EFFECTS OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY OF NGONG RIVER, NAIROBI COUNTY, KENYA.

BY

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DECLARATION

This research project is my original work and it has not been presented for approval in any other university or Institution.

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DEDICATION

This project is dedicated to my dear family, my parents, brothers and sister for their support during the entire period of study.

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LIST OF ACRONYMS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
EPA	Environment Protection Agency
TC	Total Coliform
FC	Faecal Coliform
E. coli	*Escherichia coli*
RFWR	Renewable Fresh Water Resources
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
CIDP	County Integrated Development Plan
UNEP	United Nations Environmental Programme
NEMA	National Environment Management Authority
WRA	Water Resources Authority
NMS	Nairobi Metropolitan Services

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ABSTRACT

Water quality is one of the major aspects of water availability affected by the problem of water pollution. Water pollution has recently become rampant due to an increase in urbanisation, population and industrialisation. It is therefore crucial to understand the degree of water quality in rivers that flow through urban areas in order to develop the necessary rehabilitation strategies and measures to alleviate this problem. This study evaluated the effects of anthropogenic activities on water quality of Ngong River in Nairobi County, Kenya. The study was aimed at identifying the different anthropogenic activities along Ngong River, measuring the pollution levels in Ngong River with respect to selected Physico-Chemical Parameters, and establishing the relationship between the anthropogenic activities and water quality along the Ngong River. The hypotheses that guided the study were that anthropogenic activities had no effect on the water quality of Ngong River and that there were no significant differences between physicochemical parameters at different study sites. Anthropogenic activities observed were recorded for different sites. The river was divided into three segments in which twelve water samples were collected. Water samples were analysed for pH, electrical conductivity, temperature, TDS, Total suspended solids, oil and grease, BOD, COD, nitrate, lead and Cadmium and faecal coliforms (Total Coliforms and *E.coli*). Secondary data was collected from official government reports, water sector, NEMA, and scientific publications. Water quality data set obtained was subjected to Accumulation Factor, River Recovery Capacity, Cluster Analysis and ANOVA test ($p<0.05$).

Accumulation Factor (AF) indicated that *E.coli*, Total Coliforms, BOD and COD significantly built up downstream of Ngong River. The river recovered significantly from several physicochemical parameters: COD, BOD, Total Coliforms, *E.coli*, Turbidity and TSS for wet and dry seasons. *E.coli* and Total coliforms had the highest recovery value of 99% during both seasons. Cluster analysis indicated that Ngong River's water quality was highly influenced by dumpsites, domestic and industrial effluents on the river basin. Lindi Mosque site had the highest pollution levels while Ngong Forest site had the lowest pollution levels. The ANOVA test results showed that majority of the parameters were not significantly different for the different sites (BOD, *E. coli*, pH, Total suspended solids, Total coliforms, Turbidity, Conductivity, Nitrates, Oil and grease and TDS) except COD. All the water quality variables except COD showed similar characteristics throughout the Ngong River. The non-significant difference observed in the majority of parameters indicate contribution of anthropogenic sources in the Ngong River basin. Lead (Pb) levels were all below the detectable limit (0.001ppm) for both seasons. Cadmium (Cd) was detectable during the dry season with high levels of 0.113ppm at Ngong Forest Boundary indicating upstream pollution of Ngong River with regards to Cd. The findings of this study revealed that the parameters causing variations on water quality are mainly related to anthropogenic pollution. It is recommended that anthropogenic activities, such as domestic effluents and industrial effluents discharge, be closely monitored to reduce their probable pollution of Ngong River basin.

CHAPTER ONE: BACKGROUND OF THE STUDY

1.0 INTRODUCTION

This chapter gives a background of water as an important resource and a range of services it provides. It further provides a background of aspects that cause degradation of water quality. Problem statement, research questions, research objectives, hypotheses, and justification for the study have been highlighted.

1.1 Study Background

Whereas the water quantity on earth remains constant, spatio-temporal changes occur on the water quality, and it is highly perturbed by anthropogenic activities (Kithiia, 1992). Water pollution ranks second after air pollution and is a major global concern (Erick & Hudson , 2016). Pollution levels in fresh water resources alter the chemical, physical and biological integrity, affecting the water quality in water bodies. According to Gleick (1993). Water quality is a key indicator of a country's ability to invest in its environment's health and people; it is part of a larger set of environmental and developmental challenges that must be addressed promptly by the government and residents.

Water is naturally occurring and circulating resource which is constantly recharged through the global hydrological cycle. However, despite the abundance of water on earth and given that its amount and circulation will unlikely diminish on shorter geological timescales, only a tiny fraction (2.5%) of this water is fresh water and is easily accessible by humans (Oki, 2006) since most water is reserved as salty sea water, glaciers or even deep ground water hence not accessible. As such, freshwater is considered as a finite resource despite its immense usage in domestic, industrial and agricultural activities. Despite current global withdrawals being well below the maximum limit, due to the unequal distribution of Renewable Freshwater Resources (RFWR) in place and time, around a quarter of the current global population inhabit highly water-stressed environments (Oki, 2006). Without adequate quality and quantity of fresh water, sustainable development would not be possible (Bartram *et al.,* 1996).

Freshwater resources form a crucial part of natural resources with provisioning, supporting and regulatory services (‘Networking Our Way to Better Ecosystem Service Provision’, 2016; MEWNR, 2013). Water retention and storage for industrial, agricultural, and domestic use are provisioning services, whereas regulating services include eliminating or diluting contaminants, changing water flows, and discharge and recharging of ground water resources. Their supporting services are key in soil retention and formation, and nutrient cycling. The wetland and freshwater ecosystems also act as habitats for many flora and fauna species (MEWNR, 2013).

Fresh water ecosystems face diverse threats ranging from human population pressure to land use changes which cause extensive degradation, reduction in water quality and quantity, and also loss of wetland and freshwater ecosystem goods and services (Bartram, 1996; Chapman *et al.,* 1996). River water pollution is rampant in developing as well as developed countries. However, most poor regions of the world especially in the urban setups are the worse affected by insufficient supply of water that meets the accepted standards (Agarwal & Narain, 1999; Harada & Karn, 2001). Rivers form an important component of the hydrological cycle and also, they are highly depended upon by humans for provision of water for domestic, farming and industrial uses. However, rivers passing through the urban cities are main receptacles of urban wastes. According to Harada & Karn, (2001), massive volumes of pollutants emitted by urban activities in Southern Asia nations including Bangladesh, India and Nepal, caused severe river pollution particularly near the metropolitan stretches. The Bagmati River in Kathmandu Valley, the Yamuna River in Delhi, and Dhaka's peripheral rivers (namely the Buriganga River) also have all been severely polluted due to anthropogenic activities. Meanwhile, developed countries including United Kingdom and Japan, are also grappling with challenges of river water pollution. Analysis of water samples from river basins in Kenya revealed that pollution levels in sections of rivers traversing through agricultural units, industrial areas, and informal settlements were up to 2000 times higher than the criteria permitted by the World Health Organization (WHO) (Ikiara *et al.,* 2004) hence the need to establish current pollution levels of Ngong River.

Kenya is classified among the water-scarce countries, yet forecasts suggest that per capita available water will fall to 350 m^3/year by 2020, down from 650 m^3/year in 2012 (Kithiia, 2012), possibly due to population growth. This statistic is far lower than the globally accepted norm of 1000m^3 per capita per year. As a result, immediate action is required to strengthen the water sector's capability to improve accessibility and supply of clean and safe drinking water (Kithiia, 2012). Majority of Kenyans living in rural areas and informal settlements in Nairobi have limited access to quality water. In rural areas, people travel for long distances to find water and use it for various uses while in untreated state (Kithiia, 2012). Meanwhile, in urban areas untreated water from rivers in the city is used for urban farming (Karanja *et al*., 2015), however the untreated water is mostly turbid and contains pathogens which pose a health risk to consumers (Erick & Hudson , 2016; Kithiia, 2012; Musyoki & Mbaruk, 2015a).

Anthropogenic effects including agricultural, urban and industrial activities, as well as natural processes, are important sources of water pollution. Agricultural pollution is comprised of runoff from farms with excess phosphorous and Nitrogen present in fertilizers which accelerate eutrophication on surface waters, and also different organic pesticides. In fresh water, nitrates concentrations are lower than 0.001mg/l and rarely higher than 1mg/l NO_2–N (Chapman *et al.,* 1996). Nitrates and phosphates are introduced to rivers by agricultural runoff. Meanwhile, urban pollution consists of the domestic waste runoff and sewer discharge which is treated or untreated disposal into aquatic systems resulting to faecal contamination of water bodies.

Faecal contamination introduces various pathogens into water ways. The common biological contaminants are parasitic worms, protozoa, viruses and bacteria (Mason, 2002). As such, water borne diseases including cholera (caused *Vibrio cholera),* Typhoid (caused by *Salmonella typhi),* Hepatitis A among others, remain a major hazard across the world. Such diseases can be controlled by providing people with enough and good quality water although achieving high quality standards is a secondary consideration. Industrial effluents mainly consist of heavy metals, acids and hydrocarbons. Of these, sewage and industrial effluents have high probability of causing adverse effects on water quality of the receiving body causing heavy metals pollution. The present study was conducted along Ngong River basin which originates from the Ngong forest. Ngong River cuts through the Nairobi's Industrial Area (a distance of ~10km) (Oyake, 1998) and various residential areas before joining the Nairobi River in Njiru. The Ngong River basin is 42.3 kilometers long and forms a section of the Athi River basin's upper watershed. Meanwhile, the Athi River, also known as Galana/Sabaki downstream, is a key water source for around roughly 4 million people living in the dry counties of Machakos, Makueni, and Kilifi (Marwick *et al.,* 2018). It drains its water into the Indian ocean at Malindi and it's a major supplier of Mombasa city's municipal water. According to Milner & Fuller, (1991), effects of perturbations and alterations upstream can occur in downstream stretches far from the original source, inflicting the consequences at a distance.

The sampling sites in this study were chosen to coincide with the areas where the effects of anthropogenic activities were evident. This began at the Ngong Forest boundary and ended at Mong'etho in Njiru, just before the Nairobi River's confluence. This study was helpful in identifying the sources of pollution along Ngong River, which could aid in enhancing periodic monitoring and decision making in terms of placing measures in-place to curb ongoing pollution of the river and the environment at large by relevant stakeholders such as NEMA, WRA, and so on. Additionally, the current status of Ngong River's water quality was determined and a correlation between human induced activities and the sample water qualities were determined through this study's results.

1.2 Statement of the Problem

Water pollution by toxic metals has raised concern to WHO and concerned government authorities. Pollutants are introduced into aquatic systems through anthropogenic or natural means. Human induced activities including industrial effluents, agriculture, domestic effluents and untreated sewer discharge all have an impact on water quality (Nyairo *et al.,* 2015).The physicochemical characteristics of the surface water quality, such as total dissolved oxygen, nitrate-nitrogen concentrations, phosphates, and heavy metal concentrations, are all influenced by such activities. Heavy metals are mainly introduced into rivers through industrial effluents (Suthar *et al.*, 2009), household water wastes highly influences the Total Nitrogen (TN) and Total Phosphate (TP) concentrations, while agricultural activities influence soluble Nitrogen and phosphate concentrations (Nyairo *et al.*, 2015). Pollution from human based activities including dumping of solid waste, raw sewer discharge, and industrial and domestic effluents discharge in the Ngong River's catchment area is a major concern (Odipo, 1988; Oyake, 1998). These human induced activities greatly contribute to serious pollution of Ngong River (Odipo, 1988; Oyake, 1998, Kahara, 2002).

Ngong River drains its water into Nairobi River (a major tributary of Athi River). According to prior studies, heavy metal pollution of the Nairobi River has increased considerably in recent years (Oyake,1998). This informed investigation of Ngong River for heavy metals pollution notably Lead and Cadmium from the water samples collected. Informal settlements and industrial discharges contribute to organic pollution

(Oyake,1998). As a result, assessing the effects of the various anthropogenic activities on river water is required. Notably, Nairobi has had rapid population growth and industrialization in the last century which fails to match with development of infrastructure necessary for waste disposal management, resulting to pollution of nearby water bodies (Karanja, 2011).Thus this study sought to establish the pollution levels of Ngong River which is critical in understanding the current water quality status. Ngong River confluences with Nairobi River at Njiru to later become the Athi River whose water is utilised by downstream communities living in Makueni, Machakos and Kilifi for domestic and agricultural use (Musyoki et al., 2013). Given the growing population and high demand for safe/clean water in downstream towns, it was critical to collect current data on Ngong River water quality and create an inventory of various human activities along the basin in order to know the water's appropriateness for public utilisation. Furthermore, Ngong River flows through Nairobi's and Africa's largest slum (Kibera) (Kahara, 2002), as well as Kenya's major industrial hub and other informal settlements, making it vulnerable to pollution and raising its profile as a research topic in the hope of finding a solution to the water quality crisis. Water from urban water ways and food crops grown using this water may not be fit for human consumption if no mitigation actions are taken to abate the urban rivers pollution, necessitating the need for up-to-date data on the Ngong River's water quality.

1.2.1 Research Questions

i) Which are the anthropogenic activities practiced along Ngong River?

ii) Do anthropogenic activities have an effect on water quality of Ngong River?

iii) What are the effects of the anthropogenic activities on water quality of Ngong River?

1.3 Research Objectives

The main objective of this study was to determine effects of various anthropogenic activities on Ngong river’s water quality.

The specific objectives were;

i. To identify and determine the effects of the various anthropogenic activities along Ngong River.

ii. To measure the pollution levels in Ngong River by use of selected water quality parameters.

iii. To determine the relationship between anthropogenic activities and the water quality at selected sampling points along the Ngong River.

1.4 Research Hypothesis

1. **H_O1:** Changes Ngong River’s water quality is not significantly related to the anthropogenic activities
2. **H_O2:** There is no significant difference between the values of measured parameters at different sites

1.5 Significance and Justification of the Study

Water plays a vital role in National development with respect to social, economic and environmental aspects. Water is constitutionally linked to human rights as envisioned in the Kenya constitution,2010 which acknowledges access to clean and safe water as a basic human right. As the government of Kenya commits itself in realisation of the human rights to water, and reasonable standards of sanitation, there is need to document the anthropogenic activities degrading the water quality of Ngong River as a step towards ensuring access to clean and safe water as enshrined in the Constitution. Ngong River is an essential water body, which confluences with Nairobi River at Njiru area and later joins Athi River in which Thwake dam is constructed in Makueni County to supply water in the neighboring Kitui and Makueni Counties. Several detailed studies found that untreated water from various sections of the Ngong River and Athi River is frequently utilized for domestic, agricultural, as well as other purposes, which prompted this research endeavor. This prompted more research and the compilation of up-to-date data to not only demonstrate the Ngong River's water quality state, but also to assist institutions like NEMA in implementing waste management regulations and efficiently reducing pollution in the river. This was accomplished by looking into markers of water pollution like physico-chemical parameters like turbidity and conductivity, TDS, pH, TSS, nitrates, COD, BOD, and others. Water samples were also tested for microbial contamination and heavy metals pollution. This thesis was compiled on the basis of water quality data collected and anthropogenic activities noted at various sampling stations from Ngong Forest to Njiru.

1.6 Scope and Limitation of the Study

This study identified anthropogenic activities along Ngong River basin, and their effects on water quality within the catchment area. Water quality assessment was limited to selected physico-chemical parameters (pH, temperature, electrical conductivity, TDS, TSS, oil and grease, BOD, COD, nitrate, lead and Cadmium), coliforms and *E.coli* contamination. Subsequently, a relationship between Ngong River’s water quality and anthropogenic activities along the River basin was established. The methodology used in this study was designed to ensure that the various anthropogenic activities contributing to pollution of the entire Ngong River basin were captured which can help in monitoring these activities to minimize their impacts. The water quality status of Ngong River with regards to turbidity, solid wastes, colour and foul smell was assessed visually and by smelling, during selection of sampling points. Location of identifiable industrial effluent drains, as well as sewers within the slums that were in close proximity to the river were also considered when selecting sampling points. Sampling was done in April 2021 and August 2021 that marked the wet and dry seasons, respectively. Financial considerations limited the number of samples and the frequency of collection of samples. Due to inaccessibility of some areas and risk of floods during the peak season, the study only focused on identifiable anthropogenic activities and accessible sampling points along the river. The river was also disappearing in some sections area between the dam and industrial area due to urban developments and encroachment making it difficult to trace the whole stretch. Non-point sources including urban and agricultural runoff were not be covered in this study.

1.7 OPERATIONAL DEFINITIONS

Anthropogenic effects: These include changes to the bio-physical ecosystems and environments, natural resources and biodiversity caused directly or indirectly by humans.

Anthropogenic activities: Activities derived from human activities as opposed to natural occurrences.

Water Quality: a set of conditions; physical, chemical and biological properties that defines the state of a water body

River pollution; River pollution refers to the presence of unnatural foreign materials in a river which interferes unreasonably with beneficial uses of that river.

CHAPTER TWO: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.0 LITERATURE REVIEW

2.1 Introduction

Theories related to river ecosystem, anthropogenic activities and water quality are reviewed. The relationships between anthropogenic activities and river ecological health are also discussed herein. The literature thematic discussions are given in both theoretical and empirical perspective. The researcher further describes water quality focusing on selected parameters. The chapter also gives a critical discussion on anthropogenic pollution of rivers at a global, regional and local scale. Finally, the conceptual framework for this study has been explained

2.2 Theoretical Literature

2.2.1 The Systems Approach

The recent global problems such as pollution, urbanization and environmental quality issues are complex, transcending to spatial and temporal scales (Bradley and Yee, 2015). According to the systems approach, these problems are best solved based on the principle that various components of a particular system can be understood better in the concept of their interactions and relationships with one another and with external systems (Bradley and Yee, 2015). This study has applied the systems approach in determining the effects of various anthropogenic activities on Ngong River's water quality.

The growth and expansion of Nairobi city has led to an increase in informal settlements, middle-income residential areas and industrial establishments. However, this tremendous population increase does not match the provision of basic amenities such as collection of solid waste, sanitary waste management, industrial effluents management and other amenities. In view of the systems approach, Nairobi has increased its interaction with surrounding anthropogenic activities including industries, human settlements and urban agriculture. As a result, the anthropogenic activities/ land-use practices have had an influence on the quality of water in the rivers and ecosystem dynamics in the urban setup such as Ngong River which flows through Nairobi city. Additionally, Ngong River's water quality is depends on the different land-use practices/anthropogenic activities in areas it passes through as illustrated in figure 1. River water quality is affected negatively by the contamination with heavy metals, pesticides through agriculture, suspended solids, and coliforms through raw sewage from the different anthropogenic activities along the basin. Understanding the impacts of the various anthropogenic activities on Ngong River's water quality is therefore critical since it will provide an insight on the status of the river water and the interaction with human activities and sustainable ways to manage the river water.

2.2.2 Integrated Water Resource Management approach

In 2002, the Technical Advisory Committee of Global Water Partnership defined the Integrated Water Resources Management (IWRM) "as the process that supports the management as well as coordinated development of water, land and other associated resources so as to maximize the subsequent social-economic welfare in a more equitable manner and with no compromise to the sustainability of key ecosystems." In addition, more emphasis were placed on management of water in a basin-wide context, while taking into consideration the public participation and good governance principles (Rahaman & Varis, 2005).

Water practitioners face unfamiliar challenges because their work not only promotes humans well-being but also negatively affects human health. The diseases related to water include communicable diseases such as water borne, water-washed, water-based and water related vector borne diseases in nature or non-communicable diseases due to exposure to water polluted by chemicals especially heavy metals such as Cadmium. This introduces potential carcinogens into the body, causing pains and aches in bones in the case of "itai itai" disease in Japan (Tsuchiya, 1978; Kjellstroem, 1986) and kidney damage. As estimated by Pruss-Ustun & Organization (Boelee *et al.,* 2019), waterborne as well as water-related infectious diseases account for around 3.4 million annual deaths globally. Further, it was estimated that 1.8 million deaths globally were associated with water particularly microbiological contamination, while 0.5 million annual deaths were associated with heavy metals, chemical and soil pollution (Boelee *et al.,* 2019). In view of this, the importance of a wholistic approach in management of water resources so as to avert water related health burden perhaps through integrated water resource management approach cannot be overemphasized.

As an ecosystem, Ngong River basin is fundamental in interaction of functional units of microorganism communities, animals and plants, which co-exist within the basin. Therefore, IWRM theory could be applied to establish and minimize the negative impacts of anthropogenic activities to the Ngong River's water quality. This can result to effective maximization of socio-economic benefits arising from sustainable and equitable use of the Ngong river's water among the living and the non-living organisms utilizing/inhabiting this river.

2.2.3 The Ecological Operation Model/theory

This is a water resource multi objective regulation model that takes considers the ecological needs (Lu *et al.,* 2018). The model is intended to find a compatibility and balance between ecological goals and human needs to improve and restore the river's ecosystem health to meet basic human needs (or with lesser impact) (Lu *et al.,* 2018). The model aims at improving and maintaining river hydrological and ecological relation and restoring river ecosystem health (Lu *et al.*, 2018). Based on this theory, human activities along the river's riparian system would be made aware of the impact they have Ngong River's water quality. This aspect is likely to trigger conservation efforts aimed at reducing the pollution of Ngong River's waters hence improving quality of water and eventually improve livelihoods of communities that live downstream.

2.2.4 Ecosystem Approach

This approach was defined in 1995 on the Convention on Biological Diversity (CBD) as "an approach for integrated management of land, water and living resources which promotes nature conservation and sustainable utilization in equitable manner while appreciating that humans and their cultural diversity are a fundamental component of an ecosystem" (CBD, COP 7 Decision VII/11). Ecosystem Approach considers economic, social, ecological and human aspect as integral part of the ecosystems *(Scott et al.*, 2014).

The application of this Approach is linked to adaptive management and adaptive learning practices but do not exclude other conservation and management approaches. Therefore, Ecosystem Approach goes way beyond ecosystem services and its application could only be accomplished by referring to the considerations outlined in the Malawi principles (Table 1) (Scott *et al.*, 2014).

Table 1: The principles of the Ecosystem Approach.

1.	The objectives of land, water and living resources management are a matter of societal choice.
2.	Management ought to be decentralized and to the lowest appropriate level.
3.	Ecosystem managers ought to consider effects (potential or actual) of their activities on nearby and other ecosystems.
4.	To identify the potential gains from the management, there is a need to manage and understand the ecosystem from an economic context.
5.	Conserving ecosystem structure and functioning so as to maintain ecosystem services, ought to be a priority target of the ecosystem approach.
6.	Management of ecosystems should be within the limits of their functioning
7.	The approach should be done at the appropriate temporal and spatial scales.
8.	Identifying the varying temporal scales and the lag effects which characterize processes of ecosystems and ecosystem management objectives should be set to the long term.

9.	Management should appreciate that change is inevitable.
10.	The ecosystem approach must seek an appropriate balance between, integration, use of biological diversity and , conservation.
11.	The ecosystem approach must consider all relevant information, such as scientific, innovations, practices, as well as indigenous and local knowledge.
12.	The ecosystem approach must include all relevant segments of the society as well as scientific disciplines.

Source: Scott *et al.,* (2014)

Based on the outlined principles, ecosystem approach can be applied in management of Ngong River ecosystem, whereby relevant authorities and the community at large can use a wholistic approach in the protection of the river which seeks a suitable balance between, and integration of biodiversity utilisation and conservation. This should also involve all relevant stakeholders of society and scientific disciplines while considering different forms of relevant information such as working with local CBO's in ensuring the protection of Ngong River basin. When determining possible achievements from management, it is particularly necessary to manage and understand this ecosystem from an economic perspective (Scott *et al.,* 2014). When the community have a sense of ownership or stake in the river ecosystem, they will in return provide vital information to the managers such as on the source of pollutants, this will increase surveillance thus protection of the river.

