EFFECTS OF LAND USE DISTRIBUTION ON THE SURFACE WATER QUALITY IN THE UPSTREAM SECTION OF NAIROBI RIVER

Samuel Mburu Gituara
(C50/5008/2017)

A project report submitted in partial fulfillment of the requirements for the award of the degree in Masters of Arts in Environmental Planning and Management of the Department of Geography and Environmental Studies, University of Nairobi, Kenya.

September 2021

DECLARATION

This research project is my original work and has not been presented for a degree in any other university.

____________________ Date: 16/09/2021

Samuel Mburu Gituara.
(C50/5008/2017)

Declaration by Supervisors

This research project has been submitted for examination with our approval as university supervisors.

____________________Date: 16/09/2021

Prof. George Okoye Krhoda
Department of Geography and Environmental Studies
University of Nairobi.

____________________ Date: 16/09/2021

Dr. Isaiah Ang'iro Nyandega
Department of Geography and Environmental Studies
University of Nairobi.

DEDICATION

This research work is dedicated to my wife Margaret Murugi and loving daughter Zara Mburu.

ACKNOWLEDGEMENTS

I would like to thank most sincerely the following persons and institutions for their valuable contribution in various ways towards the completion of this research project. First, I would like to thank my academic supervisors, Prof. George O. Krhoda and Dr. Isaiah A. Nyandega for their critical review, guidance and input towards enriching and elevating the research to an acceptable academic output. Secondly, I would like to extend my sincere gratitude to Ms. Joyce Kiboi and Margaret Muriithi of the University of Nairobi Public Health Engineering Lab for their assistance in the collection and analysis of water samples. The research would be incomplete without their help.

Thirdly, I would like to offer my gratitude to my colleague Solomon Karani for the help in GIS related outputs and to my friend George Gachie who guided me in the use of R program for water quality data analysis. To my wife, Margaret and daughter Zara, thank you for your patience and support throughout the process. Special thanks go to my parents, Mr. and Mrs. Gituara and family at large, thank you all for raising me and showing me the value in education.

Lastly, as it is not possible to list the names of all the persons who contributed in one way or another to the development of the research work, I appreciate you all and sincerely thankful to you. May God bless you all abundantly.

ABSTRACT

The river ecosystems play critical roles in ensuring the general human wellbeing and social-economic development. Despite their importance, surface water resources and rivers in particular face threats from several factors and key among them is the changes in land use in a watershed. Pollution of rivers contributes to the growing problem of water stress around the World, Kenya is not an exception to this experience. The main objective of this study was to understand the effects of spatial land use distribution on water quality characteristics in in the upstream section of Nairobi River extending from the source at Ondiri Swamp up to its cross section at Naivasha Road Bridge, a stretch of 10.2 kilometers. A riparian buffer strip of 500 meters on either side of the river bank was adopted for the study to allow data collection of water samples and land use types. The main objective of the study was achieved by answering the questions of what the land use types were in the study area, the state of physical, chemical, and biological water quality characteristics, and what relationship existed between the land use types and the water quality parameters. The study used GIS and remote sensing to analyze the land use types in the study area using ArcGIS version 10.8. Water quality was collected by applying systematic random sampling at an interval range of 2.0 km. and ensuring that each point was located at the tributary confluence and exhibiting distinct land use type. Water samples were analyzed *in situ* and at the University of Nairobi Public Health Engineering laboratory. Transportation of samples was done using marked glass bottles and a cooler box to avoid degeneration of samples. All samples were tested within 24hrs of collection. The relationship between the land use type and water quality was analyzed using the nonparametric Spearman's correlation test using R program version 4.0.2. The study results showed that the main land use types were agricultural, urban-settlement mix, and wetland. The water quality parameters showed significant differences between the dry and wet seasons as well as sampling sites along the river gradient. In both seasons, water quality was noted to deteriorate downstream with no discernible trends partly due to random effluence discharge at various points of the river and the hydro-geochemical processes within the river system. The wetland was found to influence water quality parameters that are indicative of pollution positively, while the urban settlement land use was found to degrade water quality particularly in the wet season. For instance, Spearman's analyses showed that pH was strongly negatively correlated with wetland in both seasons but had a strong positive correlation with residential land use, these correlations were significant at $p<0.05$. There was however strong and significant positive correlation between settlement areas and Total faecal coliforms at 0.954 with a computed P value of 0.01 (at $P<0.05$). These residential areas did not have adequate sewerage infrastructure and their location within the 500m riparian area, limited vegetation cover exacerbated the effluents drainage to the river. The study concluded that there was evidence of effects of land uses on water quality based on the degree of anthropogenic modification on a particular land use. The less modified wetland had less impact on water quality by filtering the pollutants though the encroachment could degrade the riparian vegetation around the wetland. The research recommends that increased residential densities be matched with commensurate water and sewer management infrastructure to manage levels of fecal coliform elements into the river system. Increment of vegetation cover to act as buffer zone along the riparian land and use of storm retention dam with complementary treatment works were recommended to the south of ILRI. At a policy level, the river water is expected to be suitable for augmenting water supply to Nairobi City and adjoining Counties.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ACRONYMS AND ABBREVIATIONS

BOD	Bio-Oxygen Demand
CBD	Central Business District
CCN	City County of Nairobi
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS	Geographic Information System
ILRI	International Livestock Research Institute
Km	Kilometer
NTU	Nephelometric Turbidity Units
PCEA	Presbyterian Church of East Africa
PH	Potential of Hydrogen
TDS	Total Dissolved Oxygen
UNEP	United Nations Environmental Programme
UTM	Universal Transverse Mercator
WASREB	Water Services Regulatory Board
WHO	World Health Organization
SRTM	Shuttle Radar Topography Mission
USGS	Unite States Geological Survey
NDVI	Normalized Difference Vegetation Index
NEMA	National Environment Management Authority
KEBS	Kenya Bureau of Standards
WRMA	Water Resources Management Authority

Chapter 1: INTRODUCTION

1.1 Background of the Study

Globally, the planet is being harmed to a point where we are losing biodiversity and ecological services of our natural assets at a very alarming rate, including rivers. The river ecosystems are part of the infinitesimal 2.5% of the freshwater amount available to human for various uses to meet social, economic, and ecological needs (Postel *et al.*, 1996). Despite the critical role played by the rivers in ensuring the wellbeing of humanity, there is increasing pressure on river ecosystems from growing population, climate change/variability, changes in global water consumption behavior, and land degradation from changing landuse and cover (Kummu *et al.*, 2016). Land use is an important factor in addressing the freshwater availability. According to (Foley 2005), anthropogenic activities associated with changing land use are capable of disrupting surface water equilibrium by influencing proportion of precipitation into runoff, infiltration and evapotranspiration. Similarly, the nature of some land use activities such as agriculture can affect water availability through surface and ground water withdrawals.

Most rivers globally are now being polluted to a point that they no longer support any kind of life and therefore rendered useless for any kind of utilization. Therefore, to combat water pollution, it is important to recognize the challenges causing the pollution first, then become part of the solution. According to Dudgeon *et al.* (2005), river pollution and river flow modification are indicated to pose some of the highest risks to freshwater biodiversity apart from having undesirable effects on drinking water provision, supply of water for irrigation, fisheries and related activities such as recreation. Palmer *et al.*, (2005), argued that the lost ecological and social goods and services as a results of river ecosystem degradation can be restablished through the stream restoration programs. Stream restoring closer to the natural conditions of a river will always result to their multifunctional use whether for urban related practices or for rural related purposes. The study for instance also established that it was not feasible to restore longer lengths of rivers in Europe, where river systems were found to be extensively degraded.

This determination had earlier been established by Brookes (1996), who had argued that the restoration of rivers in urbanized catchments was more difficult since the water quality problems and channelization appeared to limit the restoration options available. This led to the need for advanced knowledge in channel restoration which resulted to a pilot project which was funded by the European Community Life Fund (Brookes, 1996). It involved 3 rivers with identified sites stretching between three and twelve kilometers each, two located in low-lying England while the other was located in Denmark. This sectional restoration of rivers in Europe later bore much fruits and rivers such as the Tsiza were later restored fully. In a similar project which was undertaken independently in a number of pilot projects, typically on reaches of 2 km or less in Baden-Wurttemberg resulted to full restoration of River Danube through an elaborate plan that was later formulated to 're-naturalize' its entire length of 160 km (Larsen, 1994).

Locally, the trends in population and the socio-economic dynamics within the Nairobi River watershed have a bearing on the composition of pollutants, a situation that is compounded by the encroachment of the riparian land due to demand for housing (Mwiti, 2014). The pollutants range from organic pollutants from raw sewage; to heavy metals from industrial effluents and from the vehicular spillages as shown in a study by (Kithiia, 2006). According to Gichuki (1979), pollution of the Nairobi River had been going on for more than 75 years at the time of the research. During that time and preceding the World War II, the pollution was mainly organic material and railroad oil waste. Afterwards, pollution became a composite mix of urban sewage, industrial wastes and superficial overflow containing huge quantities of silt. Ever since, urbanization as a consequence of fast-growing population, and rapid growth in the industrial space, the four main Nairobi Rivers namely Mathare, Ngong, Athi and Kiu have been under enormous pressure. The rivers are heavily polluted from both industrial and domestic wastes directly discharged into the rivers without being treated and adversely impacting its ecology (AFD, 2012; Mwiti, 2014).

Due to the complete disregard in wastes discharge, the damaged river ecology poses a serious risk to human health and is considered an ecological health threat owing to the high concentrations of biochemical & pathological contamination. Nevertheless, (Tibaijuka, 2007) determined that approximately half of the city population in one way or the other, were still reliant on the river for urban related agriculture, in some cases for drinking or other domestic use. The situation has not changed with recent reports from the World Health Organization (WHO, 2016) reporting that most agricultural products consumed in Nairobi City contained high traces of lead elements and were harmful for human consumption. The report attributed this phenomenon to the urban agriculture practices that were found to have been highly dependent on the Nairobi River to water their crops.

In spite of this, there have been no notable efforts to research on this endemic problem in the hope of offering a solution and this becomes the entry point to this study. The outputs of the study are aimed at promoting channel restoration of the river system right form the source within a manageable environment in the hope that future restoration plans of the entire river system could be formulated from the outputs of this study.

1.2 Problem Statement

Kenya as a country has a water scarcity issue with a renewable water supply which is lower than 1000m^3 per head per year (UN Water, 2006). The situation is deteriorating for inland water bodies especially rivers which are increasingly being impacted by effects of pollution (Achieng, Raburu, & Kipkorir, 2017). River ecosystems have been found to be particularly vulnerable to pollution effects arising from the land use changes and alterations (Malmqvist & Rundle, 2002).

The study area is located at the border of Nairobi and Kiambu Counties. This area is one of the most water stressed regions due to high population growth rate. According to Ledant (2013), the population of Nairobi has doubled every 15years since independence with KNBS, (2015), classifying Kiambu County as one of most populous counties in Kenya. Ledant describes Nairobi as being in an inescapable situation of structural water shortage with a tendency to depending on water from remote sources. This is despite its strategic location in the Upper Athi River basin Kithiia (2006), most of the rivers remain underutilized due to the effects of anthropogenic activities such smallholder farming around the source of Nairobi River, human settlements and light industries downstream (Koigi, 2015).

The extent of pollution problem in the study area has been well documented in studies by (Kithiia, 2006; Koigi, 2015), among other researchers. Koigi (2015), showed the extent of pesticides and heavy metal pollution in Nairobi River including the source at Ondiri Swamp while Kithiia showed the implications of land use change had on water quality as well as flow characteristics of Nairobi River. These factors could pose a problem to decentralized water augmentation strategies that may be required in future for Nairobi to be water sufficient. The section of Nairobi River flowing through the city has been adequately studied by National Environment Management Authority (2011), and reported to be severely polluted by unabated untreated effluents, solid wastes from domestic and industrial sources. In a bid to understand the complex nature of the pollution trends in the river and hoping a viable solution to mitigate the health hazards would be recommended, this study directed its research to the other segment of the river system which has not been adequately researched on. This is the upstream river section defined by Ondiri swamp and Naivasha Road Bridge.

Macharia *et al*. (2010), established that the river ecology at Ondiri Swamp was fairly clean for human consumption but human activities around the swamp were slowly degrading the wetland. Since that time, land use change of varied intensities has occurred and continue to occur around the wetland and along river profile. If left unchecked, the continued urban sprawl causing the change in landuse will continue impacting on the quality of water and similar detrimental results as those that has been reported elsewhere downstream as the river traverses Nairobi City and informal settlements will be witnessed. On this premise, this research was timely in an attempt to establish the effects the current use of land has on the quality of water in the wetland and along the stated river section.

The researcher hopes that this study will comprehensively bring out the current land use distribution along that river section, determine the current status of water quality guided by various parameters and relate that to the land use activities. The study will be beneficial to future research on the river ecology, policy makers, various institutions and County Governments in addressing various water related risks associated with the river including augmenting water supply to the City or for Urban Agriculture practices. Additionally, the study will initiate efforts by various government institutions led by the Regeneration Committee to restore the Nairobi River basin through the anticipated restoration programs of the Nairobi River Basin. This is because it may be the start of a long-lasting phased clean-up of the river resource right from its source.

1.3 Research Questions

The research is modelled to respond to the questions outlined below:

a) What is the spatial distribution of land uses in upstream section of Nairobi River?

b) What is the state of water quality along the upstream section of Nairobi River?

c) What are the effects of the land use distribution on the water quality, and to what extent do they relate in the upstream section of Nairobi River?

1.4 Research Objectives

The overall objective of the research was to understand the effects of the various land use types (distribution) on water quality characteristics in the upstream section of Nairobi River. The study's specific objectives were to establish:

a) The spatial land use distribution in the upstream section Nairobi River
b) The water quality characteristics along the upstream section Nairobi River.
c) The relationship between the spatial land use distribution and water quality in the upstream section of Nairobi River

1.5 Research Hypotheses

The research assumed two null hypotheses outlined below:

a) **H_0** – There is no significant difference in the water quality features along the river profile
b) **H_0** – There is no significant relationship between the spatial land use distribution and water quality

1.6 Justification of the Study

Most of the studies in Nairobi River have been done by studying pollution at a catchment scale. At this scale, the non-point pollution sources including those that are agricultural related and urban settlement run off are difficult to detect. This is because there are complex interactions between the topography and geology in an area, these two factors also influence water quality. This study analyzed the effects of land use at a riparian scale by considering a riparian zone of 500m on each side of the river.

Previous studies within the study area have focused on a limited number of physicochemical parameters and neglected some of the parameters that are also indicative of impacts of anthropogenic activities on water quality in rivers. Also, by focusing on a wide range of parameters on a limited scope, the study is able to make important conclusion of impacts of land use types that are in direct interaction with Nairobi River.

In Nairobi City, the river presents a treasure that would potentially make water available for every City Dweller. However, the continued detrimental effects of the use of land on the water quality impends anthropological water uses and their life supportive capacity together with the integrity of fresh water ecologies downstream dependent on the river for recharge. In spite of this, the section of Nairobi River under study continue to undergo tremendous land use change in the last decade with little or no information researched on it to establish the effects this change in land use has on the quality of water. The findings of this study will therefore go a long way in assisting policy makers and implementers in drafting informed water management action plans, policies and regulations towards realizing sustainable use of the river resource.

Additionally, the selection of this site was considered timely considering that Nairobi City is still faced with a challenge of sustained fresh water supply with very limited alternative water source options being explored. The geographical scope of the study was informed by the fact that this section of the river does not traverse through an intense mix of land use activities and this presented an opportunity for rejuvenation and restoration of the river as much pollution was not anticipated. In that regard, augmentation of water supply to the city seemed plausible.

Further, the choice of the study area was also informed by the financial implications involved due to the logistical arrangements needed for a successful research study. The site was easily accessible from Nairobi City and this allowed the researcher to verify any samples with ease as the sample sites were accessible without much difficulties during the research period. Additionally, the water testing and sample handling equipment would have been tedious and expensive to hire if the site to undertake the research was not in close proximity to the testing labs.

1.7 Scope and Limitations

The study was conducted along a 10.2 Km stretch of Nairobi River defined by watershed boundaries derived by catchment delineation. It was limited to the riparian zone confined to the 500m belt on both side of the upper section of Nairobi River bank, that stretch from the river source at Ondiri Swamp to the confluence of various river tributaries at Naivasha Road Bridge.

The temporal scope consisted of both dry and wet seasons adopted as June and October, 2019 respectively. During these months, the sampling sites were visited once during each period. In the long run, the implementation of the recommendations advanced by this research will lead to the achievement of various sustainable development goals as well as mitigating on the adverse impacts of the climate change phenomena.

The water quality assessment was limited to the following physicochemical and biological parameters: total dissolved solids (TDS), turbidity, dissolved oxygen (DO), water pH, total hardness, temperature, sulfates, nitrates, fluorides, chlorides, total coliforms, total fecal coliforms, color, and conductivity. The study encountered the following limitations:

a) Overreliance on Landsat images for land use classification. This limitation was overcome by intensive field work and ground truthing during the land use types classification which was restricted to spatial analysis that was representative of the current spatial land use distribution status.
b) Some water quality parameters for instance heavy metals that are related to urban pollution were not investigated in this study. Instead, total coliforms were used to show pollution related to poor sanitation in urban areas.

1.8 Operational Definitions

The following terms as used in the study mean the following:

a) **Land Use** -The term refers to the economic exploitation of the land by human through the conversion of the natural environment to anthropogenic uses such as agriculture or urban settlement (Brown, Pijanowski, & Duh, 2000).
b) **Land Use Distribution**: Used in the study to mean the way **Land Use** activities are organized on land surface, often referred as spatial land use types to mean the same thing
c) **River Gradient** -Used in the study to mean to the downward trend of the river from Ondiri swamp to Naivasha road. Means the same as river profile as used in the study
d) **Urban Sprawl**- refers to hinterland between rural and urban areas where land has lost its rural characteristics and yet cannot fit the definition of an urban that can be a result of unplanned urban growth or conversion to non-agricultural purpose (Karakayaci, 2017).
e) **Water Quality**- refers to a set of biological, chemical, and physical conditions which defines the status of water for a specific use (Hydrologic Engineering Center, 1972). Used in the study as a measure of water potability.

Chapter 2: LITERATURE REVIEW

2.1 Land use

According to Penman *et al.*, (2003), land use can be defined as the nature of the anthropogenic activities being undertaken on a unit of land. Land use activities are economic activities that are meant to deliver certain social and economic benefits to human societies. Historically, human activities are known to have certain negative externalities on environment. For instance, Koellner & Scholz (2008), associated the rapid decline in biodiversity with the expansion of agricultural land use, commercial forestry, and urban settlement. A more exhaustive definition of land use incorporating the aspect of anthropogenic impacts was put forward by (Susana & Mollicone, 2012). These authors defined land use as the socioeconomic functions of the land that indicate the human impacts on the ecosystems and climate system.

2.1.1 Determination of land use

LaGrojr (2005), describes the land use hierarchical classification multilevel schemes. Based on the details required during the land use classification process, the general or level 1 includes urban settlements, agricultural, rangeland, forestland, water, wetlands, and barren. The land use classification includes the land cover. At level 2, agricultural land use is further disaggregated into cropland and pasture, horticultural areas, and confined feeding operations among others. Another important land use type is urban which comprises of residential, industrial, transportation, mixed urban and built-up land.

Yang *et al*., (2017), urges that the land use/ cover classification systems are different according to regions, scale, and study needs making it difficult for comparative analysis. The researchers therefore make a case for the harmonization of the land cover classification through different thematic maps. Accordingly, this allows for easy analysis of landscape patterns and spatial temporal changes detection.

2.1.2 Approaches in land use classification

The remote sensing technology that consists of satellite images has been used over the years to achieve land use classification in a given area. According to LaGrojr (2005), the land cover surfaces that are defined by particular land uses have different reflectance to sunlight in terms of wavelength. These differences in reflectance have been described by Richards (2013), as spectral signatures that are unique and distinct, which allows for creation of thematic maps. The remote sensed data is analyzed using the geographical information systems (GIS), a tool that has been used in many studies (Wambugu, 2018; Rwanga & Ndambuki, 2017; Ngeno, 2016; Tong & Chen, 2002) for land use and landcover analysis.

2.1.2.1 *Supervised classification*

Classification of satellite imagery is the method of assigning some of the land over to pixels that are later applied to a given area of interest (Richards, 2013). Richards further describe supervised classification as a qualitative method of analyzing the remote sensed data (satellite image) based on predefined land over types. To begin with, the process starts by identifying and selecting representative sample sites of known cover that is on the ground. Then the unique spectral signature of each pixel chosen is used as training sites (known sites used by the classifier tool to classify the whole image), identified from aerial photographs, Google images, or field visits. The supervised classification tools then use different algorithms such as the maximum likelihood that is based on probability distribution. The result is a thematic map called the land use/ cover map.

2.1.3 Land use classification in watersheds

The classification of the use of land using GIS and remote sensing tools and techniques has been used to discriminate land use types in watersheds across the world. In Daliao River Basin in China, Wang *et al*. (2013), applied remote sensing data that comprised of Landsat images to model the spatial land use pattern of the Daliao River Basin. The authors produced a thematic map with six types of land uses comprising agricultural land use which was disaggregated into paddy and dry fields; forest land use which comprised of coniferous forest, deciduous, broad-leaved, and mixed forests; the urban land use which consisted of residential settlements and industrial areas; the water bodies which comprised of rivers, wetlands, and sandy beaches; and finally, the bare land which comprised of bare rocks and bare ground. The main land uses in the Daliao River basin were shown to be agriculture, forest, and urban settlement. Wang *et al*. (2013), showed the spatial patterns of land use changed downstream. In the upstream, for example, forest land use was dominant, while downstream along the Daliao River the agricultural and urban land uses became dominant.

A study in the Duiwenhonks River watershed in the Western Cape Province of South Africa produced eleven land use types (Ogden, 2013). These land uses consisted of unvegetated bare ground, fynbons, irrigated grains, non-irrigated grains, plantations, urban/settlement, water and wetland. In this study there was no discernible land use downstream trend. However, the results of a study done in Ruiru and Ndarugu Rivers watersheds by Wambugu (2018), used supervised classification and determined that the types of landuse in these basins were: Forest, agricultural (small-scale and large-scale), grassland, urban settlement, and water. The spatial distribution of these land uses was such that forest landuse was the most dominant in the upstream zones, the upper mid-stream zones were dominated by small-scale agriculture, in the lower midstream large-scale agriculture was the dominant land use, while in the downstream areas the basins were dominated by urban settlements. There were pockets of grasslands which the author attributed to the expansion of the urban settlement.

2.2 Water quality

Globally, the world is facing the duo challenge of the growing problem of water stress as well as water quality. The latter is likely to affect economic growth targets of countries and hinder the achievement of SDGs by affecting, human health, and limit food production by impacting negatively on freshwater fisheries through the creation of dead zones (UNEP, 2016). Water quality has also been shown to impact negatively on the delivery of ecosystem services by disrupting ecosystem functions (Keeler *et al*., 2012).The three pillars of sustainable development (social, economic, and environmental) will be impacted negatively by the deterioration water quality situation.

The finite and infinitesimally small quantities of freshwater Postel *et al*., (1996), are increasing facing pollution form a plethora of anthropogenic activities. Traditionally, the discharge of waste water, and treated or untreated sewage into surface water resources especially rivers is a growing problem especially in developing countries (Ngoye & Machiwa, 2004). But some studies Biswas & Tortajada (2019), also indicate that the problem is also as widespread in the developed countries. According to UNEP (2016), one out of seven of all rivers in Africa, Asia and Latin America have severe organic pollution, and affects about four billion people without access to potable water (Biswas & Tortajada, 2019).

According to Chavoshani *et al*., (2020), the problem is compounded by emerging pollutants from dispersed sources from households such as pesticides, personal care products, plastics, pharmaceuticals, and industrial chemicals collectively called emerging micro pollutants (EMPs) . These are relatively new pollutants and their long-term impact on human and ecosystem health is still unknown.

The change of climate impacts on the quality of water cannot be underestimated even though such studies are just at inception (Delpla *et al., 2009)*. The study by Delpla *et al.* insinuated that the change of climate had possible impacts to the water quality through the modification of physico-chemical and biological parameters. These modifications arise from changing ambient temperature and the hydrological cycle (Hosseini, Johnson, & Lindensshmidt, 2017).

2.3 Water quality parameters

Water quality characteristics can be defined by physical, chemical, and microbiological components of water that have to be within certain limits suitable for various human needs and for other living organisms. Omer (2019), stated that water can be classified into four main types according to its quality, that is, potable, palatable water, contaminated, and infected water. A book by Shah (2017), defined the quality of water as a measure of the water condition when assessed against the necessities of biotic species or to any anthropogenic needs.

2.3.1 Physical parameters

The physical parameters are those parameters that are responsive to the senses of smell and taste, touch, velocity, and sight. In this study they include: temperature, turbidity, conductivity, and color.

2.3.1.1 *Temperature*

Temperature is a catalyst of chemical reactions in water solutions. It influences the presence of other parameters for instance the levels of biological oxygen demand (BOD). According, WHO (2017), there are no water quality guideline for temperature but Omer (2019), suggests that water temperature of between 10 ˚C to 15 ˚C is preferred for drinking water.

2.3.1.2 *Turbidity*

According to Lee *et al*., (2015), turbidity is the degree of the volume of cloudiness in the water, and hence its clarity based on the amount of light that can penetrate through. The clarity in water can be influenced by presence of phytoplankton and algae, or non-living elements such as sand, silt, and mud from runoff or chemical precipitates. Commonly measured in nephelometric turbidity units (NTUs) which is equal to 1 mg/l of silica in a suspension. Turbid water increases the cost of treating water and affects living organisms in water (Omer, 2019). Turbidity of <5NTU is preferred for drinking water purposes beyond which water loses its aesthetic value.

