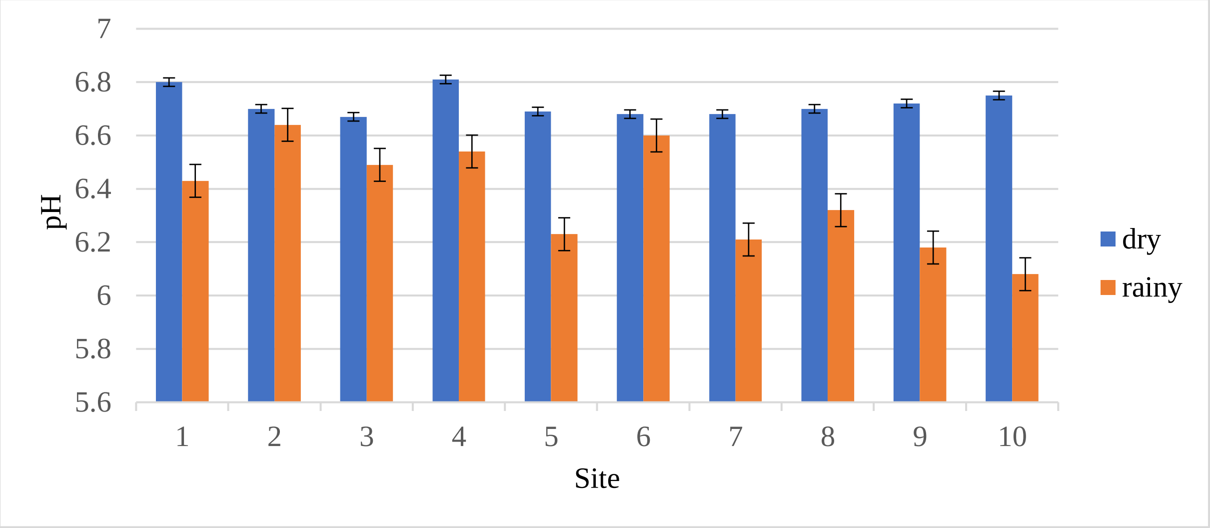

Figure 4. 7: The pH levels in water samples

The results in Figure 4.7 show that during the dry season, pH values of water samples ranged from 6.67±0.08 in Site 3 to 6.81±0.03 in Sites 4. Similarly, during the rainy season, the pH values ranged from 6.08±0.01 in Site 10 to 6.63±0.05 in Site 2 (Table 4.8). pH ranges in both seasons were within World Health Organization stipulated range of 6.5 to 8.5 for domestic purposes (WHO, 2017). The pH in all the sampling sites were higher in the dry season than rainy season. The results also showed that during the rainy season, the pH reduces in downstream (Figure 4.7). The lower pH values observed in the downstream and during the rainy season was probably due to increasing accumulation of water-soluble nutrients and metals in downstream. Accumulation of water-soluble nutrients such as nitrates and phosphates originating from agricultural farms during the rainy season lowers the water pH (Ganiyu *et al*., 2018). The relationships between water pH and chemical nutrients are presented in Table 4.9. Eliku and Leta (2018) had previously reported similar seasonal variations of pH in Awash River but in their opinion, the pH value of water decreased in the rainy season due to accumulation of carbon dioxide.

Bivariate Pearson correlation values in Table 4.9 were obtained by correlating the pH and nitrogen, phosphorous and potassium (NPK) levels from Table 4.8.

Table 4. 9: Bivariate Pearson correlation between water pH and NPK at different seasons

	Nutrients	r	Sig. (2-tailed)
Dry season	N	-.882**	.001
	P	c	-
	K	.139	.703
Rainy season	N	-.995**	.000
	P	-.754*	.012
	K	.862**	.001

* Correlation is significant at the .05 level (2-tailed)

** Correlation is significant at the .01 level (2-tailed),

[c] Cannot be computed because at least one of the variables is constant.

Significant (p=0.001) negative correlations were noticed between pH and nutrients in both seasons except potassium in dry season. Negative values are an indication that increase in nutrients levels results in low pH (Sari *et al*., 2017).

4.2.2: Dissolved Oxygen levels in water

The results of DO analyses on water samples collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.8.

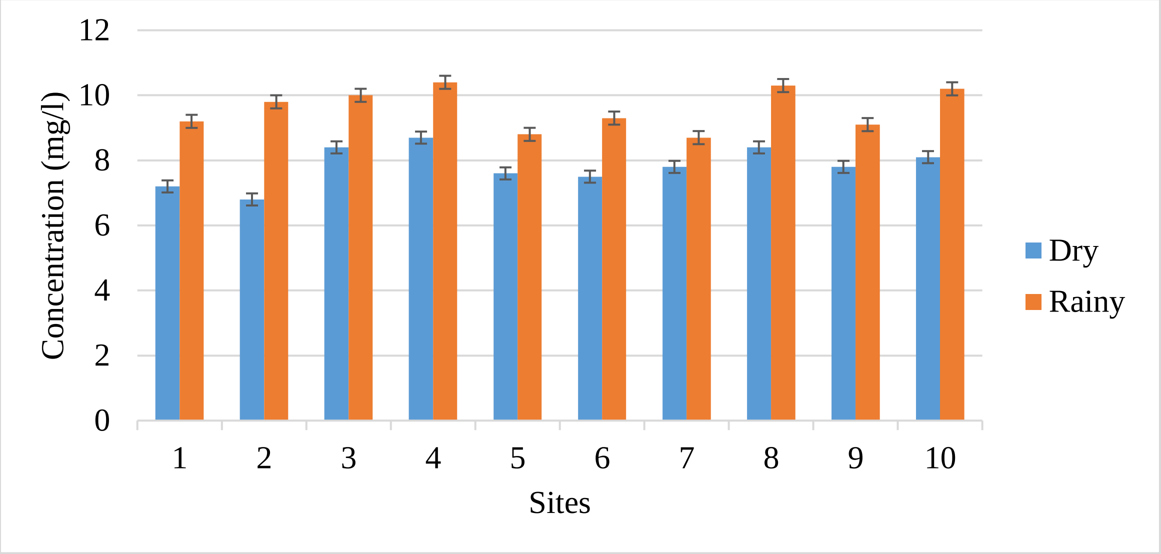

Figure 4. 8: The dissolved oxygen levels in water samples

The dissolved oxygen (DO) values during the dry season ranged from 6.8±0.06 mg/l in Site 2 to 8.7±0.11 mg/l in Site 4. During the rainy season, the DO values ranged from 8.7±0.09 mg/l in Site 7 and 10.4±0.03 mg/l in Site 4 (Table 4.8). All sampling sites had higher DO values during the rainy season than dry season (Figure 4.8). The DO values for both seasons were above the World Health Organization stipulated limit of >6.5 for survival of aquatic organisms (WHO, 2017). Therefore, the DO of the Sulal River does not adversely affect the lives of aquatic organisms. The lower DO values observed during the dry than rainy season could be due because of nitrification activity where oxygen is largely used during the process (Rounds *et al*., 2013). The correlation between dissolved oxygen and nutrients is presented in Table 4.10. The results agree with a study by Achieng *et al*. (2018) in Sosiani River, Kenya. According to Achieng *et al*. (2018), the reduced

DO levels during the dry season were attributed to higher temperatures is the dry season. Warm water holds less dissolved oxygen than cold water.

Bivariate Pearson correlation values in Table 4.10 were obtained by correlating the DO values and nitrogen, phosphorous and potassium (NPK) values from Table 4.8.

Table 4. 10: Bivariate Pearson correlation between DO and NPK in water

	Nutrients	r	Sig. (2-tailed)
Dry season	N	-.432	.412
	P	.038	.917
	K	.156	-.666
Rainy season	N	-.323	.363
	P	c	-
	K	.001	.997

There were no significant correlations between dissolved oxygen and NPK in water from Sulal River as shown by Table 4.10.

4.2.3: Electrical Conductivity levels in Water

The results of EC analyses on samples of water collected from 10 different sites during the dry and rainy seasons are shown in Figure 4.9.