2.3 Empirical Literature

2.3.1 Water as a Critical Ecosystem Service

Fresh water is a scarce resource but fundamental for maintenance and development of dynamics for every aspect of life. Despite the scarcity of fresh water, humans are estimated to consume approximately 1000-1700m3 of the world's ground and surface water annually, which constitutes between 22% and 150% of the annual world's fresh water supply (Hoekstra & Wiedmann, 2014). Furthermore, water reserved in all rivers on earth is around 2000km^3, much less than the water withdrawn each year (3800km^3/ year) by human beings, which represents less than 10% of maximum available RFWR on earth (Oki, 2006). Clearly, an adequate measure of the water availability is 45,500km^3/year of total annual discharge, majorly flowing through the rivers from land to the sea (Oki, 2006). This aspect makes sustained supply of fresh water among the most vital ecosystem service on earth (Hoekstra & Wiedmann, 2014).

Water provisioning has been found to be among ecosystem services that are largely affected by anthropogenic activities since they degrade or modify water basins (Leemans & Groot, 2003). Land-uses have potentially large effects on water resources (Stonestrom *et al.,* 2009). Anthropogenic activities including human settlements, industrial and agricultural activities pollute the water rendering it unsuitable for domestic use, recreational and other purposes. Anthropogenic effects such as release of industrial effluents introduce heavy metals, acids, and hydrocarbons, causing water pollution; sewage discharge causes faecal contamination; and Agricultural runoff increases nutrients (e.g., phosphorus and nitrogen) in water bodies, causing eutrophication (Adeosun *et al.,* 2016). The negative effects of the land-use systems on ecosystems ability to sustainably supply water can be curbed through adoption of the "Ecosystem Approach". This approach recognizes human beings as an integral part of an ecosystem, and acknowledges that the land-use practices affect the water integrity in rivers, streams, as well as other surface water resources. This approach further advocates for deliberate efforts on diverse knowledge in the natural resource management, with focus on effects of land-use practices on rivers (Scott *et al.,* 2014). Water quality assessment, therefore, gives an insight about water quality status and productivity of given water body (Adeosun *et al.,* 2016). In this respect assessing the water quality of Ngong River will inform the effects that anthropogenic activities have on this ecosystem which is critical in developing the mitigation measures to avert pollution sources.

2.3.2 Water Quality

Water quality refers to sum of all aesthetic, biological, physical and chemical characteristics of water that affect its beneficial use by humans or ecological systems. On the other hand, pollution means human alteration of biological, and physico-chemical characteristics of the water. Water resources degradation is caused by various factors that range from depletion and degradation of the fresh water resources, to effects of natural disasters, climate change and agricultural production (Corvalan *et al.*, 2005). Meanwhile, water quality indicators may involve both biological and physical parameters including single compounds such as BODs, Nitrates, Dissolved Oxygen and multiple parameters (oil, grease, coliforms (Novotny, 2002). Other indicators include water temperature which determines the Oxygen levels in that water; the colder the water, the higher the levels of oxygen, and vice versa. Additionally, coliform bacteria in the river water are an indicator of the sanitary water quality for swimming and drinking, with faecal coliforms being indicators of human induced pollution. In Kenya, the high population expansions as well as the intensive land utilization within the catchment areas often result to increased land degradation. The end result is water resources degradation, compromised water qualities in the rivers, and competition for water resources. To check the water quality for different domestic water sources in Kenya, the NEMA has established quality guidelines for drinking water (table 2). Additionally, guidelines have been set to guide industries on the thresholds to be met in order to discharge effluents into the environment as per Water quality regulations, 2006.

Table 2: NEMA and WHO Water quality standards for domestic water sources

Parameter	Units	NEMA Guide Value (maximum allowable)	WHO Guide Value (maximum allowable)
Suspended Solids	mg/l	30	30
Nitrate-NO3	mg/l	10	50
Nitrite-NO2	mg/l	3	3
pH	pH value	6.5-8.5	6.5-8.5
Total Dissolved Solids	mg/l	1200	1000
Lead	mg/l	0.05	0.01 (provisional guideline)
Cadmium	mg/l	0.01	0.003
E.coli	Per ml	NIL	NIL

NIL indicates less than the detection limit using the recommended equipments, sampling and analytical techniques as established by the concerned organisation.

Source: (NEMA,2006; WHO, 2011)

2.3.4 Water quality parameters

pH measurements give the chemical condition which prevails in the river water. The pH in natural waters is between 5.5 to 10.5; however, it varies in surface waters from season to season (Oyake, 1998). The pH of water has a marked effect on the toxicity of substances present in industrial wastes (Odipo, 1988) for instance certain conditions of acidity in water bodies polluted by industrial effluents may liberate metals insoluble form from the suspended matter contaminated by metallic compounds leading to fish mortality (Katz, 1969). Measurement of pH is associated with alkalinity or acidity of the water (Baird *et al.,* 2017). A sample with a pH <7.0 is considered acidic, and alkaline if the pH is >7.0.

Turbidity is measured as the relative clarity of a given water body. It’s also expressed as the optical property which causes light scattering and absorption instead of straight lines transmissions through a sample. Optically, black particles, for instance, that of activated carbon can absorb light and elevate turbidity levels of a given aquatic system. The clarity of water in a natural water body is a key determinant of the light penetration ability and ecological productivity of a particular ecosystem (Baird *et al.,* 2017). In surface water bodies, +turbidity is caused by suspended matter including silt inorganic and organic matter, clay, soluble-colored organic compounds, planktons as well as other microscopic (tiny) organisms making the water cloudy and opaque. High levels of particulate matter in a water body affect the ecosystem’s productivity as a result of the effect on light penetration thus inhibiting photosynthesis. Particulate matter also offers surfaces for attachment of other pollutants especially heavy metals and microbes hence turbidity can indicate potential water pollution. During low flow periods, many rivers have low turbidities (usually less than 10 NTU) and water often has clear green color. During a rainstorm, soil particles from adjacent land are often washed into the river, resulting to the water being muddy-brown color; this indicates higher turbidity values in the water. Water volumes are higher during high flows, and water velocities are faster, which increases stirring up and suspension of substances from the stream bed, resulting to higher turbidities. Turbidity levels of a given sample can be low in case the water is colored as a result of dissolved substances which absorb light (Baird *et al.,* 2017).

Conductivity is an aqueous solution's ability to conduct electricity. This ability relies on the total concentration, presence of ion, valence and mobility, and temperature. Solutions containing most inorganic compounds have good conductivity while those containing organic compounds which do not dissociate in an aqueous solution are poor conductors.TDS measurement in a water sample gives total concentration of water solids thus giving a quick assessment of the water quality. Dissolved solids consist of; phosphates, nitrates, alkalis, acids, sulphates, iron, magnesium and most of inorganic pollutants. Most dissolved solids impart the ability to conduct electricity to water hence a more rapid determination of TDS is by measuring Conductivity (Oyake, 1998).

Chemical Oxygen Demand (COD) is a key indicator for organic pollution. COD tests involves estimating the oxygen utilized by microbes during aerobic breakdown of pollutants (Allen *et al.,* 1974).Tests on Biochemical oxygen demand (BOD) establish the oxygen requirements in polluted waters, polluted waters, and effluents. It is widely applied in estimating waste loaded into a treatment plant as well as determining the efficiency of that plant in removing BOD. A test on BOD is used to measure the molecular oxygen used in a particular incubation period to; Degrade the organic material biochemically (carbonaceous demand),enable oxidation of inorganic material (for example ferrous iron and sulfides), and enable oxidation of reduced nitrogen (i.e. the nitrogenous demand), unless such reduction is prevented by the addition of an inhibitor.

Presence of oil and grease in aquatic systems could influence biological processes (anaerobic and aerobic), leading to reduction in efficiency of waste water treatment. When such water is discharged in waste water and treated effluents, they may result to shoreline deposits and surface films, resulting to environmental degradation. When there is lack of specifically modified industrial products, grease and oil contains two principle constituents: fatty substances from vegetable and animal sources, as well as hydrocarbons originating from petroleum (Baird *et al.,* 2017).

Solids include matter dissolved or suspended in water or waste water. They adversely influence water quality in different means. Water containing high levels of suspended solids could be unfit for domestic purposes including bathing. Meanwhile, analysis of solids is fundamental in biological and physical control of wastewater treatment processes and for determining compliance with regulatory agencies for waste water effluent. In the river water, amount of suspended solids is determined by the quantity and quality of wastes discharged into the river, as well as the processes occurring in the river bed and the whole catchment (Oyake, 1998). One of the common forms of pollutants in sewage and industrial effluents is the insoluble matter in suspension (Oyake, 1998).

Total coliform bacteria comprise a wide array of aerobic and facultatively anaerobic, Gram negative, and non-spore-forming bacilli that can grow in the presence of relatively high bile salts concentrations with the lactose fermentation and acid or aldehyde production within 24 h at 35–37 °C (WHO, 2011). Thermotolerant coliforms and *E.coli* are subsets of total coliforms that have the ability to ferment lactose at high temperatures. During fermentation of lactose, the total coliforms generate the enzyme b-galactosidase (WHO, 2011). Traditionally, coliforms were grouped in the genera *Citrobacter, Escherichia, Enterobacter* and *Klebsiella*. This group is however more heterogeneous and comprises many genera, including *Hafnia* and *Serratia*. The total coliforms comprises both environmental as well as faecal species .
The Total coliform bacteria (apart from *E. coli*) exist in both natural waters as well as sewage. Some coliform bacteria occur in the human and animal faeces. Many coliforms are heterotrophs and can survive in soil and water environments. Additionally, Total coliforms can grow and thrive in water distribution systems, especially when biofilms are present (WHO, 2011). Analysis of faecal indicator microorganisms is essential in verification of microbial water quality. For Ngong River basin, *Escherichia coli* was the organism of choice since it provides concrete evidence of its presence in pollution by fecal matter which should be absent in drinking water (WHO, 2011).

Heavy metals such as Cadmium metal is widely used in the plastic and steel industries. Additionally, batteries contain Cadmium compounds. Cadmium is released to the environment through wastewater, while diffuse pollution is caused by local air pollution and fertilizer-based contamination. The contamination of drinking water can also result from Zinc impurities in galvanized pipes, solders and metal fittings. Cadmium exposure is most common in food with daily ingestion being 10–35mg. Another form of cadmium exposure is through smoking.

Lead is majorly used in manufacture of solder, alloys and lead-acid batteries. Organo-lead compounds tetramethyl and tetraethyl are also widely used as lubricating and antiknock substances in petrol, but many countries are phasing out their use for this purpose. Given the decline in utilization of additives in fuel that contain lead i.e. petrol, lead containing solder used in food processing industries, the levels in air and food are decreasing, but the larger proportion of the total intake comes from drinking-water. Lead presence in drinking water is majorly from household plumbing systems containing lead (such as solder, fittings, pipes, or the service connections to homes. The total dissolved lead from the plumbing systems mainly depends on a number of factors such as temperature, pH, water hardness and standing time, with soft- acidic water standing out as the most plumbosolvent.

2.3.5 Land use practices and ecological health of the river

Land-use practices are important determinants of ecological health. Various land use practices affect sediment input into the streams and rivers, which affects the channels morphology and substratum characteristics, resulting to a reduction in river's macro-invertebrate diversity (Waters, 1995). The disturbance/removal of riverside vegetation often results to increased solar radiation that reaches the river channel, causing increased water temperatures (Quinn *et al.,* 1997), which could alter the river's thermo - profiles that are fundamental to macro invertebrates' ecology and life history (Ward & Stanford, 1982). Land-use may also alter with the hydrology and catchment of rivers/streams by adding organic nutrients originating from the terrestrial sources (Johnson *et al.*, 1997), which interacts with the increase in light and river's temperature availability, to increase the in-river primary production (Webster *et al.,* 1983). Additionally, rise in temperatures in rivers can also occur when the river is polluted by effluents rich in organic matter causing a decrease in dissolved oxygen as well as an increase in the utilization rate of oxygen dissolved by biochemical reactions which normally proceed faster at high temperatures (Oyake, 1998). This results to changes in the benthic communities' trophic structure (Gurtz & Wallace, 1984).

Meanwhile, the extent and intensity of the effect of land-use could rely distribution of different land-use practices in different catchment areas (Allan & Johnson, 1997). Organic carbon and light availability in rivers is often influenced by riverside vegetation (Gregory *et al.*, 1991). In fact, land cover within the riparian region has been found to affect erosion at the riverbank, and in-stream sedimentation. However, the characteristic of the catchment hydrology, and the availability of organic nutrients in the river, is mainly related to the activities occurring on the terrestrial landscape (Hunsaker & Levine, 1995).

2.3.6 Anthropogenic practices and pollution of Rivers

Anthropogenic pollution may be classified as having originated from agricultural, industrial or municipal sources (Gleick, 1993). Improper waste disposal into the surrounding environments through illegal discharge of industrial effluents, sewer bursts together with uncontrolled dumpsites affect the water body making it inappropriate for both primary or secondary use (Guerrero *et al.*, 2013). Domestic waste discharge into rivers and streams can change aquatic systems (i.e., their biological, chemical and physical characteristics) beyond their capacity to naturally self-purificate. High levels of suspended nutrients, turbidity, coliform bacteria and dissolved solids in rivers indicate compromised ecosystems associated with increase in pollutant load, originating mainly from human activities (Adams & Papa, 2001).

2.3.7 Anthropogenic pollution of Rivers on a global, regional and local scale

Although, river water pollution is rampant in both developing and developed countries, most poor regions in the world are the worse affected by insufficient supply of water that meets the accepted standards (Agarwal & Narain, 1999; Harada & Karn, 2001). However, developed countries including United Kingdom and Japan, are also grappling with challenges of river water pollution. Other regions such as East China Sea (ECS) have also been prone to environmental stresses owing to increased population growth and human activities along the coasts and Yangtze River drainage basin which passes through various cities before draining into the ECS (Daoji & Daler, 2004). Human activities along the Yangtze River's course such as agriculture, sewage and industries release around 40% of pollutants (waste water) to the river, with phosphates, inorganic nitrogen, organic matters, oil hydrocarbons, and heavy metals being the major pollutants (Daoji & Daler, 2004). In Nepal, water contamination/pollution has also been identified as the main public health hazard, where most of it resulted from anthropogenic activities, particularly domestic sewage.

Receiving waters and water ways near suburban and urban areas are often impaired by storm water runoff from the urban areas. Urban runoff affects the water quantity, water quality, habitat and biological resources, and also public health as well as aesthetic appearance of urban water ways. The findings of the California Storm Water Quality Task Force in 1998 aided in reviewing the constituents present in highway and urban area storm-water runoff which revealed that Zinc Lead, and copper were present in almost all urban streets as well as high way storm water in concentrations that would contravene worst case-based US EPA water quality criteria developed by the US EPA

(2000) and California Toxics Rule standards. Mercury and Cadmium present also exceeded the recommended standards. This study's findings demonstrate the possibility of some heavy metals present in urban storm water causing toxicity to aquatic life (Fred Lee & Jones-Lee, 2005).

In Southern Italy, there has been water quality degradation particularly near river's Sarno mouth (Arienzo *et al.,* 2001). Most of the pollution was found to occur at stations near the urban areas of Scafati, Pompei and Castellamare di Stabia. These findings were similar to those of Fred Lee & Jones-Lee (2005) who noted pollution of urban water ways in California's streets with heavy metals. Meanwhile, Alam *et al.,* 2008 attributes the water quality degradation issue witnessed in various urban cities to the waste menace globally due to inefficient waste management system due to increased industrialization and population growth rate. Cicchella *et al.*, 2013 showed that pollution of Sarno river basin resulted from wastes from leather tanneries, pharmaceutical industries and tomato industrial set ups in Southern Italy.

Recently, the effect of solid wastes on the water quality was found to be a key environmental hazard, particularly in the developing countries (Cointreau, 1982; Markandya, 2006). In 2006, the total global amount of domestic waste produced was around 2.02 billion tones, reflecting around 7% increase compared to 1.89 billion tones recorded in 2003 (Note, 2007). As of 2009, approximately 3.4 to 4 billion tones of industrial and municipal waste had been produced every year, where 1.2 billion tones of the industrial waste were non-hazardous (Chalmin & Gaillochet, 2009).

Additionally, the United States Environmental Protection Agency (US EPA) singles out 16 priority Polycyclic Aromatic Hydrocarbons (PAHs) found to be mutagenic and carcinogenic, and jointly with other bodies including WHO, have recommended their tolerable amounts in water (Erick & Hudson , 2016). Inefficiency in water resources management may result to increased degradation, exposing humans to cancer and other health related problem. Thus a comprehensive understanding of the effects of anthropogenic activities on various natural systems will transform our views on the way we manage the earth's resources (Winz *et al.,* 2009).

In African countries such as Nigeria, inland water bodies and estuaries are the major drinking water sources but they are often polluted through industrial activities and adjoining populations, leading to high concentrations of pollutants and sediments in water (Kanu & Achi, 2011). The Industrial wastes generated are non-biodegradable thus persistent in the environment.

Many industries generate Effluents through the production processes (Kanu & Achi, 2011). The type of industry as well as the water use can result to suspended solid matter in the effluent i.e. both biodegradable and non-biodegradable organics, greases and oils, dissolved inorganics, ions of heavy metal, coloring compounds, acids and bases (Kanu & Achi, 2011). Industrial wastes vary tremendously among industries based on the processing activities used and may contain organic and inorganic chemicals, and heavy metals including Zinc (Zn), Cadmium (Cd), and Lead (Pb), which cause toxicity to humans and aquatic organisms. The waste water especially from food processing industries contain high BODs content often ten times higher than that of domestic waste (Mara, 2013). In most cases, the industrial waste water is warm due to their use in cooling machines, which increases thermal temperature of aquatic systems. Other human activities including domestic run off, agricultural runoff and refuse dump, have been found to adversely affect the quality of water in Nigeria (Adeosun *et al.*, 2016).

In Kenya, anthropogenic pollution has been in rivers such as Nyangores and Amala which are tributaries of the River Mara in Kenya (Nyairo *et al.,* 2015). Additionally, industrial activities, agricultural activities and increased population growth (rural-urban migration) have been found to contribute to large amounts of water pollutants which cause degradation of the status of water quality in Athi and Nairobi rivers basins (Kithiia, 2007). In Ngong River, the water is mainly polluted as it passes through Nairobi city (Kithiia, 1992; Oyake, 1998). Industrial effluents play a vital role in pollution and degradation of Ngong River's water (Kithiia, 2007; Njenga *et al.*, 2009; Oyake, 1998). In addition, an assessment of macrophytes, nutrient concentrations and heavy metals in Nairobi River water established that the concentrations of Fe, Pb, Mn and Cr had exceeded the WHO tolerable limit for safe and consumable drinking water (Njuguna *et al.*, 2017), which was attributed to industrial effluents discharge, solid wastes and agricultural activities and sewerage discharge along the river. Macrophytic species that are effective heavy metals and nutrients bio-accumulators have also been identified along the river. Meanwhile, the untreated Ngong river water has been found to have Polycyclic Aromatic Hydrocarbons (PAHs) levels ranging between 2.69ng/L and 14.22ng/L, which were within the tolerable limits (Erick & Hudson , 2016). However, precaution should be taken over the use of untreated Ngong River's water to avoid PAHs accumulation in human body and other related dangers (Erick & Hudson , 2016).

Agricultural pollution is comprised of runoff from farms with excess organic pesticides, phosphorous and Nitrogen, present in fertilizers which accelerate eutrophication on surface waters. In fresh water, nitrates concentrations are lower than 0.001mg/l but rarely greater than 1mg/l NO_2 –N (Chapman *et al.,* 1996). The domestic waste water disposal is also an environmental and public health concern. Disposal of partially treated or treated effluent results to fecal contamination of aquatic systems. The common biological contaminants are parasitic worms, protozoa, viruses and bacteria (Mason, 2002). As such, water borne diseases including cholera that is caused by *Vibrio cholera,* Typhoid caused by *Salmonella typhi*, Hepatitis A among others remain a major hazard in across the world. The microbiological contamination in the Nairobi and Athi Rivers surface waters has been found to be unacceptably high based on Kenyan standards, and WHO guidelines for safe water for agricultural use and human consumption (Musyoki & Mbaruk, 2015a). This water presents a health hazard to communities whose livelihoods depend on the two rivers as their major source of water for irrigation and domestic use (Musyoki & Mbaruk, 2015a). Additionally, leafy vegetables originating from the Ngong river have been sampled from the informal markets in Kibera and Maili Saba slums located along the Ngong River and were found to contain high levels of parasitic eggs of some common intestinal parasites and faecal coliforms (Karanja *et al.*, 2009).

Industrialization, urbanization, rapid population growth and increased waste production have transformed solid waste into a serious public health and environmental concerns in the Nairobi city. In Nairobi, there is an inadequate system for management of waste. In fact, majority of slums are located within the Nairobi River Basin, and lack basic/essential sanitary provisions, leaving water bodies including Ngong River basin to be recipients of most of the waste. The situation of Nairobi's solid waste generally represents Kenya's status, which is predominantly characterized by lack of key infrastructures for management of solid waste, unregulated waste dumping leading to pollution, lack of controlled and coordinated private sector, inefficient public services, and little solid waste collection. Over 2400 tons of garbage is generated in Nairobi County per day. This is projected to rise to 3200 tons/day by year 2022. Presently, only about 60% of the total generated waste gets to the final disposal point. Around 10% of the produced waste is recycled with the rest ending up in undesignated places such as rivers (Nairobi City County, 2018), reason being waste management is complex and has very high operation cost, making it difficult for the waste operators to provide the services effectively (Kimani, 2014). The limited focus on waste management control mechanisms poses threats to health, safety and environment. Over the years, the evolving trend of solid waste composition in Nairobi has shown a decrease in organic waste, and an increase in paper content, although organic matter still remains the highest content with an average of 62.1% (Kimani, 2014).

Improper management of solid waste results in undesirable impacts on environment and human health, leading to water pollution and related diseases. Sustainable solid waste management is therefore important particularly due to vulnerability of the natural resources including underground aquifers and surface waters (Hinsby *et al.*, 2008). Solid waste deteriorates water quality and degrades water bodies physical appearance.

Considering the expansion of human settlements and industries, coupled with implementation of new waste management water policies over the past decade, an up-to-date data that could show present status of Ngong River's water quality was necessary.

Recently, the Polycyclic Aromatic Hydrocarbons (PAH) levels in Ngong river were evaluated (Erick & Hudson, 2016). However, it is evident that this study mainly focused on PAH levels, while presence and quantity of heavy metals and fecal coliforms was yet to be determined. Elsewhere, the level of Hydrocarbons and coliforms in Athi River, which receives water from Ngong River, have been examined (Ratemo, 2018). However, the presence of heavy metals, which are important parameters in contaminated water were not examined. This further necessitated the need to determine these important water quality parameters in Ngong River's for proper management, policy making and monitoring. Measurement of different water parameters, including quantity of heavy metals is necessary to provide up-to-date information on the present status of Ngong River's water quality. This is particularly important given that this water is highly utilised for urban farming in Nairobi's Kibera area (Karanja *et al.,* 2009) and downstream (Erick & Hudson, 2016; Musyoki & Mbaruk, 2015a). This study examined the Ngong River's water quality through measurement of different water parameters, and also investigated the on-spot pollution sources to Ngong River which could facilitate NEMA with data that could be valuable during compliance monitoring.