2.3.1.3 *Water color*

Pure water is colorless whereby water color reduces water aesthetic value. Water color is affected by presence of inorganic substances such as soil, rocks and organic substances such as leaf litter and other suspended material. Colour is measured on a graduated scale of color units that ranges from 0 for pure water to 70 color units. Each colour unit is equal to the colour produced by a 1 mg/L solution of potassium chloroplatinate (K_2PtCl_6).

2.3.1.4 *Total dissolved solids (TDS)*

These are solids that occur in water in a solution form after being passed through a filter and are measured in mg/l. Freshwater has TDS of <1500mg/l.

2.3.1.5 *Electrical conductivity*

The capacity of water to pass an electric current is the measure of electrical conductivity in water and is measured in standard units of micro-Siemens per centimeter (µS/cm) using electrical method. According to Omer (2019), conductivity is proportional to the quantity of total dissolved solids in a solution and are related by the equation TDS = EC x(0.55-0.7). It is an indicator of the number of ions in a water solution and therefore the conductivity in water shows its suitability for agricultural use and firefighting. As an indicator of water quality status is the fact that pure water is a poor conductor of electric current whose conductivity of drinking water ranges from 0.005-0.05S/m.

2.3.2 Chemical parameters

The chemical parameters discussed in this literature review include: pH, chloride, sulfate, nitrate, fluoride, hardness, dissolved oxygen.

2.3.2.1 *pH*

The pH of water is the measure of acidity or alkalinity determined by the concentration of H^+ hydrogen ions. The balance between the hydrogen ions and hydroxyl ions (OH^-) determined if water is either acidic or basic. The pH is measured by a pH scale that ranges from 0 - 14. When the value is 7, water is said to be neutral. Any value below 7 indicates water acidity and any values above 7 indicates basic conditions. pH is a critical parameter in water quality because it affects the water biota where according to Omer (2019), pH values that are too low or too high makes water unusable for most purposes including drinking. In water quality studies it is an important parameter because it is influenced by pollution and is determined using colorimetric methods.

2.3.2.2 *Chloride*

According to Omer (2019), chloride can be an indicator of wastewater pollution, or agricultural land use pollution but also there are background pollution sources occurring naturally from geological sources. The presence of chloride ions (Cl^-) in drinking water are benign, but in high concentrations exceeding 250mg/L can cause unpleasant salty taste. The common method of measuring chloride in water is titration method using silver nitrate.

2.3.2.3 *Sulphate*

The presence of sulphate in water has no known public health effects but drinking water with High sulphate can result to laxative effect. Sulphate ions present in water can be caused by either natural causes such as leaching in areas rich in sodium sulphate, or wastewater pollution.

2.3.2.4 *Nitrates*

Nitrogen is an important element needed by all living organisms to build protein. However, in areas where intense farming activities are practiced, the nitrate-nitrogen concentration as a result of water pollution may exceed the EPA potable water limits of 10 mg/L. Where concentrations of nitrate-nitrogen in drinking water exceed the 10 mg/l, the water becomes a health hazard if consumed, especially to the children and expectant women. The only sure way to detect nitrate elements in water is through lab testing since it has no color, odor, or taste.

2.3.2.5 *Fluoride*

Fluoride is an important water quality parameter in public health because in low concentration of about 1mg/L, it is preventive measure for tooth decay in children. However, in high concentrations and a chronic exposure it can result to dental fluorosis. Water quality standards recommend a maximum concentration of between 1.4mg/L and 2.4mg/L. It can occur in water from both anthropogenic sources as well as natural causes.

2.3.2.6 *Total hardness*

According to Neitzert 2003, water hardness refers to the measure of the water capacity to react or consume soap. Total hardness consists of carbonate and non-carbonate hardness. Soft water is water with < 61mg/L, while moderately hardness is water with hardness of between 61mg/L and 120mg/L, while hard water has hardness ranging from 121 to 180mg/L. There are no WHO guideline value limits for water hardness.

2.3.2.7 *Dissolved oxygen*

In freshwater ecosystems such as rivers, dissolved oxygen (D.O) is a critical water quality parameter. It is important for the respiration cycle of aquatic organisms and necessary for the survival of aquatic microorganisms and plants as well as the decomposition of organic matter. High concentrations of dissolved oxygen in a sample are an indicator better water quality, although dissolved oxygen is dependent on atmospheric pressure, temperature, and pH. Dissolved oxygen levels of 5.0 mg/L mean marine life is stressed up and the lesser the concentration, the higher the stress on aquatic organisms. Dissolved oxygen concentration in water can be measured using Winkler titration method.

2.3.3 Biological water quality parameters

Living organisms exists in various ecosystems including freshwater, therefore the presence or absence of certain living organism can be used as a proxy for water quality assessment. Some organisms are known to be tolerant to given levels of pollution, while others their presence can be used as an indicator of certain pollution because it is their medium (Gerhardt, 2001).

According to UNEP (2016), the presence of pathogens such as bacterial, protozoa, and any virus in water can be attributed to anthropogenic sources. Monitoring each one of these pathogens can be an expensive process at large scale, therefore water quality experts narrow down to few known indicators to indicate presence or absence of others. The various forms of fecal coliform bacteria are used as indicators to show the presence of human and animal excreta. The fecal coliform bacteria are dominated by the *Escherichia coli* (E. coli) which can be regarded as a suitable fecal indicator bacterium (FIB). Total coliforms refer to a broad range of anaerobic and aerobic, non-spore-forming, and gram-negative bacteria. In general terms these are bacteria that include both fecal and environmental genera which can grow and thrive in water in both sewerage and natural water.

Though not all fecal coliforms are pathogenic, their presence in water is an indicator of presence of dangerous microorganisms. When a water sample is confirmed positive for fecal coliforms or E. coli, it means the water is not safe for human consumption and would require purification before use. The concentration of fecal coliforms in water is determined in colony forming units per 100ml (cfu/100ml). For instance, recreational water should have <200 cfu/100ml, but drinking water should have 0cfu/100ml.

2.4 Drinking water quality guidelines

Globally, there are various international agencies mandated with oversight of various health related activities including an assessment of the measure for safe and potable water. It is every country's responsibility to set out their individual health parameters and safety standards drawn from the larger global frameworks. In light of that and within the limited scope of water quality assessment set out in this study, the researcher adopted the water quality guidelines issued by WHO (2017) and the (Kenya Bureau of Standards, 2015) to relate with the findings of the study. These are summarized in Table 2.1.

Table 2.1: Water quality Standards comparison

Water Quality Parameter	WHO Guidelines	KEBS Guidelines (Natural Potable)
pH	6.5 – 8.5	5.5 – 9.5
Temp	** 15^0c – 25^0c	20^0c – 35^0c
EC	** 500 µS/cm	1500 - 2500 µS/cm
Turb	0.5 – 1 NTU	5 - 25 NTU
THD	Upto 500 mg/L	300- 600 mg/L
FLUO	1.5 mg/L	1.5 mg/L
Nit	50 mg/L	45 mg/L
Chl	200 – 300 mg/L	250 mg/L
TCOL	Nil cfu	Nil
TFCOL	Nil	Nil
**** DO**	-	-
TDS	600 mg/L	700 - 1500 mg/L
COLR	15 TCU	15 - 50 TCU
SULF	** 250mg/L ($NaSo_4$); 1000mg/L ($CaSo_4$)	400 mg/L

Source: (WHO 2017 & KEBS 2015)

2.5 Influence of land use on water quality

Since gaining significant understanding of the adverse effects and destructive impacts of land use activities on surface water quality, a study in Brazil by Cogueto *et al.* (2011), suggested that similar studies be an area of priority in future research and development. As a result, various studies relating to land use impacts on water quality have been done and indeed confirmed that land use activities surrounding water ecosystems have an effect on the surface water quality. Studies such as (Wang *et al.*, 2013) have argued that the influence on surface water quality is scale dependent based on the levels of land use exploitation. The premise was further supported in studies by (Tong & Chen, 2002) who also argued that the impact of land use on surface water quality is dependent on the intensity of the land use since every land use would require certain intensities of utilization to affect and influence water sources. For example, Ngoye & Machiwa (2004), established that there were higher nutrient concentrations in river systems passing across agricultural farms that were utilized for heavy agro-production than in farms where subsistence agriculture or livestock rearing was practiced. Further, they suggested that some land use types such as agricultural, urban-settlement, and forest have the ability to influence both the quantity and quality of surface runoff following rainfall events. These land uses influence the nature of pollution in rivers.

Watershed degradation relates to the changing land cover as a result of land use changes, such as expansion of human settlement and agricultural land, resulting in reduced forest and riparian vegetation cover (Njue *et al*., 2016). The key driver of these land use changes can be attributed to population growth and human economic activities (Ngoye & Machiwa, 2004). The impacts of land use changes on watershed quality has been largely seen as a rural phenomenon according to a study by Njue *et al*., (2016), in Kenya. The conclusion made by these authors was based on the experiences of the destruction of Mau Forest watershed, due to demand for farmland. In a contrast to more urbanized developed countries, Cavailhe & Wavresky (2003), attributed the expansion of the destruction of watersheds to the expansion of urban-settlement and conversion of agricultural land use to residential land use.

Different land use types have different impacts on water quality parameters. A study conducted in the Chaohu lake basin, in Anhui Province of China, studied the impacts of different land use on water quality (Juan *et al.*, 2013). The study results showed that cultivated land represented by agricultural land use was associated with higher concentration of nitrates and dissolved oxygen. The authors attributed this to the application of nitrogen-based fertilizers in the farmlands. Forest land and grassland were shown to have lower concentration of phosphorous, nitrates, and chemical oxygen demand, but had high D.O concentration. These land cover have a higher vegetation hence reduce the surface runoff draining into the river channel. The urban-settlement land use was negatively correlated with nitrates and phosphorous concentration in water but had lower concentration of dissolved oxygen, showing that the impervious layer associated with this land use results in deteriorating of water quality.

A study on the influence of land use in the Ruvu River watershed in Tanzania showed that total dissolved solid (TDS) concentration was lower in the forest land areas, and higher in urban and agricultural land use (Ngoye & Machiwa, 2004). A seasonal comparison of turbidity levels showed that agricultural land use had the highest mean values in both rain and dry season. In the forest land use dominated areas, turbidity levels were low in both dry and rain season. In the agricultural land use the highest turbidity value was 840 NTU, while in the forest land use the highest turbidity value was 24NTU. Nutrients pollution was shown to be high in the agriculture and urban-settlement. In both land uses, nitrates concentration was highest in the sampling station adjacent to these land uses. Authors of the study attributed these to draining of wastes through surface run off.

In Kenya, a study by Wambugu (2018), focused on the effects of the use of land on the water quality in the Ndarugu and Ruiru Rivers Basins. The study results showed that the land uses that have undergone anthropogenic disturbances such as urban-settlement and agricultural land uses had more pollutant concentration compared to the less disturbed forest land. Urban land had the lowest dissolved oxygen concentration levels, which the researcher linked to the waste water pollution. In agriculture and urban land use pH levels were higher in wet season, while in dry season the pH levels were higher in forest land. This observation was attributed to the complex interactions between land use and geological, climate, and physiographical factors. Similar findings were made by Sliva & Williams (2001), in a study on rivers draining into Lake Ontario in Toronto Canada. The study showed that the water quality was influenced by multiple factors such watershed characteristics such as slope and silt-clay surficial geology and land use distribution mainly forest land and urban-settlement. However, of all the factors influencing water quality, urban land use had the most negative influence.

A study by (Monene, 2014) on the effects of land use change on stream flow in the Ngong River Catchment established that there was a substantial relationship between the stream flow, river pollution and changes in land use between 1976 and 2012. Further, the study revealed that there had been temporal and physical land use change in the sub-catchment. Through the period, there was clearance of forest and grassland vegetation which increased bare surfaces resulting to gully erosion at the catchment. Additionally, built-up areas and road infrastructure developments increased from 22.78% in 1976 to 50.98% in 2012 which in turn resulted to an increase in the river water quality degradation by about 80%. The deductions and inferences made by the study directly related the water quality degradation to the adverse effects of uncontrolled and unsustainable land use practices around the Ngong river sub catchment system.

These findings are similar to those observed in a study by (Muriithi & Yu, 2015) in Central Kenya where a direct correlation between land use and surface water quality was established. The authors of this study applied 'Discriminant Analysis - DA' method to assess the impact of intensive horticulture land use practices on surface water quality in Central Kenya. The strength of the discriminant analysis in their study was in its capability to deliver a statistical classification of the types of land use as pollution sources where over 89.5% accurate distinction of the types of land use was attained. The results strongly illustrated a discrete variation in water quality as caused by land use activities around water catchment areas.

Similarly, according to Kithiia (2007), the trends of surface water quality degradation and consequent pollution in the Athi and Nairobi River basins was found to be a result of varied land use distribution along the river flow gradients which ranged from industrial, agricultural, urban areas among other land uses. The study findings were supported by (Makathimo & Guthiga, 2010) who also established the same trends of surface water quality degradation along the Nairobi River basin as a consequence of land use distribution.

According to Mwiti (2014), Nairobi River was found to be highly polluted especially on the sections where agriculture was highly practiced and in areas where the river traversed concentrated and built-up areas with an urban character. Most of the pollution was attributed to Agricultural run offs, domestic effluents discharge, refuse dump run offs especially from car washes and garages among other anthropogenic factors. From the foregoing, it can be established that the adverse effects of land use activities on river water quality and ground freshwater resource base are a consequence of untenable land use and management practices surrounding water catchment areas.

2.6 Determination of the relationship between land use and water quality

According to Ding *et al*. (2015), effective water quality management measures are based on sound science that identifies the threats to water quality. This can be achieved by identifying the relationship between the particular land use type and water quality parameter, so as to formulate land use specific measures to mitigate pollution loads. To achieve this effective remedial action, statistical sound approaches are required in the identification of the explanatory variables affecting water quality. The nonparametric Spearman correlation test has been used as a reliable statistical method in various studies (Basu *et al*., 2019; Ding *et al*., 2015). A study by Li *et al*. (2012), in the Liao River Basin in China used Spearman's test in correlating land use types and water quality parameters. The study results showed that the land use metrics were correlated to certain water quality parameters. For instance, some parameters such as conductivity, hardness and sediment load were correlated with the agricultural and forestry land uses. At a given significant level, Spearman's test revealed the nature of this correlation to be that sediment load was negatively correlated with forestry land use, but had positive correlation with agricultural land use. Both of this correlation were significant a p value of 0.05. The Spearman test results revealed that an increase in the area of forest land will lead to a decrease in sediment load, while an increase in agricultural land will lead to an increase in sediment load. This analysis can be an important information to watershed managers in the identification of land uses that are of critical importance to pollution.

In the River Kaduna watershed in Nigeria, Ogbozige & Alfa (2019), used Spearman's correlation test to discern the effects of land use/ cover and seasons on water quality holding spatial scales constant. The study results showed that turbidity levels were positively correlated with urban land and agricultural land use during the dry season. The authors linked this to water scarcity during the dry season that forces people to move close to River Kaduna, whereby activities such as laundry and bathing contribute to high turbidity levels. In the agricultural land the back flow of water from irrigated farms contributed to turbid water in the sampling site located in the agricultural sites. Similar results applied to the conductivity and TDS which showed positive correlation with the urban land use. pH was shown to be negatively correlated with the agricultural and urban land use. The nature and composition of pollutants from these land uses had acidifying effect on river waters. In contrast the industrial land had a positive impact on pH, implying that the nature of pollutants had alkalizing effect on water.

2.7 Research gaps

The literature review show that the study area lacks studies that focus on the riparian zone of the upstream section of the Nairobi River right from the source on the basis of land use and water quality relationship. Similarly, there are few studies that investigate a wide range of physical, chemical, and biological water quality parameters such as the ones being investigated in the study.

2.8 Theoretical framework

The theoretical relevance of this study is underpinned on the need to understand the effects of land use on water quality. In that regard, the researcher based the understanding on the control capacity theory according to (Schrama, 1998). The control capacity theory was applied in the protection of water resources from non-point pollution sources common in agricultural land use. According to Schrama (1998), the control capacity theory is about influencing social processes such social behavior, which was applied to abate pollution from agricultural sources, by influencing the behavior of a group of farmers living close to a water source.

To understand how agricultural land use pollution on water resources can be controlled, Schrama (1998), noted that the control capacity involves three main processes. It begins with policy network analysis at national level where policies are formulated. This is followed by a specific policy analysis, for instance if there are policy instruments on mitigation of water pollution from agricultural land use. Finally, assessing the capacity of the regional water authorities and water supply companies in working directly with the land managers to control agricultural land use related pollution. Guided by the same understanding, an elaborate conceptual framework is detailed below to link the theoretical framework with this study.

2.9 Conceptual Framework

Conceptually, water contamination at source can only be prevented once the effects of land use on water quality and their connections within the river ecological system and catchment area are understood. Such information strengthens the management and improves land use planning to mitigate and lessen any adverse impacts on the ecosystem health. This study underpinned the river degradation and subsequent pollution to the lack of political goodwill and poor implementation of policy and legal legislation guiding land and land use distribution adjacent to the river ecology.

The conceptual basis of this study intimates that the river pollution originates from poor enforcement of policy and laws by the government institutions and authorities responsible for implementing the law guiding land & land use as well as the drafters of the policy and the legal instruments. To be more specific to this study, the institutions and authorities responsible for land use and development control do not strictly enforce the laws applicable to the use of land within or neighboring wetland ecosystems including rivers and streams. Eventually, rampant and haphazard development that is not anchored on any planning framework take place. More often, this kind of development lack any mitigative measures in place to control the effects it has on the wetland ecosystems. In the end, the land use developments end up degrading the river ecology in various ways including direct discharge of effluents, or other forms of overflows as surface runoff. The constant and unchecked degradation become a norm over a period of time leading to total pollution of the wetland ecosystem.

However, this is a problem that can easily be mitigated through implementation of relevant policy and legal instruments guiding land and land use in development control. Where minimal degradation of the river ecology occurs maybe from nonpoint pollution sources, then cleaner production practices could be applied to mitigate on the adverse pollution effects. This understanding can be understood in the conceptual model outlined in figure 2.1.

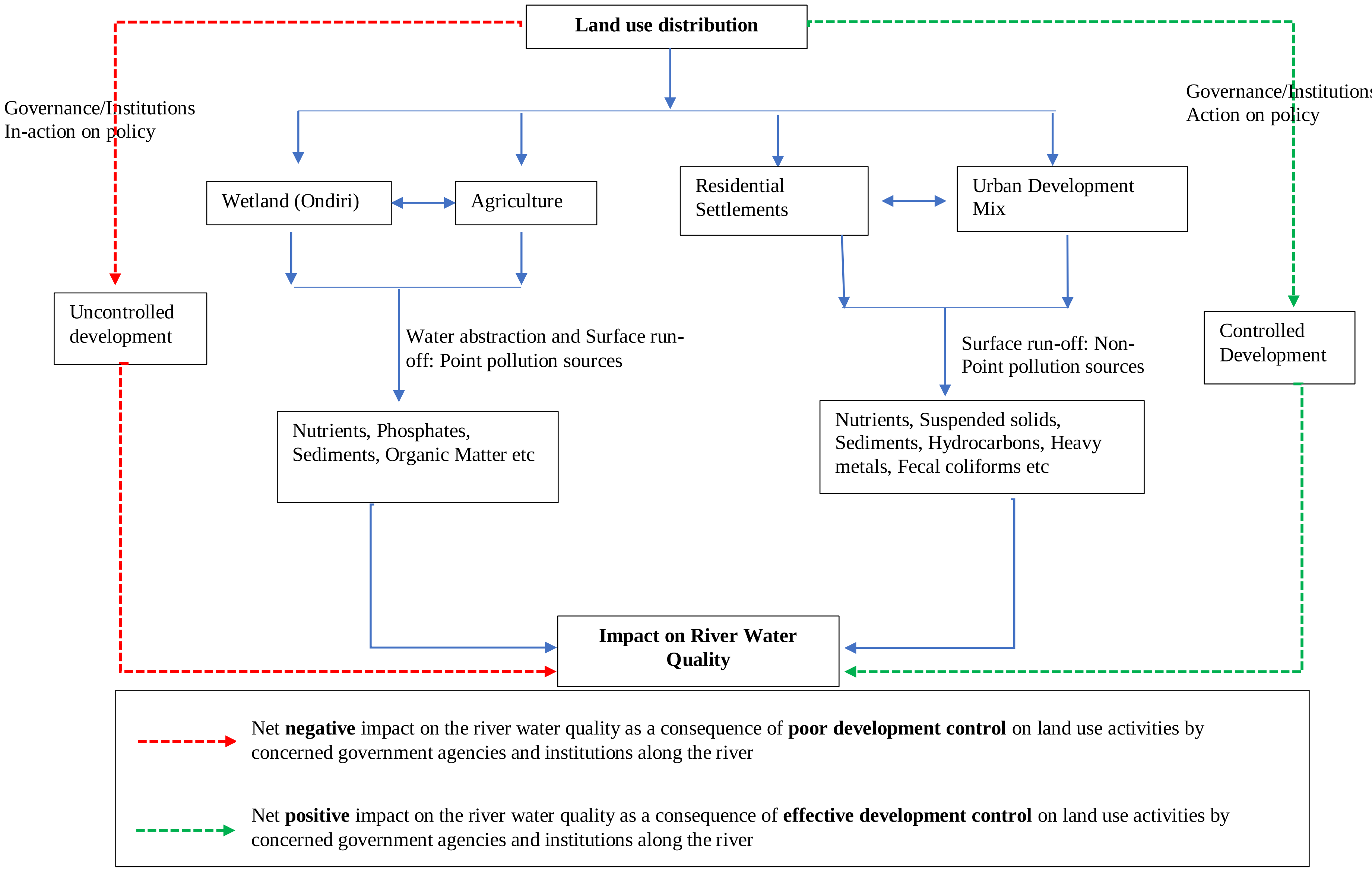

Figure 2.1: The conceptual model of the Study
Source: (Researcher 2020; Modified from Camara *et al.* 2019)

Chapter 3: THE STUDY AREA

3.1 Location and Size

Geographically, the study area traverses two administrative units of Nairobi and Kiambu Counties, where the source (Ondiri Swamp) of the river is located in Kiambu County while downstream end is located in Nairobi County at the intersection of Naivasha Road Bridge. The study area covers an approximate area of about 10km^2 between latitudes 1°15'09.3"S, 1°16'34.0"S and longitudes 36°39'45.5"E, 36°44'05.0"E with an attitudinal range between 2010 meters above sea level around Ondiri swamp to 1775 m above sea level at Naivasha Road Bridge intersection. Generally, the area is characterized by high rainfall, dense river drainage network, intense agricultural activities, and high human population density all of which combined cause intense pressure to natural resources including water quality.