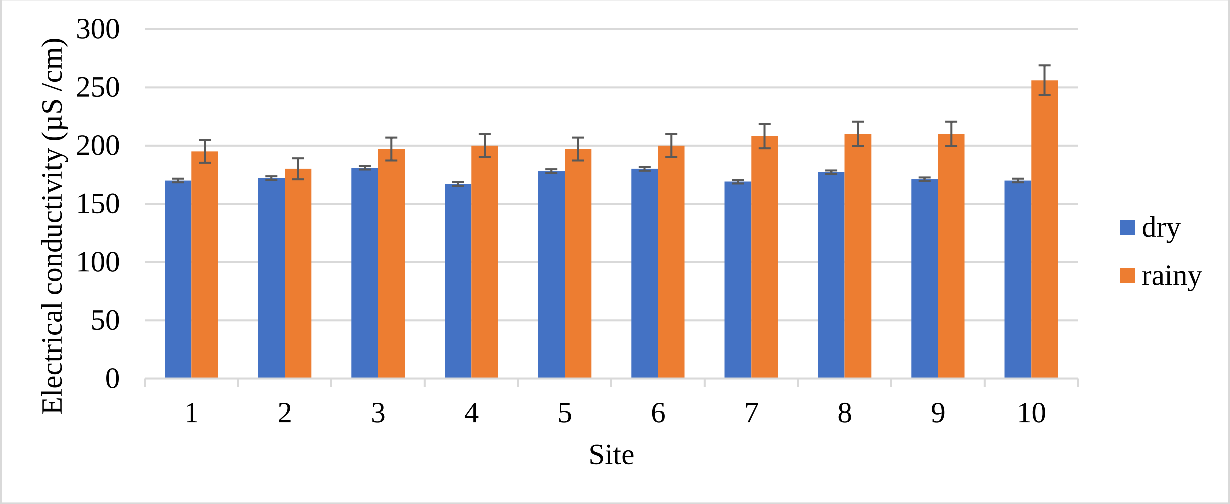

Figure 4. 9: The Electrical conductivity levels in water samples

The electrical conductivity values ranged from 167.00±3.64 µS/cm (Site 4) to 181.00±10.20 µS/cm (Site 3) in the dry season and from 180.00±9.08 µS/cm (Site 2) to 256.00±9.21 µS/cm (Site 10) during the rainy season (Table 4.8). Water samples from all the sites had lower EC during the dry season than rainy season (Figure 4.9). The results also showed an increasing EC trend from upstream to downstream during the rainy season (Figure 4.9). The electrical conductivity of water during the dry and rainy seasons was below the 1000 µS/cm standard limit specified by WHO (2017) for water for drinking and domestic use. The higher EC level during the rainy season is possibly because nutrients and other salts that conduct electricity are carried into water bodies by water run-off. The increasing trend from upstream to downstream during rainy season was probably due to increasing accumulation of water-soluble substances that can conduct electric current in downstream. The relationships between electrical conductivity and water-soluble nutrients are presented in Table 4.11. These results agree with the study by Ganiyu *et al*. (2018) in Ajakanga River, Ibadan, Nigeria and Achieng *et al*. (2018) in Sosiani River, Kenya.

Bivariate Pearson correlation values in Table 4.11 were obtained by correlating the EC and nitrogen, phosphorous and potassium (NPK) values from Table 4.8.

Table 4. 11: Bivariate Pearson correlation between EC and NPK in water

	Nutrients	r	Sig. (2-tailed)
Dry season	N	.634*	.049
	P	c	-
	K	.009	.980
Rainy season	N	.732*	.016
	P	.427	.219
	K	.480	.160

* Correlation is significant at the .05 level (2-tailed)

^{c} Cannot be computed because at least one of the variables is constant.

Water electrical conductivity had a significant positive correlation with nitrogen in both the seasons ($p<0.05$). Nitrogen is an electrolyte and thus increase the electrical conductivity of water (Mirzakhaninafchi *et al*., 2017). Similar correlation was obtained by Ganiyu *et al*. (2018) in water from Ajakanga River, Ibadan, Nigeria.

4.2.4: Total Dissolved Solids levels in water

The results of total dissolved solids (TDS) analyses on samples of water collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.10.

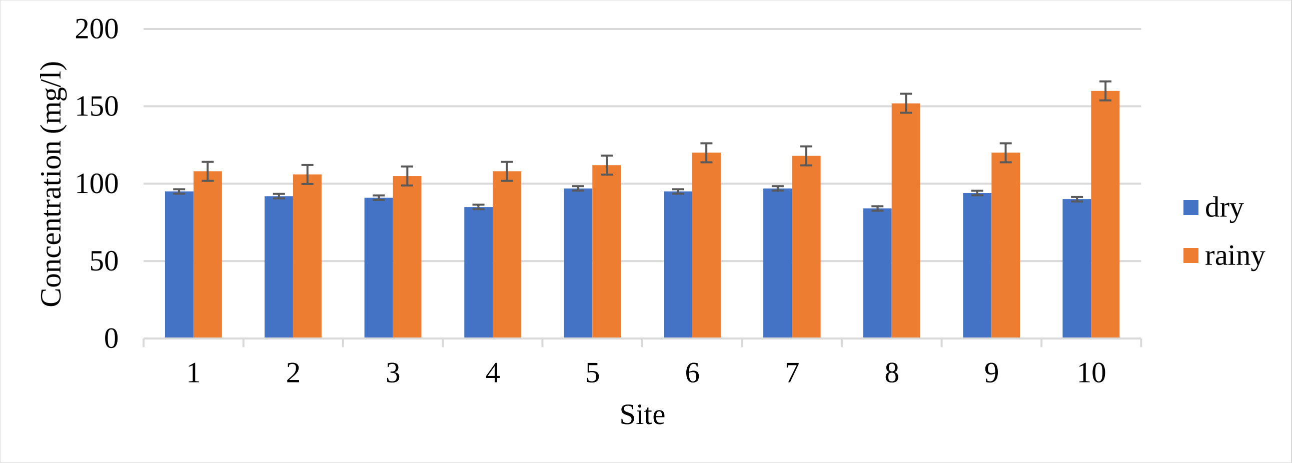

Figure 4. 10: The TDS levels in water samples

During the dry season, the levels total dissolved solids ranged from 84±6.27 mg/L in Site 5 to 97±2.80 mg/L in Site 8 (Figure 4.10). Similarly, during the rainy season the highest TDS level was recorded in Site 10 (160±2.09 mg/L) and the lowest in Site 2 (105±2.50 mg/L) (Table 4.8). TDS levels in all the sampling sites were higher during the rainy season (Figure 4.10) and this can be attributed to inflow of dissolved solids from agriculture farms (Nyongesa *et al*., 2018). The results also showed that there is an increasing trend from upstream to downstream during the rainy season and this is possibly due to increasing accumulation of total dissolved substances along the river course. These substances enter the river mainly from agricultural fields (Wu *et al*., 2018). The results of TDS were <500 mg/L levels stipulated by WHO (2017) standard limits for domestic water and for aquatic lives. Respectively. Bivariate Pearson correlation values in Table 4.12 were obtained by correlating the TDS and nitrogen, phosphorous and potassium (NPK) values from Table 4.8.

Table 4. 12: Bivariate Pearson correlation between TDS and NPK levels in

	Nutrients	r	Sig. (2-tailed)
Dry season	N	.389	.266
	P	c	-
	K	.046	.900
Rainy season	N	628	.083
	P	.122	.736
	K	.311	.381

[c] Cannot be computed because at least one of the variables is constant.

Water TDS and nutrients exhibit positive non-significant correlations ($p>0.05$).

4.2.5: Nitrogen levels in Water

The results of nitrogen analyses on samples of water collected from 10 different sites during dry and rainy seasons are presented in Figure 4.11.