2.4 Conceptual Framework

Ngong River ecosystem is highly influenced by the anthropogenic activities around it. This causes degraded water quality which is not fit for human use. This problem can be averted through the application of Integrated Water Resource Management approach so as to encourage a holistic approach in the management of river ecosystems. The understanding of the intrinsic values of ecosystems and the relationships of the river ecosystem with the surrounding anthropogenic activities (System approach) is also key in monitoring the pollution of the river ecosystems.

Drivers Pressure State Impact Response (DPSIR) framework has been applied in this study to capture, visualize, and organize the social, economic and environmental outcomes of human decisions on the management of Ngong River basin. This framework has been applied in the context of management of the environment to link socio-economic factors that drive human activities, the environmental impacts of these activities as well as future provisioning of ecosystem goods and services (Bradley and Yee, 2015).

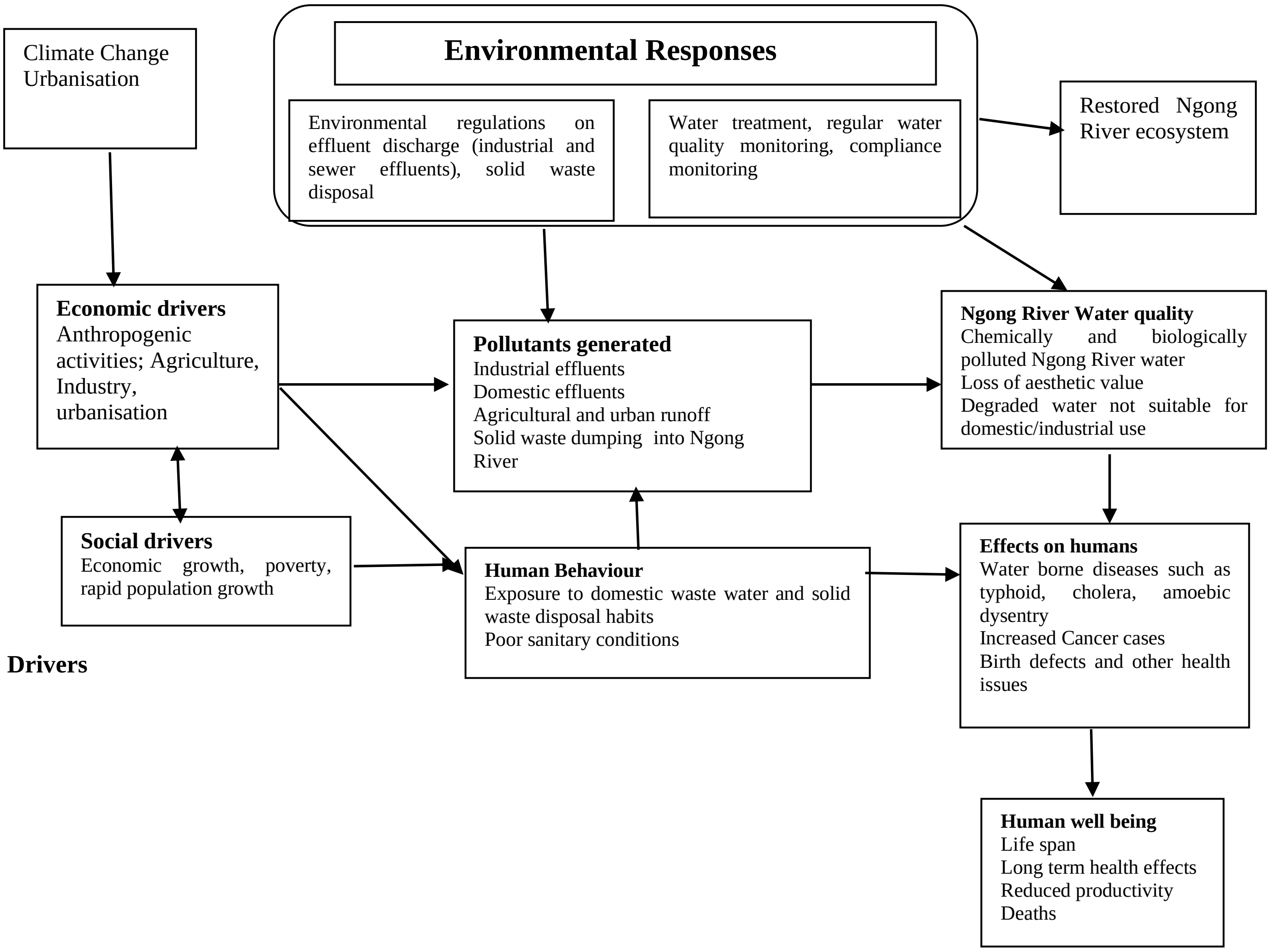

Figure 1: Cause-effect relationships between anthropogenic activities, ecosystem services and water quality of the Study area (Adopted and modified from Borja et al., (2006) and Yee *et al.*, (2012)

The conceptual framework was adapted from Borja *et al.,* 2006 ;WHO, 1997 who analysed water related health issues due to environmental pollution by applying the DPSIR framework adapted from Yee *et al.,* 2012.

This framework illustrates various levels of the cause-effect relations where drivers include climate change and urban population growth which steer economic activities in various sectors such as agriculture (food production), industrial processes and social drivers such as expansion of slum dwellings due to poverty and increased population. As a result of these drivers, ecosystem change occurs through many different interacting determinants including land use changes, agricultural intensification, urbanisation and industrialisation. This in turn leads to environmental pressures such as emissions and effluents from industries, human settlements and urban agriculture to Ngong River and the environment that people are exposed to, resulting to the water related exposure. These drivers also influence the human behaviour and human interaction with the environment, resulting to environmental pressure. Such pressures affects both human health and aquatic environmental health as a result of contamination, pollution, or breeding of mosquitoes leading to parasitic diseases or intoxication (Boelee *et al.*, 2019). Due to environmental deterioration, ecosystem services are impacted negatively, for instance through disease transmission.

The environmental impacts such as unsafe water supply can affect humans well-being, because intoxications and infections in humans can lead to disease burden and subsequently reduce the life span (Boelee et al., 2019). Landrigan *et al.* (2017) and Boelee *et al.* (2019) estimated 0.5 to 0.7 million deaths globally result of soil pollution, chemical and heavy metals pollution. In Africa, water borne diseases are the main causes of mortality and morbidity for children below 5 years. Most waterborne diseases are commonly transmitted through the faecal-oral route, which occurs when humans drink water or eat food contaminated with human faecal material, which majorly arises from improper sanitation and poor sewage management. In the Kenyan context, a study by Bongi, 2005 revealed that most toilets in Kibera slums lack connection to municipal's sewer system and emptying of the faecal sludge is particularly difficult due to inaccessibility for vehicles. As a result, gravitational emptying is a common practice whereby the pit latrine contents are directly discharged into the nearby Ngong River, or drained to flow down the gradient especially in the rainy season when the sludge is easily washed away by rain water. Such unsafe management of sewer introduces human excrete into the surrounding environment exposing the residents to waterborne diseases and soil transmitted helminths (STH). Worrel et al., (2016) reported that around 40% of both pre-school aged children (PSAC) as well as School aged children (SAC) in Kibera had acquired an infection from at least one species of soil transmitted helminths.

Based on the reviewed literature, anthropogenic activities including agriculture, manufacturing and processing industries, residential areas, solid wastes and domestic/municipal wastes have detrimental effects on most surface water bodies (Kithiia, 1992; Njenga *et al.*, 2009; Oyake, 1998). Karanja *et al.*, 2009 reported the effects of urban farming using waste waters from Ngong River, where heavy metals and faecal coliforms were present in the stems and leaves of the cultivated crops. Their study focused on the sources, quantity and type of abiotic and biotic pollutants in the water. Considering the expansion of human settlements and industries, coupled with implementation of new waste management water policies over the past decade, the present research endeavoured to come up with an up-to-date data that could show present status of Ngong River's water quality. A more recent similar study by Erick & Hudson, 2016 evaluated the PAH levels in Ngong river. In this study, the main focus was on PAH levels, while presence and quantity of heavy metals and fecal coliforms was not determined. Ratemo, 2018 examined the levels of Hydrocarbons and coliforms in Athi River, which receives water from Ngong river. Again, the presence of heavy metals, which are important parameters in contaminated water, were not examined in their study. This further creates the need to determine these important water quality parameters in Ngong River's for proper management, policy making and monitoring. As such, the present study investigated the present status Ngong River's water quality where several parameters including quantity of selected heavy metals were determined. This is essential given that this water is highly utilised for urban farming in Nairobi (specifically Kibera) (Karanja *et al.,* 2009) and downstream in Machakos and Makueni Counties (Erick & Hudson , 2016; Musyoki & Mbaruk, 2015a). Additionally, this research investigated on spot pollution sources to Ngong River which could facilitate NEMA and WRA with useful data that could be utilized during compliance and periodic monitoring.

CHAPTER THREE: STUDY AREA

3.0 Introduction

Ngong River basin is located in Nairobi County. The study area was selected due to its high population growth coupled with mushrooming of informal settlements. The river traverses the Kenya's industrial hub hence attracting scientific research due to its vulnerability of being used as an urban waste conduit for all the areas it traverses.

3.1. Location and Size

Ngong River (Fig. 2) is a small tributary that drains Nairobi City and its environs. The origin of Ngong River is Motoine Swamp Dagoretti forest, and then flows through Dagoretti area and Ngong forest and ends at Njiru. The river basin's length is about 42.3km while the total catchment area from the source to where it forms a confluence with the Nairobi River in Njiru is about 127km^2 (Kahara, 2002). The basin comprises of four different sections; upstream section of Nairobi Dam, Nairobi Dam itself, dam outlet, as well as the section from the dam out let to Njiru where it forms a confluence with the Nairobi River (Krhoda, 2002). Ngong River flows within the Nairobi City's boundary a distance of about 28km, of which 10km covered are within the industrial area. The river also passes through various informal settlements which border its river bank (Oyake, 1998).

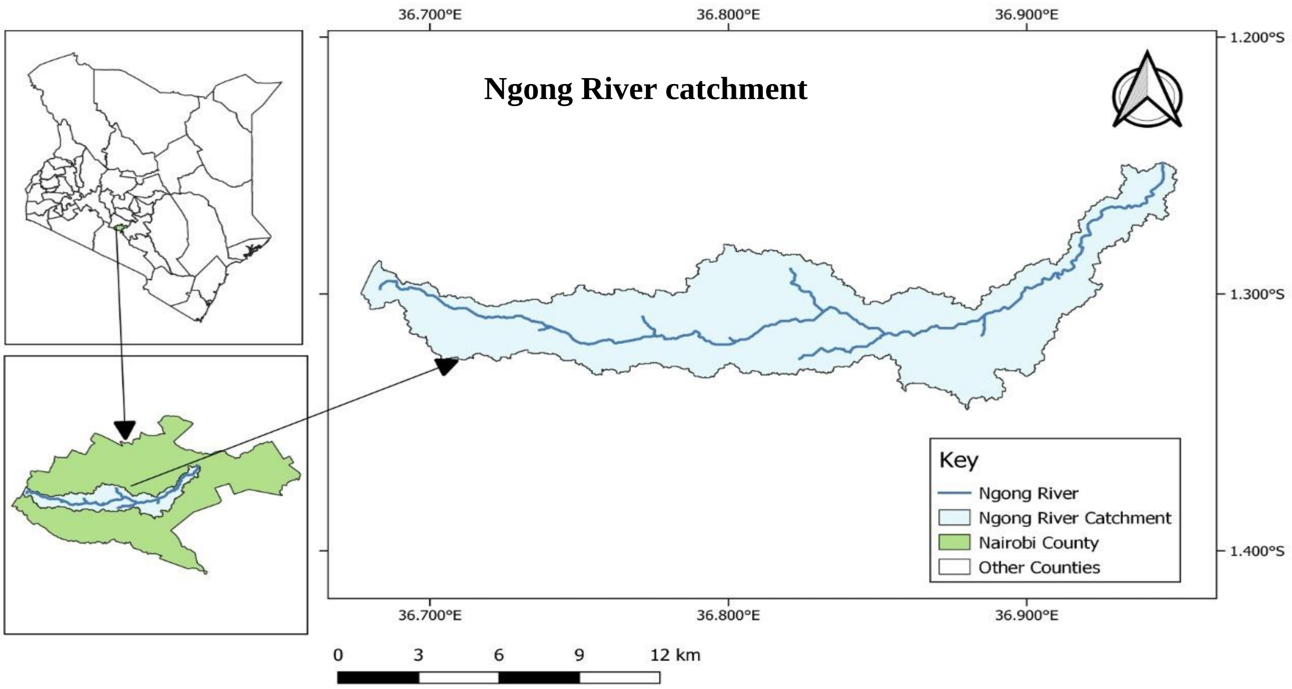

Figure 2 : Location and Size map of Ngong River

Source: Modified using Base Maps from National Aeronautics and Space Administration (NASA)

3.2 Geology and Soils

The major rock types in the study area are tertiary trachytic lavas which include Plio-Pleistocene trachytes in Kikuyu escarpment and late Miocene phonolite in Kapiti plains. Nairobi city and its environs are characterised with middle and the lower Kerichwa valley tuffs, Athi tuffs and Nairobi phonolites (Kithiia, 1992). The underlying rocks are mainly tertiary and younger sediments, tuffs, basement complex and volcanic lavas. The hydrogeology is generally controlled by nature through the volcanic lava flows as well as configuration of the old land surfaces of basement systems (Kithiia, 1997). The main soil types are the red soils and black cotton which forms distinct patches in different regions of the County. The rock beneath Dagoretti forest and Ngong road is the Upper Athi series. Section of the Dagoretti-Karen area is covered by the Nairobi trachytes while the areas from Nairobi West, South C, Industrial Area and Embakasi are covered by the Nairobi Phonolite (Mavuti, 2003). The geology of a given area is important aspect in determining the water quality (Kithiia, 1992).Infiltration capacity of rainwater, soil water storage and ground water recharge through percolation into aquifers is dependent on soil characteristics. Consequently, geology and soils have implications on water balance, drainage, land use-land cover and water quality of the nearby rivers. Different soil types have different infiltration capacities which determines the surface runoff rates (Nyangaga,2010) which influence the water quality.

3.3 Physiography and drainage

The study area’s physiography comprises of the Ngong hills in the southwest, the Kikuyu highlands, Athi plains in the east and the Rift valley to the west. The maximum elevation of the western side is around 1800m. The rivers flowing through Nairobi originates from the eastern side of the Great Rift valley and flows eastwards following gentle tilts of the land. The three major rivers flowing through Nairobi City (Ngong, Mathare and Nairobi) are tributaries of the Nairobi River and form the head waters of Athi River. They flow through Nairobi city’s area which is characterised with diverse anthropogenic activities including agricultural areas on the upper catchment, and residential and industrial areas along the city boundary. The source of Ngong river is Ngong forest. The Ngong River flows into Nairobi Dam, and then passes through Industrial area and various informal settlements before joining Nairobi River at Njiru.The physiography of an area has an influence on the land use /anthropogenic activities with the upper elevation areas characterized by forest cover and agriculture, and small-scale farming, grassland, human settlements for mid and lower elevations. These land use activities influence the water quality of Ngong River.

3.4 Climate

Ngong River catchment is located in Nairobi County in an altitude of around 1670 m above the sea-level and has an area of about 700km^2. The rainfall pattern is bimodal and long rains mainly fall between mid-March to mid-May while the short rains mainly fall between the months of October and December. April is the wettest month and it's characterized with long rains, where the average monthly rainfall is approximately 223mm. Highest rainfall experienced as short rains are recorded in November at an average of 166mm. August and September are the driest months. The Motoine Ngong River basin is within a wet climatic zone with an average annual rainfall which ranges from 1000mm to 1200mm (Mavuti, 2003). The daily maximum temperature in Ngong River basin ranges from 21.4^{0}C in August to 25.6^{0}C in March. The mean annual temperature is 17^{0}C, mean daily maximum temperature is 23^{0}C, and mean daily minimum temperature is 12^{0}C. Water samples from Ngong River were collected in April, 2021 (wet season) and August, 2021 (dry season). Temperature can affect several water parameters which influence the biotic life in river ecosystems.

3.5 Population within the Ngong River Catchment

Among all the 47 counties in Kenya, Nairobi is among the smallest counties, but the most populated. The County experiences the most rapid growths in urban centres with the city recording the highest urban population growth densities in the country. Population wise, Nairobi stands as the largest city in Kenya with around 4,556,000 inhabitants (Kenya Population and Housing Census, 2019-Volume II) that live within 704Km^2 (equivalent to 6,247 persons per sq. Km) (Table 3). The Nairobi County Integrated Development plan of 2014 notes that as per 2009 census report, Nairobi's administrative area had about 3,138,295 inhabitants that lived within 696 km^2 (equivalent to 4,509 persons per sq. Km) (Nairobi City County, 2014). The population in 2011 was 3.36 million persons (2011 census estimations). From these figures it's evident that Nairobi has continued to record a tremendous population growth rate (3.88%) as per the 2019 Kenya Housing and Population census report. This is attributed to the Nairobi's administrative and commercial hub functions in both Kenya and East African region. The increased population has increased pressure on the existing infrastructure such as water and sanitation, garbage collection, sewer systems which has led to pollution of rivers flowing through the city (Karanja, 2011; Kithiia, 1992).

Table 3: Distribution of Population by Sex, Number of Households, Land Area, Population Density and Sub Locations in Nairobi County

Sublocation	Total Population	Male	Female	Households	Land area Sq. Km	Density persons Per Sq. Km
Nairobi City	4,397,073	2,192,452	2,204,376	1,506,888	704	6,247
Dagoretti	434,208	217,651	216,526	155,089	29	14,908
Embakasi	988,808	492,476	496,270	347,955	86	11,460
Kamukunji	268,276	136,670	131,599	84,365	11	25,455
Kasarani	780,656	381,234	399,385	271,290	86	9,063
Kibra	185,777	94,199	91,569	61,690	12	15,311
Lang'ata	197,489	96,698	100,774	62,239	217	911
Makadara	189,536	96,369	93,157	70,361	12	16,150
Mathare	206,564	106,522	100,028	74,967	3	68,940
Njiru	626,482	307,642	318,809	204,492	130	4,821
Starehe	210,423	109,173	101,238	66,108	21	10,205
Westlands	308,854	153,818	155,021	103,489	98	3,167

Source: Kenya Population and Housing Census, 2019-Volume II

The catchment drained by Ngong River constitutes of six constituencies in Nairobi County (table 3); Embakasi, Kibra, Langata, Makadara, Starehe and Njiru with a total population of 2,398,515 persons and 812,845 households as per the Kenya Housing Population census report, 2019 (KNBS, 2019). Embakasi constituency has the highest population followed by Njiru downstream of Ngong River catchment. Meanwhile, Mukuru Kaiyaba and Mukuru kwa Njenga populous slums are located in Industrial area along Ngong River basin and also discharge their waste into Ngong River. Mukuru is located in Embakasi South constituency but also extends to Makadara and Starehe constituencies in Nairobi County. Kithiia (1992) and Kithiia (2007) attributed the water quality deterioration mainly downstream of the city's Central Business District (CBD) to the high population which is not matched with the existing infrastructure and social amenities. Ngong River also flows through Kibera slums, which is one of the largest slums in Africa, and despite having a high population; it has no sewage and solid waste disposal system thus all the human waste ends up into the nearby Ngong River, resulting to pollution and water quality degradation.

3.6 Ngong River catchment anthropogenic activities

The main human activities along the river include; solid waste dumping, informal settlements, raw sewage discharge, industrial activities, use of water for cleaning polythene bags for recycling, small scale farming, pig farming, quarry sites among others. In Nairobi County, approximately 61.5% of the total population use the flush toilets as the major sewer disposal method, whereas 32.1% of the population utilise pit latrines. This leaves 4.8% of the population with no means of sewer disposal. Meanwhile, only 36.1% of the communities are served by private companies for garbage collection while a similar % is collected by neighbourhood community-based groups as per the County Integrated Development Plan, 2018-2022 (Nairobi County, 2018). The rest of the garbage ends up in illegal dumps along the river banks and on the various feeder roads in the estates. This study focused on anthropogenic effects on the quality of Ngong River's water. Sampling sites were selected to coincide with human activities occurring along the stretch of the river (Figure 3) and table 3.

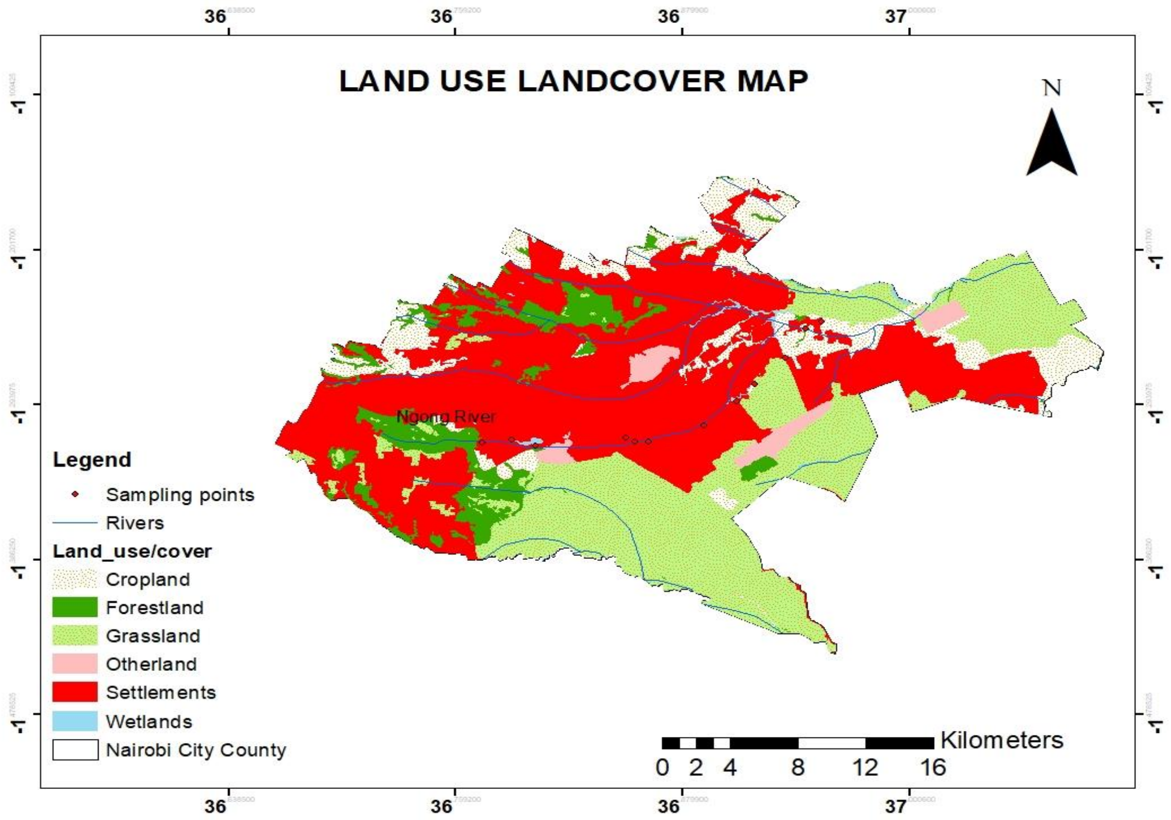

Figure 3 :Land use/land cover along Ngong River basin
Source; Landsat Image from USGS website (October, 2021)

CHAPTER FOUR: METHODOLOGY

4.0 Introduction

In this chapter, the research design, sampling procedure, sample selection and strategies that were used for data collection and analysis used in this study have been described. The tools used in data collection are discussed in this section. A criterion on arriving at the study sample and hypothesis testing or data analysis statistical techniques is also well illustrated in the chapter. A justification of the choice of study design and data collection methodology has also been described in this chapter.