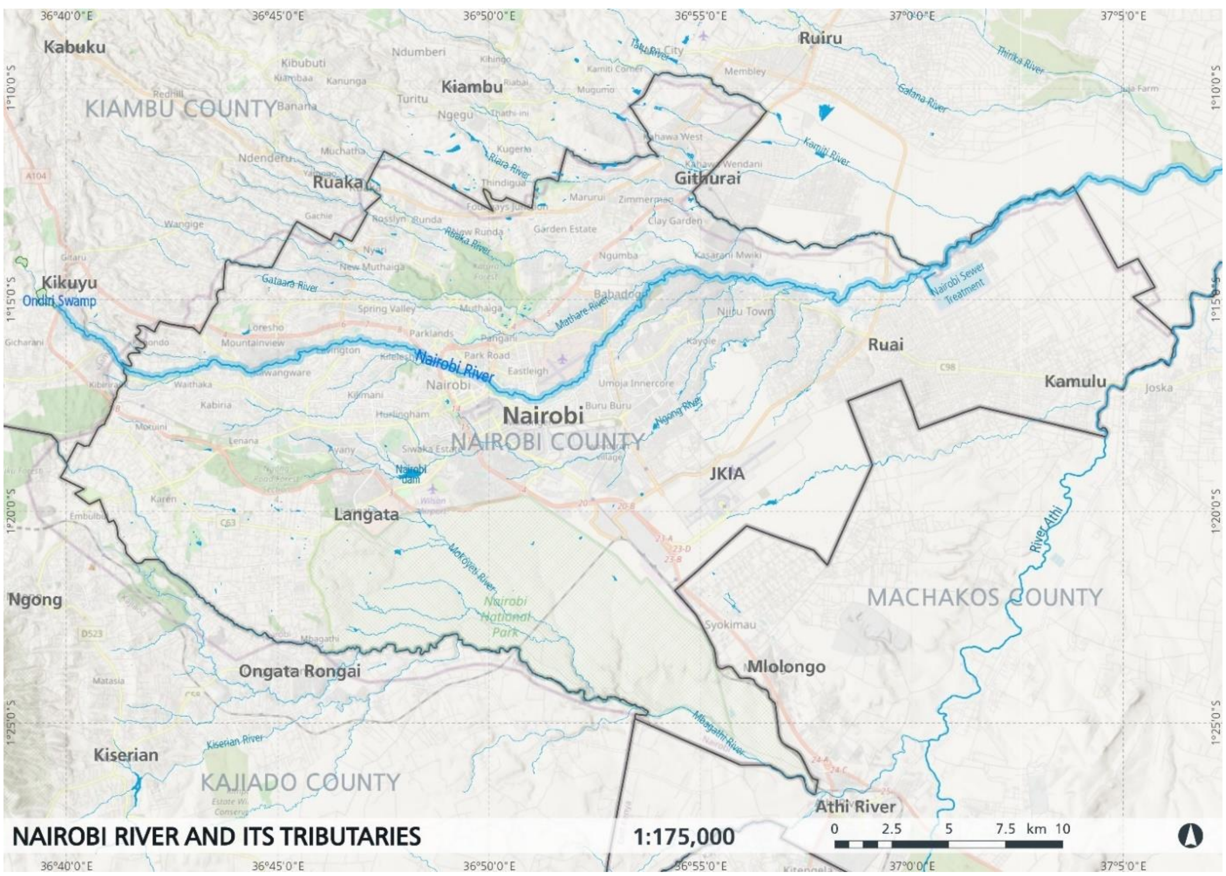

Figure 3.1: The Nairobi River ecosystem hydrological features from the source (Ondiri Swamp) as it drains to Athi River

Source: (Researcher, 2020; Modified from Survey of Kenya topographical sheets)

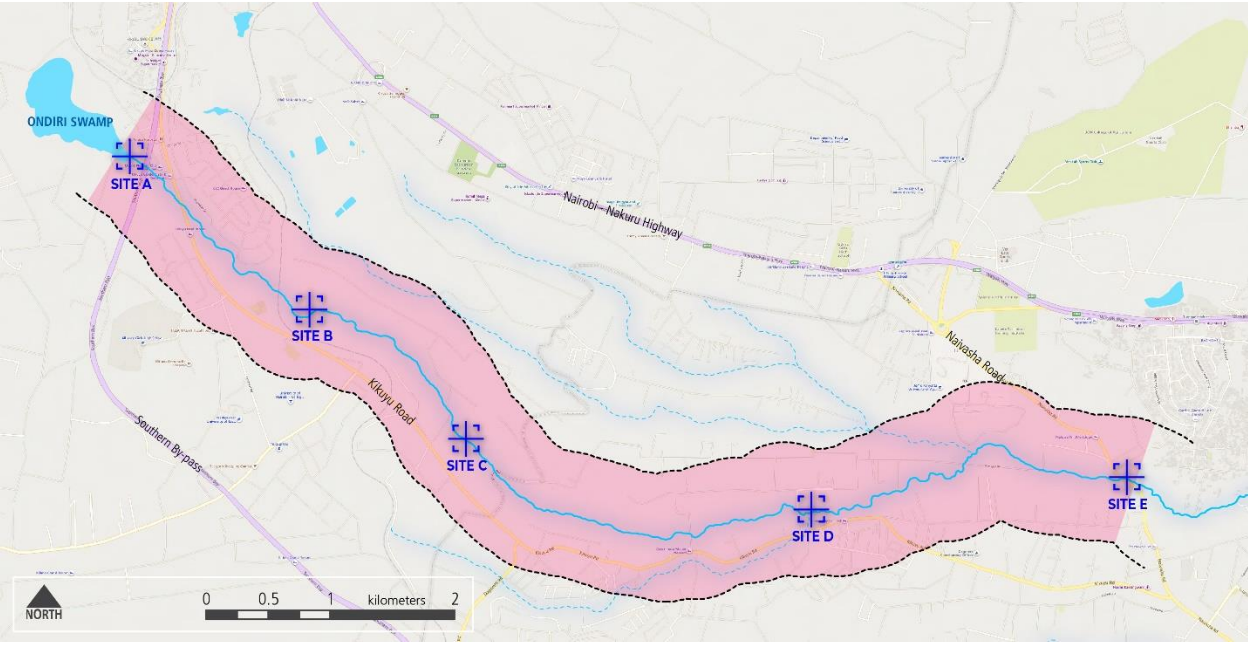

Figure 3.2: The delineated section of the river under study from Ondiri swamp to Naivasha road intersection
Source: (Researcher, 2020; Modified from Survey of Kenya topographical sheets)

Ondiri swamp is one of the most documented and researched on sources of Nairobi River and forms one of the headwaters' drainage system that eventually form Nairobi River downstream as it drains to Athi River. The swamp is located around Kikuyu Township and measures approximately 30Ha and about 3Kms in perimeter with an outflow that forms part of the river section that this study researched on. From Ondiri, the river flows in southern direction and traverses across Nairobi County right through the City's CBD, then across various informal settlements before draining into river Athi as seen on figures 3.1 and 3.2 above.

3.2 Hydrology and Drainage

Due to the topographical occurrence and altitude difference, the river flows naturally to the south east of the source. Along the flow downwards, more tributaries, most of which are seasonal join the river system to form a bigger river which then flows through Nairobi City and eventually drains into the Athi River as Nairobi River. For this reason, this area is generally believed to form the largest headwaters for Nairobi River. The hydrological nature of the river system around the study area is shown in figures 3.3 and 3.4 below.

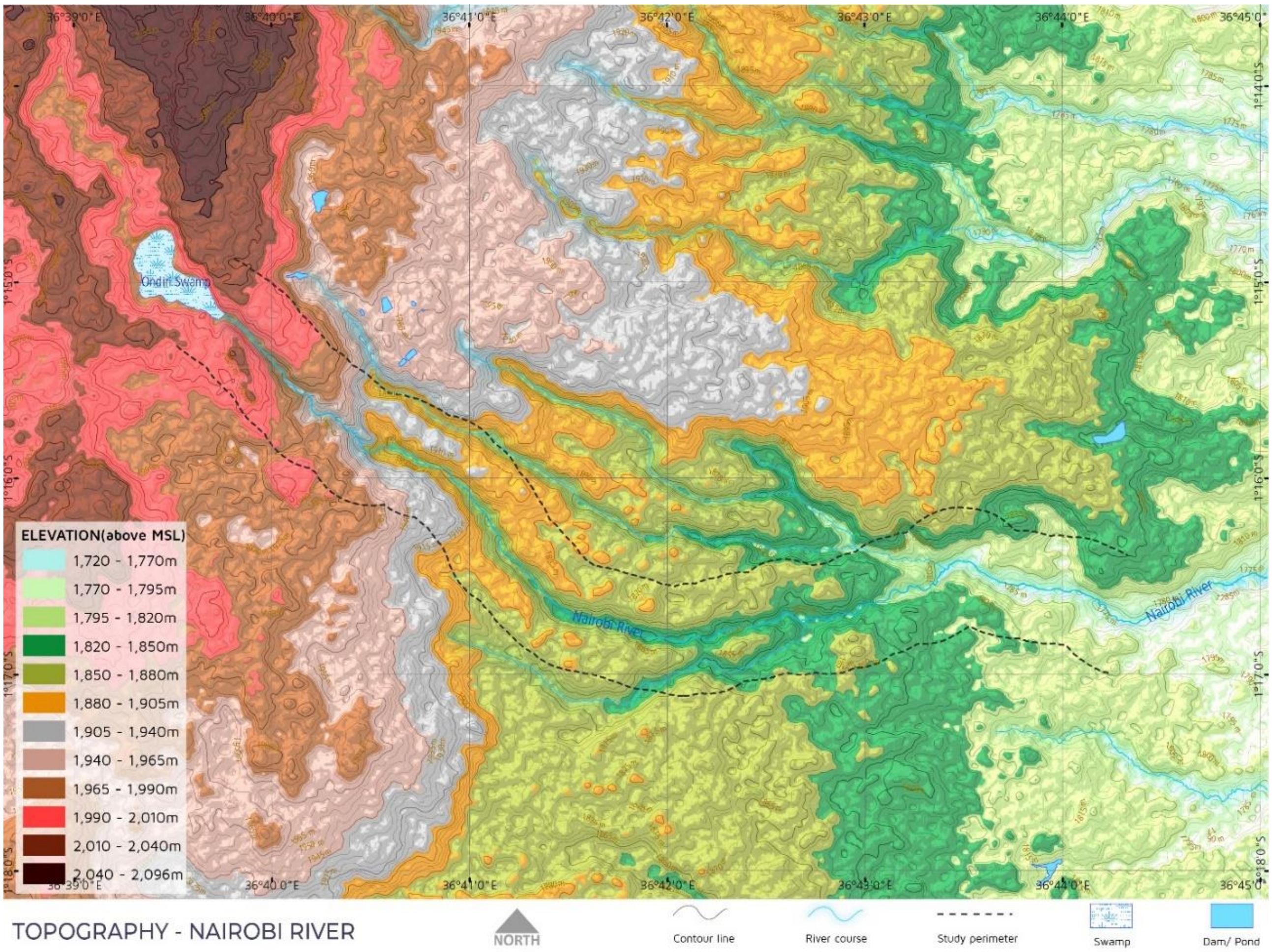

Figure 3.3: Topographic occurrence of the study area
Source: (Researcher, 2020; Modified from SRTM-USGS)

Figure 3.4: Hydrological and drainage system of the study area
Source: (Researcher, 2020; Modified from SRTM-USGS)

3.2.1 Climate

The study area experiences a bimodal rainfall pattern that consists of 'long rains' between the months of March and May, and 'short rains' between the months of October and December (Figure 3.5). This is an important aspect of the study as data had to be subjected to seasonality: the dry season (interpreted as a period of low/no rainfall); and the wet season (interpreted as a season of moderate to high rainfall over a period of time). The two seasons were expected to ultimately give varied results regarding the water quality at different sample collection points as the water discharge and amount affects the extent of dilution of foreign substances in the water and so is the water quality.

According to the atmospheric recordings of the area, rainfall characteristics in 2018 were recorded as shown in Figure 3.5.

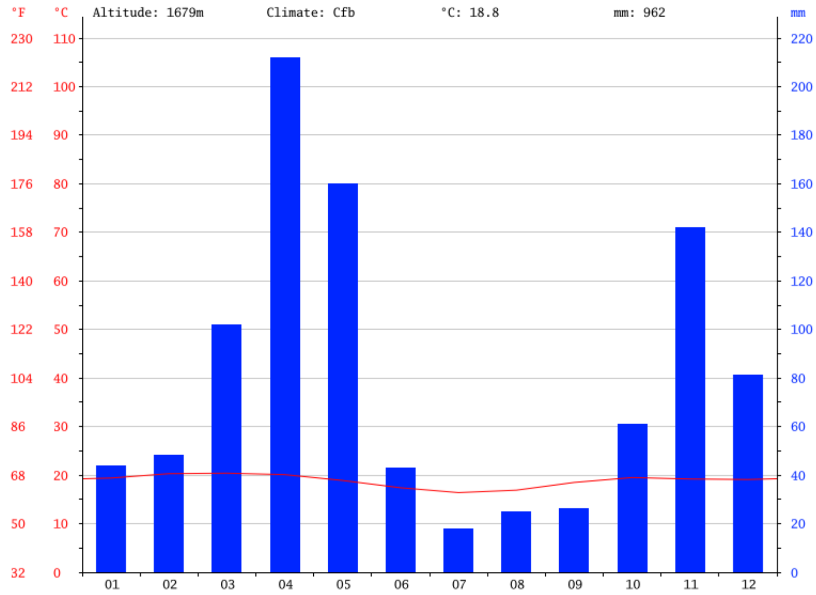

Figure 3.5: Rainfall measurement characteristics as recorded in a weather station
Source: (National Oceanic & Atmospheric Administration (NOAA), 2018)

3.2.2 Geology and Soils

The geological and soil structure of the area has determined settlement patterns as well as the drainage system of the area. The area has majorly one rock and soil structure defined by the Magadi, Kiambu, and Limuru trachytes of the Kikuyu escarpment. The underlying rocks are tertiary that lie from shallow to deep along the river profile with high ground water retention capacities. Kiithia (2006) noted that the hydrogeology of the study area is controlled by the nature of the various volcanic lava flows and the configuration of the old surface of the basement system, generally referring the area as a volcanic plateau.

3.3 Vegetation

At the source, the swamp is heavily vegetated with reeds and different kinds of vegetation and trees in the adjacent farmlands. Further down, most of the vegetated areas are noted along the immediate river buffer zone with settlements and other developments noted within the adopted buffer strip of the study area as shown in figure 3.6.

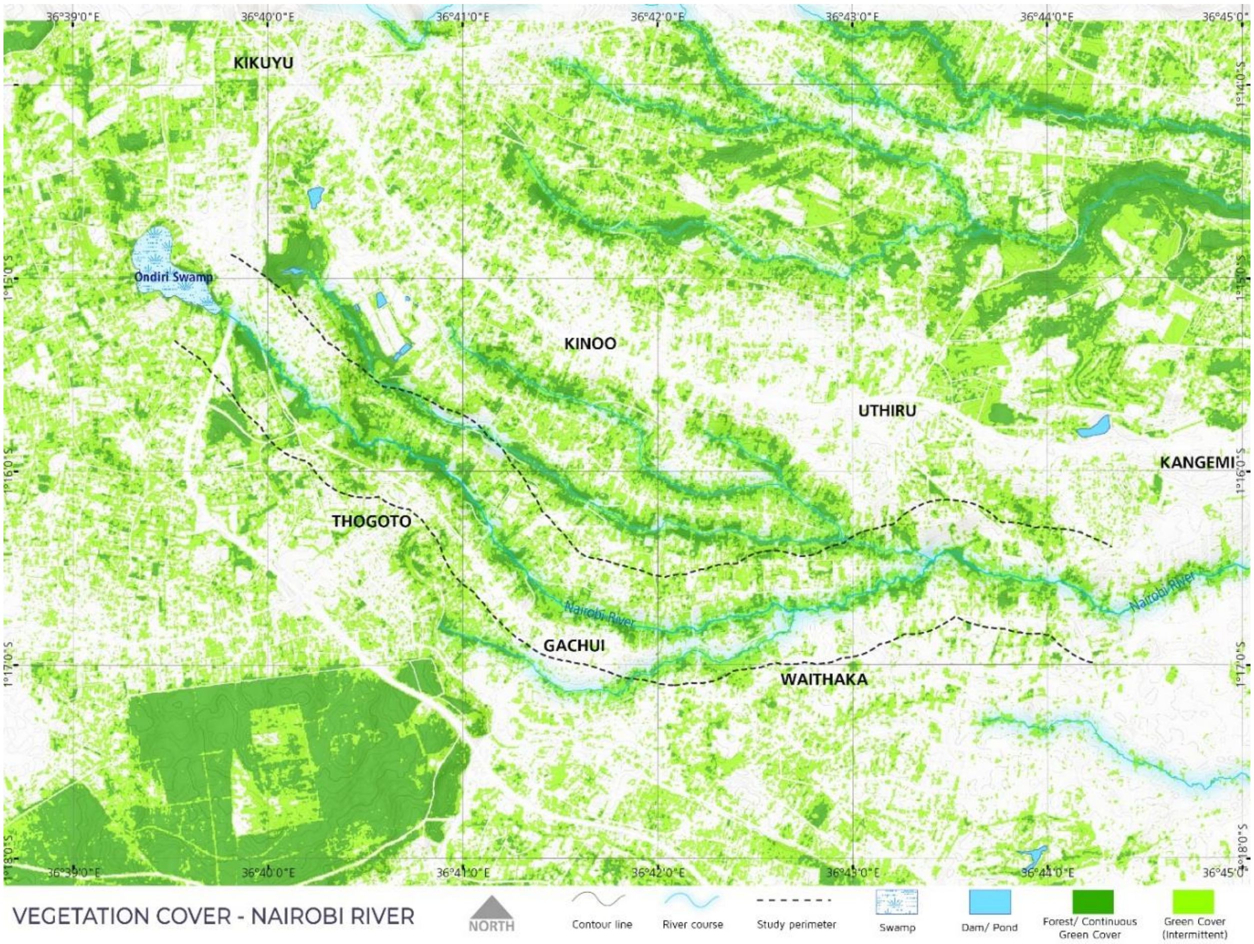

Figure 3.6: Vegetation cover map of the study area

Source: (Researcher, 2020; Modified from Sentinel 2A, 2018)

3.4 Economic activities

The anthropogenic activities in the upstream areas around the source of Nairobi River are dominated by agriculture land use which is a major source of livelihood. Agricultural activities consist of rain fed agriculture where smallholder farmers practice subsistence farming. Irrigated farms are also located around Ondiri Swamp due to availability of sufficient water for irrigation throughout the year. Irrigated areas are mainly commercial farms that produce high value crops such as vegetables grown in green houses for the burgeoning urban population.

The proximity of the study area to Nairobi has resulted in expansion of urban settlements due to demand for homes as well as the expansion of Kikuyu Town. There are also institutions such Kikuyu Hospital, Alliance High School, St Paul University, and University of Nairobi Kikuyu Campus. These institutions draw a considerable number of people in areas around the study. The proportion of settlement increases downstream towards the Naivasha Road Bridge.

Chapter 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter was prepared with the main purpose of explaining in detail the research methods used to achieve the three objectives including the types of data used, how the data analysis was carried out and which analytical tools where used.

4.2 Research Approach

This research study adopted both qualitative and quantitative data analysis as an approach to qualify and make conclusions of the study findings. On the part of qualitative data, the research made use of secondary data, field observations, ground pickings to produce and model land use data and classification that would then be related to computed statistical data on water quality measurements.

Based on previous studies, it was imperative that the methodology the study adopted revolve around evidence-based assessment of water quality through measurements of the various parameters, the analysis of the spatial layout of the study area and the impacts the spatial distribution of landuses had on the determined water quality on the selected study sites, and an elaborate analytical framework establishing correlation or lack of it between the spatial distribution of land uses and determined water quality trends. The adopted methodology integrated all the approaches with a goal of enhancing sustainable management of the Nairobi River ecosystem.

4.3 Research Design

Based on the research approach and the research problem under study, the research adopted observational and experimental study design techniques to undertake the research. On the part of sampling, the study adopted probabilistic sampling techniques and more specifically, systematic random sampling techniques to identify the study sites.

4.4 Research Instruments

The instruments of research used in this study were categorized into two, the software and hardware instruments. They are listed below:

Software Instruments: These are specifically the data and programs that were used in the computers to execute certain tasks as was required by the researcher. They included mapping related softwares which were ArchGIS 10.8; Google Earth Pro version; Earth Explorer account to access USGS and SRTM Landsat and Sentinel 2A images; Adobe Illustrator CC 2019; Ms Office suite 2016; and R Program version 4.0.2 for statistical analysis.

Hardware/Copy Instruments: These were the tools used by the researcher to either assist the performance of the software tools or to execute and conduct the research surveys and tests. They included printed hardcopy maps that were used to pick some ground control points; cameras and phones to capture photos; hand held GPS to pick crucial points of interest for the study; stationery materials for recording observed attributes of the sampling sites; sampling container, bottlers, and iced cooler box to store water samples for transport to the lab for further analysis; Laptop and desktop computers for report production.

4.5 Data Types and Sources

The data required and obtained for this research was of both primary and secondary data sources as discussed below.

4.6 Sampling Strategy

The study sites were carefully selected through probabilistic; systematic random sampling based on the distinct land use distribution and the hydrological occurrence along the river gradient of the study area. The consideration of these factors was helpful in the determination of the study sites that informed the knowledge base intended to be acquired through this study. In particular, the points where surface runoffs recharge the river were prioritized as study sites to enable the researcher draw inferences to nonpoint pollution sources. This meant that within the approximately 10km stretch of the river study area, distinct land uses and river confluence points were identified after every 2km and mapped using a GPS as summarized in Table 4.1 and Figure 4.1.

Table 4.1: The X, Y coordinates of the identified sample sites

SITE	LATITUDE (X)	LONGITUDE (Y)
A	-1.252581798	36.66263474

SITE	LATITUDE (X)	LONGITUDE (Y)
B	-1.263808802	36.67597121
C	-1.273235928	36.68687029
D	-1.27852436	36.71176455
E	-1.276103021	36.73472706

Source: Field data, 2020

Figure 4.1: Selected sampling points overlaid on the drainage system in the study area
Source: Researcher, 2020

4.7 Objective Specific Data Collection & Analysis Methods

The collection of data within the study area was organized according to the three specific study objectives as follows:

4.7.1 Objective 1: Determining the land use distribution

4.7.1.1 *Reconnaissance Survey*

Before undertaking the study, a reconnaissance visit to the study area was made with an interest in identifying the general attributes of the area, the challenges that the research team would be faced with while undertaking the study, testing the instruments of research, and also to identify the sample sites. During this reconnaissance, sample sites were identified and the research instruments were confirmed to be in good working condition to produce valid and credible results.

4.7.1.2 *Data types and sources*

The objective was achieved by use of primary and secondary data sources. Primary data was the data derived from field during reconnaissance and during the actual field work and was collected through observations, ground mapping and by taking photographs of the land use types along the riparian zones around the sampling stations. The secondary data consisted of satellite images and topographical maps of the study area. The study area was covered by one sentinel 2A satellite image which had a resolution of 10m and was acquired in the year 2020. This image was used to discriminate the spatial land use types through the image classification process. The elevation data of the study area was derived from digital elevation model (DEM) STRM data. Both satellite image and DEM data were obtained from the United States Geological Survey (USGS), Earth Explorer website.

4.7.1.3 *Image Processing*

The satellite image was projected and geo-referenced using the UTM Coordinate System (WGS84; Arc 1960/UTM Zone 36S) on ArcGIS/ArcMap 10.8. This ensured that the data captured in the model was consistent with all other geo-referenced national spatial outputs and could be retrieved for other use from the system at any point in time. This data was then used to design different thematic layers as a basis of analysis and drawing logical inferences of the study.

4.7.1.4 *Spatial Land Use Classification*

The GIS layers formed included a layer that showed the spatial position of the river system and surrounding land uses, and a layer with the locations of the various identified sampling sites for the assessment of water quality parameters. All the layers were presented differently with an aim of standardizing the intended outputs, communication and data presentation purposes. In this study, the researcher adopted the gazetted Physical Planning land use tenure systems to categorize the land as contained in the Physical Planning Handbook (2007) (Table 4.2).

Table 4.2: Classification of Land Uses as per the Kenyan Physical Planning Handbook (2007)

Zone No.	Land Use Category	Colour Scheme
0	Residential (High; Medium; or Low Density)	Shades of Brown Colour
1	Industrial (Light; Heavy; or obnoxious)	Shades of purple colour
2	Educational	Orange Colour
3	Recreational/Conservation	Light Green Colour
4	Public purpose	Yellow
5	Commercial	Red
6	Public Utilities	Blue
7	Transportation	Grey
8	Agriculture	Dark Green

Source: Physical Planning Handbook (2007), Physical Planning & Land Use Regulations (2019)

The actual classification of land uses in this study was based on actual and accurate field observations; verifications; ground control points actual picking; and use of satellite imagery to categorize land according to the predominant observed or picked land use category as per the Physical Planning Scheme above. Previous studies have established that the study area was predominantly used for agricultural purposes along its profile while the more urban settings were manifested around the lower end around Naivasha Road Bridge intersection (Alukwe, 2015). However, this research established that this general trend in land use distribution along the river gradient have slowly been changing with the conversion of agricultural lands into either urban commercial or residential nodes.

4.7.2 Objective 2: Current state of water quality

4.7.2.1 *Data types and sources*

To achieve this objective, the study relied on primary data collected in the field from the five sampling stations using *in-situ* and *ex-situ* measurement procedures, tools, and standards. Sampling was done twice, during the dry season in the month of June and during the rainy season in the month of November. This allowed for seasonal comparison. The samples were taken in replicates below the water surface using sterile bottles starting downstream to upstream at particular sampling station. The physicochemical parameters of interest to this study were: pH, temperature (˚C), conductivity (µS/cm), turbidity (NTU), total hardness (Mg/L), fluoride (Mg/L), nitrates (Mg/L), chloride (Mg/L), total coliforms (cfu), total fecal coliforms(cfu), dissolved oxygen (Mg/L), total dissolved solids (Mg/L), color (TCU), and sulfates (Mg/L).

All the water quality parameters were measured ex-situ except the water temperature that was measured *in-situ* using a thermometer (Plate 4.1). *Ex-situ* measurements were collected using bottles that were cleaned using deionized water prior to the water sampling and correctly labelled with the sampling point details including GPS coordinates. The bottles were then tightly closed and stored in cool box (Plate 4.1), and taken to University of Nairobi School of Engineering laboratory and analyzed using parameter specific standards. The transport and storage methods were designed to maintain structural and chemical quality of the water samples. The photos below (Plate 4.1) were captured at Ondiri swamp and are used to summarize the procedure used in collection, measurement and storage of the water samples in all the sample sites.

Plate 4.1: Water sample collection at Ondiri (A), in-situ water temperature measured (B), storage procedure of the Exsitu water samples (C).
Source: Field data, 2019

4.7.2.2 *Data Analysis*

The raw data of replicate samples taken from the five sampling sites was organized and cleaned in excel. This data was then imported into R program version 4.0.2 (RCoreTeam, 2019). Prior to any inferential statistics, the data was tested for normality using Shapiro-Wilk test. Data that did not meet the normality criteria was analyzed using the nonparametric Kruskal-Wallis H test to test if significant difference existed between seasons. While significant differences among the sampling sites was tested using the Dunn's Post Hoc test. All these analytical tests were conducted at P value ($p>0.05$) using the program as detailed out in Appendix 2.

4.7.1 Objective 3: Land use distribution & water quality relationship

4.7.1.1 *Data types and sources*

To achieve this objective the study used two primary datasets, the spatial land use metrics (value attached to a certain land use in measured in Ha) data from objective one, and the statistical water quality data derived from objective two.

4.7.1.2 *Data Analysis*

The relationship between the land use types and water quality characteristics was analyzed using the nonparametric Spearman rank correlation in R program using the rcorr function. The Spearman rank-order correlation coefficient is a nonparametric measure of the strength and direction of association that exists between two variables. The result is always in the range of +1 or -1 meaning a strong positive or negative relationship. To achieve this, land use proportions were computed and presented in hectares while the water quality observations remained as recorded. This test gave the nature and magnitude of relationship for each land use type and the measured water quality parameter.

Chapter 5: RESULTS AND DISCUSSION

5.1 Introduction

This study findings are discussed in this chapter. They are discussed systematically as per the three study objectives. Findings of the land use distribution and riparian conditions from the Nairobi River source at Ondiri Swamp are elaborated first. The discussion is followed by the findings on the status of water quality limited to the study physicochemical parameters for both dry and wet season. Finally, the findings on the assessment of the relationship between the land use distribution and water quality are discussed.

5.2 Land use distribution in the study area

In this section, land and land use development character is detailed in summary with observed characteristics around the five sampling points. Land use classification within the study area showed that the greatest percentage of land utilization is settlement related (residential/commercial/institutional land uses) followed by agriculture as summarized in Table 5.1 and Figure 5.1 below.