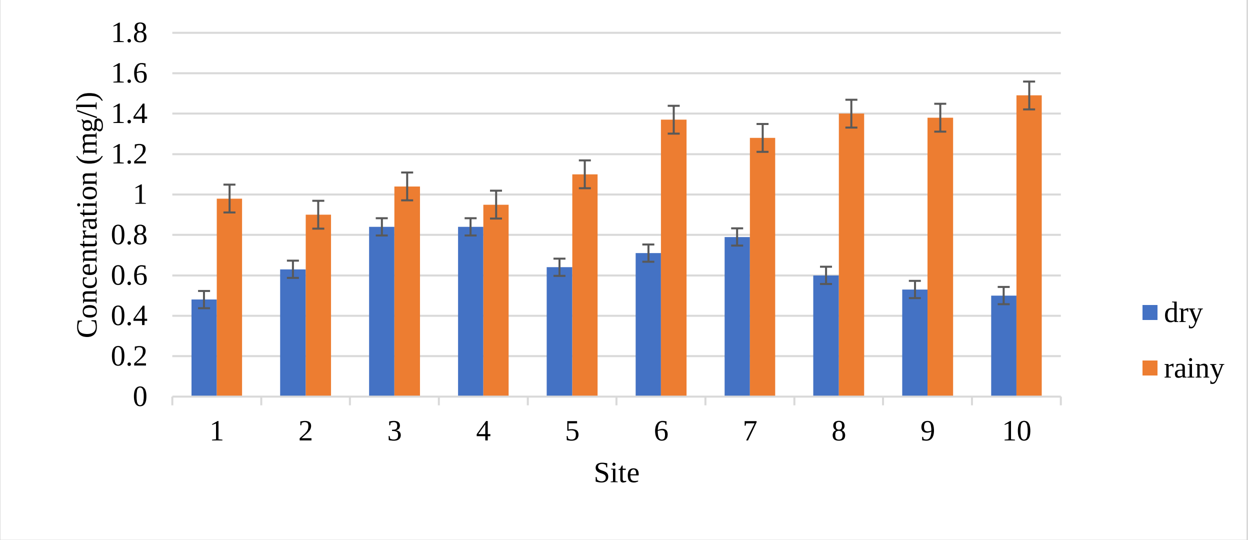

Figure 4. 11: Nitrogen levels in water samples

The results in Figure 4.11 showed that during the dry season the level of nitrogen in water samples ranged from 0.48±0.06 mg/L in Site 1 to 0.84±0.72 mg/L in Sites 3 and 4. During the rainy season, the level of nitrogen in water samples ranged from 0.90 mg/L in Site 2 to 1.49±0.30 mg/L in Site 10 (Table 4.8). The levels of nitrogen increased from Site 1 to Site 10 during the rainy season and this possibly because along the river course, there is an increasing accumulation of nitrates from agricultural fields. Nitrates are loosely bound to soil hence, easily washed by rain into surface water (Barker and Bryson, 2016). Nitrate levels in water samples for both seasons remained below the WASREB standard limit of 2.5 mg/L (WASREB, 2008) to support eutrophication and those stipulated by KEBS (KEBS, 2012) and WHO (WHO, 2017) of < 10 mg/L for drinking and domestic use. Thus, nitrogen is not considered to pose a problem to the domestic use of water from Sulal River. The results also showed that nitrogen levels in all the sites were higher in the rainy season than dry season (Figure 4.11). The paired t-tests values in Table 4.13 were obtained by comparing the mean values of nitrogen between two seasons from Table 4.8.

Table 4. 13: Paired water tests for difference in means of nitrogen between two seasons

	Nitrogen		Paired differences			
	Means (mg/l)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	0.42	0.24	Dry-rainy	9	-6.128	.000
Rainy season	1.19	0.20				

The mean level of nitrogen in water was higher in the rainy season than the dry season and the difference was statistically significant. High nitrogen level during the rainy season is possibly due to accumulation of considerable amounts of nitrate in the water body as a result of water run-off from the agricultural farms. It is known that the nitrate form of nitrogen is loosely bound to soil and hence, easily washed by rain into surface water (Barker and Bryson, 2016). The seasonal variation of nitrate-nitrogen observed in this study agrees with that reported from Nyamasogota River, Kisii County by Nyaboke (2013) and Awash River- Ethiopia by Eliku and Leta (2018).

4.2.6: Phosphorous levels in Water

The results of phosphorous analyses on samples of water collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.12.

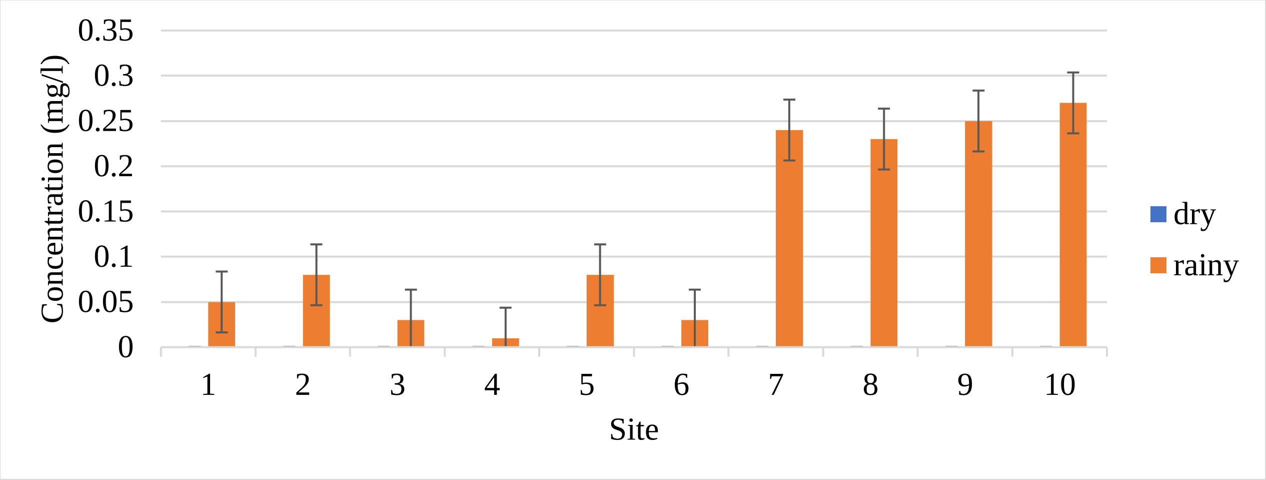

Figure 4. 12: Phosphorous levels in water samples

The phosphate-phosphorous concentrations during the dry season were below the detection limit of <0.012 mg/L (Figure 4.12). According to Kroiss, *et al.* (2011), there isn't a lot of ortho-phosphate in water during the dry season because it is incorporated into sediments and aquatic plants during the rainy season. Continuous accumulation of soil sediment in the bottom of the river makes phosphorus to settle too deep to be reintroduced to the water column (Dunn *et al.*, 2017). During the rainy season, phosphate concentration ranged from 0.01±0.02 mg/L in Site 4 to 0.27 ±0.01 mg/L in Site 10 (Table 4.8). The potential source of phosphate contamination in water during the rainy season were farms where fertilizers had been applied. Rain can flush out soil containing phosphates from the farm and carry them into nearby waterways (Boer *et al.*, 2019). A similar observation was made by Raguwanshi *et al.* (2013) in Parashari River in India and they attributed high phosphates levels in water to domestic sewage, agricultural runoff, industrial effluents and fertilizers.

The results also showed that the levels of phosphorous increase from Site 1 to Site 10 during the rainy season (Figure 4.12) and this is possibly because along the river course, there is an increasing accumulation of phosphorous from agricultural fields. The values were found to be above the 0.025 mg/L permissible limit for drinking water (KEBS, 2012; WHO, 2017) and the Kenya WASREB limit for phosphorous in water systems that will reduce the likelihood of eutrophication (0.005 mg/L) (WASREB, 2012). This confirms the pollution status of Sulal River with phosphorous. Phosphorous increases the growth of aquatic vegetation in water decreasing the amount of dissolved oxygen and hence the death of aquatic organisms (Jones *et al*., 2015). These results agree with a study by Omwoma *et al*. (2011) in Kuywa River in Western Kenya that phosphates which are not utilized by plants get washed from sugarcane farms into the river during the rainy seasons.

4.2.7: Potassium levels in Water

The results of potassium analyses on samples of water collected from 10 different sites during the dry and rainy seasons are shown in Figure 4.13.