4.1 Research design

The study focused on anthropogenic effects on Ngong River' water quality. This work endeavoured to present the research design which sought to investigate the study objective. It aimed at achieving a more thorough and detailed explanation of the effects of anthropogenic activities on the water quality of Ngong River. Purposive sampling survey design was adopted for this particular study. Sampling points were purposively selected to evaluate the impact of anthropogenic activities on the Ngong River's water quality. This involved collection of water samples at different sampling stations along the river basin, analysis of the selected parameters in the laboratory, and finally comparing the results with existing NEMA standards for effluent discharge (NEMA, 2006) and WHO drinking water quality standards (WHO, 2011). The sample point located at the boundary of Ngong forest served as the control point because it's at the upstream of Ngong River's pollution sources. The last point to be sampled was in Mong'etho in Njiru area just before confluence with Nairobi River. The other sampling points were distributed at different sections of the river based on the anthropogenic activities present as indicated in Table 4.

4.2 Data types and sources

A GPS receiver was used to collect location and time data which was later transferred electronically to a data folder for the selected sampling points. The following physico-chemical parameters were measured for water quality evaluation: pH, turbidity, Conductivity, Nitrate, Total Dissolved Solids, temperature, BOD, COD, oil and grease and Total suspended solids, for physico-chemical analysis.

The observed anthropogenic activities were recorded manually and by use of Photography.

Secondary data was collected through the review of relevant materials/literature including books, online journals and reports. Both unpublished and published resources were used. Landsat image was downloaded from USGS website, and subsequently used to produce land use/cover map using the ArcGis 10.4.

4.3 Data Collection

4.3.1 Pilot survey

A reconnaissance study was conducted which consisted of an initial analysis and review of existing literature on water quality data from the Water Resource Authority, NEMA and other relevant institutions. An initial site visit was carried out so as to assess the accessibility of the possible sampling points along Ngong River and to familiarise the researcher with the study area and the topography.

4.3.2 Target Population and Sample Size

The study was conducted along Ngong River. Twelve sampling points (Table 4) were established as follows; one at the source (Ngong forest boundary), the rest distributed in the middle reaches and downstream before Njiru, where Ngong river joins Nairobi River. Water sampling was conducted in April, 2021 during high flows and August, 2021 during low flows. This is because the quality of water is determined by amount of water that receives pollution from various sources. According to a study by Kithiia, (2007) on trends, levels of pollution, and the degree of the river's water quality showed that the degradation of the water quality reached alarming levels in the dry season, presenting an urgent need to carry out sampling in both dry and wet season.

4.3.3 Sampling procedure

Water samples were collected purposively at various sampling sites along the stretch. Each sampling site was chosen to coincide with specific anthropogenic activities/human activities along the River. Sampling points selection was based on their characteristics (land use patterns, the water's physical appearance, and surrounding economic activities) and location along Ngong River. The characteristic of each sampling site/area was observed and all notable anthropogenic activities occurring at the time of sampling was noted. Prior information regarding the sites found to be major contributors in pollution of Ngong River was also considered during site selection. GPS coordinates were pre-loaded into a GPS (Garmin touch Oregon 550 model) at the time of sampling (Plate 1, Table 4).


Plate 1: Research Assistant loading the GPS coordinates at Mung'etho sampling site at Njiru during the wet season
Source: Field data (2021)

Table 4: Summary of the sampling points and surrounding Anthropogenic activities

Sampling Point	Observed anthropogenic activities
SP1 Ngong Forest boundary 36.773918, -1.316723	Informal settlements near the forest boundary Small scale farming
SP2 Kibera Lindi Mosque 36.789409, -1.314737	Kibera informal settlements Ongoing road construction in close vicinity Raw sewer discharge into the river Solid waste dumping
SP3 Nairobi dam 36.801664, -1.318324	Kibera Silanga informal settlements Informal reclamation and encroachment of the dam by residents Small scale farming of Sugarcane, Kales, Spinach, Arrow roots, sugarcane, maize farming
SP4 Outering Rd Bridge 36.891182, -1.306702	Illegal dumpsite Informal settlements
SP5 Enterprise Rd Bridge 36.861962, -1.315906	Industrial activities Industrial discharge evident-black in color Paint and paper industries within the vicinity Informal settlements-Mukuru slums Direct sewer discharge Solid waste dumping-leachate noted
SP6 Likoni Rd Bridge 36.854686, -1.315993	Dumpsite Use of river water to clean polythene papers for recycling Industrial discharge noted
SP7 Mukuru Kayaba 36.849808, -1.313388	Solid waste dumped into the river channel Sewer pipes channelled to the river Informal settlements, Mukuru Kayaba
SP8 Soweto Embakasi Bridge 36.909088, -1.292102	Informal settlements Dumpsite

SP9 Kayole 36.918681, -1.281739	Informal settlements Sewage discharge Dumpsite
SP10 Matopeni -Twiga 36.934911, -1.265998	Informal Settlements Dumpsite-medical waste evident Quarry site Small scale farming
SP11 Njiru-Kangundo Rd Bridge 36.945836, -1.248449	Informal Settlements Factory Dumpsite, dumping of medical waste evident
SP12 Mong'etho before confluence 36.9541, -1.244761	Informal settlements Small scale agriculture Pig farming Dumpsite Domestic runoff drains channelled to river

Source: Field data (2021)

Plate 2: Water sample collection along Ngong River at Matopeni, Twiga site during the wet season

Source: Field data (2021)

4.3.4 Collection of samples for lab analysis

Surface water samples were collected in 2 litres plastic bottles for the twelve sampling points (Labeled SP_1 - SP12, Figure 4). The 500 ml bottles were first rinsed with the sample water three times before filling. Three replicate samples were collected below the river water at the same sampling point, but 10 meters from each other. The collected water samples were subsequently mixed in a 3-litre bottle. From the mixture, a 2-litre sample was drawn into a 2litre bottle for laboratory analysis. Collected samples were stored under ice conditions to maintain temperatures of about 4˚C, and subsequently transported to the Central water testing laboratory and Materials government laboratory for refrigeration. Water samples analysis was performed at the Central Water Testing Laboratory of Water Resource Authority (WRA) using APHA, 2017 standard procedures (Baird et al., 2017).

Sampling Points

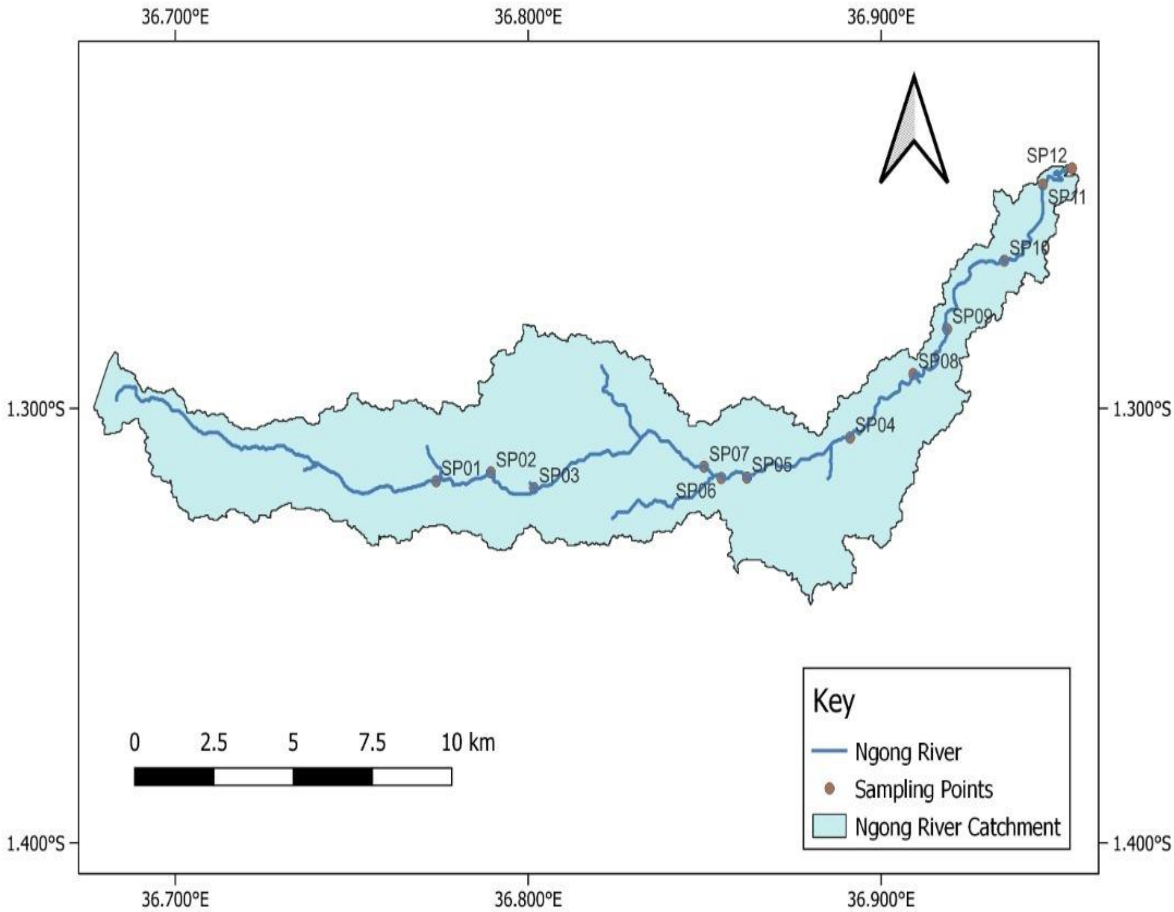

Figure 4: Location of Sampling points along Ngong River

Source: Modified using Base Maps from National Aeronautics and Space Administration (NASA)

Plate 3: Samples delivered to the Central Water Testing Lab. The sample on the extreme right was collected from the source, Ngong Forest Boundary site during the dry season
Source: Field data (2021).

4.3.5 Measurement of Physical and chemical parameters

The water samples collected from selected points along Ngong River were analysed for; pH, turbidity, Conductivity, Nitrate, Total Dissolved Solids, temperature, BOD, COD, oil and grease and Total suspended solids, for physico-chemical analysis.

4.3.5.1 pH (4500 H^+ B)

pH for Ngong River water was determined in the laboratory using Standard methods APHA, 2017; Electrometric method (4500 H^+ B). This method determines hydrogen ions activity by potentiometric measurement using a reference electrode and a standard hydrogen electrode. The hydrogen electrode comprises of a platinum electrode where hydrogen gas is often bubbled at a pressure of 101 kPa. In this method the glass electrode is commonly used because of the possible of poisoning hydrogen electrode. The glass electrode system produces electromotive force (emf) which tends to vary linearly with pH**.** The linear relationship is often illustrated by plotting the emf against the different buffer's pH. Sample's pH is established by extrapolation (Baird et al., 2017). Testing pH levels indicates the alkalinity or acidity of Ngong River's water samples. Additionally, pH is influenced by chemicals present in water hence it's an important indicator of chemical pollution in rivers such as Ngong River. Drastic changes in pH can have detrimental effects of the river's ecological health.

4.3.5.2 Turbidity (APHA 2130 B)

Measurement of turbidity levels for water samples from Ngong River was conducted in the laboratory using Standard methods, APHA, 2017 (APHA 2130 B); Nephelometric method. This method involves comparing light intensity scattered by a sample under particular conditions, with light intensity scattered by standard reference suspension under similar conditions. High scattered light intensity indicates high turbidity. In this case, the primary standard reference suspension used was Formazin polymer. Concentration of a specified Formazin suspension is defined as 4000 NTU according to APHA,2017 (Baird et al., 2017). Turbidity levels for Ngong River were determined so as to reveal the level of suspended sediments in the river water. Particulate matter offers surfaces for attachment of other pollutants such as heavy metals hence turbidity is an important indicator of water pollution. Additionally, turbidity limits light penetration affecting photosynthesis in river ecosystems hence altering the composition and distribution of aquatic life. For Ngong River, the upstream source water was less turbid as compared to other sites (see Plate, 3).

4.3.5.3 Electrical Conductivity (EC APHA, 2510 B)

Conductivity of Ngong River water was determined in the laboratory using Standard Methods APHA, 2017; Laboratory method (APHA, 2510 B). In this method, conductance/ resistance of standard KCl solution was measured and from the respective conductivity, and a cell constant was calculated. After the cell constant was set or determined, unknown solution’s conductivity was displayed by the meter (Baird et al., 2017).

Once the samples are measured for conductivity and pH, a 10% Nitric acid (HNO_3) was used to bring the sample to a pH of <2 for heavy metal analyses, biological and chemical tests. Water samples are likely to have alterations in chemical composition due to microbial activities and chemical reactions (Allen *et al.*,1974) hence maintaining the pH by adding nitric acid prevents metabolic processes and adsorption within the samples. Water samples from Ngong River basin were analyzed following the Standard procedures according to American Public Health Association APHA, 2017 (Baird et al., 2017). Conductivity for Ngong River was determined so as to indicate the levels of dissolved substances, minerals and chemicals present in the river water. This was significant since a high amount of these impurities cause a high conductivity indicating pollution.

4.3.5.4 Nitrate (APHA 4500 NO_3- D)

The nitrate levels for Ngong River water samples were determined in the laboratory using Nitrate Electrode Method (APHA 4500 NO_3^- D). Nitrate ion electrode is simply a selective sensor which builds some potential across a porous, thin, and inert membrane which holds a water immiscible lquid ion exchanger (Baird et al., 2017). The electrode responds to Nitrate (NO_3^-) ion activity that /ranges from 0.14 - 1400 mg nitrate-N/L. Meanwhile, WHO guideline value for NO_3^- in water for drinking is 50mg/l (WHO,2011). High concentrations of nitrates in water bodies cause eutrophication which reduces the oxygen levels in aquatic systems thus death of aquatic organisms. This informed the testing of Ngong river water samples for nitrates levels.

4.3.5.5 Total Dissolved Solids (TDS APHA 2510 A)

The sample's Total dissolved solids (TDS) was measured in the laboratory following APHA 2510A procedures described in APHA,2017 (Baird et al., 2017).

4.3.5.6 Temperature

Temperature was determined in the field during sampling using a portable multiparameter device. Temperature is an essential water quality parameter since it plays a role in regulating the maximum dissolved oxygen levels, affects chemical and biological reactions rates and governs aquatic life. Temperatures could also affect the coliform and *E. coli* life in water. Temperature is influenced by different land use activities such as industrial discharges which can cause thermal pollution leading to impairment of the river habitat and death of aquatic life. This made it critical to determine temperature levels of Ngong River.

4.3.5.7 Chemical Oxygen Demand (COD APHA 5220 C)

The COD for Ngong River water samples was measured using standard methods; Closed reflux, Titrimetric method, and APHA 5220 C. When using this method, oxidation of most organic matter can be achieved by a boiling sulfuric and chromic acids mixture. A sample of Ngong River water was refluxed in a strongly acidic solution with excess (known) amount of potassium dichromate ($K_2Cr_2O_7$). Upon digestion, the unreduced $K_2Cr_2O_7$ was titrated with a ferrous ammonium sulphate in order to establish the consumed amount of $K_2Cr_2O_7$, and oxidizable organic matter was further calculated based on oxygen equivalent (Baird et al., 2017).COD measurement is important in determining the effects of domestic and industrial effluents on oxygen levels in Ngong River.

4.3.5.8 Biological Oxygen Demand (BOD APHA 5210 D)

BOD from water samples for Ngong River was determined in the laboratory using APHA 5210 D (Respirometric method) 5 day BOD test procedure (Baird et al., 2017). This method directly measures the oxygen that microorganisms have utilised from air or oxygen enriched environments, in particular a closed-up vessel that is in constant agitation and temperatures. Respirometry method measures the uptake of oxygen continuously over time. Respirometric method is valuable in determining the chemical biodegradation; treating organic industrial wastes; influencing certain toxic compounds levels on the oxygen uptake reaction of a given organic chemical; the concentration in which wastewater or a pollutant evidently prevents biological degradation; the impact of various treatments such as pH adjustment on oxidation rates and disinfection, nutrient addition and; oxygen requirements for full oxidation of matter (Baird *et al.*, 2017).

The sample water from Ngong River was filled to an overflowing, airtight 1litre water bottle later incubated for 5 days at specified temperatures. The dissolved oxygen was determined before-and-after incubation, and BOD was subsequently computed from the difference obtained between the initial DO and final DO (Baird *et al.,* 2017). Noteworthy, BOD testing determines the relative oxygen requirement of polluted waters, wastewaters and effluents.

4.3.5.9 Oil and Grease (APHA, 5520 B)

Emulsified or dissolved grease and oil were extracted from Ngong River's water sample by close contact with the extracting solvent following APHA 5520B-Partition-Gravimetric Method procedure. Some extractables, particularly unsaturated fatty acids and fats, oxidize readily; therefore, special precautions with respect to temperature as well as displacement of solvent vapor were taken to minimize this effect. When organic solvents are shaken together with certain samples they can generate an emulsion that is not easy to break. This method therefore provides a way of handling such emulsions (Baird *et al.,* 2017). Grease and oil interferes with both aerobic and aneorobic biological processes in aquatic systems affecting the composition and distribution of aquatic life. When discharged in treated effluents or wastewater, they may lead to shoreline deposits as well as surface films, resulting to the environmental deterioration. This factor advised the measurement of grease and oil levels for Ngong River.

4.3.5.10 Total Suspended Solids (TSS APHA, 2540 A)

Total Suspended Solids (TSS) for Ngong River water samples was determined in the laboratory following APHA 2540 A procedures (Dried at 103°C –105°C). Here, a weighed standard glass fiber filter was used to filter a thoughly mixed sample, and the residue held on this filter was dried (at 103°C–105°C) to a constant weight. Total Suspended Solids of the sample was obtained from the weight increase of the filter (Baird et al., 2017).

4.3.6 Measurement of Total Coliforms and *E.coli* (APHA, 9223A)

Water samples from Ngong River basin were analysed for faecal coliforms (*E.coli*) which are indicators of feacal contamination. The coliform group is a key indicator of water's suitability for industrial and domestic use, and so on (Baird *et al.*, 2017; WHO,2011). The collected water samples were put in ice pellets, and then transported to the lab within three hours after collection. Analysis of

E.Coli and total coliforms was done using the Enzyme Substrate Coliform test -APHA 9223A (Baird et al., 2017).

The enzyme substrate test uses substrates that are hydrolyzable for simultaneous detection of *Escherichia coli* and total coliform bacteria. When this enzyme method is applied, the total coliform group is described as all categories of bacteria that possess the β-D-galactosidase enzyme, which cleaves chromogenic substrate, causing chromogen release. *E. coli* can be described as bacteria that posses the enzyme β-glucuronidase and gives a positive total coliform response that cleaves fluorogenic substrates, causing fluorogen release (Baird *et al.*, 2017).

A specified sample volume (typically 100 mL) was first mixed up with commercially developed enzyme substrate before incubating at 35 +/- 0.5 C. The enzyme Beta-galactosidase (produced by total coliforms), was revealed by hydrolysis of chromogenic substrates namely chlorophenol red-beta-D-galactopyranoside(CPRG) and ortho-nitrophenyl-beta-D-galactopyranoside (ONPG). Beta-glucuronidase, generated by the *E. coli*, was determined through fluorescent substrate 4-methylumbelliferyl-beta-D-glucuronide (MUG) hydrolysis. Generally, hydrolyzed ONPG appears yellow in color upon incubation for 24h to 28 h period; hydrolyzed CPRG appears red or magenta upon incubation for 28h to 48 h. Either of these conditions indicates positivity for total coliforms. Absences of colors from ONPG, or sometimes yellow color from the CPRG, imply lack of total coliforms. The hydrolyzed MUG appears as a blue fluorescence when observed under the long-wavelength (366-nm) ultraviolet (UV) light, suggesting a positive test for *E. coli* (Baird *et al.*, 2017).

Analysis of faecal indicator microorganisms is essential in verification of microbial water quality. For Ngong River basin, *Escherichia coli* was the organism of choice since it provides reliable evidence of a recent faecal pollution which should not be absent drinking water (WHO,2011).

4.3.7 Measurement of Heavy Metals (Lead and Cadmium-APHA 3111B)

Water samples derived from Ngong River were analyzed for the presence of heavy metals (Lead and Cadmium). This was done using APHA 3111B-flame atomic absorption spectrometry whereby a given sample was aspirated into flame and then atomized. A light beam was passed through a flame, onto a monochromator, and finally onto a detector which measures light quantity absorbed by the atomized element within the flame. Considering that each metal possess unique absorption wavelength, the source lamp comprising of a specific element was used as per APHA,2017 (Baird *et al.*, 2017). Heavy metals contamination for Ngong River was determined owing to their persistence, toxicity and abundance (Islam et al., 2015a). Heavy metals pollution has been increasing in urban waters due to urbanization and industrialization (Martin *et al.*, 2015). Increased pollution with heavy metals has adverse effects on humans, fish and invertebrates (Martin et al., 2015). For this reason, heavy metals were selected as one of the parameters in this study.

4.4 Secondary data collection

Secondary data was collected through review of relevant literature materials including books, online journals and reports. Both unpublished and published resources were used. Relevant official as well as non-official documents within NEMA and WRA offices were also considered in obtaining relevant information. Landsat image was downloaded from the USGS website and analysed using ArcGIS 10.4 to generate land cover/landuse map for the study area.

4.5 Statistical Analysis

Data for heavy metal concentrations and physicochemical parameters of Ngong river water was first analyzed using descriptive statistics and visualized through graphs.

The level of contamination resulting from anthropogenic effects was estimated using the Accumulation Factor (AF). The AF is defined as the ratio of the mean level of a particular parameter downstream (i.e., after a source discharge) to a corresponding mean level upstream (i.e., before the source discharge) (Fakayode, 2005).

Accumulation Factor (AF) was computed by dividing the mean parameters values downstream with the upstream values (Fakayode, 2005).

The level of River Recovery Capacity (RRC) for Ngong River was computed using the formula recommended by Ernestova and Seminova (1994) (Adeogun *et al*., 2012) as modified by (Fakayode, 2005) given as:

$$RRC = (S0-S1)/S0 \times 100 \text{ (Expressed in \%)}$$

Where:

S0 is the level of a parameter downstream (i.e. immediately after discharge point)

S1 is the corresponding average level upstream where the water is relatively unpolluted.

Water quality data which was further subjected to Cluster Analysis (CA). CA was used to describe the spatial variations of the different sites in order to detect similar groups between the sampling sites. ANOVA test was used to determine the significance difference of various parameters at different study sites and different seasons. Statistical analysis was done using SPSS version 17.0.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.0 Introduction

This chapter presents the results and discusses the findings from this study. Results of each objective has been presented, discussed and compared with previous reports.

5.1 Anthropogenic activities along Ngong River

5.1.1 Ngong Forest Boundary

Ngong River which originates from Motoine swamp and Dagoretti forest is used upstream for livestock farming, irrigation, as well as other domestic uses. The river flows into Ngong Forest where it is also used for small scale agriculture, livestock farming and domestic use. Various informal settlements were observed near the stream at the Ngong forest boundary, which served as a source point for the present study. Despite evidence of human activities at the source, the background water appeared clear and clean with no odour. Natural vegetation dominated the Ngong Forest boundary. Forest and grasslands were also evident. This point was used as a reference point for the study (See plate 4) of the Ngong River and had the lowest level of pollution as compared to other sites as illustrated on Figure 18.