Table 5.1: Classification of land use types by percentage in the study area

No.	Land Use Type	Land Size (Ha)	Percentage (%)
1.	Agricultural	990	25
2.	High Density Residential	887	23
3.	Medium Density Residential	648	17
4.	Low Density Residential	301	8
5.	Forested/Conserved areas	264	7
6.	Educational/Institutions	207	5
7.	Transportation Infrastructure	184	5
8.	Public Purpose Areas//Institutions	150	4
9.	Commercial	113	3
10.	Horticulture	60	2
11.	Industrial	29	1
12.	Commercial cum Residential	28	1

Source: Field data, 2020.

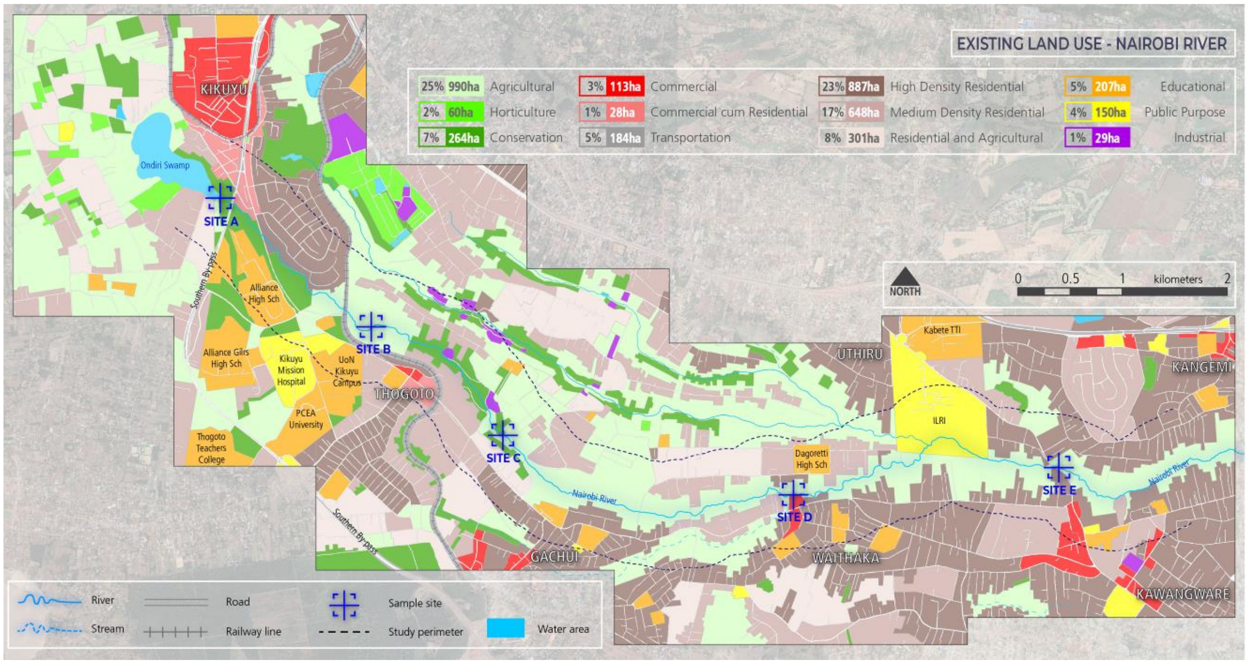

Figure 5.1: Land use distribution in the study area and along the river gradient
Source: Researcher, 2020.

As a way of projecting the likelihood of continued land use change along the entire stretch of the study area, the researcher conducted a spatial temporal analysis with an interest to establish the degree of land use change over a period of the last 10 years (Figure 5.2). The observations established that in a period of 10 years, the study area had experienced a lot of change in terms of land use with forests and other vegetation going down by about 8%, farmlands and agricultural land by 5%, and the built-up area going up by about 13% in the same period. This therefore corresponded the findings by Kiithia (2006); and Macharia (2010) who noted that land use was rapidly changing in that section of the river. This meant that in the absence of any interventions, development would continue with corresponding impacts related to water quality.

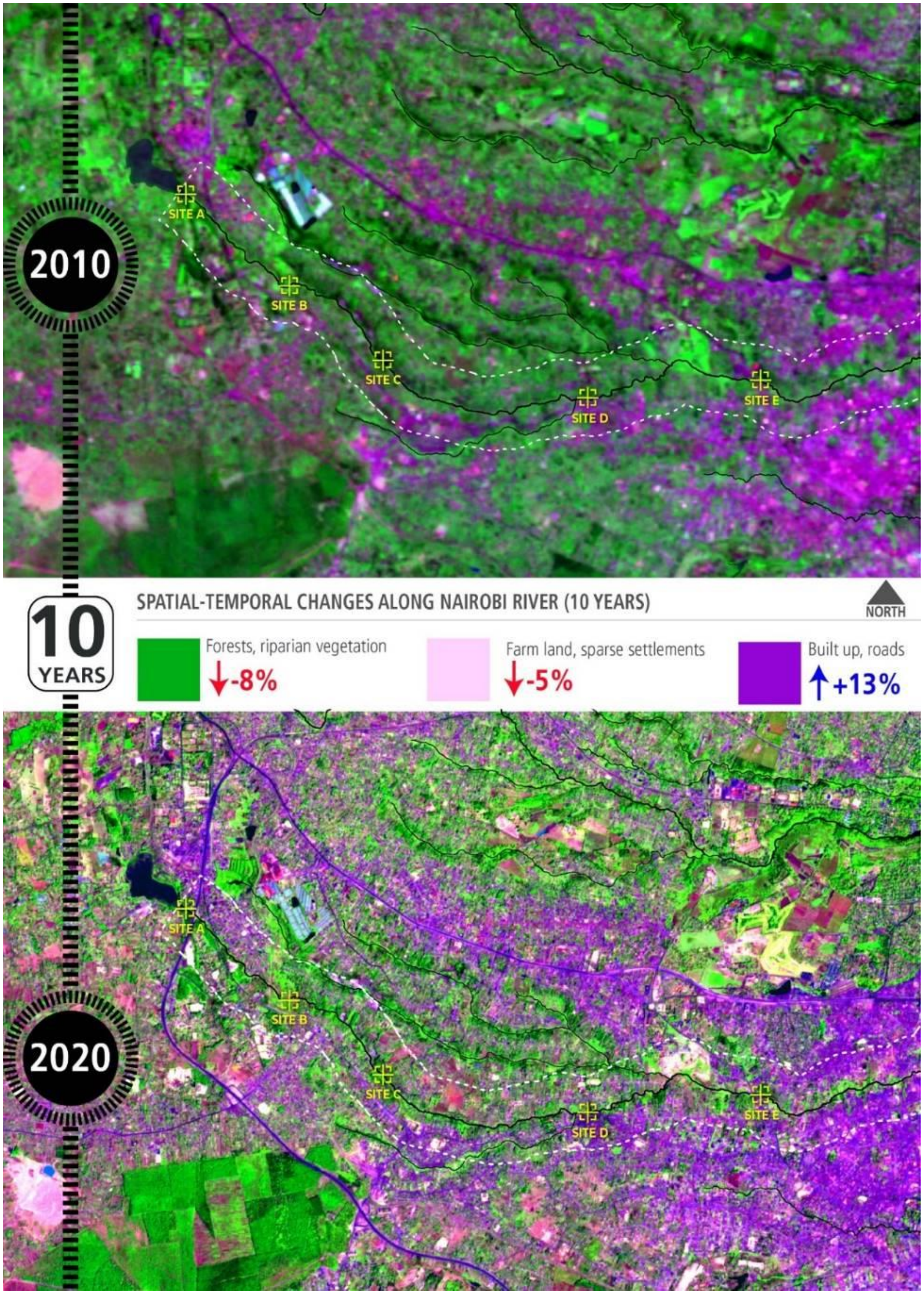

Figure 5.2: Spatial temporal analysis of the study area in a period of 10 years
Source: Researcher, 2020

5.2.1 Land use distribution at sampling point A

The sampling site A was located at Ondiri Swamp, the source of Nairobi River. Water recharges into the swamp as underground water from the highlands further away from the swamp and also from surface water draining into the swamp from surrounding areas. The immediate vicinity of the sampling site is dominated by aquatic vegetation mostly reeds. The water sample was collected at the edge of the swamp where the Nairobi River forms an outlet (Figure 5.3). Ondiri Swamp contains relatively good quality water with minimal temporal fluctuations. Therefore, it is a major source of clean water for surrounding settlements, institutions and also provides water for irrigation.

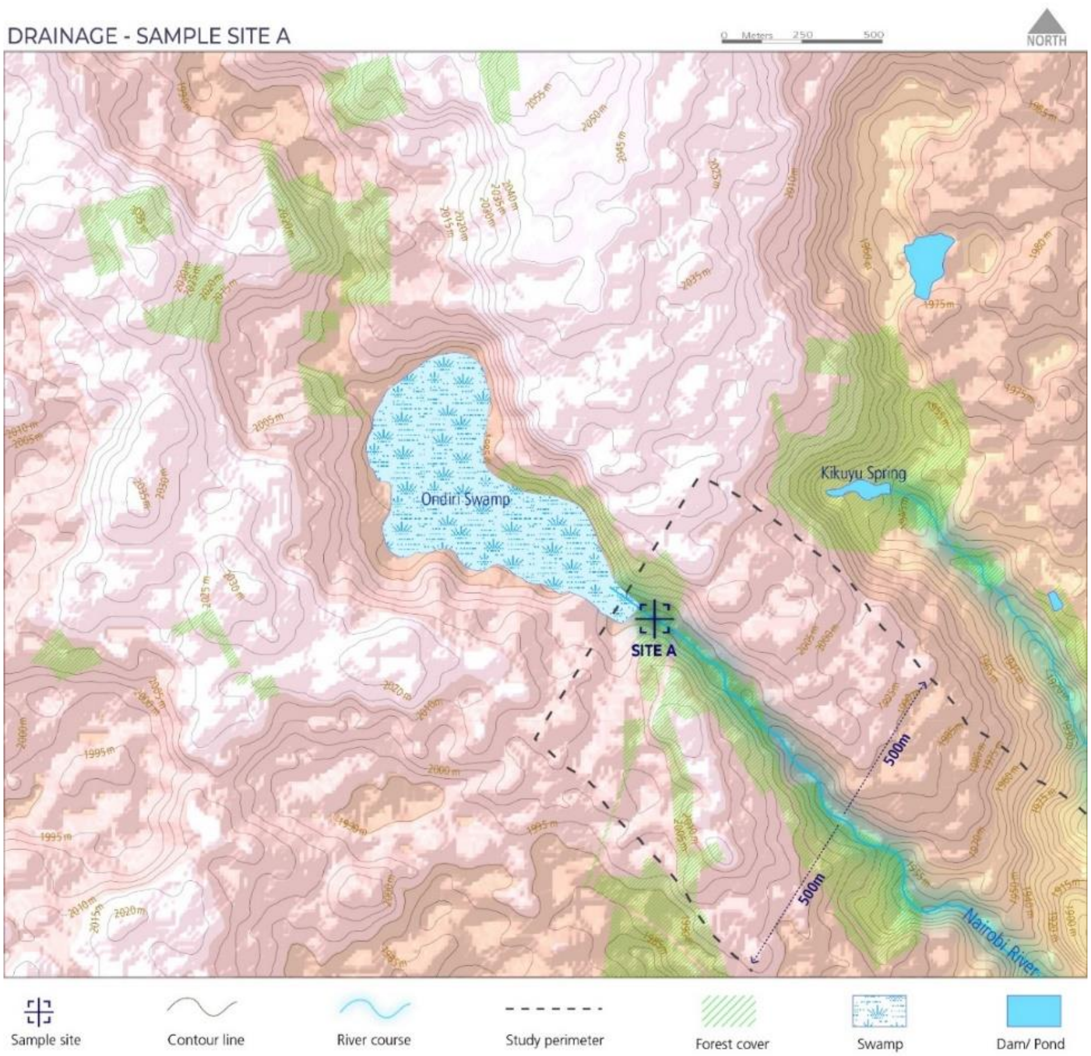

Figure 5.3: Drainage system around Ondiri swamp (Sample Point A)
Source: Researcher, 2019

The water availability in the swamp explains why predominant economic activities within and around Ondiri swamp are agriculture, urban settlements including Kikuyu Town (Figure 5.4). The agricultural activities happening around the swamp are intensive mostly dominated by greenhouse farming which are known for intensive water use and agrochemical use to boost yields of high value crops such as vegetables (Plate 5.1). These agricultural activities explains the presence of organ chlorides and organophosphates as the commonly used ingredients of pesticides as was shown in a study findings by (Koigi, 2015). The study by Koigi demonstrated that the encroachment of the swamp was a threat to water quality.

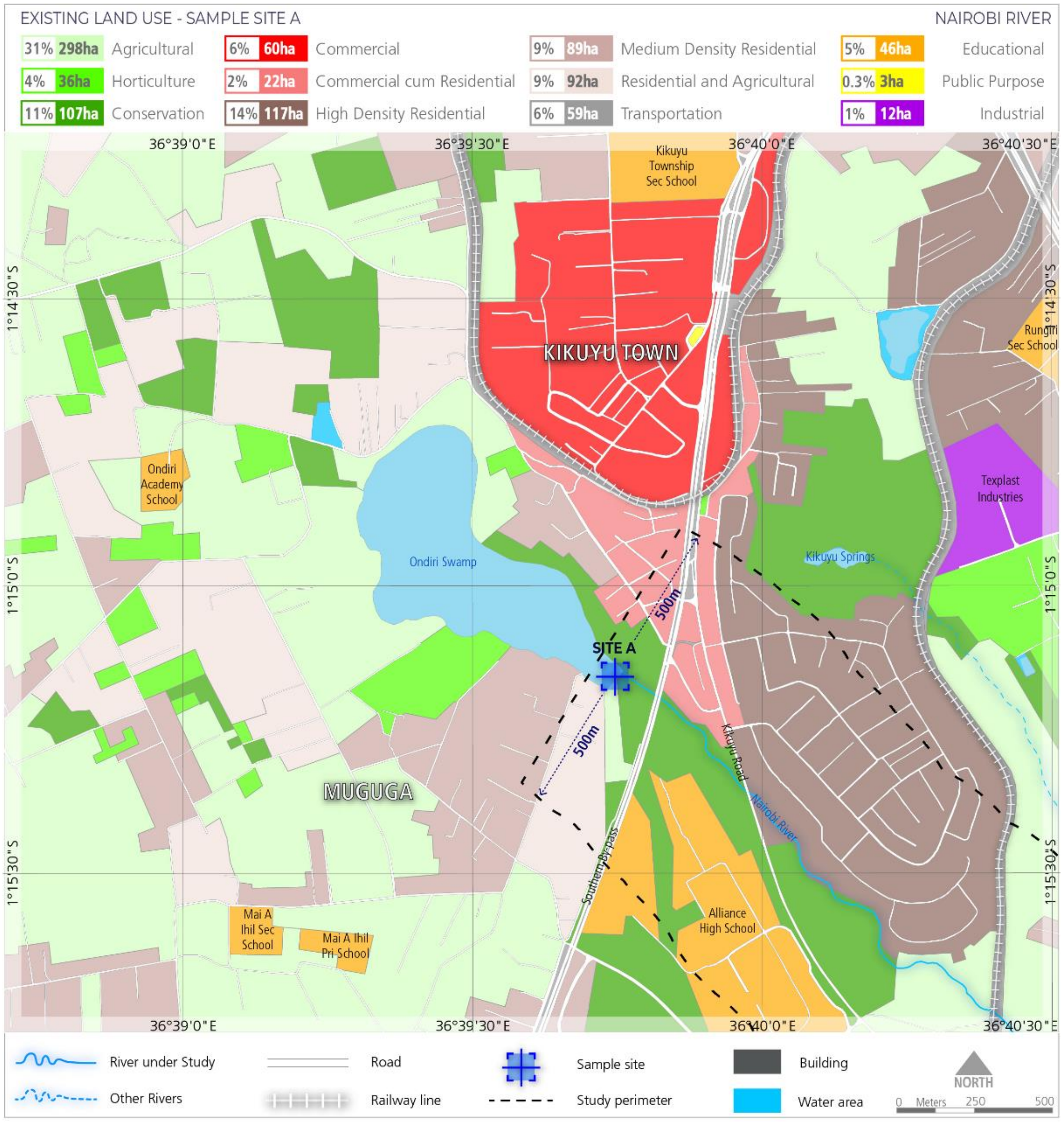

Figure 5.4: Land Use distribution around Ondiri Swamp
Source: Researcher, 2019

Plate 5.1: Mushrooming green houses around the swamp (A), and on the impact of human encroachment in Ondiri swamp (B)
Source: Field study, 2019

5.2.2 Land use distribution at sampling point B

The sampling point B was located 2 km downstream of point A (Figure 5.5). Around this point, land use has developed at varying intensities with the immediate context to the site on about 200 meters from the sample point characterized by subsistence agriculture. On about 300-400 meters to the West of the sampling point, it is influenced by a densely populated area as formed by Kidfarmaco residential estate. Further down towards the river, a few industries have been established while the immediate environs around the river remain predominantly Agriculture. There is a possibility of point and non-point pollution since all the surface runoff from these land use activities directly drain into the main river channel from the civil drains and natural drains.

To the south west of the sample point and within the 500 meters study area radius, the land is utilized for predominantly educational activities including the University of Nairobi, Kikuyu campus, Musa Gitau primary/secondary schools, PCEA Thogoto Old Peoples' home, Kikuyu Mission Hospital and a strip of residential activities to the south east of the sampling site (Figure 5.6). These land use activities, however, have their drainage systems hindered from flowing directly into the river as that sampling point by the railway line that cuts across but within the 500 meters buffer strip. However, their effluents discharge into the river is assumed to be taken into consideration on the fourth and fifth points which culminates the overall observations made within the study area as all streams and tributaries flow as one river from the fifth sampling point.

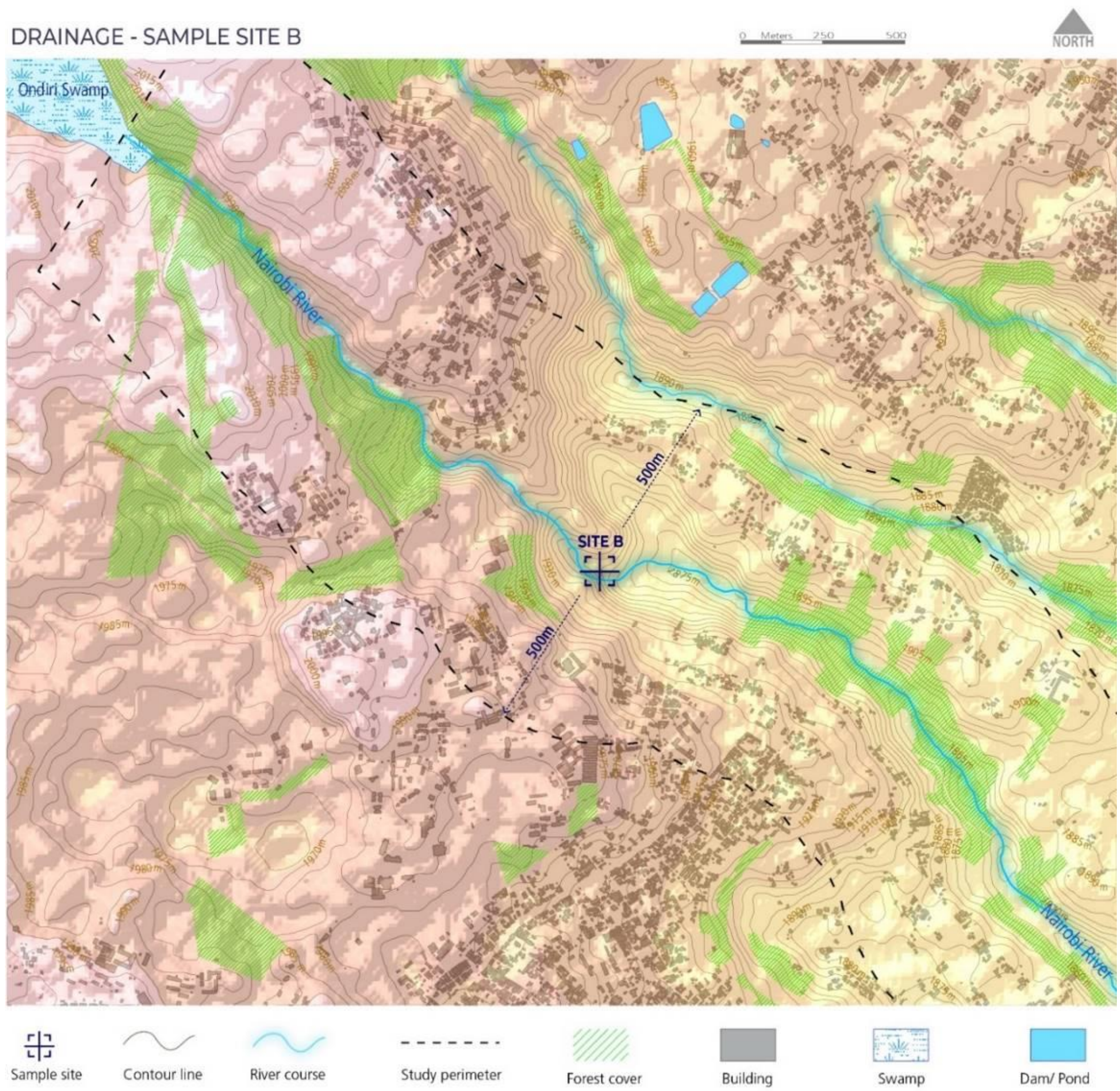

Figure 5.5: Drainage pattern around the second sampling point
Source: Researcher, 2019

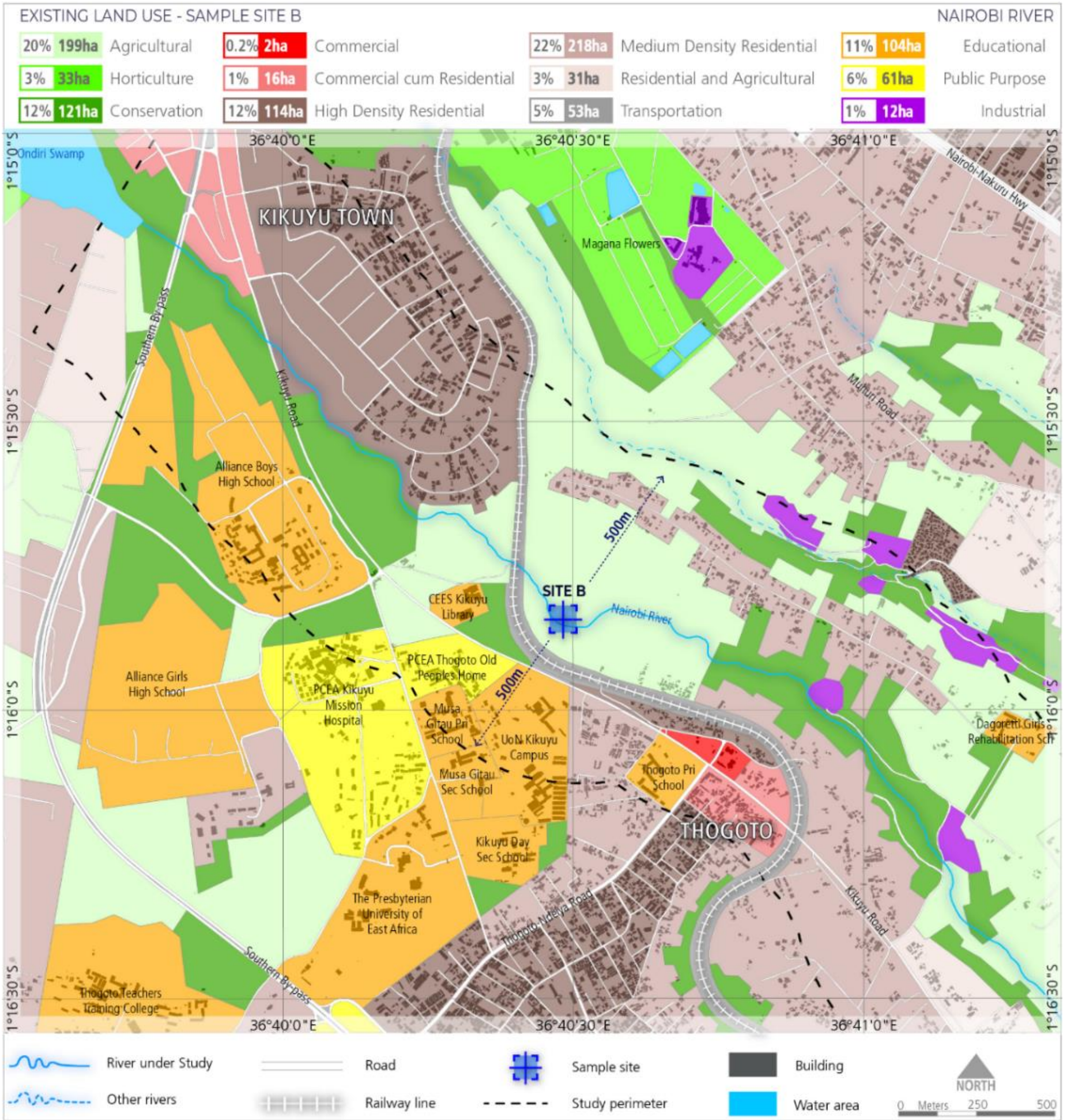

Figure 5.6: Land use distribution around the second sample point
Source: Researcher, 2019

Plate 5.2: Catchment degradation at Sampling point B: Evidence of severe surface runoff (Plate A), and evidence of encroaching human settlement in the Nairobi River riparian zone (Plate B)
Source: Field Data, 2019

5.2.3 Land use distribution at sampling point C

This point was found to be unique in that it is dominated by a proliferating informal residential settlement to the North West and an area of economic livelihood characterized by a string of stone quarries around the site, some of which are currently abandoned. This presented unique land use features that are associated with different impacts on water quality. The drainage system around which the water samples were collected is shown in figure 5.7 below.