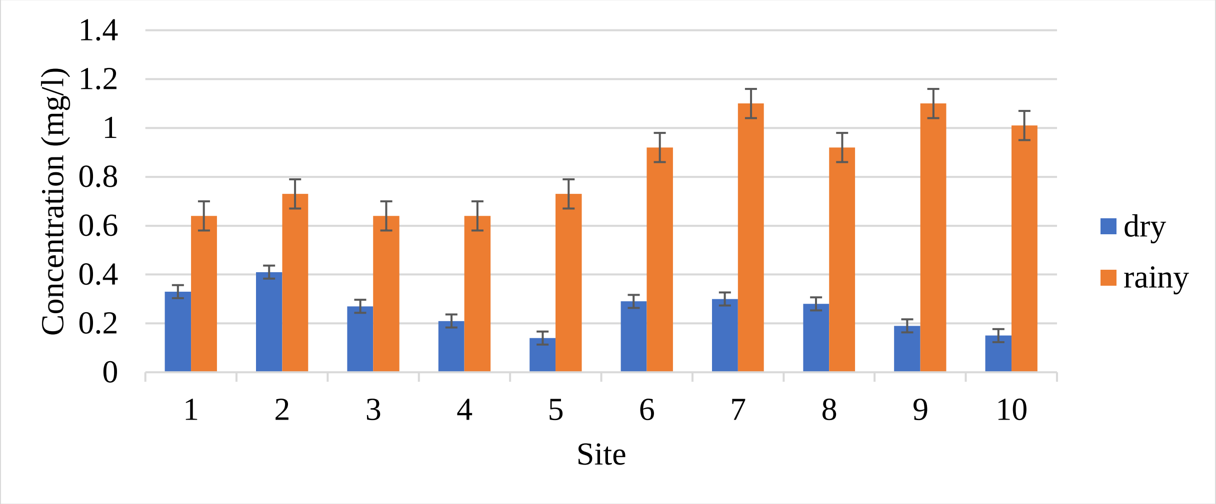

Figure 4. 13: Potassium levels in water samples

The level of potassium during the dry season ranged from 0.14±0.02 mg/L in Site 5 to 0.41±0.09 mg/L in Site 2 (Figure 4.13). During the rainy season, the potassium levels ranged from 0.64±0.32 mg/ L in Site 4 to 1.10±0.48 mg/L in site 9 (Table 4.8). The results also showed that the levels of potassium during the rainy season were higher in downstream than upstream, and this is possibly because accumulation of potassium from agricultural fields increases along the river course. There is no evidence of potassium being likely to pose much risk to the consumers' health and therefore potassium permanganate is used to treat water for domestic use (WHO, 2004). All sites had higher potassium levels during rainy season than dry season (Figure 4.13). The paired t-tests values in Table 4.14 were obtained by comparing the mean values of phosphorous between two seasons from Table 4.8.

Table 4. 14: Paired water tests for difference in means of potassium between two seasons

	Potassium		Paired differences			
	Means (mg/l)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	0.26	0.24	Dry-rainy	9	-8.611	.000
Rainy season	0.84	0.20				

The mean level of potassium in water was higher in the rainy season than the dry season (Table 4.14). The difference was statistically different. The variation is possibly because potassium in soil is not bound to organic materials (Majumdar *et al*., 2017) and so significant amounts can be washed by surface runoff during the rainy season. Similar variation was recorded by Kimani *et al*. (2016) in Chania River catchment in Kenya.

4.3: Physicochemical Characteristics and Nutrients in Sediments

The levels of physicochemical parameters (pH, electrical conductivity (EC), water content (WC)) and major nutrients (nitrogen (N), phosphorous (P) and potassium (K)) in 10 different sites were computed in triplicate results in the dry and rainy seasons. The results are shown in Table 4.15 and Figures 4.14 to 4.19.

Table 4. 15: Physicochemical parameters and major nutrients in sediment samples

	Dry season					
Parameter/ Site	**pH**	**WC (%)**	**EC** (µS /cm)	**NO_3^- N (mg/kg)**	**PO_3-P (mg/kg)**	**K (mg/kg)**
1	6.65±0.48	111.54±0.91	60±5.00	0.30±0.18	0.27±0.02	2.05±0.43
2	6.70±0.50	114.00±2.30	62±10.50	0.60±0.23	0.46±0.13	1.31±0.72
3	6.68±0.43	115.81±2.02	64±5.61	0.17±0.03	0.18±0.08	2.12±0.91
4	6.75±1.08	123.28±3.01	69±10.06	0.63±0.08	0.99±0.32	1.21±0.32
5	6.80±0.56	107.89±0.89	56±8.03	0.90±0.41	0.26±0.09	1.23±0.62
6	6.72±0.82	120.03±1.03	72±2.58	0.36±0.08	0.54±0.17	1.44±0.27
7	6.68±0.09	115.03±2.50	73±5.38	1.14±0.09	0.52±0.20	2.19±0.71
8	6.57±0.15	107.74±1.39	70±11.09	0.83±0.25	0.69±0.26	1.45±0.60
9	6.10±0.92	121.99±3.00	78±4.98	1.17±0.87	0.30±0.12	0.99±0.32
10	6.52±0.52	123.24±3.41	67±9.30	0.90±0.22	0.68±0.42	1.04±0.45
M±SD, n=10	**6.62±0.20**	**116.96±3.95**	**67±6.66**	**0.7±0.35**	**0.49±0.25**	**1.53±0.45**
	Rainy Season					
1	6.95±0.24	136.80±1.20	43±3.90	0.13±0.15	0.91±0.19	2.65±0.87
2	6.87±0.90	130.53±0.81	51±12.21	0.62±0.29	0.88±0.20	2.47±0.80
3	6.91±0.91	121.85±3.45	42±9.1	0.20±0.08	0.78±0.50	2.65±0.80
4	6.78±0.29	137.95±1.08	41±8.03	0.21±0.03	0.89±0.35	2.56±0.43
5	6.75±0.50	128.34±1.28	50±10.00	0.34±0.11	0.70±0.35	2.93±0.50
6	6.88±1.10	127.56±2.91	53±6.72	0.79±0.09	1.08±0.98	3.20±0.63
7	6.45±0.57	130.56±3.41	45±5.08	0.07±0.02	1.15±0.67	3.20±0.09
8	6.77±0.67	125.10±5.02	67±7.57	0.67±0.21	1.65±0.61	3.39±0.89
9	6.48±0.80	132.76±4.76	69±8.90	0.53±0.40	1.89±0.70	2.75±0.44
10	6.68±0.32	126.98±4.08	60±7.50	0.61±0.09	1.43±0.80	2.84±0.79
M±SD, n=10	**6.75±0.17**	**129.84±5.00**	**52±10.19**	**0.42±0.23**	**1.14±0.40**	**2.86±0.31**

4.3.1: pH levels in Sediment

The results of pH analyses on sediment samples collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.14.

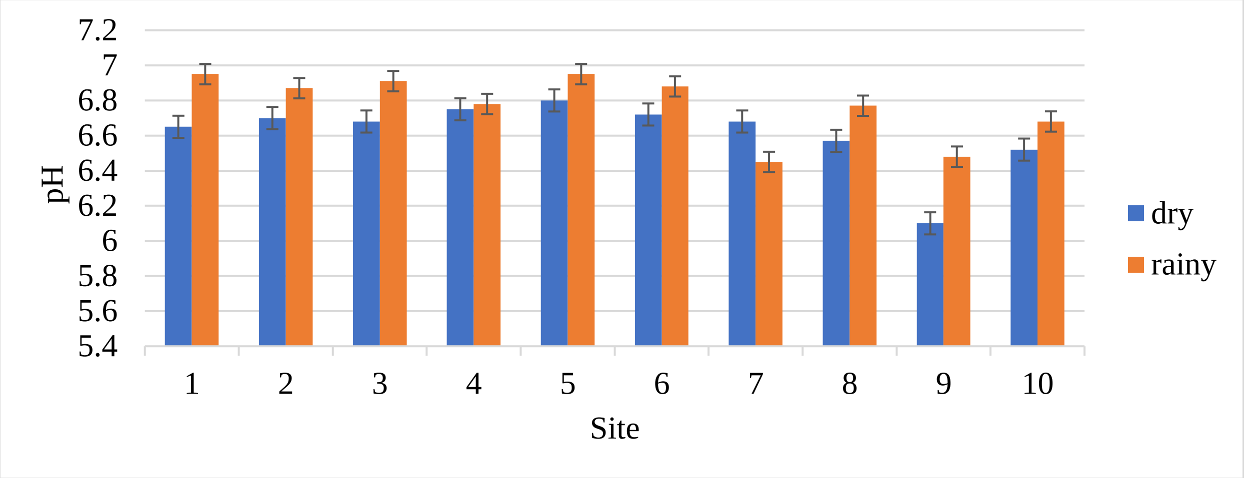

Figure 4. 14: The pH levels in sediment samples

During the dry season, the sediment pH ranged from 6.10±0.92 in Site 9 to 6.80±0.56 in Site 5 while, during the rainy season, the sediment pH ranged from 6.45±0.57 in Site 7 to 6.95±0.24 in Site 1(Table 4.15). The diverse levels of pH in different sites are possibly due to irregular deposition of different substances in the bottom of the river, however the slightly different pH in sediments (Table 4.15) from that of water (Table 4.8) is possibly due to sedimentation of soil particles containing heavy metals, pesticides, and fertilizers along the riverbed (Boyd 2019). The results also showed that the pH of sediment samples in all the sites except Site 7 were higher during rainy season than during dry season and this may be because of dilution effects of rain (Aigberua, 2018).