Plate 4: Ngong Forest Boundary vegetation cover and Informal settlements
Source: Field data (2021

5.1.2 Ngong River at Lindi Mosque, Kibera

From the Ngong forest Boundary, Ngong River flows through the highly populated Kibera slum. This area is characterised by informal settlements, which generally lack basic sanitary provisions hence the river acts as a sink for all the domestic waste (both solid waste and sewer waste) generated by the Kibera residents. Samples were collected at Lindi Mosque located within Kibera. The water was grey in color with a strong odour both during the wet and dry season. Solid waste and raw sewage from the nearby informal settlement was found to be discharged directly into the river. Due to the observed sewer discharge, this site recorded a high level of *E. coli* 214×10^{6} MPN/100ml during the wet season. The highest fecal contamination for Ngong River was also recorded at this site with total coliforms levels of 866 $\times10^{7}$ MPN/100ml for wet season. Ngong River is the main conduit of sewer waste hence bacterial contamination.

An ongoing road construction was observed at Lindi Mosque during the field study (See plate 5-6). The observed high level of Oil and Grease of 1.7mg/l from the water samples obtained from Ngong River at this site could be attributed to the ongoing road construction and also domestic effluents from the populous slum containing fats and oils. High conductivity observed along Ngong River is attributable to the sewer discharge which introduces chlorides, Phosphates and Nitrates into Ngong River. Lindi mosque site was not exceptional since it recorded high conductivity levels as a result of pollution.

Plate 5: Solid waste clogging the Ngong River, Informal settlements at Lindi Mosque Kibera

Source: Field data (2021)

Plate 6 : Ongoing Road construction near Ngong River at Lindi Mosque, Kibera
Source: Field data (2021)

The location of this site downstream of Ngong forest boundary clearly demonstrated the effects of anthropogenic activities on Ngong River. From the dendogram generated by Cluster analysis (Figure 18), this site was dissimilar from the Ngong Forest site upstream due to the onset of pollution observed at this site due to the high population which lacks basic sanitary amenities.

5.1.3 Ngong River at Nairobi Dam

Ngong River (Motoine River) enters into Nairobi Dam as it flows downstream. The dam is heavily silted and encroached upon by urban farmers at Silanga area of Kibera. Various crops observed to be cultivated in this part of the dam included kales, spinach, arrow roots, sugarcane, and maize among others. This food crops are supplied to various markets in Nairobi town. The sampled area of the dam had only small pockets of water during the wet and dry season in this section where samples were taken during the field study. Farming was the major anthropogenic activity in the dam area. The sampled area of the dam is located near Silanga Kibera informal settlements and Kibera Laini saba slums (see plate 7-8).

Plate 7 : Solid waste dumped in the encroached part of the dam
Source: Field data (2021)

Plate 8: Arrowroots and Kales farming in the dam, wet season
Source: Field data (2021)

5.1.4 Ngong River at Mukuru Kayaba in Industrial area

From the Nairobi dam to Industrial area just before Mukuru Kayaba informal settlements, Ngong River traverses well sewered industrial set ups and residential areas. However, upon reaching Mukuru Kayaba, the river becomes the main receptacle for the waste generated in Mukuru Kayaba slums. Sewer outlets were observed to be directly channeled to the river. Open defeacation and direct sewer discharge was observed on the banks of the river. The levels of coliform bacteria and *E.coli* were high on this section of the river which is attributed to the observed sewer discharge. Low electrical conductivity was however noted at this site probably due to high levels of oil and grease from the domestic effluents and also oil cans disposed into the river. Oil has poor conductance thus low conductivity levels. Solid waste including plastics, food waste and other organic wastes were observed to clog the river channel. In addition, open drains with domestic effluents were also noted to be channeled to the river. The river water in this section appeared grey in color during the wet season and blackish during the dry season (See plates 9-12). The water had a strong odour of sewage.

Plate 9: Open drain discharging domestic effluents into Ngong River at Mukuru Kayaba, dry season (Blackish river water)
Source: Field data (2021)

Plate 10: Sampling at Mukuru Kayaba during the wet season
Source: Field data (2021)

Plate 11 : Direct sewer discharge into Ngong River by informal settlements at Mukuru Kayaba (wet season)
Source: Field data (2021)

Plate 12: Solid waste clogging Ngong River Channel at Mukuru Kayaba Bridge (wet season)
Source: Field data (2021)

5.1.5 Ngong River at Likoni Bridge

This section is in industrial area just after the Mukuru Kayaba slums. The river water in this section was noted to be a source of livelihood to some of the Mukuru slum dwellers. Women were observed washing polythene bags from the nearby dumpsite for recycling at various factories (See plates 13-

14). An expansive dumpsite is also located in along Ngong River extending from Likoni Bridge up to the section of Ngong River behind Kartasi Industries. The dumpsite was also noted to be source of income for various residents of Mukuru Kayaba and Mukuru kwa Reuben located along enterprise road. This site is the downstream of Mukuru Kayaba site. The BOD levels though low at Mukuru Kayaba 30mg/l, this value had a drastic increase at Likoni bridge with concentration level of 450mg/l indicating downstream transportation of pollutants both in liquid and solid form from Mukuru Kayaba slums during the wet season. Pollution levels for this site are attributed to industrial and domestic effluents discharges into Ngong River.

Plate 13 : Use of Ngong River water at Likoni bridge for cleaning polythene bags for recycling
Source: Field data (2021)

Plate 14 : Solid waste chocking the river channel at Likoni Bridge
Source: Field data (2021)

5.1.6 Ngong River at Enterprise Road bridge

This section is located in Nairobi's industrial hub. Informal settlements, Mukuru Kwa Reuben also border Ngong River on one side of the enterprise road. Several industries are located in close proximity to the river; Kartasi industries, Glory Paints industry, Kings way tyers industry, Sky labels, Iota Engineering and construction company, General Plastics, Chuma Fabricators limited among others. The river acts as a receptacle for the various types of wastes generated by the industries and the informal settlements established along the river. Black effluent discharge was noted at the time of sampling during the wet season at Enterprise Bridge (plate 19) revealing likelihood of industrial effluents discharge into Ngong River. Solid waste was observed to be dumped into the river (plate 15,17) whereas the sewer from the informal settlements was directly channeled into the river (see plate 18). This could be due to lack of a sewer system serving the Mukuru informal settlements. The section of Ngong River behind Kartasi industries also receives leachate waste from the expansive dumpsite located herein.

Plate 15: Leachate from the dumpsite along Ngong River behind Kartasi Industries
Source: Field data (2021)

This site is located on the downstream of Likoni bridge site. Though the BOD levels recorded for Likoni site were high 450mg/l, at Enterprise Road bridge site the levels dropped drastically to 5mg/l indicating the effects of industrial effluents on BOD demand by microorganisms. Leachate from the dumpsite a few meters from the sampling point could also be a source of other contaminates including heavy metals and inorganic compounds which could have an effect on the BOD levels for Ngong River at this sampling site.

The River water is used to clean polythene bags and sacks for recycling (Plate 16). The dumpsite and the river in this section is also a source of livelihood to various residents of the neighboring Mukuru slums. Collection of cartons, paper bags and glasses for recycling purposes was also carried out at the dumpsite, thus acting as a source of income to the Mukuru slum dwellers.

Plate 16: Cleaning of polythene bags and sacks for recycling along Ngong River at Enterprise Road behind Kartasi Industries (dry season), River water is blackish

Source: Field data (2021)

Plate 17: Sampling at Enterprise Road bridge during the dry season, dumpsite and informal settlements along Ngong River

Source: Field data (2021)

Plate 18 : Sewer pipes from the Mukuru Kwa Reuben Informal settlements along Enterprise Road discharging Sewage directly into Ngong River

Source: Field data (2021)

Plate 19 : Industrial discharge at Ngong River along Enterprise Road Bridge

Source: Field data (2021)

5.1.7 Ngong River at Outering Road

This section is located downstream of industrial area. The main anthropogenic activities are human settlements. A dumpsite was also found to exist along the river bank. The river water was dark black due to waste carried along from the industrial area which is on the upstream of this section. Soil dumping was also evident in this sampling point (see plates 20).

Plate 20: Informal settlements and soil dumping at Outering bridge
Source: Field data (2021)

5.1.8 Ngong River at Embakasi Bridge

At Embakasi Bridge, there mainly exists informal settlements and dumpsite along the river. The river water was dark black in color with an odour during the dry season (plate 21). There was little vegetation along the river bank however most of the river bank is encroached upon by human settlements. Houses along the bank of the river lack a connection to the sewer system and hence directly discharge of sewage into the river. Dumpsites were also evident along the river (See plate 21).

Plate 21: Dumpsites and informal settlements along Ngong River at Embakasi bridge (wet season)
Source: Field data (2021)

Plate 22 : Sampling along Ngong River at Embakasi Bridge (near Soweto informal settlement) during the dry season (river water, blackish in color)
Source: Field data (2021)

5.1.9 Ngong River at Kayole

Anthropogenic activities at this section of the river were mainly noted to be human settlements, solid waste dumping and direct sewer discharge into the river particularly during the wet season (See plate 23-24). The observed lack of sewer connection contributes to bacterial contamination of the river.

Plate 23 : Sewer outlet discharging directly into Ngong River
Source: Field data (2021)

Plate 24 : Dumpsite along Ngong River at Kayole
Source: Field data (2021)

5.1.10 Ngong River at Matopeni, Twiga

This sampling station was located downstream of Ngong River. The main anthropogenic activities along this stretch included informal settlements, dumpsite, small scale quarrying and small-scale farming. Deserted quarry sites also were observed with several houses set up at the quarry adjacent to Ngong River. Leachate was noted on one of the dumpsites along the river this could also contribute to river pollution (see plates 25-26). Solid waste was noted to clog the Matopeni, Twiga Bridge and also deposits into the river bank.

Plate 25 : Small scale Quarry site along Ngong River at Matopeni, Twiga
Source: Field data (2021)

Plate 26: Leachate from solid waste along Ngong River and Solid waste clogging the river channel at Matopeni (Dry Season)
Source: Field data (2021)

5.1.11 Ngong River at Kangundo Road bridge

The main anthropogenic activities noted at this sampling point included informal settlements, factory (i.e. united paints factory), and solid waste dumping. Solid waste transported from other sections of the river was noted to be deposited along the river bank (See plate 27).

Plate 27: Ngong River at Kagundo Road Bridge during the wet season
Source: Field data (2021)

5.1.12 Ngong River at Munge'tho Chokaa in Njiru

This sampling site was at the downstream of Ngong River just before confluence with Nairobi River. Informal settlements, small scale farming and livestock faming (including pig farming) were noted along the river bank (Plate 28-29). The river bank had riverine vegetation which was less disturbed as compared to other sampling stations. Open drains from the informal settlements were noted to discharge on the river. Dumpsites were also observed along the river. Pollution levels were noted to be relatively high due to the existing anthropogenic activities. This is well illustrated on the dendogram (Figure 18) which showed the site to be similar to other polluted sites in the middle reaches of Ngong River. The river water was brown in color during the wet and grey in dry season. River bank erosion was noted at Mung'etho during the wet season resulting to brownish color of the water (See plate 28). High turbidity levels observed downstream of Ngong River are attributable to river bank erosion especially during the wet season.

Plate 28: Pig farming and informal settlements along Ngong River at Mung'etho site before confluence (wet season)

Source: Field data (2021)

Plate 29 : Dumpsite along Ngong River at Mong'etho site in Njiru (dry season)

Source: Field data (2021)

5.2 Anthropogenic effects on Water Quality of Ngong River

Data for physicochemical parameters and heavy metal concentrations of Ngong river water was first analyzed using descriptive statistics and visualized through graphs. The level of contamination resulting from anthropogenic effects was estimated using the Accumulation Factor (AF). CA was used to describe the spatial variations of the different sites in order to detect similar and different groups between the sampling sites. ANOVA test was used to determine the significance difference of various parameters at different study sites and different seasons.

5.3 Results and Discussion

For each sampling point along the Ngong River, the values for each physicochemical parameter recorded during the wet and dry seasons were summarized in table 10 and table 11, respectively.

The result from physico-chemical analysis of water samples collected from various sampling points was compared against water quality standards recommended by NEMA and WHO (Table 5).

Table 5: NEMA and WHO drinking water quality standards

Parameter	**Units**	**NEMA's Water Quality standards guide value (Maximum Allowable)**	**WHO Drinking Water Quality standards guide value (Maximum Allowable)**
Ph	pH Scale	6.5-8.5	<8
Turbidity	N.T.U	NA	<1.5
Conductivity (25˚C)	µS/cm	NA	250
Nitrate	mg/l		
(NO3-N) & Nitrate (NO3-)		10	50
Total Dissolved Solids	mg/l	1200	1000
Temperature	˚C	-	-
COD	mgO_2/l	-	-
BOD (20˚C)	mgO_2/l	-	-
Oil & Grease	mg/l	-	-
Total Suspended Solids	mg/l	30	-
Total Coliforms	MPN/100mL	-	NIL
E. coli	MPN/100mL	Nil/100mL	NIL
Cadmium	mg/l	0.01	0.003
Lead	mg/l	0.05	0.01

Sources: NEMA,2006; WHO, 2011

5.3.1 Physicochemical Analysis

5.3.1.1 BOD levels in Ngong River

The BOD values at the source Ngong Forest boundary (SP 1) were below 5mg/l during both the wet and dry season. The BOD value increased to 230mg/l and 370mg/l during the wet and dry season respectively at Lindi Mosque (SP2), Kibera suggesting pollution from the Kibera informal settlements. Low BOD values 5mg/l were also recorded at Nairobi dam (SP 3 at the farms) and enterprise road bridge during the wet season. At Mukuru Kayaba (SP9) the BOD level was 30mg/l. However, at Likoni bridge (SP8) this level was the highest at 450mg/l indicating downstream transportation of pollutants from the Mukuru Kayaba slums during the rainy season. At Enterprise Road bridge the BOD levels were also low 5mg/l indicating that other pollutants from industrial effluents influence negatively the biological oxygen demand by microorganisms in natural waters. High BOD values were also observed at Outering road bridge (SP6) all the way to Mong'etho Njiru (SP12) indicating an increase in organic loads from the sewer discharged by informal settlements and leachates from dumpsites located along the river basin. The BOD values for Ngong River were comparable to those of Oyake, 1998. The BOD values were about twenty times in excess of the maximum permissible level for drinking water of 3.0mg/l (Oyake, 1998).

Low BOD values were observed during the wet season while the dry season recorded high BOD levels indicating that surface runoff reduces organic pollution in Ngong river hence low BOD values during the rainy season. A BOD value of 5mg/l observed at Ngong Forest (SP 1) indicates upstream pollution possibly from the informal settlements around the forest and/or agricultural activities taking place around Dagoretti area (Kahara, 2002). The BOD for all the sampled sites is shown in figure 5.

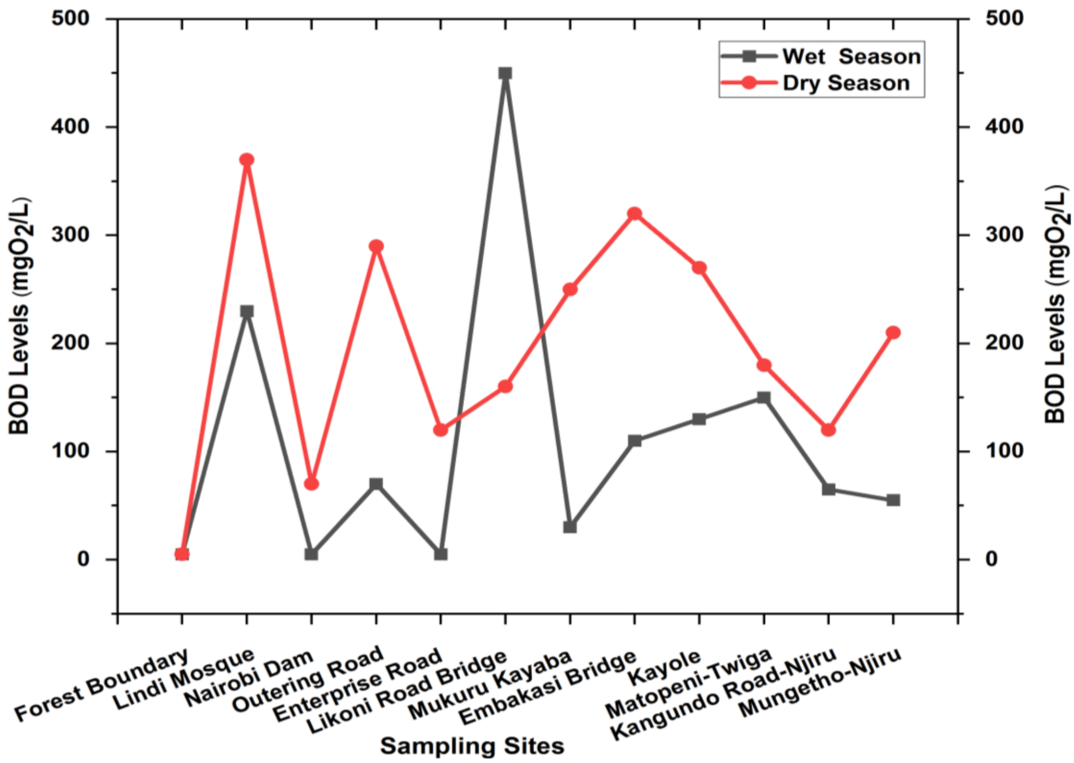

Figure 5: BOD levels for Ngong River for wet and dry season
Source: Field data (2021)

The findings on BOD values for Ngong River were in line with those of Ona River in Nigeria (Adeogun et al, 2012), which showed that BOD values remarkably increased effluent discharge points throughout the the period in which sampling was done, suggesting the contribution of effluents to the increasing values. Ngong River's BOD values increased tremendously on the onset of receiving domestic effluents discharge from Kibera informal settlements at Lindi Mosque (SP 2) up to the last sampling point at Mung'etho Njiru (SP12). The whole basin is characterized by informal settlements on the river banks hence their effect on the river's BOD. This finding indicates the effect of anthropogenic activities on BOD levels and subsequent degradation of water quality of Ngong River. Continued increase in BOD in the Ngong River could lead to depletion of oxygen necessary for aquatic life, thus compromising the integrity of this ecosystem.

5.3.1.2 COD levels in Ngong River

COD levels for Ngong River ranged from 106 mg/l to 2182mg/l during the wet season and 35mg/l to 1411mg/l during the dry season. The sampling point at the Ngong forest boundary (SP1) had the lowest COD values during both seasons, while Lindi mosque (SP2) in Kibera recorded the highest COD values for both seasons. At Lindi mosque sampling site, the river was found to receive a wide range of pollutants from the Kibera informal settlements, which could explain the high COD values observed. A low COD value of 35mg/l at Nairobi dam (SP3) during the wet season could be attributed to self-purification of the water. Ngong Forest Boundary (SP1) had a relatively high COD value of 106mg/l during the wet season indicating upstream pollution possibly from high levels of decaying plant matter from the forest, and informal settlements encroaching upon the forest. COD values generally increased downstream from Kibera to Njiru due to the effects of anthropogenic activities such as sewer discharge, industrial effluents discharge and garbage disposal along the river basin. Seasonal variation in the COD values for Ngong River where the values obtained were low for the wet season in April and High during the dry season in August was recorded. This could be attributed to the dilution effect due to long rains in the wet season. This was further supported by the River Recovery Capacity values for COD at 84% and 95% (Table 6-7) showing that Ngong River had a strong recovery for COD. The high COD value (2182mg/l) for Ngong River observed was comparable to that of Odipo, 1988 and Oyake, 1998 who recorded maximum values of 2500mg/l and 2000mg/l COD values, respectively, for Ngong River. Elsewhere, Adeogun *et al.,* 2012, also observed an increase in COD values at the point of effluent discharges along Ona River, Nigeria. The recorded COD value (2182mg/l) was way higher than the NEMA's standards for effluent discharge into the environment, indicating high organic pollution that could deplete the oxygen in water. This can subsequently affect the aquatic life in water. The COD levels for all the sampled sites in the present study were illustrated in figure 6.

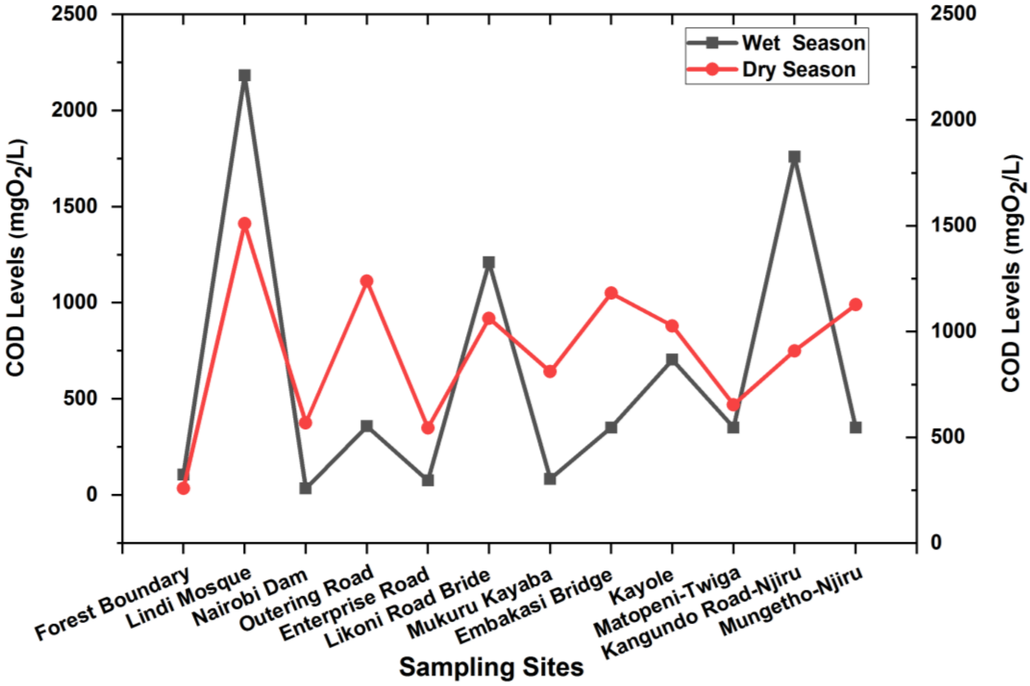

Figure 6: COD levels for Ngong River
Source: Field data (2021)

5.3.1.3 Total Coliforms and *E.coli* levels in Ngong River

The Total coliforms and *E. coli* levels for Ngong River for both wet and dry seasons are presented in Figure 7 and Figure 8, respectively. Total coliforms and *E.coli* were detected in all sites, suggesting fecal pollution even at the source of Ngong River. A downstream cumulative effect was observed in the contamination of the River water. The highest fecal contamination for Ngong River was recorded at Lindi Mosque- Kibera (observed as a single peak in figure 7), with total coliforms levels of 866 $\times10^7$ MPN/100ml for wet season. This could be attributed to increased direct discharge/release of raw sewer (human fecal matter) into the river during the wet season. Low levels of total coliforms 930 MPN/100ml were recorded at Enterprise Road Bridge. Ngong Forest boundary sampling site had a total coliform level of 81,000MPN/100ml and 143MPN/100ml during the wet season and dry season, respectively, indicating fecal contamination of water at the source. The total coliforms recorded were alarming along the entire Ngong River basin, revealing that direct sewer discharge had an influence on the water quality. The informal settlements established along the river are not sewered hence direct discharge of human fecal matter (Plate 11, Plate 22) into the river; an issue that the relevant authorities should address.