Figure 5.7: Drainage system around the third sampling point
Source: Researcher, 2019

This distribution of land use was represented by a low percentage of commercial and educational land uses while the agricultural and residential land use comprised of both medium and high-density residential enclaves dominating the immediate context surrounding the sample site on the 500 meters radius study area. Other areas that have high density of settlements were located beyond the 500 meters buffer zone but still impacting on the water quality at the sample point from surface runoff. The land use distribution index is shown in Figure 5.8.

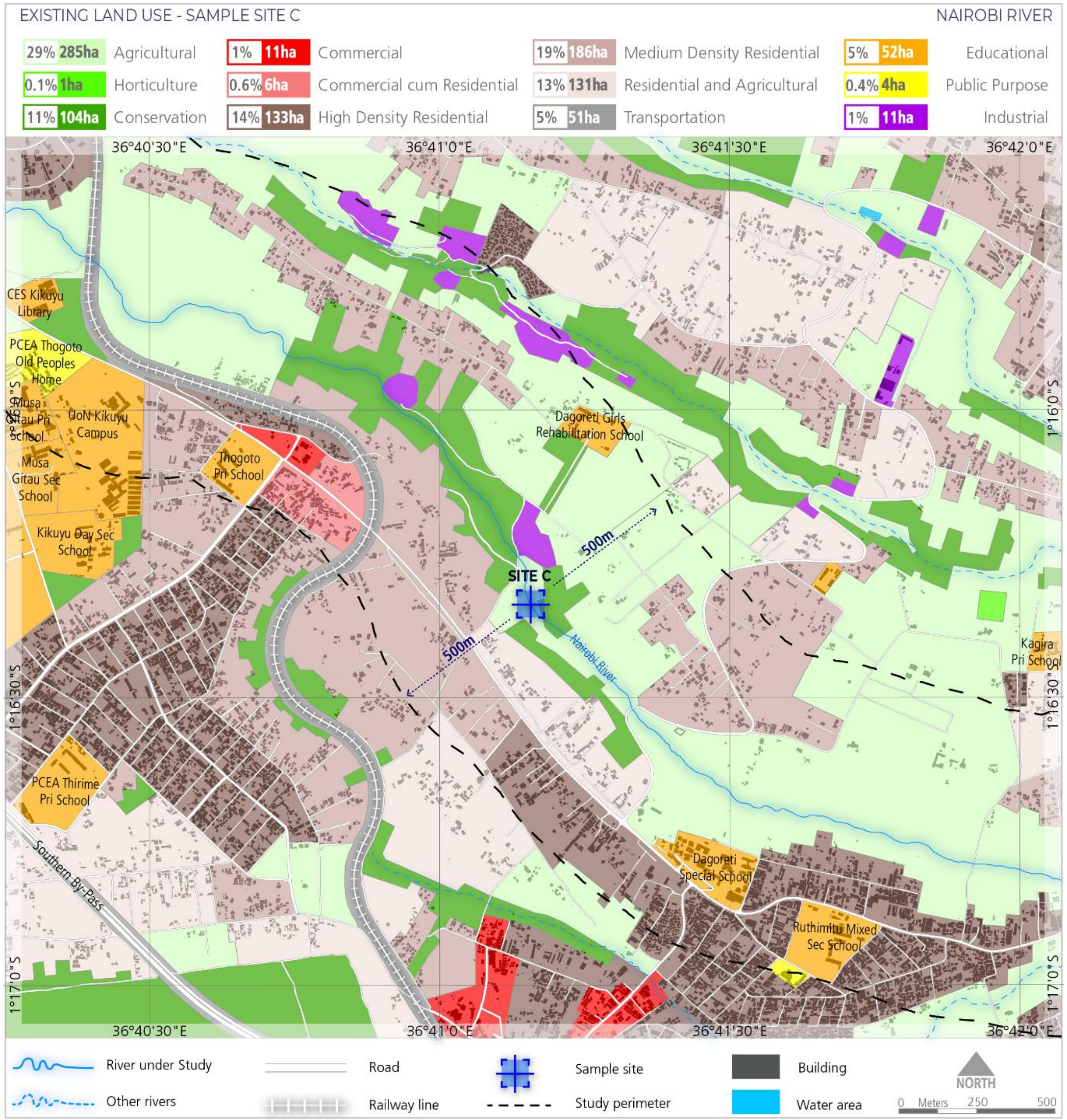

Figure 5.8: Land use distribution around the third sampling point
Source: Researcher, 2019

5.2.4 Land use distribution at sampling point D

This is the area to the south of Uthiru neighborhood. The land use distribution around this point is such that agriculture is practiced on the immediate river buffer with surrounding areas predominantly developed with dense residential settlements located to the north of the sampling point and all drainage systems and storm water from the developed areas draining water at this point (Figure 5.9). The dense activity and settlement zones are comprised of the larger Waithaka residential neighborhood with a small strip of a commercial node located within the immediate context of the sampling point while Dagoretti high school is located about 300 meters to the North east of the sampling point (Figure 5.10). The river is joined by a secondary tributary to form a bigger river as it flows towards Naivasha Road and Athi River eventually at this point.

Figure 5.9: Drainage system around the fourth sampling point
Source: Researcher, 2019

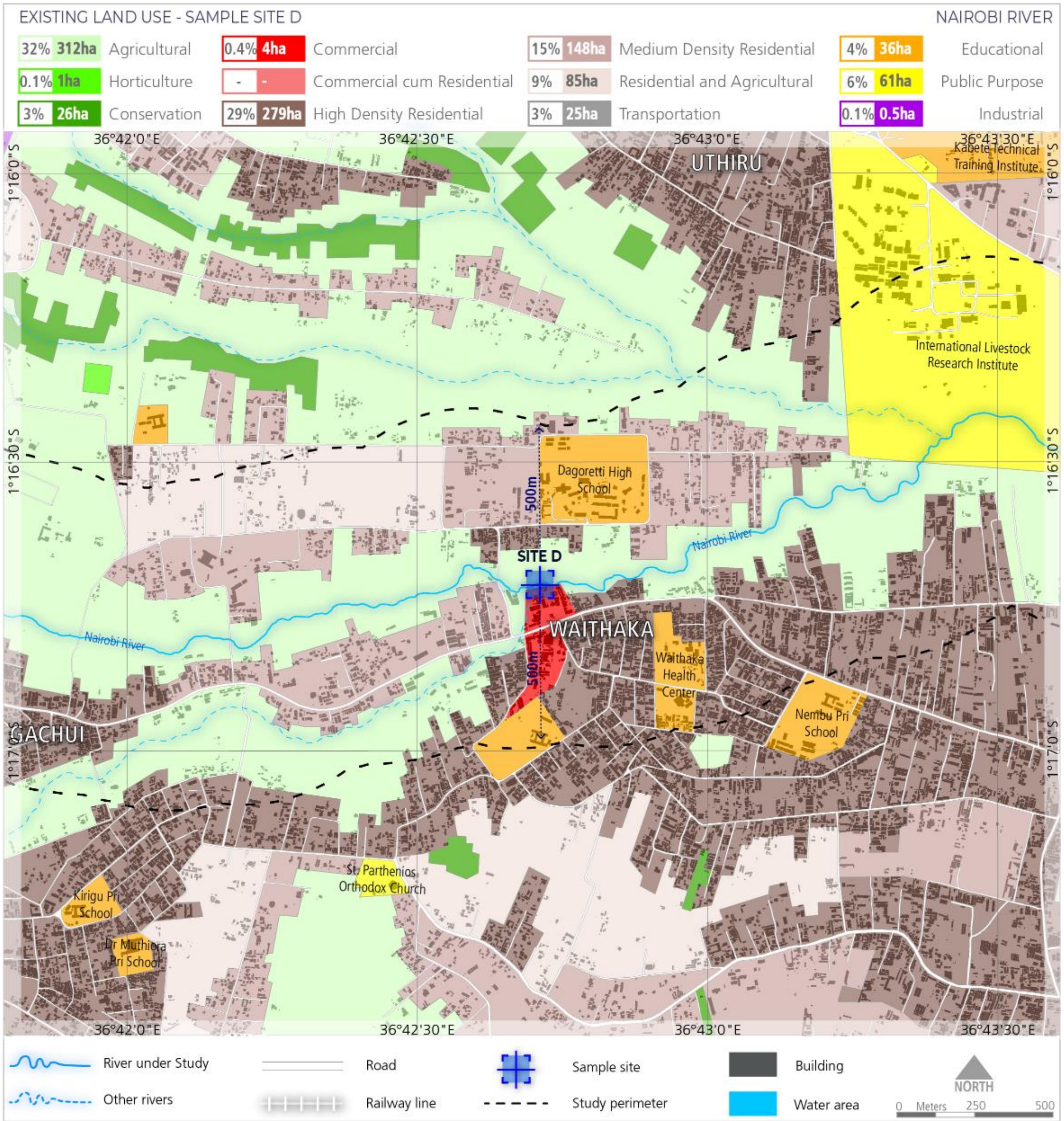

Figure 5.10: Land use distribution character around the fourth sampling point
Source: Researcher, 2019

5.2.5 Land use distribution at sampling point E

This is the point where the river crosses Naivasha road as it flows towards Nairobi (Figure 5.11). The area around this point is highly developed with both residential and commercial land uses within and around the point. Within the proximity of the sampling point on the Nairobi River bank, there were polluting activities associated with motor vehicle washing and informal car servicing garages. These activities are associated with heavy metal pollution and release of toxic sustenance according to study conducted on surface water bodies traversing Kisii Town by (Nyangau & Mayoyo, 2015). Waste water surface runoff from Uthiru shopping Centre drain into the river through the established civil drains along the road. There is an established sewer line at this point but the capacity to match the demand or establish the number of connections was not determined.

Figure 5.11: Drainage system around the fifth (Naivasha Road) sampling point
Source: Researcher, 2019

The International Livestock Research Institute (ILRI) is located within the immediate context of the sampling point as a major land use feature. Other land uses that were recorded to have a major impact on the water quality at this point as non-point sources are the Kawangware shopping Centre located to the south east of the sampling point and a band of Agricultural land uses to the north of the sampling point. Other major land use contributors to water quality situation around the point are the predominant residential developments which mostly do not have adequate sewer management systems and/or are not connected to the existing sewer line. This is as shown in figure 5.12.

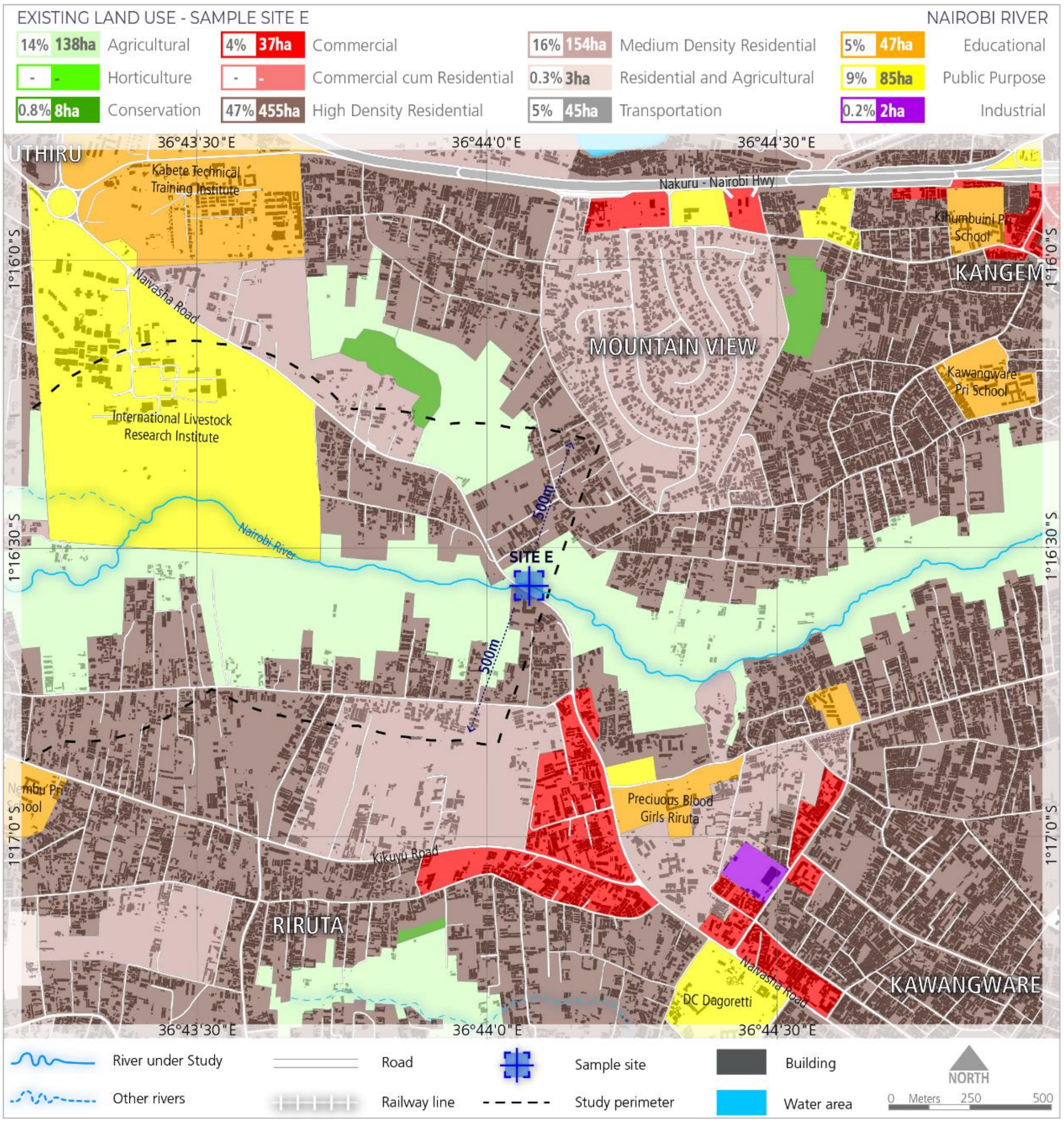

Figure 5.12: Land use distribution character around the fifth (Naivasha Road) sampling point
Source: Researcher, 2019

As the research observed, the area around the sampling point has experienced intense land use change over the last decade attributed to the proximity to Nairobi City and the level of infrastructure development including a sewer system which supports a higher population catchment within the residential developments. Even though the land use change may not have direct impact to the river system, it is important to understand that it is changing rapidly and until scientific research determines the change do not necessarily affect the river water quality, then research must be done to determine current status as a way of leveraging knowledge for future studies. The observations for water quality recorded at this last point were deemed to be the cumulative water quality observation of the entire study area as this point represented the convergence of all tributaries and drainage systems to form one big river as it flows towards Nairobi City and Athi river eventually.

5.3 Water quality characteristics

The mean values of the results for the water quality parameters observed in the wet and dry seasons among the five sites are summarized in Table 5.2 and Table 5.3. All parameters except Chlorine did not show normal distribution all at $p<0.05$, therefore Kruskal-Wallis test was performed to determine if significant differences exist in water quality values between the dry and wet season. Further, Kruskall-Wallis followed by Dunn's *post hoc* test was done to determine if significant differences existed among the sampling sites at the level of significance, $p<0.05$.

Table 5.2: Summarized Mean of observed water quality parameters in the two seasons

Water Quality Parameters (units)	**N**	**Dry Season**	**Wet Season**	**P-value**
		Mean±SD	Mean±SD	
pH	15	6.64±0.57	6.57±0.59	0.147
Temperature (˚C)	15	19.6±0.63	23.04±1.3	0.000*
Conductivity (µS/cm)	15	239±55.95	284.8±66.6	0.04*
Turbidity (NTU)	15	18.17±9.86	21.99±9.18	0.0095*
Total hardness (Mg/L)	15	84.13±17.44	91.13±20.83	0.245
Fluoride (Mg/L)	15	0.31±0.19	0.31±0.09	0.69
Nitrates (Mg/L)	15	4.14±2.19	4.64±2.18	0.52
Chloride (Mg/L)	15	117.67±20.02	110.47±20.81	0.35
Total coliforms (cfu)	15	30.8±13.91	239.8±119.54	0.0000*
Total fecal coliforms(cfu)	15	2.53±1.56	17.26±19.03	0.003*
Dissolved oxygen (Mg/L)	15	6.78±1.4	6.43±2.01	0.71
Total Dissolved solids (Mg/L)	15	263.13±58.10	252.73±70.82	0.58
Color (TCU)	15	16.33±9.06	16.13±5.06	0.45

Sulfates (Mg/L)	15	4.1±2.14	11.0±6.71	0.004*

Source: Researcher, 2019

Table 5.3: Observed statistical summaries for the water quality parameters

Water Quality Parameters	No. of Observations	Min	Max	Mean	Median
pH	15	5.420	7.240	6.606	6.850
Temperature (˚C)	15	19.10	24.60	21.32	20.85
Conductivity (µS/cm)	15	148.0	374.0	262.1	278.0
Turbidity (NTU)	15	10.40	39.70	20.08	17.65
Total hardness (Mg/L)	15	50.00	110.00	87.63	93.00
Fluoride (Mg/L)	15	0.100	0.5600	0.3090	0.2400
Nitrates (Mg/L)	15	0.500	6.00	4.393	5.700
Chloride (Mg/L)	15	78.0	147.0	114.1	116.5
Total coliforms (cfu)	15	9.0	400.0	135.3	49.0
Total fecal coliforms(cfu)	15	0.0	55.0	9.9	4.0
Dissolved oxygen (Mg/L)	15	2.40	7.9	6.607	7.250
Total Dissolved solids (Mg/L)	15	120.0	337.0	257.9	274.0
Color (TCU)	15	8.0	34.0	16.23	15.50
Sulfates (Mg/L)	15	1.80	22.0	7.55	6.50

Source: Researcher, 2019

5.3.1 Water pH

The observed pH values ranged from 5.42 to 7.24 in sites 1 and Site 5 respectively as shown in table 5.3. The Shapiro-Wilk test showed that the pH data was not normally distributed with p value<0.05. Kruskall-Wallis test showed that the seasonal mean pH values had no significant differences ($p>0.05$). However, Kruskal-Wallis test on the mean pH values among sites revealed that there were significant differences among the sample sites. Multiple comparison using Wilcoxon rank test revealed that that significant differences in pH values existed between Site 1 and all other Sites, while Site 2 was significantly different with Site 3, 4 and 5. The trends in pH values for dry and wet season among sites are shown in Figure 5.13.

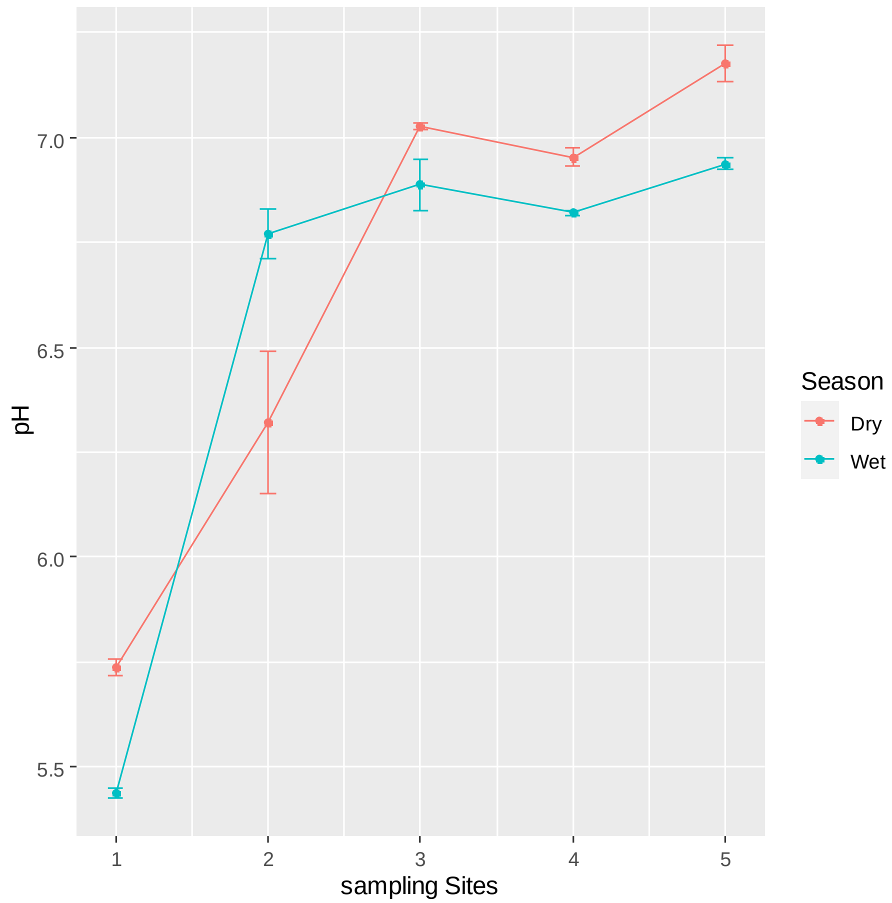

Figure 5.13: pH trends in the different sample sites and seasons
Source: Researcher, 2019

The pH of pure water is 7. WHO water quality guidelines prescribe that the pH values should be within 6.5- 8.5, Site 1 exceeded the lower limit of pH value, recording 5.42. Site 1 was located at the source of Nairobi River in Ondiri Swamp. Research conducted by Macharia, Thenya & Nderitu 2010, showed that the pH values in Ondiri swamp ranged from 6.1 to 8.2. The difference in observation could be attributed to the point of collection of the water sample, season/time or generally the change in land use character around the swamp. Nevertheless, according to the Environmental Protection Agency (EPA), pH isn't a quality that falls under their regulations because it's considered an aesthetic quality of water. However, they still recommend that municipal drinking water suppliers keep their water supply at a pH of 6.5 to 8.5.

5.3.2 Water temperature

The measured values for water temperature ranged from 19.10°C to 24.60°C among the sampling sites as shown in table 5.3. Shapiro-Wilk test showed that the water temperature did not meet normality conditions, hence the adoption of non-parametric techniques. Kruskal-Wallis test revealed that there were no significant differences in spatial variations in values among sites. However, the seasonal means between dry and wet season were significantly different at p value<0.05 as shown in Table 5.2 above and figure 5.14 below.

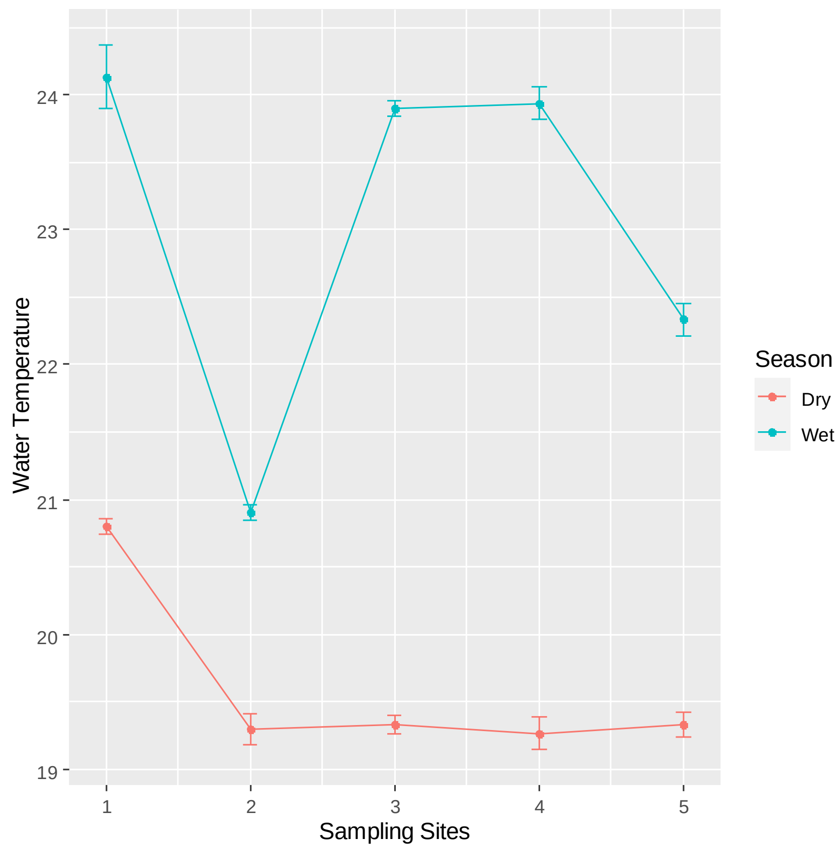

Figure 5.14: Trends in temperature among the sampling sites and the seasons
Source: Researcher, 2019

According to Gordon *et al*, 2004, water temperature in rivers varies longitudinally, both diurnally and seasonally influenced by riparian conditions such as extent of modification. Temperature values for dry season were significantly lower than the temperature values observed during the wet season. The findings of this study contradict the findings made in Ruiru and Ndarugu River

Basins where Mwangi 2018, observed lower temperature during the wet season. This can be attributed to diurnal temperature changes or a difference in observation times.

However, according to EPA and WHO, temperature is a very important indicator for water quality since an increase in the water temperature means decreasing solubility of oxygen in the water. Additionally, an increase in the water temperature enhances the growth of aquatic microorganisms resulting in higher consumption of dissolved oxygen and therefore, reduces the amount available in the water. Further, water temperature affects disinfection process because its efficiency is lesser at lower temperature.

5.3.3 Conductivity

Shapiro-Wilk test showed that the observed conductivity values were not normally distributed with p value<0.05. Mean conductivity values showed variations among the five sampling stations as shown in Table 5.2 while the range was recorded as 148.0 to 374.0µS/cm as shown in Table 5.3. This range was within the WHO threshold of 1000 µS/cm.