Bivariate Pearson correlation values in Table 4.16 were obtained by correlating the pH and nitrogen, phosphorous and potassium (NPK) levels from Table 4.15.

Table 4. 16: Bivariate Pearson correlation between sediment pH and NPK

	Nutrients	r	Sig. (2-tailed)
Dry season	N	-.952**	0.000
	P	-0.381	0.277
	K	.303	.394
Rainy season	N	-.151	0.677
	P	-.020	.957
	K	.001	.989

** Correlation is significant at the .01 level (2-tailed),

Correlation of pH and nitrogen was significantly different ($p<0.001$) at 95% confidence level. Negative correlations indicate that increase in nitrogen and phosphates results in decrease in sediment pH levels (Table 4.16). The correlations agree with results by Ajithamol *et al*. (2016) in sediments of Manakudy estuary, Tamilnadu, Sothern India.

4.3.2: Water Content levels in Sediments

The results of water content (WC) analyses on sediment samples collected from 10 different sites during dry and rainy seasons are presented in Figure 4.15.

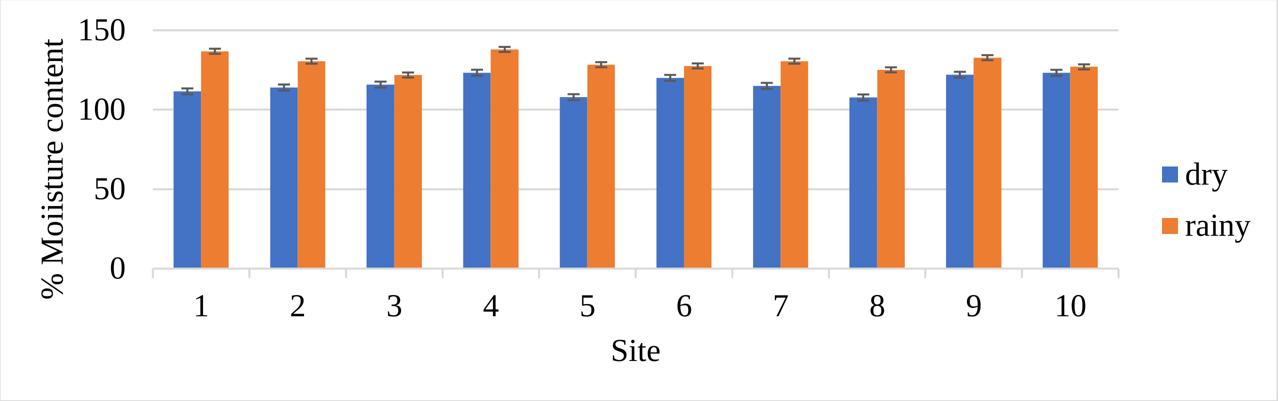

Figure 4. 15: The moisture content levels in sediment samples

The results in Figure 4.15 show that during the dry season, water content ranged from 111.54±0.91 % in Site 1 to 123.24±3.41 % in Site 10 while during the rainy season ranged from 121.85±3.45 % recorded in Site 3 to 137.95±1.08 % recorded in Site 4 (Table 4.15). The variations of sediment water contents in different sites are attributed to different amounts of organic matter that include nutrients from agricultural sources (Avimelech *et al*., 2011) while seasonal variation is due to the effect of rainfall. The correlations between sediment water content and soil nutrients in sediments are shown in Table 4.17.

Bivariate Pearson correlation values in Table 4.17 were obtained by correlating the water content and nitrogen, phosphorous and potassium (NPK) values from Table 4.15.

Table 4. 17: Bivariate Pearson correlation between sediment WC and NPK levels

	Nutrients	r	Sig. (2-tailed)
Dry season	N	.209	.561
	P	.286	.423
	K	.110	.561
Rainy season	N	.260	0.468
	P	.338	.339
	K	.282	.431

The correlations between sediment water content and NPK levels were not significantly different (Table 4.17).

4.3.3: Electrical Conductivity levels in Sediments

The results of electrical conductivity (EC) analyses on sediment samples collected from 10 different sites during the dry and rainy seasons are shown in Figure 4.16.

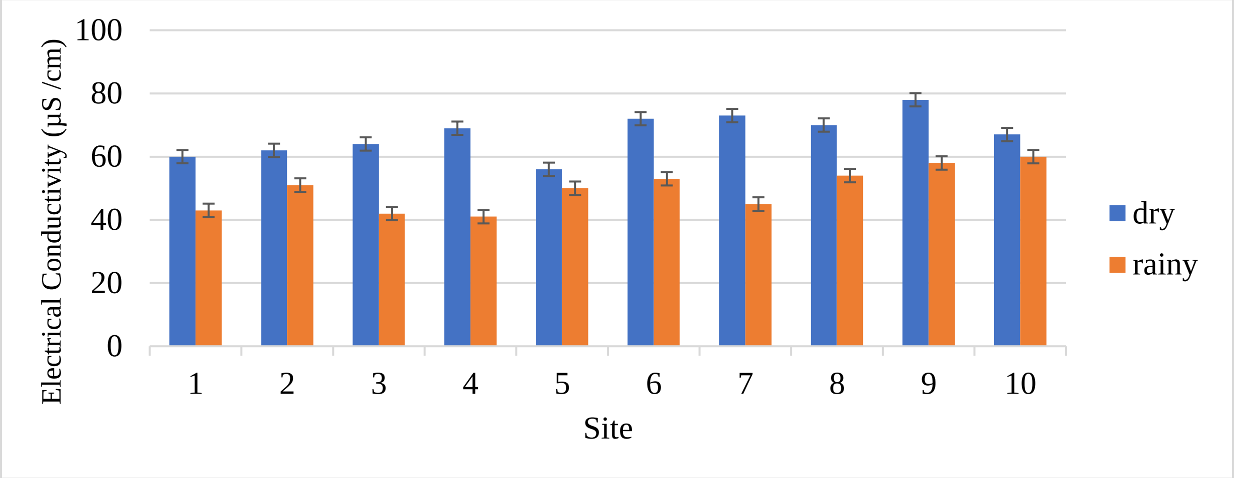

Figure 4. 16: Electrical conductivity levels in sediment samples

The highest electrical conductivity (EC) during the dry season was obtained in Site 9 with 78.00±4.98 µS/cm and the lowest was in Site 5 with 56±8.03 µS/cm. During the rainy season, the highest EC was recorded in site 10 with 60±7.50 µS/cm and the lowest in site 4 with 41.00±8.03 µS/cm (Table 4.15). The trend in EC increased from site 1 to 10 in both seasons and this is attributed to increasing sedimentation of soil particles containing substances that can transmit electricity conductivity downstream (Boyd 2019). Electrical conductivity (EC) levels for all samples were higher during the dry season compared to the rainy season (Figure 4.16) and this is possibly because salts tend to settle in sediments after the rains and are flushed out during the rainy season (Burdige, 2006). These results agree with a recent study under a similar environmental condition by Ondoo *et al*. (2019). According to their findings, the different levels of EC observed in this study could be probably attributed to different levels of nutrients in sediments. Bivariate

Pearson correlation values in Table 4.18 were obtained by correlating the EC and nitrogen, phosphorous and potassium (NPK) levels from Table 4.15.

Table 4. 18: Bivariate Pearson correlation between sediment EC and NPK in different seasons

	Nutrients	r	Sig. (2-tailed)
Dry season	N	.739*	.015
	P	.065	.859
	K	.498	.143
Rainy season	N	.492	.149
	P	.482	.429
	K	.470	.171

* Correlation is significant at the .05 level (2-tailed)

During the dry season electrical conductivity and nitrogen levels had significant positive correlation but low during wet season due to dilution (Table 4.18). The positive correlation indicate that sediment EC increased as the nutrients concentrations increase.

4.3.4: Nitrogen levels in Sediments

The results of nitrogen levels analyses on sediment samples collected from 10 different sites during dry and rainy seasons are shown in Figure 4.17.