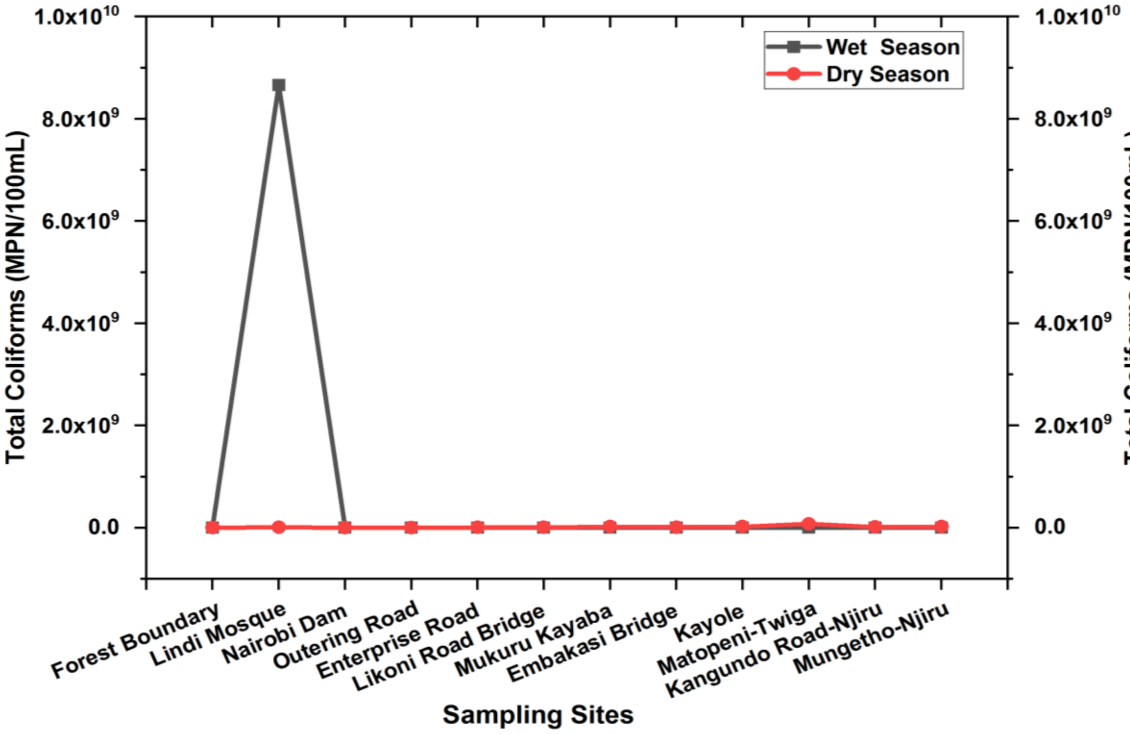

Figure 7: Total Coliforms levels in Ngong River
Source: Field data (2021)

The *E. coli* values for Ngong River showed a downstream increase trend, similar to that of total coliforms. *E. coli* was also detected at all sites sampled. *E. coli* levels were low at the Ngong Forest Boundary 2MPN/100ml during the dry season and at Enterprise Road bridge 30MPN/100ml during the wet season. *E. coli* was highest at Lindi Mosque, Kibera 214×10^{6} and at Mukuru Kayaba 92×10^{5} during the wet season and dry season, respectively (Figure 8). These high values are presented as high peaks in figure 8. These high levels of fecal bacteria can be attributed to rampant and direct discharge of human fecal waste into the river. This was evident during sampling.

The field data collected revealed that sewer discharge is alarming particularly during the rainy season however due to the dilution capacity of the river the values recorded for wet season (on average) were lower than those of the dry season indicating the importance of surface runoff and the rain water in self-purification of the river. Meanwhile, *E. coli* was not detected at Nairobi dam during the wet season. Meanwhile, the NEMA standards for effluent discharge allows maximum limit of NIL count/100ml and 30 counts/100ml of *E.coli* and Total Coliforms, respectively. The recorded *E.coli* and total coliform bacterial counts recorded at different sampling points of Ngong River were higher than the aforementioned NEMA standards, suggesting increased health risks particularly in downstream regions of the Athi River where this water is utilized for domestic purposes.

These findings concurred with those of (Bojarczuk *et al*., 2018) which found out that fecal and *E. coli* contamination of River Bialka, Southern Poland due to an establishment of a Ski resort along the river. Musyoki & Mbaruk, (2015) reported bacterial contamination of Nairobi and Athi river basins of Kenya, the levels were unacceptably high than the National and WHO standards hence unsuitable for domestic and agricultural use.

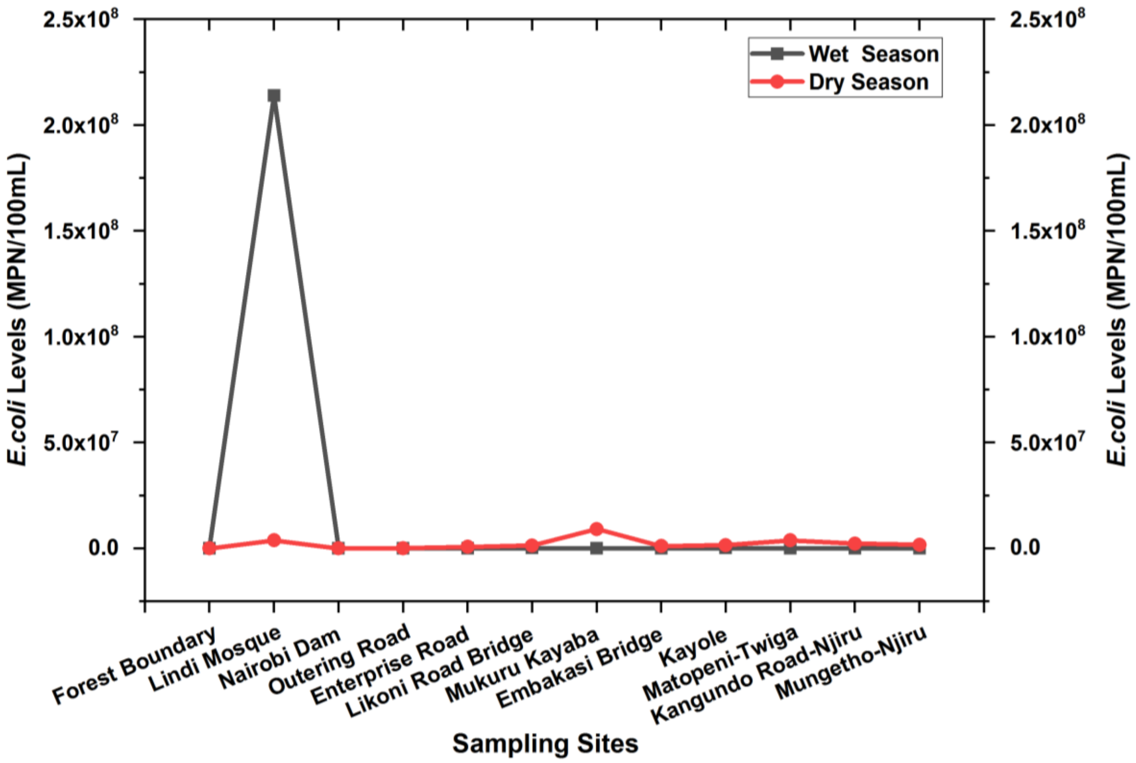

Figure 8: ***E. coli*** **levels for Ngong River**
Source: Field data (2021)

5.3.1.4 Conductivity levels in Ngong River

Conductivity levels for Ngong River are presented in Figure 9. These levels ranged from 314 to 950 µS/cm during the wet season and 509 to 1239 µS/cm during the dry season. Upstream at Ngong forest boundary (SP1) had the lowest conductivity of 509 µS/cm observed during the dry season. This value increased drastically to 1102 µS/cm at Lindi Mosque, Kibera (SP2) suggesting considerable levels of dissolved substances entering the river from the Kibera informal settlements. Conductivity showed an increasing trend downstream with highest values 1261 µS/cm being observed at Kayole, indicating high level of pollution. Matopeni and Kangundo road bridge also recorded high conductivity values during the dry season 1239 µS/cm. Values remained high from sampling points SP2 to SP13 downstream, indicating that considerable levels of dissolved substance through effluent discharges into the river stay in the waters between Kibera and Kangundo road, which indicates a high degree of anthropogenic activities along the river basin. The entire Ngong River from Kibera to Kangundo road was dominated by informal settlements, which lack proper sewage disposal mechanisms (Plate 11, Plate 22). As a result, chloride, phosphates and nitrate ions are potentially introduced into Ngong River, which could account for the high conductivity values observed. The conductivity level however reduced to 934 µS/cm at the last sampling point, Mong'etho indicating that the river was able to recover from conductivity at 53% (Table 7).

Electrical conductivity was higher during the dry season. The lower conductivity observed during the wet season could be due to dilution as a result of increase in the volume of water. Lower levels of conductivity observed at Mukuru Kayaba and industrial area generally could be as a result of pollutants discharged such as oils and grease which are poor conductors of electricity. Meanwhile, higher conductivity suggests presence of high levels dissolved substances, minerals or chemicals in water. As such, biochemical processes (such as osmoregulation) and aquatic life in the Ngong River basin may be affected. Given the elevated conductivity, Ngong river's water is also unfit for domestic use.

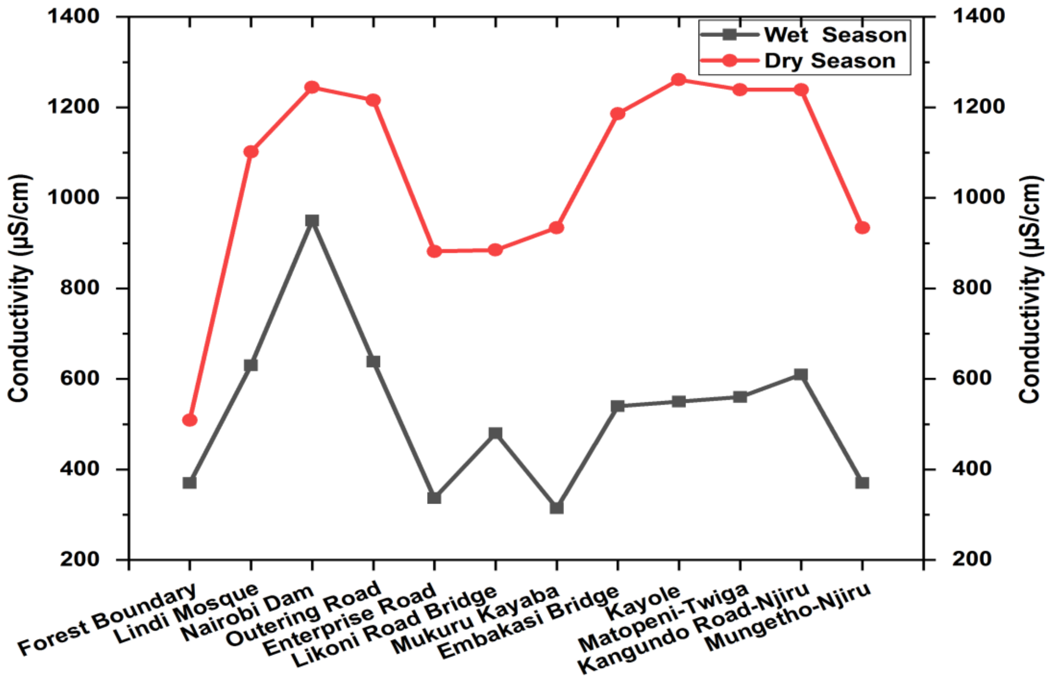

Figure 9: Conductivity Levels of Ngong River measured in April and August

Source: Field data (2021)

5.3.1.5 Nitrates levels in Ngong River

Nitrates levels in Ngong River are presented in Figure 10. Nitrate concentration for Ngong River water was low during the wet season in April. All sampled sites recorded levels below the NEMA and WHO standards for drinking water. The levels ranged from <0.01 mg/l at Outering road to 3.33 mg/l at Kangundo road bridge during the wet season Nitrates in natural surface waters are normally below 5mg/l since they are readily taken up by plants (Oyake, 1998). In 1998, Oyake observed nitrates levels that ranged between 0.99 to 1.83mg/l for Ngong River while Odipo in 1985/86 observed nitrates levels ranging between 0.1 to 1.61mg/l along Ngong River basin.

There however seems to be an increase in Nitrates levels from the two study periods by Oyake and Odipo. This is because the nitrates concentration for the dry season ranged from 9.8 to 36.53mg/l along Ngong River. These levels were above the NEMA maximum permissible levels for drinking water of 10mg/l, but were below the WHO permissible levels of 50mg/l. The high levels recorded during the dry season could be because of decreased volume of water in Ngong River as compared to the wet season when the dilution is high due to high volumes of water in the river. The river had a low recovery for Nitrates downstream at 32% (Table 6) indicating that less than 50% of nitrates were removed by self-purification of the river downstream. High nitrates levels also suggest river contamination due to sewage and waste water discharge, and industrial discharge. The high nitrate levels at the forest boundary could be possibly due to decomposition of organic matter within the forest, as well as fecal waste from large number of livestock that exist around the forest boundary.

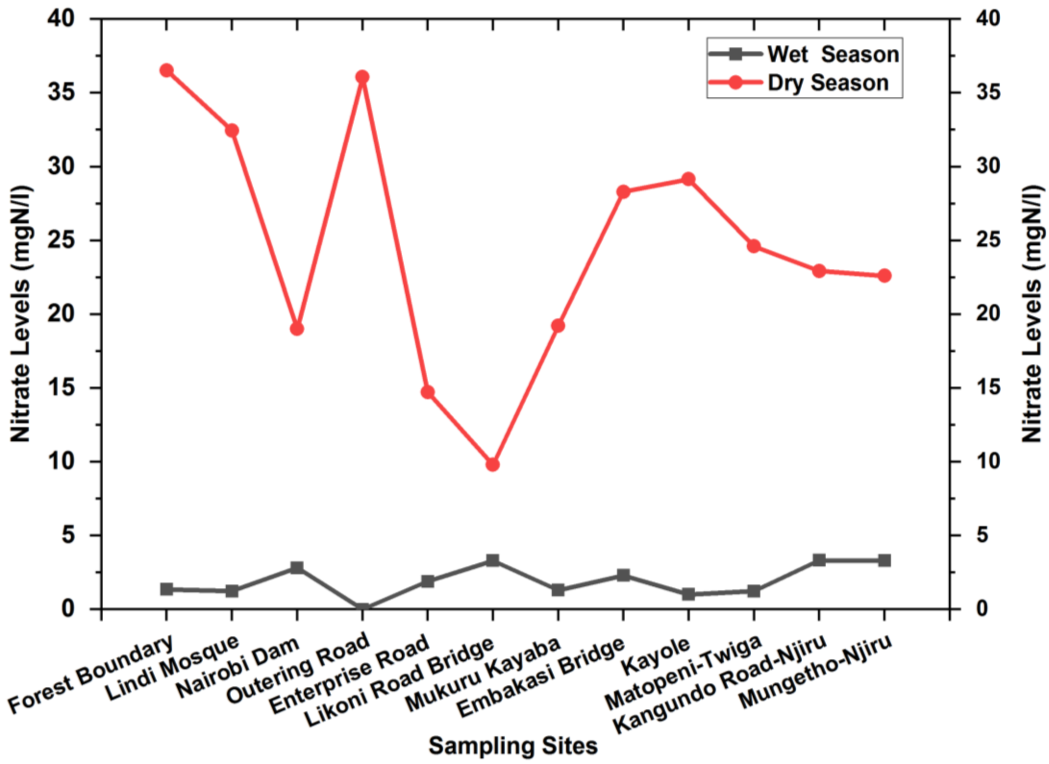

Figure 10 : Nitrates levels in Ngong River
Source: Field data (2021)

5.3.1.6 Oil and Grease levels in Ngong River

Oil and grease levels for Ngong River ranged between 0.25mg/l to 1.7 mg/l during the wet season and 0 to 0.06mg/l during the dry season. Oil and grease levels were relatively high during the wet season as compared to dry season. The highest value of 1.7mg/l was recorded at Lindi Mosque in Kibera indicating contamination of the river water. This could be from the ongoing road construction works near Ngong River at Lindi Mosque. The levels for Oil and grease for Ngong River are presented in Figure 11.

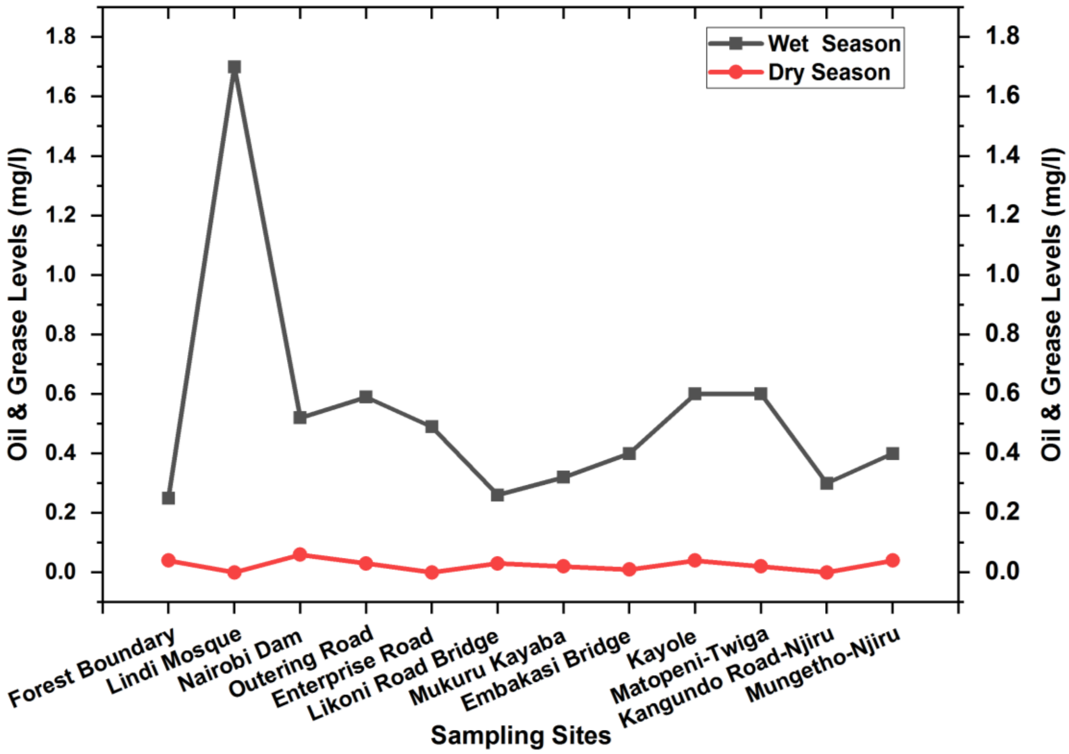

Figure 11: Levels of Oil and Grease for Ngong River
Source: Field data (2021)

5.3.1.7 pH levels in Ngong River

The pH levels for Ngong River ranged between 6.77 to 7.68 and 6.75 and 7.72 (Figure 12) during the wet and dry seasons, respectively. The levels of pH were within the NEMA and WHO drinking water standards of 6.5 to 8.5 and <8, respectively. This also shows that domestic and industrial effluents discharged into Ngong River were within the standards for effluent discharge into the environment (Ngong River basin) had little or no effect on the river pH. The neutral pH in the water indicates that Ngong River's water is not corrosive and unlikely to affect biological and chemical processes in the water.

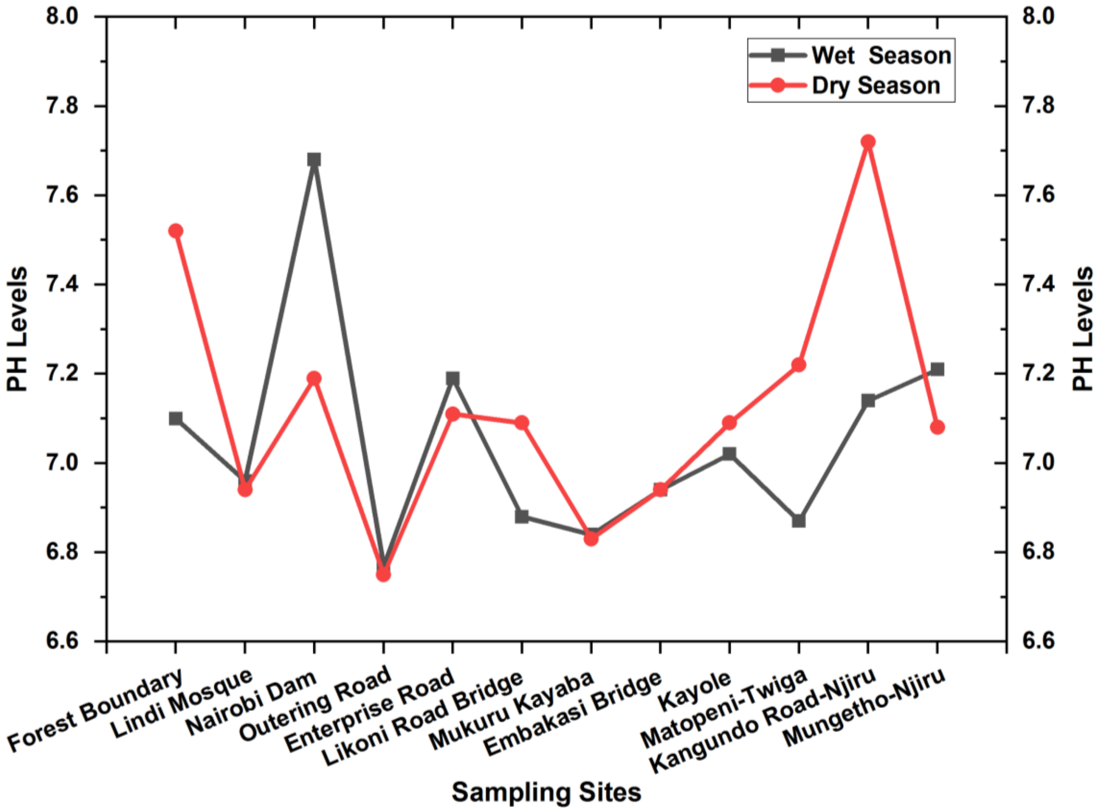

Figure 12: pH levels for Ngong River

Source: Field data (2021)

The pH values for Ngong River were consistent with those previously recorded which ranged between 6.8 and 7.6 (Odipo, 1988).

5.3.1.8 Temperature levels in Ngong River

The temperature values for Ngong River ranged from 22.2°C to 23.2°C during the dry season and 20.1°C to 20.5°C during the wet season. This suggests that anthropogenic activities along Ngong River had little or no effect on the river's water temperature as it was relatively room temperature across the basin.