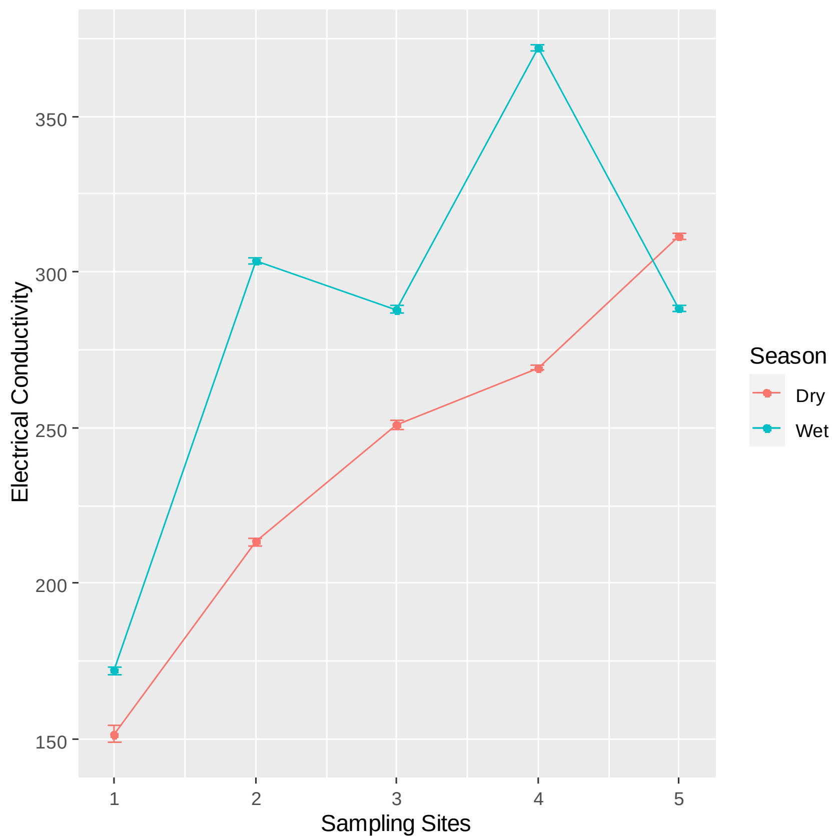

Figure 5.15: Seasonal trend of conductivity among the sampling points
Source: Researcher, 2019

The Kruskal Wallis test results revealed that the spatial differences among the sites were significant at $p<0.05$. Multiple Wilcoxon rank test showed that electrical conductivity values for Site 1 were significantly different from all other sites, but the Sites 2,3,4 and 5 showed no significant differences. There were significant ($p<0.05$) temporal differences in conductivity between dry and wet seasons, where the wet season mean values were higher that dry season values. The dry season conductivity trends showed an increasing trend downstream, while the wet season values showed no discernible trends.

5.3.4 Turbidity

The turbidity values ranged from 10.40 to 39.70 NTU, which were beyond the 4NTU limit for visible turbidity as shown in table 5.3. The mean turbidity values showed spatial variation among the sites as shown in figure 5.16. Kruskal-Wallis test revealed spatial differences among sites were not significant with p value>0.05. The temporal variations between the dry and wet season were however significantly different with Kruskal-Wallis p value<0.05, whereby wet season values were significantly higher than dry season values. This can be attributed to influx of runoff into rivers during the rainy season, while the observed downstream increase can be attributed to increasing human disturbance along the river gradient.

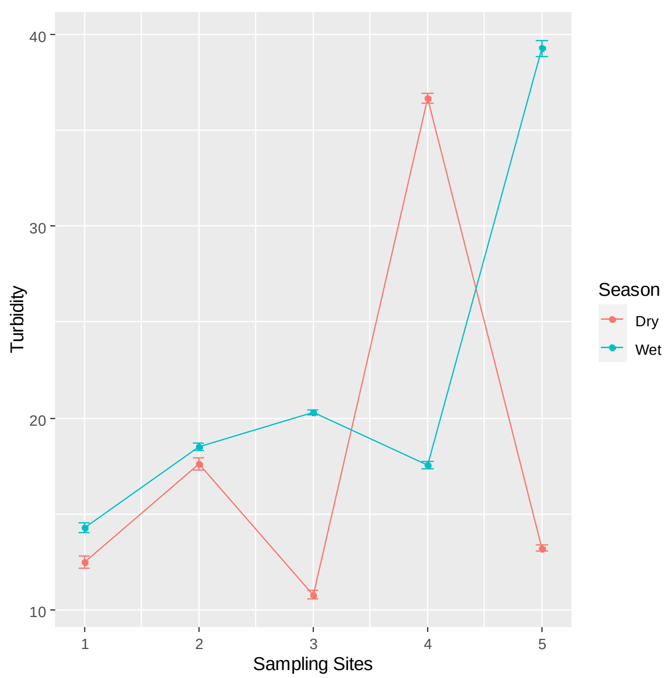

Figure 5.16: Turbidity seasonal variation trends among the sampling points
Source: Researcher, 2019

5.3.5 Total hardness

The total hardness values ranged from 50 to 110 mg/L according to table 5.3. These values exhibited an increasing downstream trend. Site 1 had the least total water hardness which can be attributed to surrounding land cover conditions of wetland vegetation. Kruskall-Wallis test revealed significant spatial total hardness variations among sites with p values <0.05 as shown in Figure 5.17. However, the temporal variation between dry and wet season were found to have no significant differences with p value >0.05. The Multiple comparison from the Wilcoxon rank test showed that the values were significantly different between Site 1 and Sites 2,3,4, and 5, and between Site2 and Site 5.

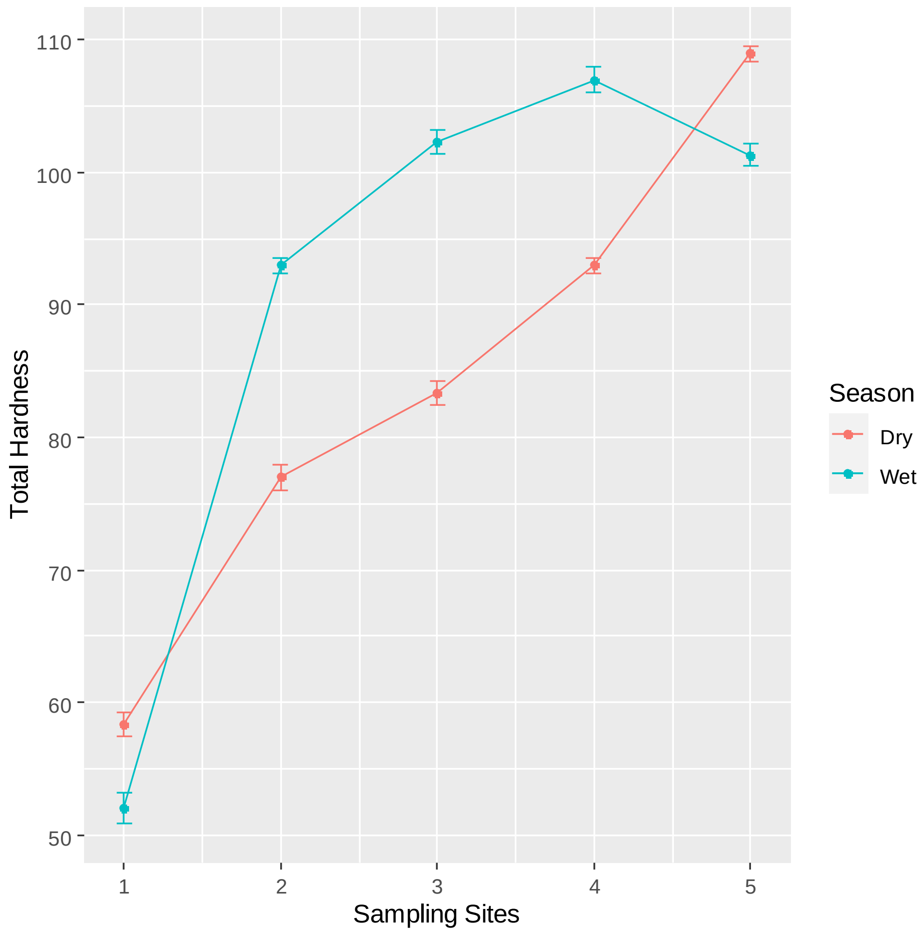

Figure 5.17: Total hardness seasonal variation trends among the sampling points
Source: Researcher, 2019

5.3.6 Fluoride

The Shapiro-wilk test showed that fluoride did not follow a normal distribution. The fluoride values ranged from 0.1 to 0.56 mg/L (Table 5.3), which were below the WHO water quality guideline which limits Fluoride content in water to 1.5mg/L. The observed fluoride values showed spatial variations according to figure 5.18. The Kruskall-Wallis test revealed that these spatial and seasonal variations among sites and between dry and wet season were not significantly different with p values > 0.05.

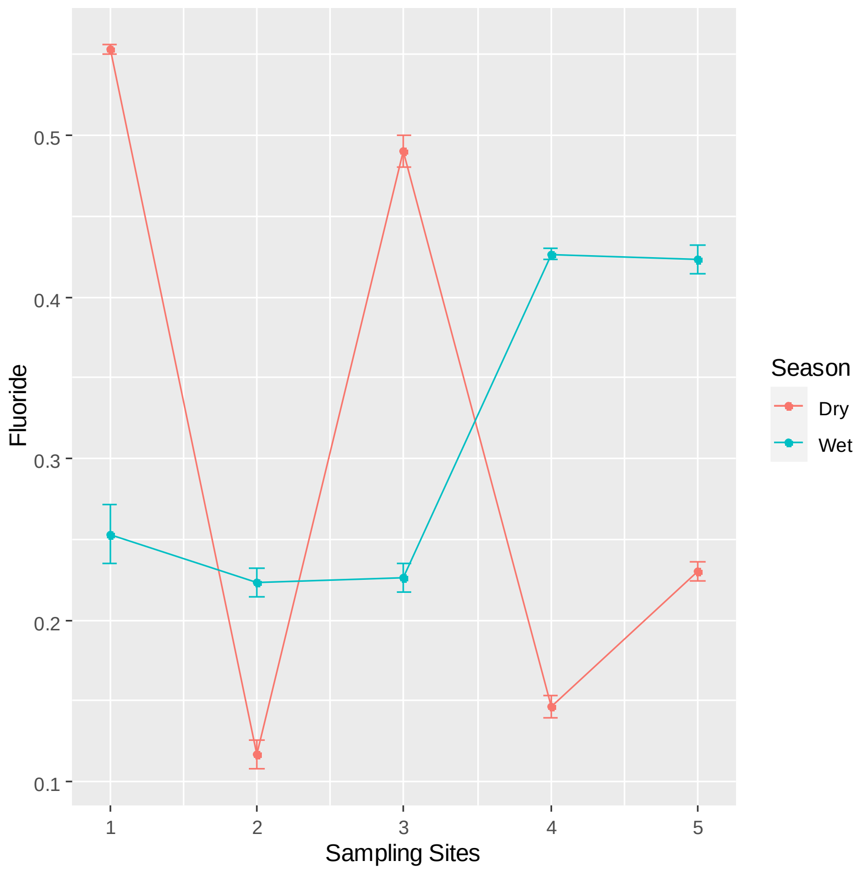

Figure 5.18: Fluoride seasonal variation trends among the sampling points
Source: Researcher, 2019

5.3.7 Nitrates

Shapiro-wilk test revealed that the concentration of nitrate in water was not normally distributed with p value <0.05. The concentration of nitrates was measured within a value range of 0.5 and

6.0 mg/L (Table 5.3); these values were below the WHO water quality standards of 50mg/L. The least value was recorded in Site 1 while the highest value was recorded in Site 4, where by Nitrate exhibited an increasing downstream trend. The Kruskal-Wallis test results showed the mean nitrates values had significant differences among the sampling sites with p value <0.05, but had no significant differences between dry and wet season with p value >0.05 (Figure 5.19). The multiple comparison Wilcoxon rank test revealed that the first sampling point (Site 1) was significantly different to when compared to all the other sites. Site 2 was significantly different to Site 4, while Site 3 showed differences with Site 4 and Site 5, Site 4 also showed significant differences with Site 5.

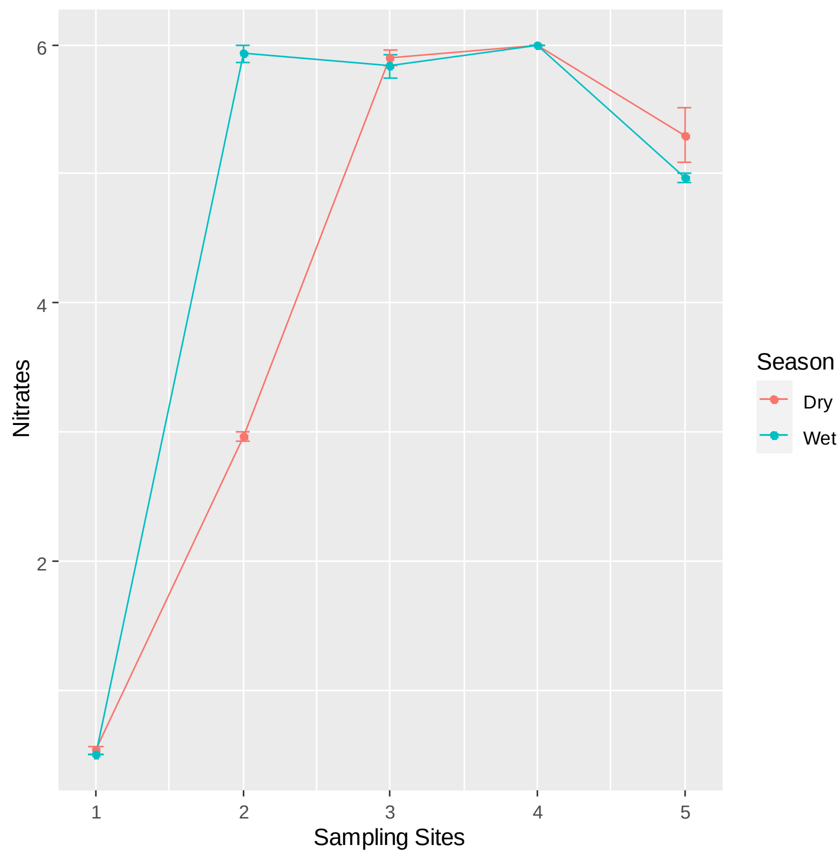

Figure 5.19: Nitrates seasonal variation trends among the sampling points
Source: Researcher, 2019

5.3.8 Chloride (Cl^-)

The observed chloride values ranged from 78 to 147mg/L (Table 5.3), these values exceeded the WHO guidelines limit of 5mg/L. Shapiro-Wilk test revealed that the data was not normally distributed with p value<0.05. Chloride values showed variations among the sampling sites and between dry and wet season as shown in figure 5.20. These spatial variations were found to be significantly different with Kruskall-Wallis p value<0.05, while the seasonal variations had no significant differences with p value>0.05. The multiple comparison Wilcoxon rank test revealed that Chloride values where significantly different between Site 1 and Sites 2, 3, 4, and 5, while Site 2 was only significantly different with Site 5. The temporal variations between the dry and wet seasons showed no significant differences from the Kruskal-Wallis test (Table 5.2).

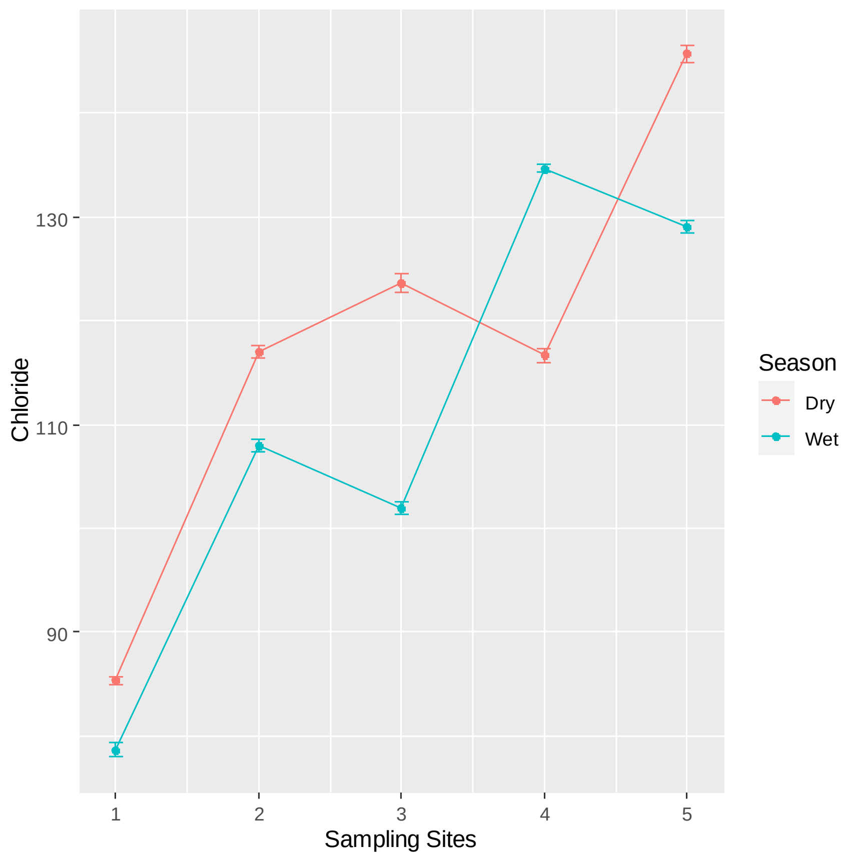

Figure 5.20: Chloride (Cl^-) seasonal variation trends among the sampling *points*
Source: Researcher, 2019

5.3.9 Total coliform (TC) bacterial

Total coliforms refer to a broad range of anerobic and aerobic, non-spore-forming, and gram-negative bacteria. In general terms these are bacteria that include both fecal and environmental genera which can grow and thrive in water in both sewerage and natural water. This characteristic makes them an important part of water quality assessment protocol, since their source is animal and human excreta, as well as inoculum in the natural environment. In this study total coliforms were measured per 100ml and the results ranged from 9 to 400 cfu/100ml (Table 5.3). The least recorded value was in Site 1 and the highest in site 4 signifying an increasing trend downstream.

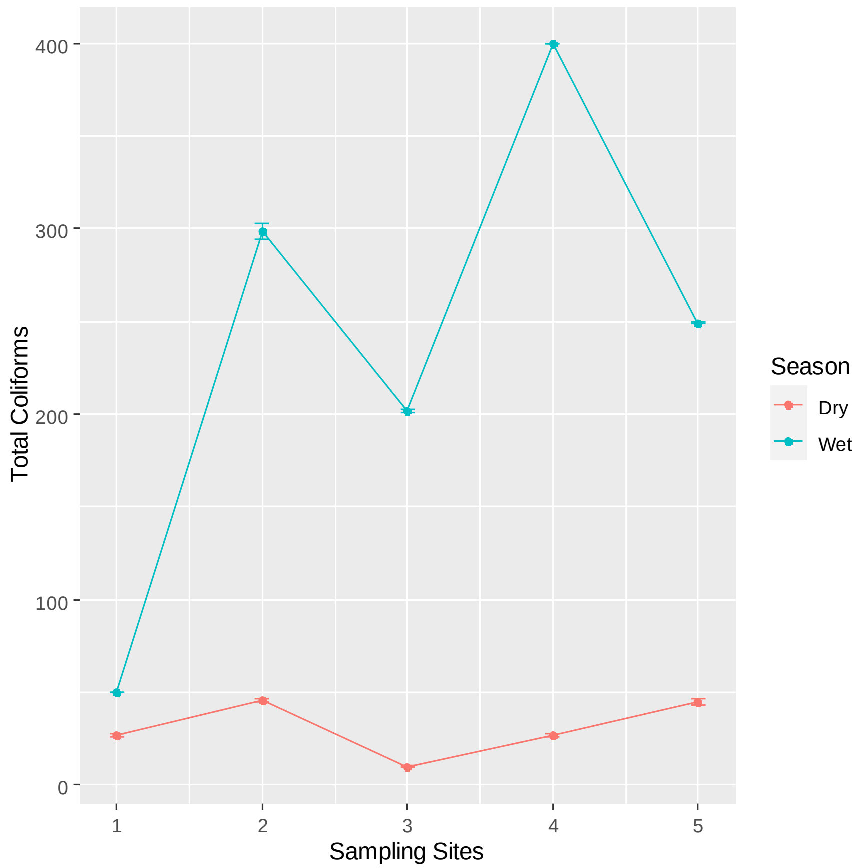

Figure 5.21: Total Coliforms seasonal variation trends among the sampling points

Source: Researcher, 2019

The drinking water quality standards limit the presence of total coliforms to 30 counts per 100ml (WASREB 2006; and WHO 2017). This implies that the water in Nairobi River beyond Site 1 can be considered as unfit for potable use and for irrigation purposes. The WHO warns of 10% risk of gastrointestinal infections in a single-exposure, for values> 500cfu/100ml.

Shapiro-wilk test revealed non-normality at p value<0.05. Non-parametric Kruskal-Wilk test revealed that the spatial variations among sites was not significant at p value>0.05, however, the seasonal difference between the dry and wet season was significant at p value <0.05. The mean wet season values being higher than those dry seasons Figure 5.21. Similar findings were reported in the Red River basin, North Viet Nam (Nguyen *et al.*, 2016). The Researchers found out that TC counts were higher in the wet season than in the dry season. This could be attributed to more surface overflow during the wet season when compared with the dry season.

5.3.10 Total fecal coliforms

The fecal coliform bacteria are dominated by the *Escherichia coli* (E. coli) which can be regarded as a suitable fecal indicator bacterium (FIB). This is because they occur in large numbers in human and animal excreta, or water that has had recent contamination with excreta especially fecal. Their presence in potable water is affected by temperature and nutrients and have higher sensitivity to disinfectants. Fecal coliforms ranged from 0.0 to 55 cfu.100ml, the least value was recorded in Site 1 and the highest in Site 5 depicting an increasing downstream trend (Table 5.3; and Figure 5.22).

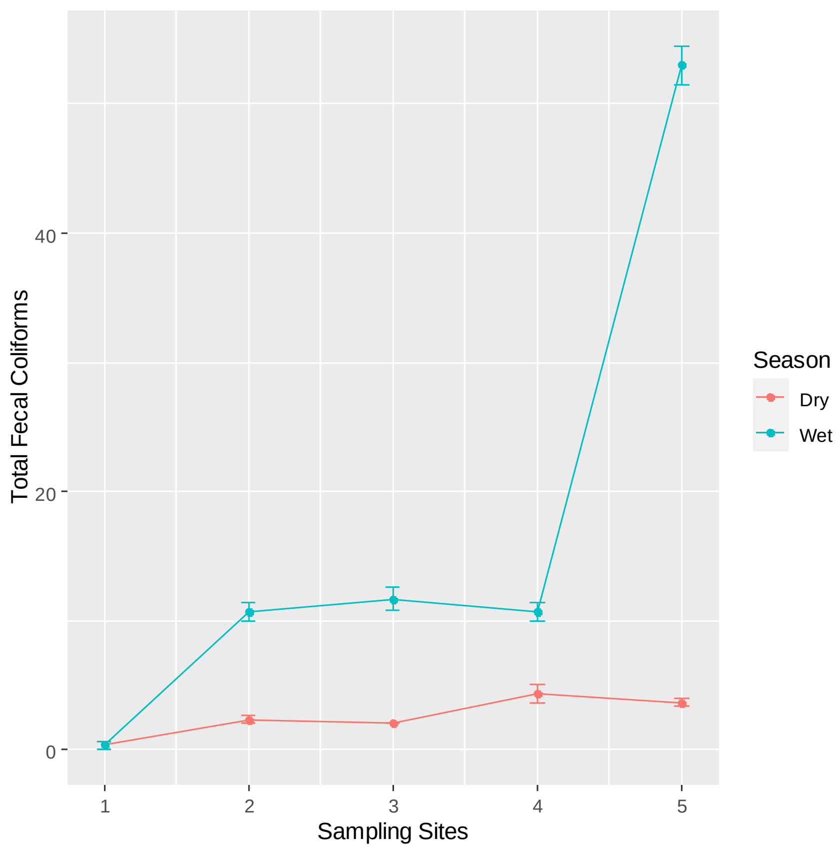

Figure 5.22: Total Fecal Coliforms seasonal variation trends among the sampling points
Source: Researcher, 2019

All sites except Site 1 exceeded the WHO and the Kenyan drinking water standards that stipulate for nil counts/100ml. Shapiro wilk test indicated non-normality, while the non-parametric Kruskall-wallis test indicated that both spatial and seasonal differences between dry and wet season existed with p values <0.05. The multiple comparison Wilcoxon rank test showed that only Site 1 had significant differences with other sites, while the wet season values were higher than the dry season values. This study agreed with Nguyen *et al*, Ngoye and Machiwa, 2004 who attributed the presence higher counts of fecal coliforms in the wet season being a result of deficient sanitation infrastructure in areas in close proximate to the rivers.

5.3.11 Dissolved oxygen (DO)

This is the concentration of oxygen in water by biotic and abiotic factors such as temperature, altitude, and chemical processes. The DO in this study ranged from 2.4mg/L to 7.90mg/L (Table 5.3). The least DO values were recorded in Site 1 and the highest in Site 3 as seen in Figure 5.23.

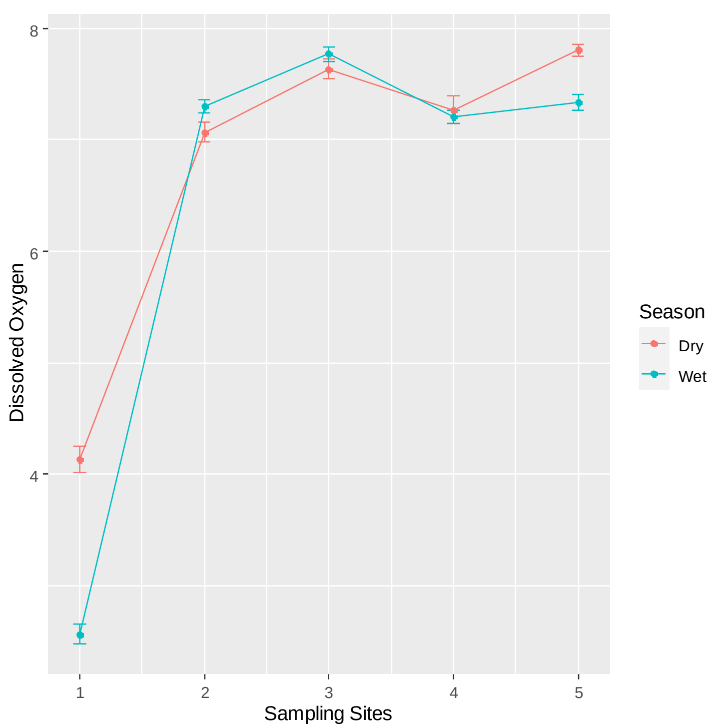

Figure 5.23: Dissolved Oxygen seasonal variation trends among the sampling points
Source: Researcher, 2019.