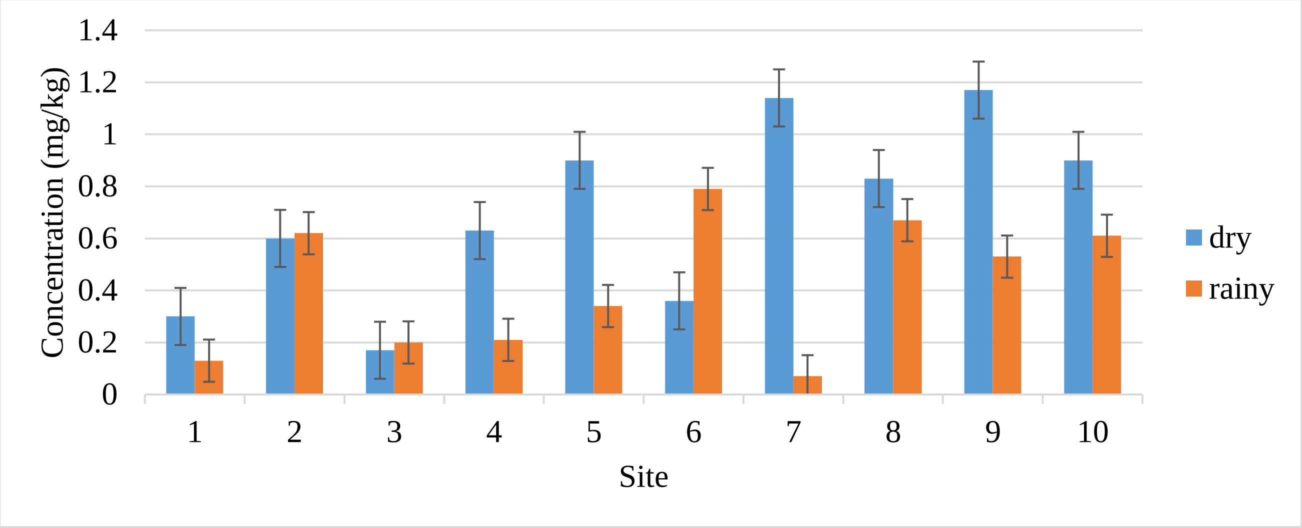

Figure 4. 17: Nitrogen levels in sediment samples

The level of nitrate-nitrogen during the dry season ranged from 0.17±0.03 mg/kg in Site 2 to 1.17±0.87 mg/kg in Site 9. During the rainy season the levels ranged from 0.07±0.02 mg/kg in Site 7 to 0.79±0.09 mg/kg in Site 6 (Table 4.15). Nitrate-nitrogen levels in all the samples during both seasons were within the Kenya WASREB (<2.5ppm) limit for likelihood of eutrophication. Therefore, the nitrogen level of the Sulal River does not adversely affect its waters. Upstream levels were slightly lower than downstream in the dry season (Figure 4.17). Except sediments from Sites 2, 3 and 6, all other sampling sites had higher nitrate-nitrogen levels during the dry season than the rainy season (Figure 4.17). The paired t-tests values in Table 4.19 were obtained by comparing the mean values of nitrogen between two seasons from Table 4.15.

Table 4. 19: Paired sediment tests for difference in means of nitrogen between two seasons

	Nitrogen		Paired differences			
	Means (mg/kg)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	0.7	0.24	Dry-rainy	9	1.975	.080
Rainy season	0.48	0.20				

The mean level of nitrogen during the dry season was higher than during the rainy season, however, the difference was not statistically different (Table 4.19). The higher levels of nitrogen in dry season may be due to sedimentation of fertilizer nutrients after the rains and from decomposition of organic matter that had settled on the top surface (Burdige, 2006). The low nitrate levels observed in the rainy season may be attributed to heavy flooding that remove the top layer of sediments and continuous flow of water in the river systems (Barker and Bryson, 2016). The observation differed from those of Ruto *et al.* (2017) in sediments along Saiwa Swamp Ecosystem, and Tukura *et al.* (2012) in Mada River, Nigeria where the levels of nitrates was lower during the dry season than the rainy season. Similar variation was recorded by Ondoo *et al*. (2019) in River Sio, Busia who concluded that heavy rains wash out nitrate from sediments and nitrate levels decrease drastically with continuous rains.

4.3.5: Phosphorous levels in Sediments

The results of phosphorous analyses on sediment samples collected from 10 different sites during the dry and rainy seasons are presented in Figure 4.18.

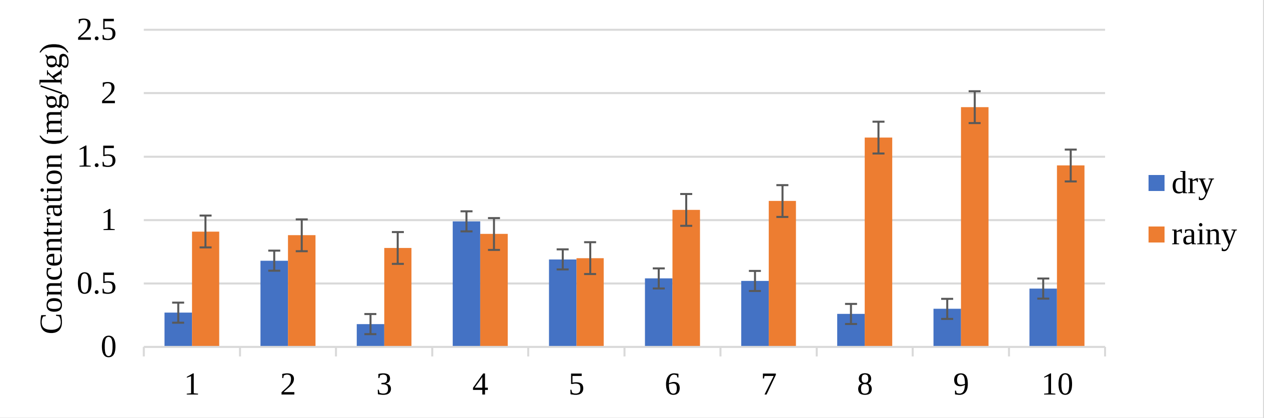

Figure 4. 18: Phosphorous levels in sediment samples

Phosphate-phosphorous levels during the dry season were minimum at Site 3 with 0.18±0.08 mg/kg and maximum in Site 4 with 0.99±0.32 mg/kg, while during the rainy season, the minimum was at Site 5 with 0.70±0.35 mg/kg and maximum at Site 9 with 1.89±0.70 mg/kg (Table 4.15). Upstream concentration levels were slightly higher than downstream in the rainy season. The values of phosphorous obtained in both seasons were all above 0.005 ppm minimum limit for the likelihood of eutrophication (WASREB, 2008). This confirms the polluted status of Sulal River by phosphorous. Ondoo *et al*. (2019) also reported higher phosphorous levels in sediments in River Sio and they attributed it to discharge of detergents containing phosphorous, water runoff from phosphorous fertilized farms and discharge of domestic sewage. High phosphorus in sediments can lead to eutrophication (Jones *et al*., 2015). Except in Site 4, phosphorous levels were all higher in the rainy season than dry season (Figure 4.18). The paired t-tests values in Table 4.20 were obtained by comparing the mean values of phosphorous between two seasons from Table 4.15.

Table 4.20: Paired sediment tests for difference in means of phosphorous between two seasons

	Phosphorous		Paired differences			
	Means (mg/kg)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	0.49	0.24	Dry-rainy	9	-3.720	.005
Rainy season	1.14	0.20				

The mean level of phosphate-phosphorous was higher in the rainy season than the dry season and the variation was statistically different (Table 4.20). The higher level of phosphorous in the rainy season observed may be due to discharge and subsequent sedimentation of suspended particulates from phosphate fertilizers, and domestic wastes discharged into the river as a result of rainfall. Unlike nitrogen, phosphates cling tightly to sediments and is not washed away easily (Karkanas and Goldberg, 2018). The variation agrees with a research by Basweti, *et al*. (2018) in sediments in River Nzoia, Kakamega County, Kenya.

4.3.6: Potassium levels in Sediments

The results of potassium analyses on sediment samples collected from 10 different sites presented in Figure 4.19.