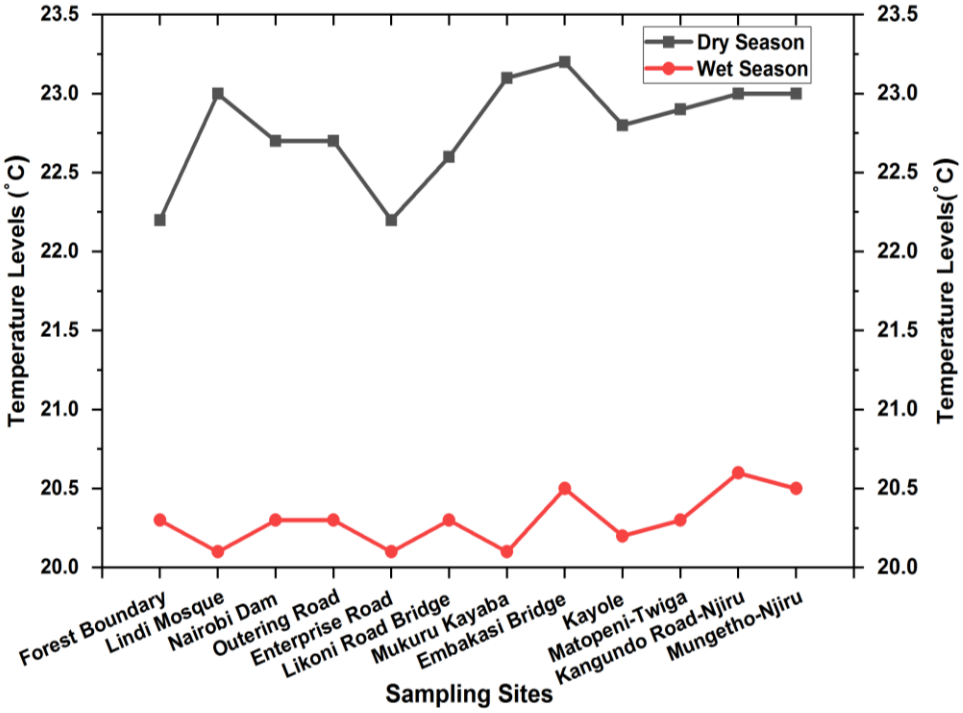

Figure 13: Temperature levels for Ngong River
Source: Field data (2021)

5.3.1.9 Total Dissolved Solids levels in Ngong River

Total dissolved solids levels in Ngong River ranged from 195 mg/l to 589 mg/l during the wet month and 316 mg/l to 782mg/l during the dry months. Generally high TDS values were observed during the dry months while low TDS values were observed during the wet months possibly due to dilution effect resulting from the heavy rains, while the high TDS values recorded during the dry months were due to evaporation effect, causing increased concentrations during the dry weather. High TDS values during the wet season were recorded at Nairobi dam, Silanga in Kibera (SP3), where farming took place at the encroached part of the dam. Such high TDS concentrations could be attributed to probable use of fertilizers for farming at the dam which may add a variety of ions into this part of the dam.

An increasing trend was observed for TDS levels along Ngong River especially during the dry season which could be due to organic waste matter both from sewers and leachates rich in phosphates and nitrogen compounds from dumpsites and informal settlements established at the various sampling stations along the entire river basin. There was an observed relationship between TDS levels and levels of Nitrate ions whereby when Nitrates levels were high, TDS values were also high as can be seen in Table 10-11 in Appendix 1. The TDS levels recorded during the dry and wet seasons in all the sampling sites is also presented in figure 14.

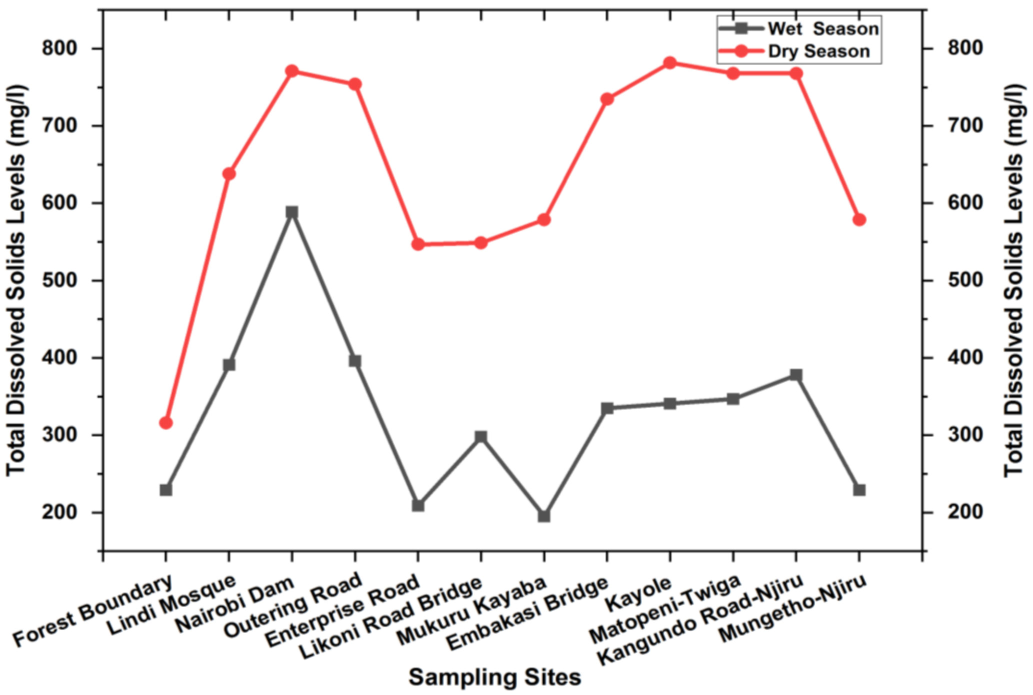

Figure 14 : Total Dissolved Solids levels for Ngong River
Source: Field data (2021)

The Total dissolved solids levels for Ngong River observed on all sampling stations were below the NEMA and WHO maximum permissible level in drinking water of 1200mg/l and 1000mg/l, respectively. The recorded TDS levels were also below the NEMA's maximum permissible level for effluent discharge into the environment suggesting that TDS was less or hardly affected by the prevailing human activities, making it less risky (for agricultural or domestic use) as far as TDS is concerned.

5.3.1.10 Total Suspended Solids levels in Ngong River

Total Suspended Solids levels for Ngong River ranged from 10mg/l to 600mg/l during the dry season and 10mg/l to 367mg/l during the wet season. Lowest TSS values of 10mg/l were recorded at Nairobi dam (SP3) during the wet season and at Ngong Forest boundary (SP1) during the dry season. The comparatively lower TSS values observed in Nairobi dam (SP3) could be attributed to possible purification by settling effect of the substances onto the dam. The values differed significantly for various stations with the highest value of 600 mg/l being observed at Outering Road bridge during the dry season. Matopeni downstream had a higher value recorded for the wet season at 367mg/l which could be attributed to the effects of domestic waste, erosion and runoff, however this level reduced to 71 and 88mg/l at Kangundo Road Bridge and Mong'etho respectively during the wet season, indicating river recovery due to dilution. TSS levels for Ngong River were lower during the wet season as compared to the dry season. This indicates that most suspended solids in Ngong River were as a result of industrial effluent discharges as compared to the heaped garbage which is usually washed off into the river during the wet season. This is supported by the highest value observed at Outering Road of 600mg/l during the dry season. Total Suspended Solids levels for Ngong River are presented in Figure 15.

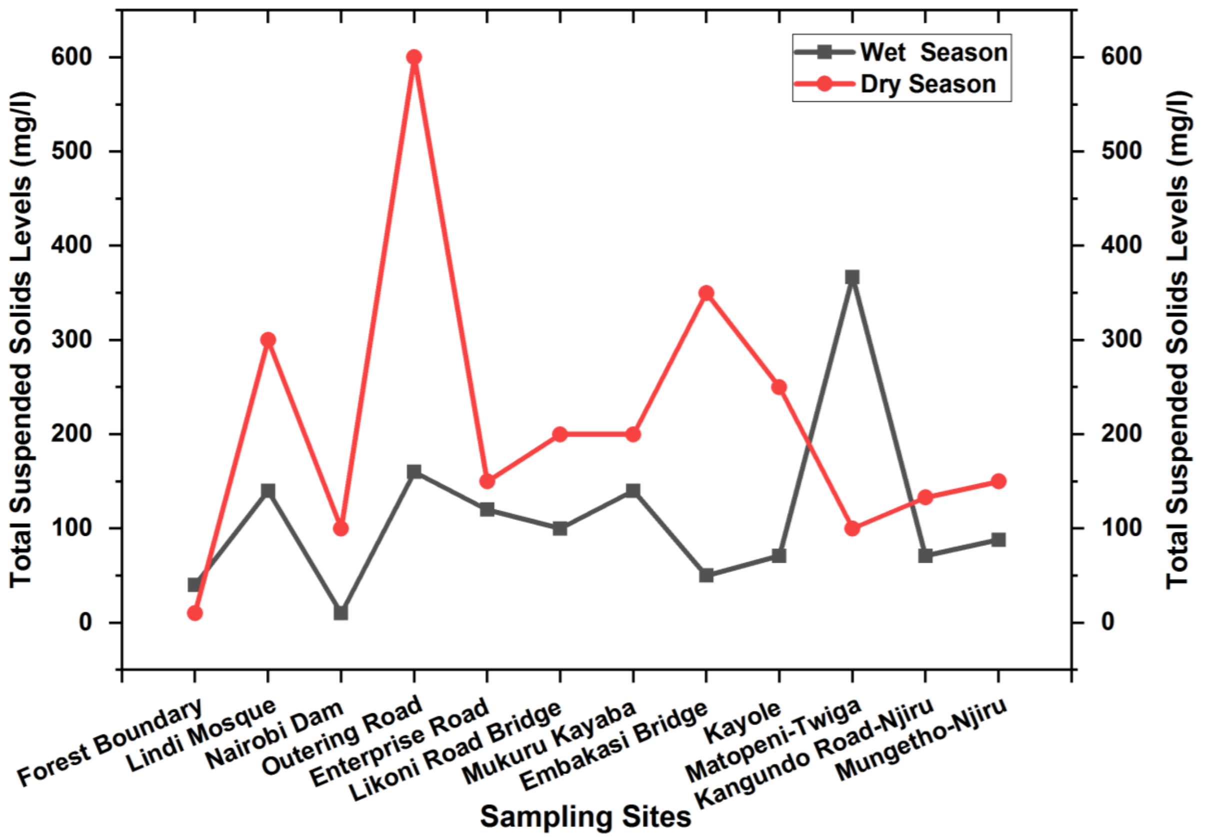

Figure 15 :Total Suspended Solids levels for Ngong River
Source: Field data (2021)

Except for Ngong Forest Boundary (SP1), all other sampling stations had Total Suspended Solids levels above the NEMA maximum permissible level for drinking water of 30mg/l.

5.3.1.11 Turbidity levels in Ngong River

Turbidity levels for Ngong River ranged from 4.75 NTU to 30.6 NTU during the wet season and 0 to 26 NTU during the dry season. Turbidity levels at Ngong Forest boundary (SP1) were below the detectable limit (ND) during the dry season probably due to low levels of water and settling of suspended solids. The water was more turbid at outering road 26NTU during the dry season while at Matopeni high turbidity levels were observed during the wet season due to the high level of total suspended solids (367mg/l) recorded at the same station. At Ngong Forest boundary, the Total suspended solids were 10mg/l below the NEMA drinking water Standards of 30mg/l hence no turbidity was detected during the dry season. However, the turbidity levels observed at SP1 during the wet season could be attributed to the high level of suspended solids due to erosion of particles into the river. Turbidity levels are presented in Figure 16.

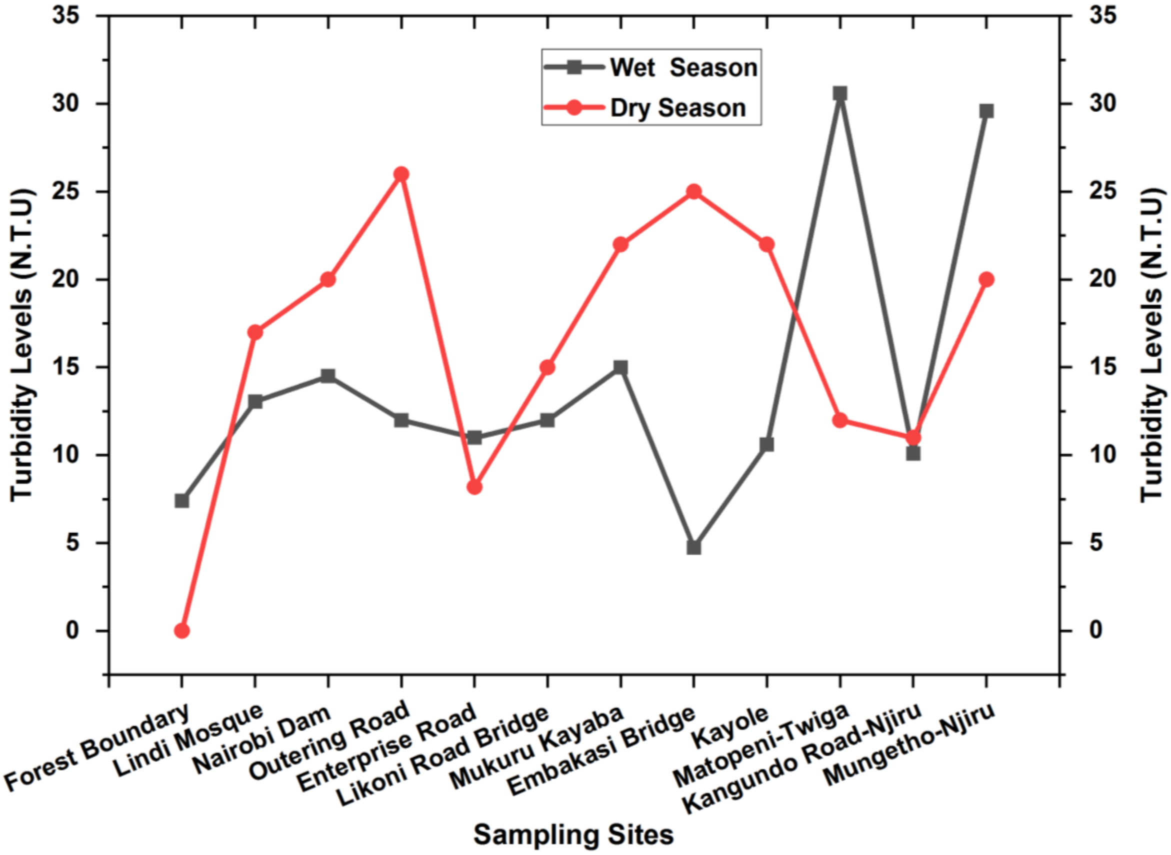

Figure 16: Turbidity levels for Ngong River
Source: Field data (2021)

Turbidity levels at all the sampling points exceeded the WHO maximum allowable limit of 5 NTU for drinking water for the wet season. During the dry season turbidity levels were high above 5NTU except for Ngong forest boundary which were below the detectable limit (0). Noteworthy, turbidity has been found to affect aquatic life as well as other parameters such as temperatures (high turbidity may result to increased water temperatures in the river).

5.3.1.12 Levels of Lead and Cadmium in Ngong River

Lead and Cadmium concentrations for Ngong River were below the detectable limit of 0.001ppm during the rainy season. Lead was low below the detectable limit in the dry season while Cadmium concentrations ranged from 0.049 ppm at Enterprise Road to 0.113ppm at Ngong Forest Boundary (SP1) indicating upstream pollution of Ngong River with heavy metals (Figure 17). Meanwhile, there is a higher tendency of lead being retained in sediments than being released into the water column which was illustrated by a negative correlation of Pb in water and Pb in sediment in a study in Ona River, Ibadan South west Nigeria (Adeogun *et al.,* 2012). Also, Netpae & Phalaraksh, 2009 reported that sediments hold a very large percentage up to 99% of the total quantity of a metal present in an aquatic system. This could explain why the Pb levels were below detectable limits for Ngong River. There could also be a possibility of material substitutes of Pb containing raw materials with others which do not contain lead; an area that needs future research.

The presence of high Cadmium concentration levels of 0.113ppm at Ngong Forest Boundary (SP1), 0.11ppm at Mukuru Kayaba and 0.105ppm at Matopeni during the dry season could be attributed to the inputs of Cd from anthropogenic activities such as domestic waste discharge into the river. All the three sites coincided with informal settlements. Nordberg *et al.,* 2014 reported sewage from industrial and municipal areas as major sources of Cd into fresh water system. Additionally, mining, industry, agriculture and application of fertilizers and sewage sludge have been found to be the main sources of Cd contaminants (Adriano, 2001). Based on these reports, direct sewer discharge into the river at Mukuru Kaiyaba, and existence of an abandoned quarry site at Matopeni may explain high Cd levels observed in these sites.

All sites sampled for Ngong River except for Kangundo Road during the dry season had levels of Cd exceeding the WHO and NEMA maximum allowable limit of 0.003ppm and 0.01ppm, respectively, for drinking water. This indicates high levels of pollution rendering the water unfit for domestic and agricultural use. This is because Cd is a heavy metal which is highly carcinogenic with adverse effects on human health. Heavy metals also bioaccumulate up the food chain and hence in plants concentrations may be relatively higher which accumulate further due to human consumption.

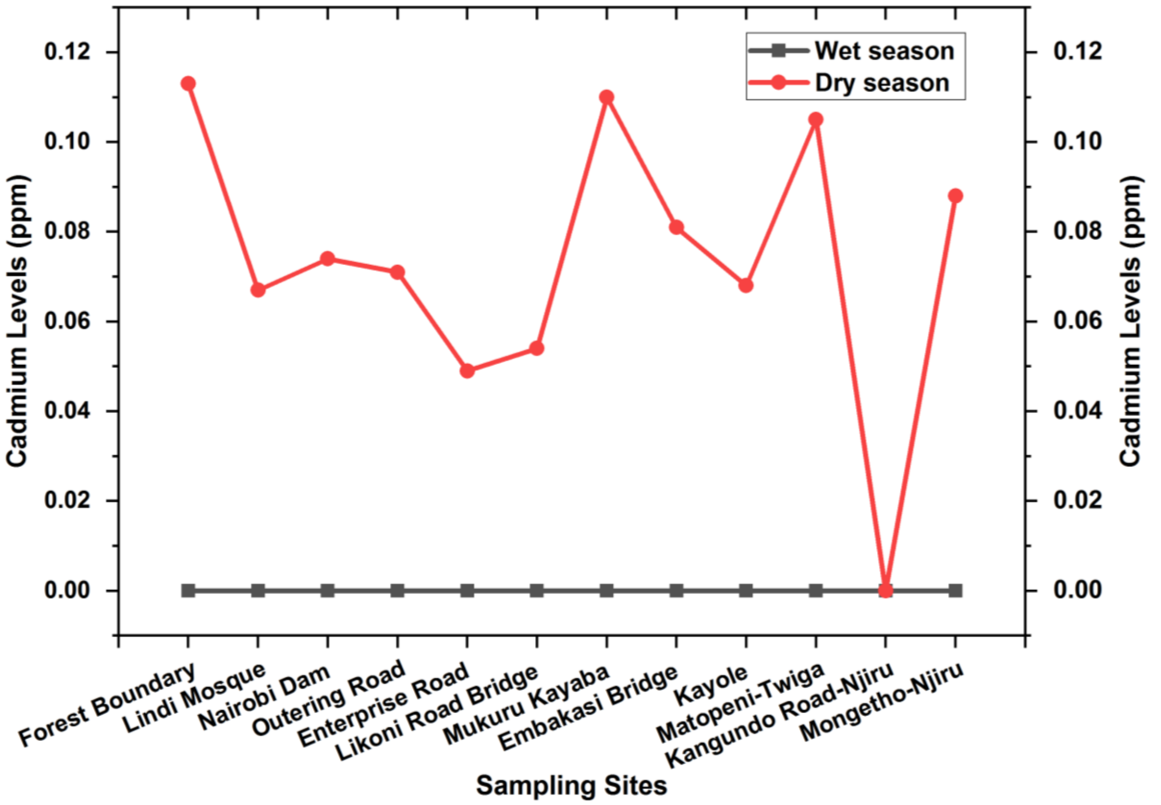

Figure 17: Cadmium (Cd) concentrations in Ngong River
Source: Field data (2021)

5.3.2 River Recovery Capacity(RRC) and Accumulation Factor (AF)

The River Recovery Capacity (RRC) and the Accumulation Factor (AF) of the physicochemical parameters during the wet and dry sampling periods are presented in Table 6 and Table 7. The trend in the accumulation factor of parameters indicated that the BOD of downstream water was 24 times more than the value observed upstream for the wet season and 42 times for the dry season. COD of water downstream was 6 times more than the value observed upstream during the wet season and 23 times more for the dry season. *E. coli* and Total Coliforms trend showed the highest accumulation factor of 6,724 times and 9,734 times respectively more than upstream values observed for the wet season. The trend in accumulation factor for *E. coli* and Total Coliforms depicted that these parameters accumulated significantly during the dry season with *E. coli* of water downstream being approximately one million times more than the value observed upstream and the Total Coliforms AF value was approximately one hundred thousand times more than upstream values. TSS trends revealed a significant built up with an AF of 3 and 23 times more downstream than upstream levels during the wet and dry season, respectively. The other parameters revealed an average AF of 2.

Table 6: River Recovery Capacity and Accumulation Factor for physicochemical parameters of Ngong River wet season

	BOD	COD	Conductivity	*E.Coli*	Nitrate	Oil & grease	pH	Temperature	Total Coliforms	TDS	TSS	Turbidity
RRC	95%	84%	32%	99%	32%	55%	0.7%	3%	99%	32%	67%	50%
AF	24	6	1.5	6,724	1.5	2.2	0.99	1	9,734	1.5	3	2

Source: Field data (2021)

Table 7: River Recovery Capacity and Accumulation Factor for physicochemical parameters of Ngong river dry season

	BOD	COD	Conductivity	*E.Coli*	Nitrate	Oil & grease	pH	Temperature	Total Coliforms	TDS	TSS	Turbidity
RRC	97%	95%	53%	99%	-55%	-100%	6%	0%	99%	53%	95%	100%
AF	42	23	2	1,178,363	0.6	0.5	0.9	1	134,633	2.1	23	0

Source: Field data (2021)

There was a significant recovery of Ngong River from several of physicochemical parameters: BOD (95% and 97%), COD (84% and 95%), *E. coli* (99%), Total Coliforms (99%), TSS (67% and 95%), and Turbidity (50% and 100%) for wet and dry season, respectively. *E. coli*, Total coliforms had the highest recovery value of 99% during both seasons. Turbidity had the highest recovery of 100% for the dry season. There were low recovery values for conductivity (32%), Nitrate (32% and -55%), pH (-0.7% and -6%), temperature (3% and 0%) suggesting little / no change in the values downstream compared to the values recorded upstream particularly for nitrates and pH. Oil and grease had a high recovery value of 55% during the wet season and a low recovery value (-100%) for the dry season. There was no change in temperature downstream compared to upstream levels. The high recovery values observed for some parameters particularly during the wet season suggest that the corresponding or influencing substances were being released into the Ngong River in quantities lower than the removal carrying capacity of this river. The lower levels of these influencing substances do not surpass the river recovery capacity for the low recovery values recorded for some parameters especially during the dry season, the vice versa is true (Adeogun *et al.*, 2006).

5.3.3 Cluster Analysis

Cluster analysis (CA) is basically a multivariate technique used for classification of objects into clusters to indicate their intrinsic characteristics on the basis of their similarity or nearness (Bu *et al.*, 2010). Cluster analysis is useful in solving classification problems by placing variables into groups such that the association level is strong between the same cluster members and weak between different cluster members (Bhat *et al.*, 2014). Hierarchical clustering analysis (HCA) is the widely used approach that uses the Euclidean distances as a measure of similarity to form higher clusters.

The cluster results is usually demonstrated using a dendrogram which gives a visual summary of clustering processes, showing high internal (or within cluster) homogeneity as well as high external (or between clusters) heterogeneity (Bu *et al.*, 2010). Cluster analysis for Ngong River was carried out in order to detect dissimilar or similar groups among the sampling points.

The analysis is performed in recursive procedure where by the two most similar variables are identified, the two variables found at point 1, they are linked in a cluster, and finally computation of a similarity index of the new cluster versus all the other variables is done. The calculation criterion of the similarity index differs depending on the selected clustering method, but the operation has the common result of substituting in the similarity matrix the rows and columns related to the two objects which have just been linked with a new row and column that report the similarity index of the new cluster with all the remaining objects.

In this study, centroid linkage criterion was used in which substituting the objects that forms the new clusters with the centroid of the cluster, such that the updated similarity matrix comprises of distances between centroids of the new clusters. The squared Euclidean distance with between groups linkage was used as a measure of similarity. The results of Cluster Analysis for wet and dry season for Ngong River are illustrated in Figure 18 and Figure 19.