The DO values depicted an increasing trend downstream, this is expected because running water contains higher DO than still water as the case in Site 1 (Gleick *et al.*, 2001). WHO has no guidelines on DO concentration for drinking water, however the importance of water to aquatic life requires the concentration to be >5mg/L. Shapiro-wilk test showed that the DO concentration values were not normally distributed. Subsequently, the non-parametric Kruskall-wallis test was adopted and the results showed that only significant spatial differences existed among sites. The multiple comparison following Wilcoxon rank test showed that the DO values in site 1 were significantly different to those observed in Sites 2,3,4, and 5. Site 2 was significantly different to Sites 3 and 5, while Site 3 was significantly different with Site 4.

5.3.12 Total dissolved solids

Total dissolved solids refer to the sum total of all dissolved minerals constituents in a given water sample. TDS is proxy measure of salinity and therefore can affect was palatability if TDS exceeds 600mg/L. Even though there are no health guidelines prescribed by WHO, Kenyan standards limit TDS in drinking water to 1200mg/L. TDS values ranged from 120 to 337mg/L with the least value recorded in Site 1 and the highest value in Site 5, exhibiting an increasing downstream trend.

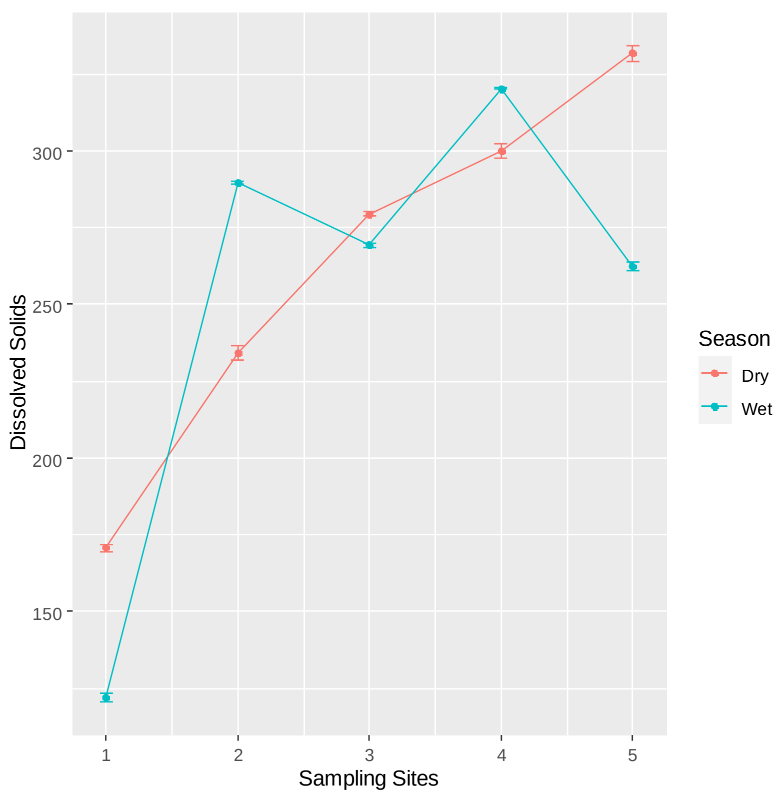

Figure 5.24: Total Dissolved Solids seasonal variation trends among the sampling points
Source: Researcher, 2019

Shapiro-wilk test indicated non-normality, Kruskall-Wallis test revealed that there was significant spatial differences amongst the sites with p value<0.05, but no seasonal significant differences between dry and wet season. The multiple comparison Wilcoxon rank showed that TDS values in Site 1 were significantly different to all the other sampling sites. Site 2 showed significant differences with site 3, while Site 3 showed differences with Site 4.

5.3.13 Sulfates

Sulfates are found naturally in compounds of various minerals such as gypsum, that often have commercial applications in industries, and which are eventually released into streams WHO 2017. Their application in household products such as soaps, detergents and farm inputs mean that the presence of sulfate in water can also be associated with anthropogenic activities. There are health guidelines on sulfate concentration in drinking water, however, WHO (2004), reported a taste threshold of between 250-500mg/L. Sulfates concentration values ranged from 1.8 to 22.0mg/L, the least value was recorded at site 1 and the highest value in site 4 indicating an increasing downstream trend (Table 5.3; and Figure 5.25).

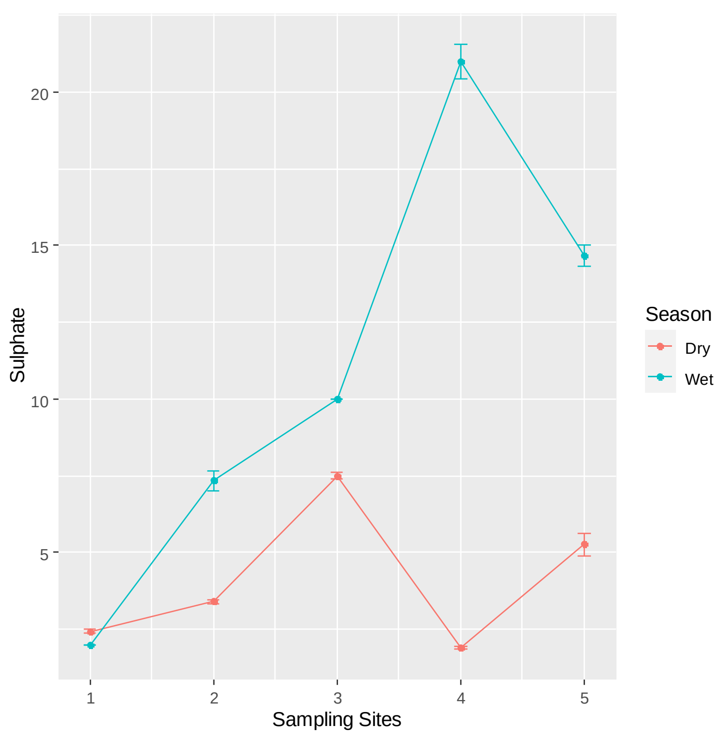

Figure 5.25: Sulfates seasonal variation trends among the sampling points
Source: Researcher, 2019

Shapiro-Wilk test showed non-normality. Kruskal-Wallis test results showed that significant differences existed among the sampling sites and between wet and dry season at $p<0.05$. Multiple Wilcoxon test showed significant differences of sulphate values between Sites1 and Sites 2 and 3, while Site 2 showed significant differences with Site 3. The mean sulphate values for the wet season were significantly higher than the mean values for the dry season.

5.3.14 Water Colour

Naturally, clean/pure water has no colour. If any type of colour appears in water, it is deemed or an indication of pollution. More often than not, natural water systems will have some colour because of the presence of foreign materials. For instance, suspended materials give water a colour known as apparent colour while dissolved materials that remain even after removal of suspended material is called true/real colour. Globally, 15 TCU (True colour unit) is the generally accepted maximum value for drinking water. In the study area, water colour ranged from 8 to 34 TCU, there was no discernible longitudinal trends in water colour values.

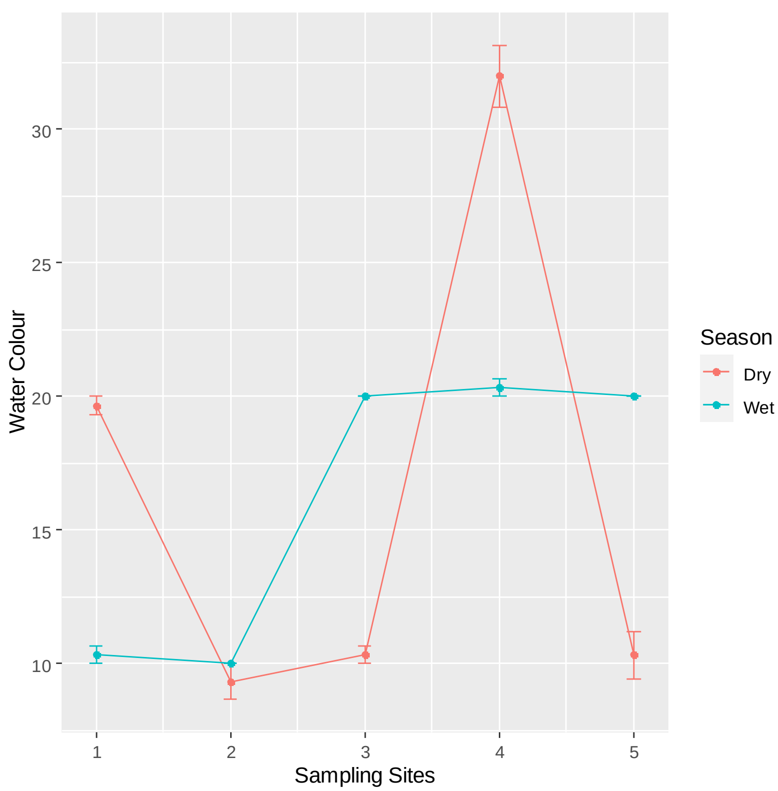

Figure 5.26: Water Colour seasonal variation trends among the sampling points
Source: Researcher, 2019

The water color values exhibited both spatial and seasonal variations. Kruskall-Wallis test results showed that there were significant differences in water color values among the five sampling sites. The values in Site 1 were significantly different to those of Sites 2 and 4, while Site2 showed significant differences with Site 3 and Site 4. Site 3 showed significant differences with Site 4, while Site 4 showed significant difference with Site 5. Temporal variation between wet and dry season were not significantly different.

5.4 Relationship between spatial land use characteristics and water quality

To make comparison between land use and water quality, the data was organized as follows:

a) The land use data was aggregated into three broad categories namely Agriculture, Settlements (aggregated percentage of residential; educational; industrial; commercial and transportation land uses) and the Wetland (Ondiri Swamp) – see Table 5.4

b) The land use data was utilized under different categories of land use types as shown in Table 5.5

Thereafter, the data was correlated under Spearman's ranking model to show correlation between land use and water quality, this is discussed below.

Table 5.4: Aggregated land uses ranked using Spearman's model at $P<0.05$

Water Quality Parameters	**Riparian Land Use/Cover Types**		
	Agriculture	**Settlements**	**Wetland**
pH	-0.530	0.60	-0.99 (0.001)
Temperature	0.604	-0623	0.48
Conductivity	-0.538	0.603	-0.95(0.01)
Turbidity	-0.717	0.748	-0.66
Total Hardness	-0.634	0.696	-0.97(0.007)
Fluoride	0.285	-0.304	0.342
Nitrates	-0.345	0.423	-0.99(0.001)
Chloride	-0.776	0.825	-0.89(0.04)
Total Coliforms	-0.436	0.486	-0.74
Total Fecal Coliforms	-0.945(0.02)	0.954(0.01)	-0.54
Dissolved Oxygen	-0.469	0.539	-0.97(0.007)
Dissolved Solids	-0.530	0.598	-0.98(0.004)
Color	0.084	-0.05	-0.32
Sulphates	-0.450	0.517	-0.93(0.02)

Source: Researcher, 2019

Table 5.5: Disaggregated land uses ranked using Spearman's model at P<0.05

	Percentage Land use Types											
Water Quality	Agricultural		Commercial		Residential		Industrial		Transportation Infrastructure		Wetland	
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season
pH	-0.666	-0.59	-0.102	-0.14	0.915	0.73	-0.639	-0.43	-0.608	-0.52	-0.954	-0.97
Temp	0.521	0.42	0.169	-0.41	-0.671	-0.06	0.411	-0.17	0.556	-0.19	0.951	0.17
EC	-0.834	-0.36	0.168	-0.19	0.979	0.61	-0.741	-0.61	-0.625	-0.84	-0.900	-0.87
Turb	-0.001	-0.96	-0.054	0.59	0.238	0.82	-0.661	-0.49	-0.894	-0.12	-0.333	-0.48
Hardness	-0.897	-0.53	0.305	-0.21	0.985	0.76	-0.775	-0.54	-0.614	-0.67	-0.841	-0.99
Fluoride	0.516	-0.70	-0.339	0.51	-0.436	0.80	0.503	-0.99	0.595	-0.79	0.537	-0.45
Nitrate	-0.489	-0.38	-0.289	-0.29	0.821	0.57	-0.616	-0.33	-0.699	-0.55	-0.970	-0.93
Chlorine	-0.867	-0.72	0.214	0.23	0.889	0.86	-0.504	-0.86	-0.359	-0.85	-0.851	-0.83
Coliform	-0.601	-0.38	0.844	-0.05	0.186	0.55	-0.189	-0.62	0.017	-0.83	0.036	-0.78
F Coliform	-0.677	-0.98	0.179	0.62	0.843	0.84	-0.861	-0.55	-0.882	-0.18	-0.834	-0.50
Dissolved Solid	-0.790	-0.40	0.103	-0.21	0.971	0.60	-0.749	-0.48	-0.663	-0.70	-0.921	-0.91
DO	-0.619	-0.50	-0.131	-0.23	0.773	0.66	-0.437	-0.34	-0.499	-0.48	-0.975	-0.96
Color	0.251	-0.50	-0.076	-0.19	0.019	0.86	-0.558	-0.71	-0.705	-0.67	0.055	-0.81
Sulfate	-0.225	-0.53	-0.373	0.02	0.328	0.81	0.232	-0.90	0.298	-0.96	-0.465	-0.81

Source: Researcher, 2019

The results of the study on Nairobi River indicated that Agricultural, commercial, residential, industrial, roads, wetland land us/ cover had significant impacts on the water quality of the study area as shown in Table 5.5. The Spearman analyses showed that pH was strongly negatively correlated with wetland in both seasons but had a strong positive correlation with residential land use, these correlations were significant at $p<0.05$. Temperature had a strong significant positive correlation with wetland in the dry season. Electrical conductivity showed strong negative significant relationship with wetland in the dry season, but had a strong positive significant relationship with residential. Turbidity had strong negative relationship with agricultural land use in the wet season. Similarly, it had strong significant negative relationship with roads and associated infrastructure on the dry season.

Hardness exhibited a strong negative significant relationship with agricultural land use in the dry season, the case was similar with the wetland in wet season. However, it showed a strong positive significant relationship with residential in the dry season. Fluoride showed a strong negative but significant relationship with industrial land use in the wet season. Nitrates showed significant negative relationship with wetland in both seasons, this observation could be linked to the presence of fringing macrophytes that are known to filter nutrients entering wetland ecosystems Macharia and Thenya (2010). The problem of inadequate sanitation facilities in urban areas of Sub-Saharan Africa explained by Ngoye (2004), could explain the strong positive correlation between Nitrates and residential in dry season attributed to sewerage leaks or clandestine discharges. Similar results were reported in a study on River O-hori basin in Central Japan (Bahar *et al.,* 2008). The Researchers reported that residential land use had positive correlation with nitrates, conductivity, and hardness. However, the study contradicted this study with regards to the correlation between nitrates and agricultural land.

In this study nitrates had weak relationship with agricultural land, while in O-hori basin, nitrates were reported to have a significant positive relationship with farmland, and the observation was linked to the use of nitrogen-based fertilizers. Chlorine showed significant positive correlation with residential land use in the dry season. It also showed strong relationships that were not significant with agricultural, commercial, industrial, and wetland. These findings contradict the research findings in Bobos Rivers Basin Mexico on the impacts of land use on water quality along a human disturbance gradient (Romero *et al*., 2018). The researchers found out that chlorides were positively correlated with rain fed agriculture land use. While a study done on Nairobi River basin the presence of chloride in Nairobi River was linked to natural factors such as geology as well as anthropogenic activities (Kithiia, 2006).

Total coliforms did not show any significant relationship with any of the land use metrics in the two seasons, fecal coliforms on the other had showed significant strong negative relationship with agricultural land use. It also showed strong positive relation with residential land use in both seasons and a strong negative relationship with wetland in dry season. Agriculture dominated land uses are not major contributors of fecal contamination of streams hence the strong negative relationship, the same case with wetland where the natural filtration process of the macrophytes helps to reduce fecal contamination. Conversely, the residential land use contributes to fecal contamination through in adequate sewage infrastructure.

The findings of this study agree with those of Felisters (Zimbabwe) where the Researcher recorded higher fecal coliform values in urban dominated areas. DS showed strong positive significant relationship with residential land use in the dry season, but had strong negative significant relationship with wetland in both dry and wet season. DO showed strong negative and significant relationship with wetland, these can be attributed to lack of turbulent waters in samples collected in site 1, in the area dominated by wetland land cover. Similarly, this can be attributed to high temperatures recorded in Site 1 where higher temperatures reduced the O_2 absorbing capacity of water (Gordon *et al*., 2004).

Color did not show any significant relationship with any of the land use types but had strong positive relationship with residential land use in the wet season, this agrees with the study on Bobos River basin, Mexico, where color was correlated with urban land use, probably due higher run off coefficient in urban areas. Sulfate showed strongly, negative significant relationship with industry and roads in wet season, this can be attributed to surface runoff.

Chapter 6: SUMMARY, CONCLUSIONS, AND RECOMENDATIONS

6.1 Summary of the Findings

The study findings correspond to the study objectives which were meant to establish the following:

a) The current land use distribution of the study area;
b) The current water quality status (among the different sample sites – spatial; and in different climatical seasons);
c) The relationship between the land use distribution and the observed water quality trends

In that regard, the findings have been elaborately discussed in sections above but summarized in the sections below.

6.1.1 Land use distribution in the study area

The study established that there is a gradual land use change along the river gradient. The land use change is characterized by varying intensities of land development ranging from subsistence Agricultural models around Ondiri swamp (sampling point A) and sampling point B; to a mix of moderate to intense urban land use activities from sampling point C to Naivasha road sampling point (E). However, it is worth noting that on all the sampling points other than E, the recommended buffer zone of about 15 meters on either side of the river had been observed - though actively utilized for varying agricultural practices - and this was considered to have had a net effect to the observed water quality measurements.

6.1.2 Water quality status

The water quality parameters showed both seasonal and spatial variations. The mean values of conductivity, turbidity, total coliforms, and total fecal coliforms were higher in the wet season compared to dry season mean values. These higher mean values can be attributed to run off from the adjacent land uses leading to pollution load. The mean value of conductivity was 239 µS/cm in the dry season and 284 µS/cm in wet season. Total fecal coliforms mean values were 2.53 cfu/100ml in the dry season, but in wet season the mean levels were 17.26 cfu/ 100ml.

In summary, the water along the river section is not potable naturally in the absence of a few treatment remedies. This is as summarized in table 6.1 below.

Table 6.1: Water quality parameters comparison index (degree of safety) along the river section

SUMMARIZED STATISTICAL MEANS FOR MEASURED WATER QUALITY PARAMETERS					
Water Quality Parameter	**WHO Guidelines**	**KEBS Guidelines (Natural Potable)**	**Study's Recorded Measurements**		**Study Remark**
			Season	Record	
pH	6.5 – 8.5	5.5 – 9.5	Dry	6.64±0.57	Safe
			Wet	6.57±0.59	Safe
Temp	** 15^0c – 25^0c	20^0c – 35^0c	Dry	19.6±0.63	Safe
			Wet	23.04±1.3	Safe
EC	** 500 µS/cm	1500 - 2500 µS/cm	Dry	239±55.95	Safe
			Wet	284.8±66.6	Safe
Turb	0.5 – 1 NTU	5 - 25 NTU	Dry	18.17±9.86	Safe
			Wet	21.99±9.18	Unsafe
THD	Upto 500 mg/L	300- 600 mg/L	Dry	84.13±17.44	Safe
			Wet	91.13±20.83	Safe
FLUO	1.5 mg/L	1.5 mg/L	Dry	0.31±0.19	Safe
			Wet	0.31±0.09	Safe
Nit	50 mg/L	45 mg/L	Dry	4.14±2.19	Safe
			Wet	4.64±2.18	Safe
Chl	200 – 300 mg/L	250 mg/L	Dry	117.67±20.02	Safe
			Wet	110.47±20.81	Safe
TCOL	Nil	Nil	Dry	30.8±13.91	Unsafe
			Wet	239.8±119.54	Unsafe
TFCOL	Nil	Nil	Dry	2.53±1.56	Unsafe
			Wet	17.26±19.03	Unsafe
**** DO**	-	-	Dry	6.78±1.4	Safe
			Wet	6.43±2.01	Safe
TDS	600 mg/L	700 - 1500 mg/L	Dry	263.13±58.10	Safe
			Wet	252.73±70.82	Safe
COLR	15 TCU	15 - 50 TCU	Dry	16.33±9.06	Unsafe
			Wet	16.13±5.06	Unsafe
SULF	** 250mg/L ($NaSo_4$); 1000mg/L ($CaSo_4$)	400 mg/L	Dry	4.1±2.14	Safe
			Wet	11.0±6.71	Safe

Source: WHO 2017; KEBS 2015 and Researcher's computed water quality analysis

6.1.3 Relationship between land use and water quality

Most parameters showed spatial variations downstream, where the study held the view that the human disturbance gradient increased downstream. Station A was the least disturbed, then stations B, C, D, and E had increasing anthropogenic disturbance gradient. Station A was located in the Ondiri Swamp which was surrounded by wetland vegetation that acts as a natural filter. Therefore, the lowest conductivity values of 148.0 µS/cm were recorded in station A while the highest conductivity value of 374.0µS/cm was recorded in station D.

The spearman correlation test revealed the individual relationship between water quality parameters and land use types. This was done by testing the statistical significance of the correlation coefficient. For instance, some water quality parameters exhibited strong significant correlation with the aggregated land use types e.g., pH had a strong negative relationship of -0.99 correlation coefficient. Conductivity, total hardness, and nitrates had negative correlation coefficient of -0.95, -0.97, & -0.99 respectively. Total fecal coliforms showed negative correlation with agricultural land where the correlation coefficient -0.945 but had a positive correlation with urban- settlement which had a correlation coefficient of 0.954.

6.2 Conclusion

From the summary of the findings, this study concluded that the spatial land use distribution had influence on water quality by influencing the various water quality parameter characteristics. The dominant land uses in the study area were agriculture, wetland, and a mix of urban related settlements. Due to this influence resulting from anthropogenic activities, the water quality of the upstream section of Nairobi River is degraded when some of the critical parameters are considered. The ecosystem services rendered by the riparian vegetation that acts as natural vegetation have been disrupted due to the encroachment of the riparian zone for varied agricultural practices.

More specifically, the study concluded that the less disturbed land use represented by the wetland that was around the Nairobi River source at Ondiri Swamp, had positive influence on water quality. The wetland had negative correlation with coliforms, and conductivity which indicated that the wetland vegetation mitigated the pollution getting into the Nairobi River. Urban settlement land use influenced water quality negatively because it exacerbated the problem of presence of coliforms that are indicators of raw sewage pollution.

In light of the observations stated above, it is important to note that land use development control by the respective County governments need to be enhanced to avoid deterioration of the water quality to unmanageable levels since the research established that the water in this section of the river is still relatively safe, though not potable because of the presence of fecal coliforms. However, if real efforts were put towards conservation of the riparian buffer and investment in water and sewer infrastructure, then some of the degrading factors may be contained.

This research provides significant data that can be validated and used a tool for decision making in water and development control sectors.

6.3 Recommendations

Upon review of the research findings, this research advances the following recommendations:

6.3.1 Policy recommendations

I. In terms of policy, both Nairobi and Kiambu Counties in consultation with other agencies such as NEMA, and WARMA will need to synergize and form an integrated water catchment policy for the Nairobi River headwaters to ensure that enforcement authority is derived from a single policy direction.

II. It is critical that development control be enhanced to ensure that settlement areas are allowed to develop in areas with adequate water and sewer infrastructure; and where such infrastructure lacks, then developers should show the capacity for onsite handling of waste.

6.3.2 Action/Management recommendations

III. The riparian land should be reserved at 15 meters on either side of the river, clearly demarcated and surveyed and a tree and grass planting initiative commenced along the entire stretch of the river up to Ondiri swamp

IV. The horticultural activities currently happening around Ondiri swamp and water abstraction to cease with immediate effect and the high-water mark determined, demarcated, surveyed and gazetted as a critically fragile ecosystem requiring protection

V. If the recommendations above are achieved, then, there is potential of determining a viable site to the south of ILRI land before the Naivasha road bridge intersection where a small dam and water treatment facility could be established with a keen interest to augment water supply to Nairobi

6.3.3 Recommendations for further research

I. This research was not completely exhaustive in terms of the assessment of water quality parameters especially those that have a direct impact to the determination of water portability like coliforms, heavy metals, fluorides, Nitrates, Turbidity among others. This was because of the time period and resources available to conduct the research. On that note, it is imperative that a research be conducted in the same area, the entire headwaters basin as opposed to the river section only but all the streams in that headwaters area, samples be collected over a longer period of time to validate the accuracy of the data collected. Such a study would be more accurate in validating the degree of water portability or lack of it in that headwaters area basing it on the parameters listed above.

II. The study suggested above should be complimented by another study and/or the same study that computes the river discharge at various intervals and if possible, project/model the observations made to a future scenario at nil-intervention status, and when interventions are applied

III. A current study on the impact of land use activities around Ondiri swamp would go a long way in documenting the current status the swamp as an important water source to Nairobi

REFERENCES

Achieng, A. O., Raburu, P. O., & Kipkorir, E. C. (2017). Assessment of water quality using multivariate techniques in River Sosiani, Kenya. *Environimental Monitoring Assessment*, *189*(6).