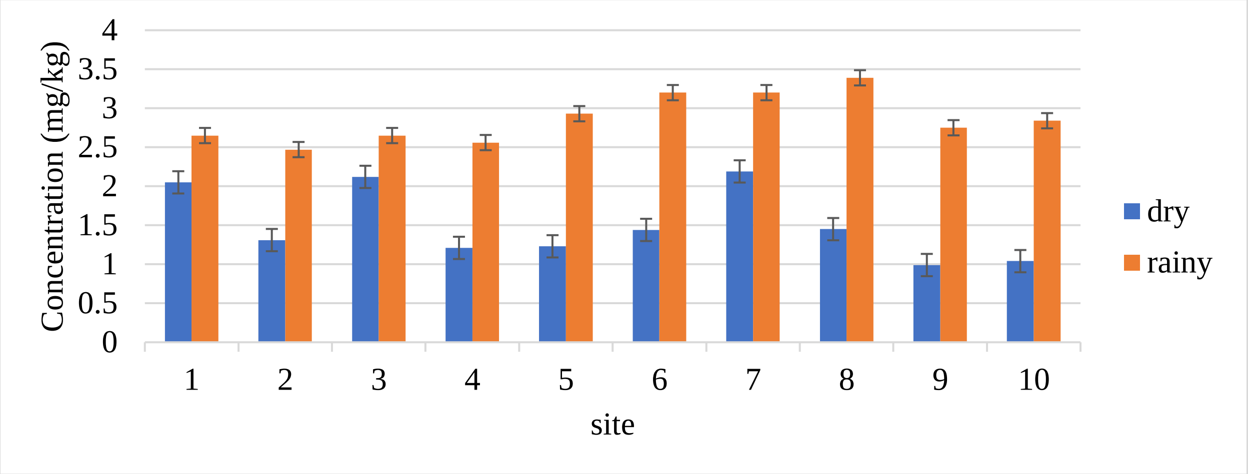

Figure 4. 19: Potassium levels in sediment samples

Figure 4.19 shows that during the dry season the potassium levels were minimum at Site 9 (0.99±0.32 mg/kg) and maximum at Site 7 (2.19±0.71 mg/kg), while during the rainy season, the minimum level was at Site 2 (2.47±0.80 mg/kg) and maximum at Site 8 (3.39±0.89 mg/kg) (Table 4.15). Manohar *et al*. (2017) had reported similarly low values of potassium in sediments, but higher than in water. They concluded that potassium tends to settle to the bottom, and consequently ends up in sediment mostly. All sampling sites had higher potassium levels during the rainy season than during the dry season (Figure 4.19). The paired t-tests values in Table 4.21 were obtained by comparing the mean values of potassium between two seasons from Table 4.15.

Table 4.21: Paired sediment tests for difference in means of potassium between two seasons

Potassium			Paired differences			
	Means (mg/kg)	Std. Deviation		df	t	Sig. (2-tailed) 95% CL
Dry season	1.5	0.24	Dry-rainy	9	-8.344	.000
Rainy season	2.86	0.20				

The seasonal variation was significantly different (Table 4.21). The higher concentration of potassium in the rainy season might be due to inflow of agricultural influents from the surrounding farms and is readily retained by the soil constituents of sediments. Similar observation was recorded by Ruto *et al*. (2017) in sediment samples collected along Saiwa Swamp Ecosystem, Trans Nzoia County, Kenya.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1: Conclusion

The results of the analyses of soil samples collected at different sampling sites showed the soils in both seasons had low major nutrients levels. Physicochemical parameter examination showed that soil was moderately acidic. Soil acidity in tea farms is attributed to continuous heavy application of chemical fertilizer (Owuor *et al.*, 2011). Significant correlations were observed between moisture content and electrical conductivity, moisture content and phosphorous, moisture content and potassium, Electrical conductivity and phosphorous, electrical conductivity and potassium, and phosphorous and potassium. The mean levels of electrical conductivity, moisture content, phosphorous and potassium were higher in the rainy season than dry season while pH and nitrogen values were higher in dry season than rainy season. Seasonal variation of potassium in soil was significantly different ($p<0.05$).

The results of the analyzed physicochemical parameters of water showed that Sulal River is polluted with phosphorous in the rainy season. The high level of phosphate may have eutrophic effect on Sulal River. All other levels of the investigated water parameters in both seasons were within the permissible levels stipulated by KEBS (2012), WHO (2017), and Kenya WASREB (2008). Except for the pH and dissolved oxygen, all other analyzed parameters (total dissolved solids, electrical conductivity, nitrogen, phosphorous and potassium) had higher levels during rainy season than during the dry season, and it can be concluded that agricultural applications of fertilizers during the rainy season may be a potential source of nutrient load in water. Seasonal variations of NPK in water from Sulal River were all significantly ($p<0.05$) higher in rainy season than dry season.

The results of sediment samples collected at different sampling sites showed diverse levels confirming that the nutrient levels in sediment samples were due to irregular sediment deposition in the river from the farms. Physicochemical parameter examination revealed that the level of phosphorous in sediments in both seasons was higher than the Kenya WASREB (2008) stipulated limit for likelihood of causing eutrophication. Seasonal variations showed that potassium was significantly higher in the rainy season than the dry season.

5.2: Recommendations from the study.

i. Farmers should not apply fertilizers during the onset of heavy rainfall since much are washed away and drained into the river water. This deprives plants nutrients, resulting in economic loss to the farmer as well causing pollution of Sulal River.

ii. People who use water from Sulal River for drinking and domestic purposes should purify water before use or use other alternative water sources.

iii. Protection of Buffer zones should be made mandatory to protect soil containing agricultural nutrients from entering Sulal River.

iv. A study should be undertaken to determine the pesticide residue levels in Sulal River catchment area.