Alukwe, I. (2015). Modelling Nitrogen and Phosphorus Fluxes in Nairobi City, Kenya. *World Journal of Environmental Engineering*, *3*(3), 67–81.

Biswas, A., & Tortajada, C. (2019). Water quality management: a globally neglected issue. *Internaltional Journal of Water Resources*, *35*(6), 913–916.

Brookes, A. (1996). River restoration experience in Northern Europe. *Regulated Rivers: Research and Management*, *5*(1), 45–56.

Cavailhe, J., & Wavresky, P. (2003). Urban influences on periurban farmland prices. *European Review of Agricultural Economics*, *30*(3), 333–357.

Chavoshani, A., Hashemi, M., Amin, M., & Ameta, S. (2020). *Micropollutants and Challenges* (First Edit). Chennai: Elsevier.

Delpla, Jung, A., Baures, E., Clement, M., & Thomas. (2009). Impacts of cliamte change on surface water quality in relation to drinking water production. *Environment International*, *35*(8), 1225–1233.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Naiman, R. J., Knowler, D. J., … Sullivan, C. (2005). Freshwater biodiversity : importance , threats , status and conservation challenges. *Biol.Rev*, *81*(2006), 163–182.

Foley, J. A. (2005). Global Consequences of Land Use. *Science*, *309*(August).

Gerhardt, A. (2001). Bioindicator species and their use in biomonitoring. *Environmental Monitoring*, *I*.

Hosseini, N., Johnson, J., & Lindensshmidt, K.-E. (2017). Impacts of Climate Change on the Water Quality of a Regulated Prairie River. *Water*, *9*(199).

Juan, Zhan, J., Yan, H., Wu, F., & Deng, X. (2013). Evaluation of the Impacts of Land Use on Water Quality : A Case Study in The Chaohu Lake Basin. *The Scientific World*, *2013*, 7.

Keeler, Polasky, S., Brauman, K., Johnson, K., Finlay, J., O'Neill, A., … Dalzell, B. (2012). assessment and valuation of ecosystem services. *PNAS*, *6*, 18619–18624.

Kenya Bureau of Standards. (2015). Drinking Water Quuality Standards. Nairobi.

Kithiia. (2006). *THE EFFECTS OF LAND USE TYPES ON THE HYDROLOGY AND WATER QUALITY OF THE UPPER-ATHI RIVER BASIN , KENYA*. University of Nairobi.

KNBS. (2015). *County statistical abstract Kiambu county 2015*. Nairobi.

Koigi, Njuguna, R. (2015). *Assessment of spatial and temporal trends of pesticides residues in* *sediments an water from Nairobi River*. University of Nairobi.

Kummu, M., Guillaume, H., de Moel, H., Eisner, S., Florke, M., Porkka, M., … Ward. (2016). The world's road to water scarcity: shortage and stress in the 20th century and pathway towards sustainability. *Scientific Reports*.

Larsen, P. (1994). *Restoration of River Corridors: German experiences*.

Ledant, M. (2013). Water in Nairobi : Unveiling inequalities and its causes. *OpenEdition Journals*, *263*(April 2019), 289–392. https://doi.org/10.4000/com.6951

Lee, Z., Shang, S., Hu, C., Du, K., Weidemann, A., Hou, W., … Lin, G. (2015). Secchi disk depth : A new theory and mechanistic model for underwater visibility. *Remote Sensing of Environment*, *169*, 139–149. https://doi.org/10.1016/j.rse.2015.08.002

Macharia, J. M., Thenya, T., & Ndiritu, G. G. (2010). Management of highland wetlands in central Kenya: The importance of community education, awareness and eco-tourism in biodiversity conservation. *Biodiversity*, *11*(1–2), 85–90. https://doi.org/10.1080/14888386.2010.9712652

Makathimo, & Guthiga. (2010). Land Use Policies and Natural Resource Management in Kenya: The Case of Nairobi River Basin. In *FIG Congress*. Sydney.

Malmqvist, B., & Rundle, S. (2002). Threats to the running water ecosystems of the world. *Environmental Conservation*, *29*(2), 134–153.

Monene. (2014). *Effects of land use change on stream flow, channel erosion and river geomorphology: A case study of Mutoine/Ngong River Catchment, Nairobi River Basin, Kenya*. University of Nairobi.

Muriithi, F., & Yu, D. (2015). Understanding the Impact of Intensive Horticulture Land-Use Practices on Surface Water Quality in Central Kenya. *Environments*, *2*, 521–545.

Mwiti, M. S. (2014). *Riparian zone conservation in a changing urban land use environment: a case of nairobi river basin, kenya muketha*. University of Nairobi.

National Environment Management Authority. (2011). *Kenya The state of Environment and Outlook 2010*. Nairobi.

Ngoye, E., & Machiwa, J. F. (2004). The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. *Physics and Chemistry of the Earth*, *29*, 1161–1166.

Njue, N., Koech, E., Hitimana, J., & Sirmah, P. (2016). Influence of Land Use Activities on Riparian Vegetation, Soil and Water Quality: An Indicator of Biodiversity Loss, South West Mau Forest, Kenya. *Open Journal of Forestry*, *6*, 373–385.

Nyangau, T., & Mayoyo, N. (2015). The eco-sensitive carwash technology in management of waste water in river ecosystem. *Journal of Environment and Earth Science*, *5*.

Omer, Hassan, N. (2019). Water Quality Parameters. In K. Summers (Ed.), *Water Quality-*

Science,Assessments and Policy (p. 182).

Palmer, M. A., Bernarhardt, E. S., Allan, J. D., Lake, P. S., & Alexander, G. (2005). Standards for ecologically successful river restoration. *Journal of Applied Ecology*, *42*, 208–217.

Postel, S. L., Daily, G. C., & Ehrlich, P. R. (1996). Human Appropriation of Renewable Fresh Water. *Science*, *271*(February), 785–788.

RCoreTeam. (2019). R: A language and an Environment for Statistical Computing. Vienna, Austria: R Core Team.

Richards. (2013). Supervised Classification Techniques.In Remote Sensing Digital Image Analysis. *Springer*, 247–318. https://doi.org/10.1007/978-3-642-30062-2

Schrama, G. (1998). Theoretical Framework. In G. Scharma (Ed.), *Drinking Water Supply and Agricultural Pollution* (First). Springer Science.

Sliva, L., & Williams, D. D. (2001). Buffer zone versus whole catchment approaches to studying land use impact on river water quality, *35*(14), 3462–3472.

Tibaijuka. (2007). *Nairobi and its Environment, in Kenya Atlas*.

Tong, S. T. Y., & Chen, W. (2002). Modeling the relationship between land use and surface water quality. *Journal of Environmental Management*, *66*, 377–393.

UN Water. (2006). *Kenya National Water Development Report: A WWAP case study prepared for the 2nd UN world water development report: Water, a shared responsibility (2006). Un-Water/Wwap/2006/12*. Nairobi.

UNEP. (2016). *A snapshot of the World's Water Quality: Towards a global assessment*. Nairobi.

Wambugu, G. M. (2018). *Spatio-temporal dynamics of land use change on rivers in tropical watersheds: A case study of Ruiru and Ndarugu basins, Kiambu County, Kenya*. University of Nairobi.

Wang, G., Yinglan, A., Xu, Z., & Zhang, S. (2013). The Influence of Land Use Patterns on Water Quality at Multiple Spatial Scales in a River System. *Hydrological Processes, 28*(20).

WHO. (2017). *Guidelines for Drinking-water Quality* (Fourth edi). Geneva: World Health Organization.

A P P E N D I C E S

Appendix 1: Summary of water quality parameters observed measurements

Sampling Site	Water Quality Parameter (Dry Season)													
	pH	**Temp**	**EC**	**Turb**	**THD**	**FLUO**	**Nit**	**Chl**	**TCOL**	**TFCOL**	**DO**	**DSLD**	**COLR**	**SULF**
1	5.77	20.8	150	12.7	60	0.55	0.5	86	25	0	4.2	170	20	2.5
	5.74	20.9	148	11.9	58	0.55	0.6	85	26	1	3.9	169	19	2.5
	5.7	20.7	157	12.9	57	0.56	0.5	85	29	0	4.3	173	20	2.3
2	6.5	19.1	214	17	78	0.1	3	117	45	2	7.2	230	10	3.5
	6.48	19.3	211	18.1	78	0.13	3	116	47	2	7.1	234	10	3.3
	5.98	19.5	215	17.8	75	0.12	2.9	118	45	3	6.9	238	8	3.4
3	7.03	19.4	254	10.4	82	0.5	6	122	10	2	7.6	280	10	7.5
	7.04	19.4	250	11.2	83	0.5	5.8	125	11	2	7.5	280	11	7.7
	7.01	19.2	249	10.8	85	0.47	5.9	124	9	2	7.8	278	10	7.3
4	6.99	19.1	270	36.8	94	0.16	6	116	25	3	7.1	300	30	2
	6.95	19.2	270	37	92	0.14	6	116	26	5	7.2	304	32	1.9
	6.92	19.5	268	36.2	93	0.14	6	118	29	5	7.5	296	34	1.8
5	7.2	19.5	310	13.1	110	0.23	5	144	45	4	7.7	330	10	5
	7.09	19.3	313	13.5	108	0.24	5.7	146	42	3	7.8	337	9	6
	7.24	19.2	311	13.1	109	0.22	5.2	147	48	4	7.9	328	12	4.8

Sampling Site	Water Quality Parameter (Wet Season)													
	pH	**Temp**	**EC**	**Turb**	**THD**	**FLUO**	**Nit**	**Chl**	**TCOL**	**TFCOL**	**DO**	**DSLD**	**COLR**	**SULF**
1	5.46	24	174	14.8	50	0.23	0.5	78	50	0	2.7	120	10	2
	5.42	23.8	170	13.9	52	0.29	0.5	80	50	0	2.4	125	10	2
	5.43	24.6	172	14.2	54	0.24	0.5	78	50	1	2.6	121	11	2
2	6.87	21	302	18.5	94	0.21	6	108	300	10	7.3	290	10	8
	6.77	20.9	305	18.2	93	0.22	6	109	290	10	7.4	289	10	7
	6.67	20.8	304	18.8	92	0.24	5.8	107	305	12	7.2	290	10	7
3	6.99	24	288	20.5	102	0.24	6	102	200	10	7.7	270	20	10
	6.89	23.9	286	20.1	101	0.23	5.7	103	201	13	7.7	270	20	10
	6.78	23.8	290	20.3	104	0.21	5.8	101	204	12	7.9	268	20	10
4	6.83	24	372	17.9	108	0.43	6	135	400	10	7.1	320	20	20
	6.82	23.7	370	17.5	105	0.42	6	134	400	10	7.2	320	21	21
	6.81	24.1	374	17.3	108	0.43	6	135	400	12	7.3	321	20	22
5	6.96	22.5	290	39.7	100	0.41	5	130	250	50	7.4	260	20	15
	6.91	22.1	287	39.7	101	0.42	4.9	129	248	55	7.4	265	20	14
	6.94	22.4	288	38.4	103	0.44	5	128	249	54	7.2	262	20	15

Appendix 2: Using R-Program to conduct various analytical tests

This study computed the Shapiro's test for normality using R Studio program using the 'shapiro.test' function in R programming. First the researcher organized the data in excel and saved the file in a folder directory as shown in Figure below.

Water_Q_Dry_WET.csv - Excel

pH		Temp	EC	Turb	THD	FLUO	Nit	Chl	TCOL	TFCOL	DO	DSLD	COLR	SULF	Season	Site
5.46		24	174	14.8	50	0.23	0.5	78	50	0	2.7	120	10	2	Wet	1
5.42		23.8	170	13.9	52	0.29	0.5	80	50	0	2.4	125	10	2	Wet	1
5.43		24.6	172	14.2	54	0.24	0.5	78	50	1	2.6	121	11	2	Wet	1
6.87		21	302	18.5	94	0.21	6	108	300	10	7.3	290	10	8	Wet	2
6.77		20.9	305	18.2	93	0.22	6	109	290	10	7.4	289	10	7	Wet	2
6.67		20.8	304	18.8	92	0.24	5.8	107	305	12	7.2	290	10	7	Wet	2
6.99		24	288	20.5	102	0.24	6	102	200	10	7.7	270	20	10	Wet	3
6.89		23.9	286	20.1	101	0.23	5.7	103	201	13	7.7	270	20	10	Wet	3
6.78		23.8	290	20.3	104	0.21	5.8	101	204	12	7.9	268	20	10	Wet	3
6.83		24	372	17.9	108	0.43	6	135	400	10	7.1	320	20	20	Wet	4
6.82		23.7	370	17.5	105	0.42	6	134	400	10	7.2	320	21	21	Wet	4
6.81		24.1	374	17.3	108	0.43	6	135	400	12	7.3	321	20	22	Wet	4
6.96		22.5	290	39.7	100	0.41	5	130	250	50	7.4	260	20	15	Wet	5
6.91		22.1	287	39.7	101	0.42	4.9	129	248	55	7.4	265	20	14	Wet	5
6.94		22.4	288	38.4	103	0.44	5	128	249	54	7.2	262	20	15	Wet	5
5.77		20.8	150	12.7	60	0.55	0.5	86	25	0	4.2	170	20	2.5	Dry	1
5.74		20.9	148	11.9	58	0.55	0.6	85	26	1	3.9	169	19	2.5	Dry	1
5.7		20.7	157	12.9	57	0.56	0.5	85	29	0	4.3	173	20	2.3	Dry	1
6.5		19.1	214	17	78	0.1	3	117	45	2	7.2	230	10	3.5	Dry	2
6.48		19.3	211	18.1	78	0.13	3	116	47	2	7.1	234	10	3.3	Dry	2
5.98		19.5	215	17.8	75	0.12	2.9	118	45	3	6.9	238	8	3.4	Dry	2

The data was thereafter imported to the program using the 'read.csv("..")' function for statistical analysis. This required computation of the statistical summaries to make the data ready for Shapiro Wilk computations. The statistical summaries were calculated using the 'summary' function on R as shown below.

RGui (64-bit) - [R Console]

File Edit View Misc Packages Windows Help

```
Type 'license()' or 'licence()' for distribution details.

  Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> waterQ2=read.csv("C:/Users/sami/Documents/Water_Q_Dry_WET.csv")
> head(waterQ2)
    pH  X Temp  EC Turb THD FLUO Nit Chl TCOL TFCOL  DO DSLD COLR SULF Season
1 5.46 NA 24.0 174 14.8  50 0.23 0.5  78   50     0 2.7  120   10    2    Wet
2 5.42 NA 23.8 170 13.9  52 0.29 0.5  80   50     0 2.4  125   10    2    Wet
3 5.43 NA 24.6 172 14.2  54 0.24 0.5  78   50     1 2.6  121   11    2    Wet
4 6.87 NA 21.0 302 18.5  94 0.21 6.0 108  300    10 7.3  290   10    8    Wet
5 6.77 NA 20.9 305 18.2  93 0.22 6.0 109  290    10 7.4  289   10    7    Wet
6 6.67 NA 20.8 304 18.8  92 0.24 5.8 107  305    12 7.2  290   10    7    Wet
```

Shows the imported data on R Program

```
> names(waterQ3)
 [1] "pH"      "Temp"    "EC"      "Turb"    "THD"     "FLUO"    "Nit"     "Chl"     "TCOL"    "TFCOL"  "DO"      "DSLD"    "COLR"    "SULF"    "Season" "Site"
> summary(waterQ3[,c("pH","Temp", "EC", "Turb","THD","FLUO","Nit","Chl","TCOL","TFCOL","DO", "DSLD", "COLR","SULF")])
       pH             Temp             EC             Turb            THD              FLUO              Nit              Chl              TCOL            TFCOL
 Min.   :5.420   Min.   :19.10   Min.   :148.0   Min.   :10.40   Min.   : 50.00   Min.   :0.1000   Min.   :0.500   Min.   : 78.0   Min.   :  9.0   Min.   : 0.0
 1st Qu.:6.485   1st Qu.:19.40   1st Qu.:214.2   1st Qu.:13.20   1st Qu.: 78.00   1st Qu.:0.2125   1st Qu.:3.000   1st Qu.:102.2   1st Qu.: 29.0   1st Qu.: 2.0
 Median :6.850   Median :20.85   Median :278.0   Median :17.65   Median : 93.00   Median :0.2400   Median :5.700   Median :116.5   Median : 49.0   Median : 4.0
 Mean   :6.606   Mean   :21.32   Mean   :262.1   Mean   :20.08   Mean   : 87.63   Mean   :0.3090   Mean   :4.393   Mean   :114.1   Mean   :135.3   Mean   : 9.9
 3rd Qu.:6.982   3rd Qu.:23.77   3rd Qu.:303.5   3rd Qu.:20.25   3rd Qu.:102.75   3rd Qu.:0.4300   3rd Qu.:6.000   3rd Qu.:128.8   3rd Qu.:248.8   3rd Qu.:10.0
 Max.   :7.240   Max.   :24.60   Max.   :374.0   Max.   :39.70   Max.   :110.00   Max.   :0.5600   Max.   :6.000   Max.   :147.0   Max.   :400.0   Max.   :55.0
       DO             DSLD             COLR            SULF
 Min.   :2.400   Min.   :120.0   Min.   : 8.00   Min.   : 1.80
 1st Qu.:7.100   1st Qu.:235.0   1st Qu.:10.00   1st Qu.: 2.50
 Median :7.250   Median :274.0   Median :15.50   Median : 6.50
 Mean   :6.607   Mean   :257.9   Mean   :16.23   Mean   : 7.55
 3rd Qu.:7.575   3rd Qu.:299.0   3rd Qu.:20.00   3rd Qu.:10.00
 Max.   :7.900   Max.   :337.0   Max.   :34.00   Max.   :22.00
> head(waterQ3)
    pH Temp  EC Turb THD FLUO Nit Chl TCOL TFCOL  DO DSLD COLR SULF Season Site
1 5.46 24.0 174 14.8  50 0.23 0.5  78   50     0 2.7  120   10    2    Wet    1
2 5.42 23.8 170 13.9  52 0.29 0.5  80   50     0 2.4  125   10    2    Wet    1
3 5.43 24.6 172 14.2  54 0.24 0.5  78   50     1 2.6  121   11    2    Wet    1
4 6.87 21.0 302 18.5  94 0.21 6.0 108  300    10 7.3  290   10    8    Wet    2
5 6.77 20.9 305 18.2  93 0.22 6.0 109  290    10 7.4  289   10    7    Wet    2
6 6.67 20.8 304 18.8  92 0.24 5.8 107  305    12 7.2  290   10    7    Wet    2
> head(waterQ3meanL)
Error in head(waterQ3meanL) : object 'waterQ3meanL' not found
> head(waterQ3)
    pH Temp  EC Turb THD FLUO Nit Chl TCOL TFCOL  DO DSLD COLR SULF Season Site
1 5.46 24.0 174 14.8  50 0.23 0.5  78   50     0 2.7  120   10    2    Wet    1
2 5.42 23.8 170 13.9  52 0.29 0.5  80   50     0 2.4  125   10    2    Wet    1
3 5.43 24.6 172 14.2  54 0.24 0.5  78   50     1 2.6  121   11    2    Wet    1
4 6.87 21.0 302 18.5  94 0.21 6.0 108  300    10 7.3  290   10    8    Wet    2
5 6.77 20.9 305 18.2  93 0.22 6.0 109  290    10 7.4  289   10    7    Wet    2
6 6.67 20.8 304 18.8  92 0.24 5.8 107  305    12 7.2  290   10    7    Wet    2
> shapiro.test(waterQ3$pH)
```

Computed statistical summaries on R Program

This was followed by applying the ‘shapiro.test’ function for purposes of establishing the normality test. This was done for every individual water quality parameter and results for the P value recorded in an excel document. The results are shown in figure 4.6.

```
> shapiro.test(waterQ3$pH)

        Shapiro-Wilk normality test

data:  waterQ3$pH
W = 0.7902, p-value = 4.368e-05

> shapiro.test(waterQ3$Temp)

        Shapiro-Wilk normality test

data:  waterQ3$Temp
W = 0.83895, p-value = 0.000367

> shapiro.test(waterQ3$EC)

        Shapiro-Wilk normality test

data:  waterQ3$EC
W = 0.93393, p-value = 0.0625

> shapiro.test(waterQ3$Turb)

        Shapiro-Wilk normality test

data:  waterQ3$Turb
W = 0.76812, p-value = 1.812e-05

> shapiro.test(waterQ3$THD)

        Shapiro-Wilk normality test

data:  waterQ3$THD
W = 0.88083, p-value = 0.002946

> |
```

Results for P values on R Program for normality test for individual water quality parameters

Testing for significant Seasonal and Sampling Sites Variation (Kruskal Wallis & Dunn's Post Hoc Tests)

Similarly to Shapiro's Wilk test, these tests were also conducted on the R program. The Kruskal-Wallis ranking test was used to determine statistical and significant differences between the two seasons and along the sampling sites which was done by applying the Dunn's Post Hoc test functions on the program. The screen capture in figure 4.7 show some of the functions applied to give the results.

```
kruskal.test(Temp~Season,data=lineTemp)

pairwise.wilcox.test(KWTemp$Temp, KWTemp$Season,
                 p.adjust.method = "BH")
dunn.test(KWTemp$Temp, KWTemp$Season,
                 p.adjust.method = "BH")
library(dunn.test)
dunn.test(variable,variable with group, method="bonferroni")
dunn.test(KWTemp$Temp,Temp~Season,method="bonferroni")

#############################################################
kruskal.test(Temp~Season,data=lineTemp)

###ELECTRICAL CONDUCTIVITY
kruskal.test(EC~Season,data=lineEC)
####tURBIDITY
kruskal.test(Turb~Season,data=lineTurb)

kruskal.test(Turb~Season, data = turb)
#####TOTAL HARDENESS
kruskal.test(THD~Season,data=lineTHD)
##########FLUORIDE
kruskal.test(FLUO~Season,data=lineFLUO)
#######NITRATES
kruskal.test(Nit~Season,data=lineNit)
#########CHLORIDE
kruskal.test(Chl~Season,data=lineChl)
######tOTAL COLIFORM
kruskal.test(TCOL~Season,data=lineTCOL)
##########TOTAL FECAL COLIFORM
kruskal.test(TFCOL~Season,data=lineTFCOL)
#########DISSOLVED OXYGEN
kruskal.test(DO~Season,data=lineDO)
#########SULFATES
kruskal.test(SULF~Season,data=lineSULF)
```

Some of the functions applied on R program to run Kruskal Wallis and Dunn's Post Hoc Tests

Spearman's rank-order correlation coefficient to test for land use and water quality relationship

The Spearman rank-order correlation coefficient was used to measure the level and direction of association between the different variables under study. The result is always in the range of +1 or -1 meaning a strong positive or negative relationship. To achieve this, land use proportions were computed and presented in hectares while the water quality observations remained as recorded.

The data was then arranged in an Ms Excel to allow importing on the R program which was used for ranking the data by applying the necessary functions as shown in the script in figure 4.8.

```
wet<-read.csv("C:/Users/SAMMY/Documents/Water_Q_Wet2.csv")
head(wet)
wetm=aggregate(cbind(pH,Temp,EC,Turb,TH,FLUO,Nit,Chl,TC,FC,DS,DO,COLR,SULF)~Sites,wet,mean)
head(wetm)
wets<-wetm[,-1]

names(wets)
head(wets)
spearseptw<-cbind(wets,LULU1)
names(spearseptw)
spearseptwt=spearseptw[,-1]

wetspear<-scale(spearseptw)

head(wetspear)

wetspear2<-rcorr(wetspear)

head(wetspear2)
wetspear2sL<-as.matrix(wetspear2[[3]])

wetspear2r<-as.matrix(wetspear2[[1]])

write.table (wetspear2sL, file="Wet_significancelevels.txt",sep=",",quote=FALSE,row.names=T)
```

Appendix 3: Research clearance permit no: NACOSTI/P/19/73312/29583

THIS IS TO CERTIFY THAT:
MR. SAMUEL MBURU GITUARA
of UNIVERSITY OF NAIROBI, 38849-100 NAIROBI,has been permitted to conduct research in *Kiambu , Nairobi Counties*

on the topic: *EFFECTS OF LAND USE PATTERNS ON THE SURFACE WATER QUALITY ALONG NAIROBI RIVER*

for the period ending:
23rd April,2020

Permit No : NACOSTI/P/19/73312/29583
Date Of Issue : 25th April,2019
Fee Recieved :Ksh 1000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013

The Grant of Research Licenses is guided by the Science, Technology and Innovation (Research Licensing) Regulations, 2014.

CONDITIONS

1. **The License is valid for the proposed research, location and specified period.**
2. **The License and any rights thereunder are non-transferable.**
3. **The Licensee shall inform the County Governor before commencement of the research.**
4. **Excavation, filming and collection of specimens are subject to further necessary clearance from relevant Government Agencies.**
5. **The License does not give authority to transfer research materials.**
6. **NACOSTI may monitor and evaluate the licensed research project.**
7. **The Licensee shall submit one hard copy and upload a soft copy of their final report within one year of completion of the research.**
8. **NACOSTI reserves the right to modify the conditions of the License including cancellation without prior notice.**

National Commission for Science, Technology and innovation
P.O. Box 30623 - 00100, Nairobi, Kenya
TEL: 020 400 7000, 0713 788787, 0735 404245
Email: dg@nacosti.go.ke, registry@nacosti.go.ke
Website: www.nacosti.go.ke

REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEARCH LICENSE

Serial No.A 24271

CONDITIONS: see back page

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/19/73312/29583**

Date: **25th April, 2019**

Samuel Mburu Gituara
University of Nairobi
P.O. Box 30197-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Effects of land use patterns on the surface water quality along Nairobi River"*** I am pleased to inform you that you have been authorized to undertake research in **Kiambu and Nairobi Counties** for the period ending **23rd April, 2020.**

You are advised to report to **the County Commissioners and the County Directors of Education, Kiambu and Nairobi Counties** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kiambu County.

The County Commissioner
Nairobi County.

The County Director of Education
Kiambu County.

The County Director of Education
Nairobi County.