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APPENDICES

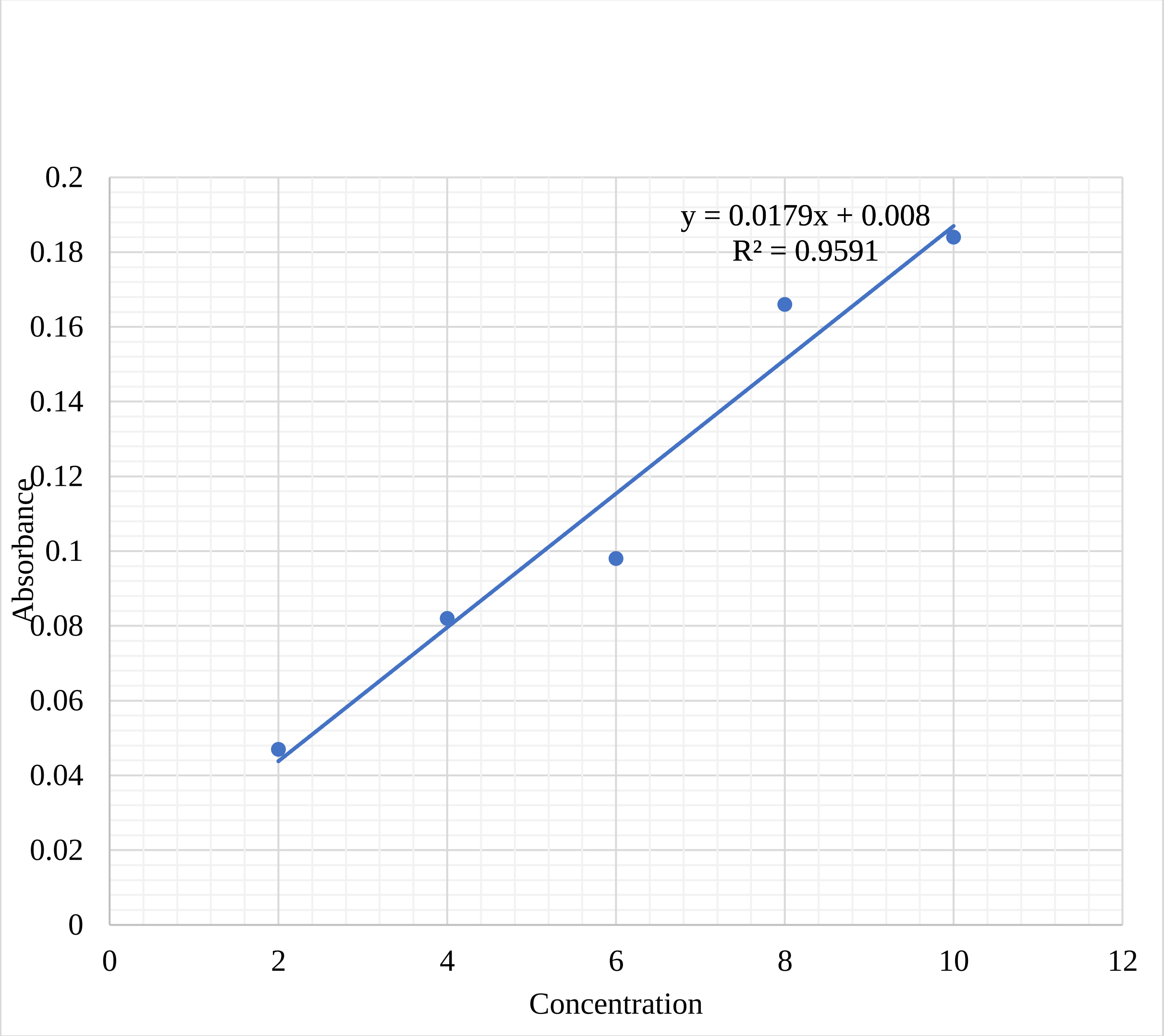

Figure 4 a: Calibration curve for NO_3^- N

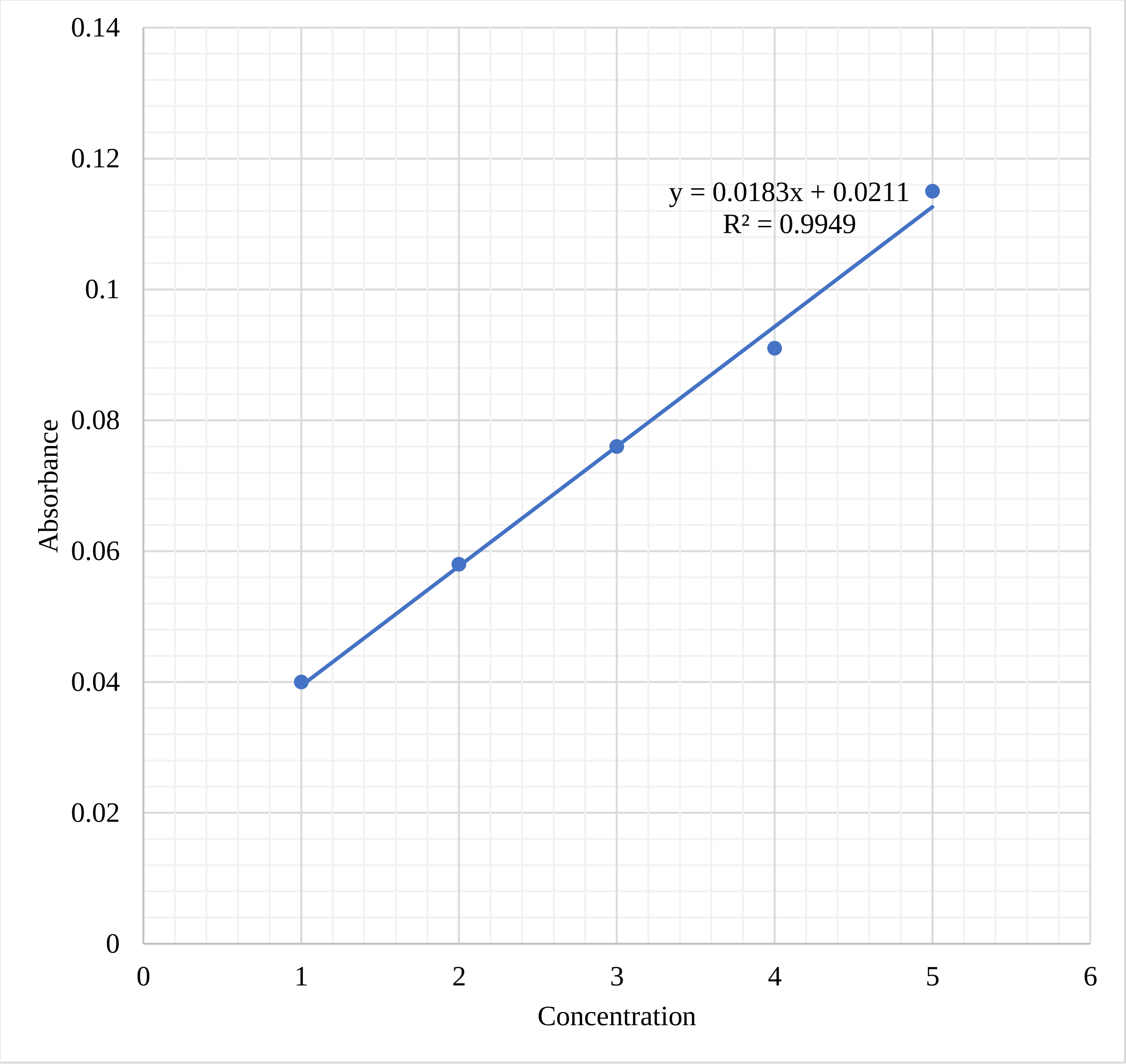

Figure 4 b: Calibration curve for $PO_4{}^{-}$ P

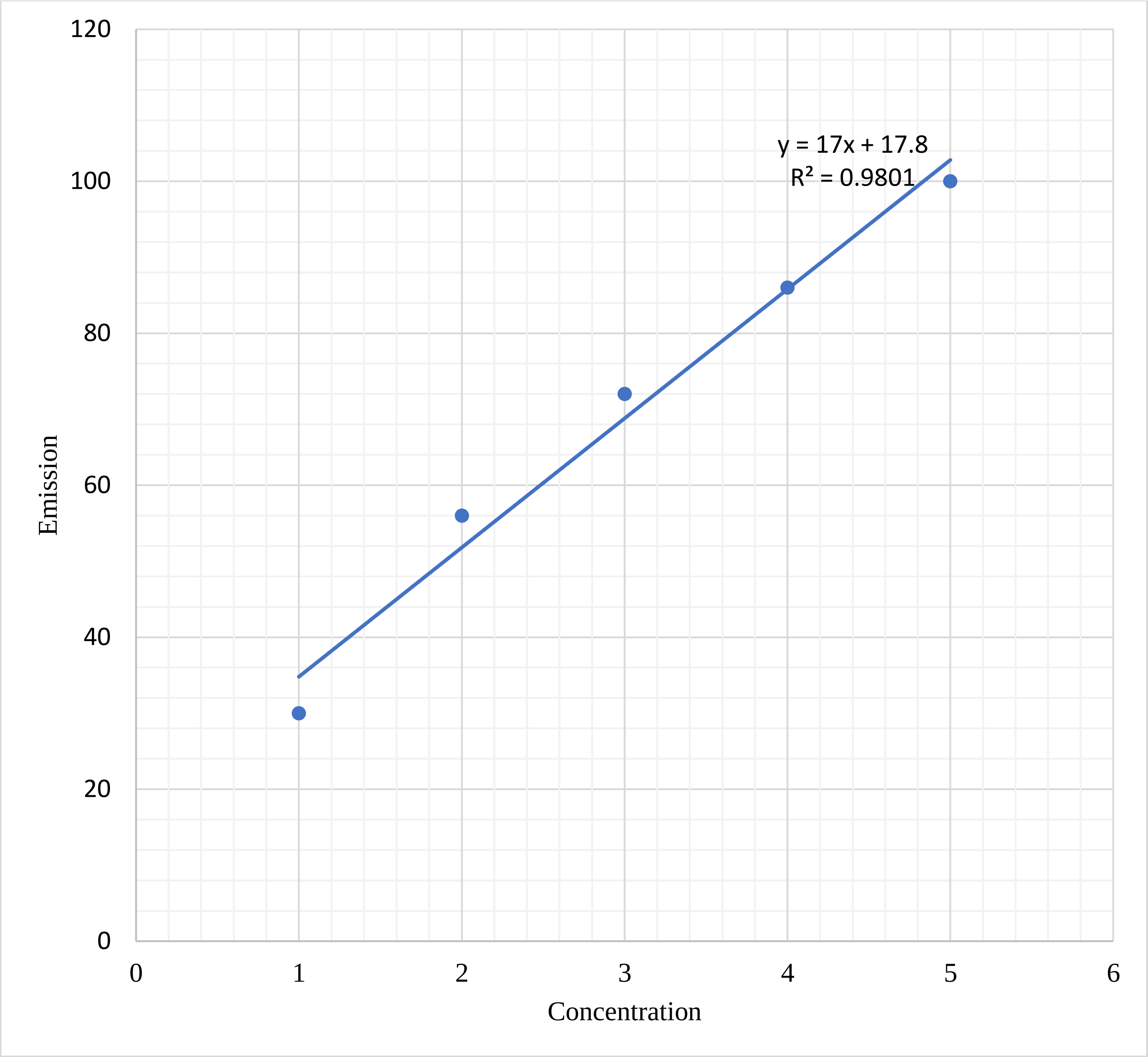

Figure 4 c: Calibration curve for K