In this study, Cluster analysis categorized the 12 sampling sites into three distinct clusters for the wet season. The sampling sites of Cluster 1(site 1, 5, 4, 9, 8, 7, 11, 12, 6 and 10) are located on the upstream, middle reaches and downstream of Ngong River basin. The sites showed a strong similarity indicating the dilution effects on anthropogenic pollutants due to increased volume of water in the river as a result of surface runoff during the rainy season. The sampling site in cluster 2 (site 3) was less similar to the other sites probably due to the agricultural runoff from the farming activities carried out on the encroached part of the Nairobi dam. Contrary to these sites, Site 2 in Cluster 3 showed the maximum dissimilarity with other sites during the wet season (Figure 18). Site 2 (Lindi Mosque) is located downstream of site 1. This site receives sewer effluents and other forms of waste from the highly populated Kibera informal settlement. The dendrogram therefore clearly indicates that the water quality degradation of site 2 is attributed to anthropogenic impacts including the sewer discharge which was revealed by the highest *E.coli* Levels (214×106 MPN/100ml) recorded for the wet season (Figure 8). This also shows that site 2 is highly polluted above the dilution capacity of the river during the wet season.

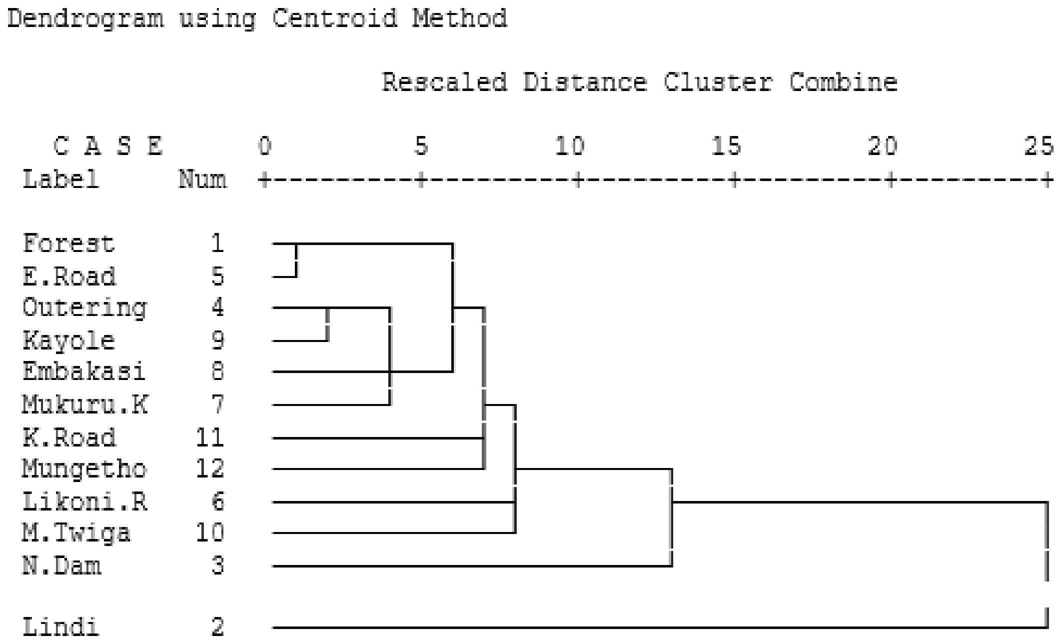

Figure 18: Dendrogram of the cluster analysis for 12 sampling sites based on water quality parameters of Ngong River, Kenya for the wet season (The sample sites were represented as follows: Forest Boundary (1), Lindi Mosque (2), Nairobi dam (3), Outering bridge (4), Enterprise Road (5), Likoni road (6), Mukuru Kaiyaba (7), Embakasi bridge (8), Kayole (9), Matopeni Twiga (10), Kagundo Road bridge (11), and Mungetho-Njiru (12)

Source: Field data (2021)

The CA for the dry season was however different from that of the wet season as shown in Figure 19. This indicates a spatial and temporal variation of pollution factors, and suggests spatio-temporal variations on the effects of human activities on water quality of Ngong River. The dendrogram shows pollution levels and the effect of contamination at various sampling sites by grouping the sampling sites on the basis of the dissimilarity and similarity of water quality parameters. The pollution levels were high during the dry season owing to high concentration of contaminants due to evaporation effect.

The CA produced 3 distinct clusters. Sampling sites in Cluster 1 were site 6, 12, 3, 4, 8, 9, 2, 7, 10 and site 5. These sites are located in the middle and downstream stretch of Ngong River Basin. Site 2 which is Lindi Mosque in Kibera is located just after the forest and is highly populated, lacking basic sanitary provisions hence domestic effluent discharge into Ngong River and solid waste dumping. Sites 5, 6 and 7 (Enterprise Road, Likoni Road Bridge and Mukuru Kayaba) are all located within the Nairobi's industrial hub. These sites receive industrial waste (Plate 19), sewer discharge (Plate 11, 18) and other domestic effluents (plate 15) from the existing industries and the highly populated Mukuru slums. Dumpsites are also common on all the sites located along this stretch (Plate 18).

Sites 4, 8 and 9 (Outering road, Embakasi and Kayole) are located downstream of the industrial area hence the impacts of industrial activities upstream and the existing human settlements along Ngong River in this section are revealed. Dump sites were also evident in these sampled sites while direct sewer discharge was evident at site 9-Kayole (plate 22). Site 12 (Mong'etho) is located downstream of Ngong River just before confluence with the Nairobi River. The site also shows a similarity with the other middle stream sites indicating the impacts of anthropogenic activities in the downstream of the river. Small scale farming, informal settlements lacking proper domestic and sewer disposal, dumpsite and pig farming were evident in this site making it similar to the other sites due to pollution.

Contrary to these sites, Ngong Forest site 1 which formed Cluster 3 indicated maximum dissimilarity with the other sites during dry season as its located on the head section of the stream. This indicates that anthropogenic activities on the Ngong River at site 1 is relatively low (Figure 19) resulting to minimal pollution.

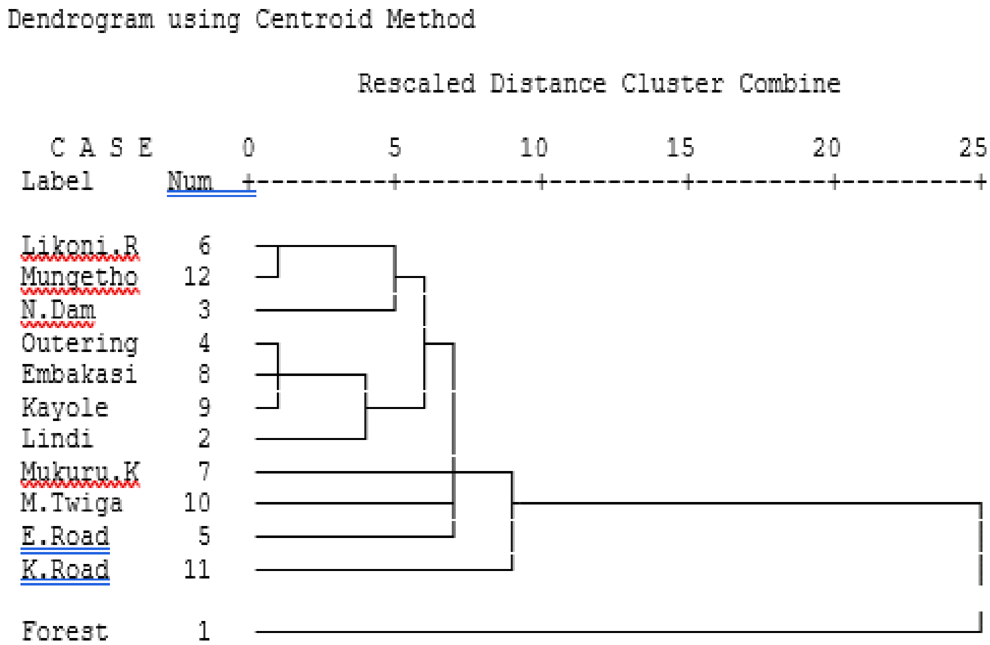

Figure 19: Dendrogram of the cluster analysis for 12 sampling based on water quality variables of Ngong River, Kenya for the dry season. (The sample sites were represented as follows: Forest Boundary (1), Lindi Mosque (2), Nairobi dam (3), Outering bridge (4), Enterprise road (5), Likoni road (6), Mukuru Kaiyaba (7), Embakasi bridge (8), Kayole (9), Matopeni Twiga (10), Kagundo Road bridge (11), and Mungetho-Njiru (12)

Source: Field data (2021)

Cluster 2 Sampling site (Site 11) was also relatively dissimilar from other sites. Human settlements were not located so close to the river at Site 11 as compared to other sites, hence minimal impacts on the water quality parameters. The pollution level was moderate, indicating that the river has a good self purification capacity.

Several successful applications of CA to water quality assessments have been reported in recent studies (Bhat *et al.,* 2014; Bu *et al.,* 2010; Voza *et al.,* 2015). The analytical results in this study indicate that this technique is useful in offering reliable classification of surface waters. The present findings are consistent with the recent studies on Hindawi River, Jonshui and Marova river systems as reported by (Bhat *et al.,* 2014; Bu *et al.,* 2010; Voza *et al.,* 2015).

The entire Ngong River basin, except the forest area (SP1), is characterized by dense human settlements encroaching on the river riparian zones and lacking proper waste handling mechanisms contributing to the observed degradation of the water quality (Figure 3 and Table 4) along the entire basin. The forest had a few settlements observed during the study.

5.3.4 Analysis of variance (ANOVA)

ANOVA test was performed (at 0.05 significance level) on the physicochemical parameters for Ngong River. This was used to determine significance difference of various parameters from the 12 study sites. The ANOVA test results showed that majority of the parameters were not significantly different for the different sites (BOD, *E. coli,* pH, Total suspended solids, Total coliforms, Turbidity, Conductivity, Nitrates, Oil and grease and TDS) however, there was a significant difference in COD at 0.05 significance level Table 8). In this case all the water quality variables except COD showed similar characteristics throughout the Ngong River hence the null hypothesis (H_0 1: There is no significant difference between the values of measured parameters at different sites failed to be rejected. The non-significant difference observed in the majority of parameters indicate contribution of anthropogenic sources in the Ngong River basin (Table 4 and Figure 3). This indicates that the water quality of Ngong River is significantly related to anthropogenic activities along the basin, and as such the null hypothesis (H_0 2: Changes Ngong River's water quality is not significantly related to the anthropogenic activities along the river basin) was rejected. The significance difference in COD indicates a high level of oxidizable organic matter from effluents discharged into Ngong River. High COD levels cause a decline in Dissolved Oxygen in the river water hence deterioration of water quality. COD levels were remarkably high at Lindi Mosque site, Likoni Bridge and Kangundo road sites.

Table 8: Physicochemical parameters ANOVA for Ngong River

Parameters	df	F	Sig.
BOD	11	1.400	.286
COD	11	3.206	.028
Conductivity	11	.461	.895
Nitrate	11	.098	1.000
Oil & Grease	11	.363	.948
E.coli	11	1.054	.462
pH	11	2.391	.075
Temperature	11	.027	1.000
Total Dissolved Solids	11	.464	.893
Total Suspended Solids	11	.925	.548
Total Coliforms	11	1.001	.496
Turbidity	11	1.132	.415

Source: Researcher, (2021).

One way ANOVA test at 0.05% significance level was also performed to determine whether there was a significance difference in the water quality of Ngong River for the wet and dry season using the different water quality variables (Table 9). The results showed that Conductivity, Nitrate, Oil and grease and total dissolved solids were found to be significantly different during the dry and wet season. However, BOD, COD, *E.coli*, pH, Total Coliforms, TSS and Turbidity were found not to be significantly different during the wet and dry season. The non - significant difference in BOD, COD, *E.coli*, pH, Total Coliforms, TSS and Turbidity variables reveal that anthropogenic activities have an impact on the water quality of Ngong River in both dry and wet season.

Table 9: Physicochemical parameters ANOVA for Ngong River

Parameters	df	F	Sig.
BOD	1	3.359	.080
COD	1	.254	.620
Conductivity	1	39.287	.000
E.coli	1	.775	.388
Nitrate	1	88.685	.000
Oil and Grease	1	20.696	.000
PH	1	.479	.496
Temperature	1	558.835	.000
Total coliform	1	.955	.339
Total Dissolved Solids	1	38.506	.000
Total Suspended Solids	1	3.670	.068
Turbidity	1	.523	.477

Source: Researcher, 2021

CHAPTER SIX: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

6.0 Introduction

This chapter discusses the key findings in relation to the study objectives and field data. It briefly highlights the results and discussion on the anthropogenic activities along Ngong River, the pollution levels of Ngong River with respect to measured water quality parameters and the relationship between anthropogenic activities and water quality of Ngong River and indicated in the sub-sections below.

6.1 Major Findings

6.1.1 Anthropogenic activities along Ngong River

Ngong River basin is characterized by informal settlements from upstream to downstream. The informal settlements along the river basin have dense populations which result to pollution of Ngong River. This is due to the observed dumping of solid wastes on all sampled sites along Ngong River except at the Ngong Forest Boundary study site. The settlements also lack basic sanitary provisions leading to fecal contamination of Ngong River due to direct sewer discharge. This was observed for various study sites along Ngong River. The middle stretch of Ngong River is a mixed-use development zone consisting of both industrial and human settlements anthropogenic activities. This contributes to industrial effluents discharge and domestic effluents discharge coupled with sewer discharge hence water quality degradation of Ngong River. Downstream of Ngong River, informal settlements and small-scale faming was observed which also contributes to the observed pollution trends. Farming was also evident at the Nairobi dam.

6.1.2 Water quality on Ngong River

The water quality parameters varied at different study sites and during different seasons. The variations were mostly as a result of the anthropogenic activities at different sampling sites (spatial) and temporal variations during the different season. The pollution levels were low at the source (Ngong Forest boundary) due to fewer anthropogenic activities while the levels increased due to discharges from the human settlements and industrial establishments along the river channel. Pollution levels were alarming during the dry season due to concentration of pollutants due to evaporation. Effects of dilution were evident as the water quality was better during the wet season due to the heavy rains. Forested areas have better water quality than areas dominated by other anthropogenic activities indicating that these activities have a negative impact on the water quality of Ngong River.

6.1.3 Relationship between anthropogenic activities and water quality

The results of this study established that there exists a relationship between anthropogenic activities and water quality of Ngong River. This is due to the observed pollution trends observed along Ngong Rivers different study sites. The variability in different parameters at different sites was an indication of the effects of anthropogenic activities along the basin. The high pollution observed during the dry season is an indication that the river is the main recipient of various anthropogenic wastes generated by land use activities along the basin. During the dry season, there is a high degree of concentration of nutrients and other ions hence high pollution levels. During peak seasons, the waste discharged in to the river is diluted due to large volumes of water hence low pollution levels. Solid wastes are also washed off from the river banks hence clogging the river channel. This is opposite to the dry season where the leachates are generated as a result of decomposition of the organic waste contributing to high pollution levels during the dry season. Sewer discharge contributes to high organic loads in the river basin hence the observed degradation of the water quality at the various study sites which had informal settlements. The river's source had high traces of Cadmium a heavy metal indicating upstream pollution of Ngong River due to the observed human settlements at the source.

6.2 Conclusion

This study has shown that the highest sources of water quality variations in Ngong River water are due to anthropogenic activities. The level of pollution was relatively high due to domestic effluents and sewer discharge particularly from the informal settlements which lack proper mechanisms of sewer disposal (e.g. drainage, sanitary facilities and sewerage works). Open dumpsites along the river banks resulting from the existing settlements also contributed to degradation of Ngong River and loss of aesthetic value. Additionally, the industrial discharge was also a major source of contaminants for the Ngong River as observed in various sites where water quality parameters were also largely compromised.

Meanwhile, several sampled parameters indicated spatial variability. Multivariate Analysis (Cluster Analysis) clustered the river into three distinct clusters according to the levels of pollution (Low level, moderate level and high level of pollution). From the results of the CA, it could be construed that water quality of Ngong River is primarily influenced by anthropogenic activities along its course. The findings further indicated that domestic effluent discharges, dumpsites and industrial discharges on the river basin are the main contributors of water quality deterioration of Ngong River.

Heavy metals levels for Ngong River also varied at different sites with the source recording high levels of Cd indicating pollution of the source with heavy metals. Therefore, unless measures are put in place to address the source of contaminants and related factors, degradation of the water quality in Ngong River will likely continue.

One way ANOVA results indicate that in the peak flow season, the concentration of most inorganic and organic parameters is raised by runoffs. The observed increase in the level of pollution and the non-significant difference observed in various parameters from upstream to downstream of Ngong River basin during the wet season indicated progressive anthropogenic pressure along the basin. Contrary to this observation, levels of pollution of Ngong River were found to be extremely high during the dry season indicating that the river is able to self purificate during the wet season. Therefore, accumulation of contaminants particularly during the dry season is a potential health hazard to communities that utilize Ngong River's water for domestic use or a source of income. Indeed, most parameters showed levels above the WHO and NEMA recommended limits for discharging effluents into the environment as well as drinking/domestic water, suggesting that Ngong River's water in its present state (untreated state) is unfit for both agricultural and domestic use.

6.3 Recommendations

Institutions mandated to protect the environment and water resources should enforce the existing Rules and regulations for catchment protection and riparian land. Water Quality Regulations, 2006 and Solid Waste Management Regulations should be enforced to reduce the observed pollution due to anthropogenic sources such as the observed direct sewer and industrial discharges and illegal dumpsites along Ngong River so as to curb their probable enhancement on river pollution especially the heavy metals and fecal pollution.

In places where dumping has already taken place as it was evident at various sampling stations along Ngong River, NEMA and Nairobi Metropolitan Services (NMS) should collaborate with local Community Based Organization (CBOs) to clear the dumpsites on the river bank and ensure that uncontrolled dumping of solid waste is stopped along the Ngong River.

Nairobi Sewerage Company should ensure that Informal settlements such as Kibera, Mukuru, Kayole, and Njiru built along the river bank are sewered in order to minimize sewer discharges into Ngong River.

Water Resources Authority should establish water quality monitoring stations along Ngong River to ensure regular monitoring of the river basin in order to curb pollution sources. Regular monitoring data is also necessary for comparison purposes; water quality data for Ngong River was not available as they are no monitoring stations. WRA should also develop an Integrated Watershed Management

Plan which will provide a holistic approach in recovering the observed degradation of Ngong River's water quality through engagement of different stakeholders in the water sector.

Kenya Forest Service (KFS) should look into the observed encroachment into Ngong Forest which is on the upstream section of Ngong River to prevent further encroachment and pollution of the source of Ngong River which eventually affects downstream communities. KFS should also endeavour to restore the lost riverine vegetation along Ngong River basin especially in areas where human settlements have encroached upon the river. This will help in assimilation of some of the pollutants such as the heavy metals hence their removal from the river water. Vegetation restoration will also help in improving the riverine ecosystem health thus improve the water quality of Ngong River which will reverse the observed degradation trends.

6.3.1 Recommendations for further research

The present study evaluated the influence of only two heavy metals (Lead and Cadmium) on the Ngong River's water quality, for which high levels of Cadmium were recorded in some sampling sites. Considering that Ngong River is an important tributary of Athi River which supplies water to the downstream communities (in Machakos, Makueni and Kitui Counties), coupled with discharge of industrial waste observed during this study, there is need to evaluate the presence of other heavy metals (e.g. Mercury, Copper and Chromium) in Ngong River's water. Therefore, future studies should focus more on other heavy metal pollution of Ngong River to provide an in-depth understanding of water quality in this river.

In the present study levels of Lead metal were undetectable in Ngong River, which could mean a possibility of material substitution by industries or effective effluent treatment. In future studies may be conducted to find out whether there is application of cleaner production by industries and the effects of this practice on water quality of Ngong River.

The findings of this study showed that levels of most water quality parameters were beyond NEMA and WHO maximum allowable limits for drinking water and effluents discharge into the environment. Future studies could focus on determining the effect of such variations (from acceptable standards) on aquatic life in the Ngong river basin.

The current study investigated the effects of anthropogenic activities along the Ngong River, pollutions levels, the relationships between anthropogenic activities and pollution in Ngong river basin, starting and from its source to where it confluences Nairobi River. However, a comparative study can also be conducted to check whether the trend of pollution decreases or increases past the confluence of Ngong River and Nairobi River. Additionally, a study can also be conducted on the perceptions of Ngong River usage by communities living along the river. Community engagement is also necessary in rehabilitation of Ngong River.

Meanwhile, the present study showed evidence of direct sewer discharge into the Ngong River, which was linked to high Total coliforms and *E. coli* levels in Ngong River. Future studies could investigate other water quality parameters including phosphate and Ammonium-Nitrogen to provide more insights on the role of anthropogenic activities on Ngong River's water quality.

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APPENDIX 1: NGONG RIVER WATER QUALITY LEVELS (WET AND SEASON)

Table 10: Ngong River water quality levels (wet season)

Parameters	**Units**	**Ngong Forest Boundary**	**Lindi Mosque-Kibera**	**Nairobi Dam-Kibera Silanga**	**Mukuru Kayaba**	**Likoni Rd bridge**	**Enterprise Rd Bridge**	**Outering Rd**	**Embakasi Bridge-Soweto**	**Kayole**	**Matopeni Twiga**	**Kangundo Rd Bridge Njiru**	**Mong'etho Chokaa Njiru**	**NEMA DW STDS**	**WHO DW STDS**
pH	pH Scale	7.10	6.96	7.68	6.84	6.88	7.19	6.77	6.94	7.02	6.87	7.14	7..21	6.5-8.5	<8
Turbidity	N.T.U	7.40	13.06	14.5	15	12	11	12	4.75	10.6	30.6	10.1	29.6	NA	<1.5
Conductivity (25˚C)	µS/cm	370	630	950	314	480	337	638	540	550	560	610	370	NA	250
Nitrate (NO3-N) & Nitrate (NO3-)	mgN/l	1.35	1.24	2.82	1.3	3.3	1.9	<0.01	2.30	1.01	1.24	3.33	3.3	10	50
Total Dissolved Solids	mg/l	229	391	589	195	298	209	396	335	341	347	378	229	1200	1000
Temperature	˚C	20.3	20.1	20.3	20.1	20.3	20.1	20.3	20.5	20.2	20.3	20.6	20.5	-	-
COD	mgO_2/L	106	2182	35	85	1210	76	358	352	704	352	1760	352	-	-
BOD (20˚C)	mgO_2/L	5	230	5	30	450	5	70	110	130	150	65	55	-	-
Oil & Grease	mg/l	0.25	1.7	0.52	0.32	0.26	0.49	0.59	0.4	0.6	0.6	0.3	0.4	-	-
Total Suspended Solids	mg/l	40	140	10	140	100	120	160	50	71	367	71	88	30	-
Total Coliforms	MPN/100Ml	81000	8660000000	50000	19700	1414000	930	3080000	276000	6870000	548000	440000	242000	-	NIL
E. Coli	MPN/100mL	2900	214000000	ND	1400	250000	30	10000	21000	187000	4300	1000	17330	Nil/100mL	NIL
Cadmium	mg/l Cd	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0.01	0.003
Lead	mg/l Pb	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0.05	0.01

Table 11: Ngong River water quality levels (Dry Season)

Parameters	**Units**	**Ngong Forest Boundary**	**Lindi Mosque-Kibera**	**Nairobi Dam-Kibera Silanga**	**Mukuru Kayaba**	**Likoni Rd bridge**	**Enterprise Rd Bridge**	**Outering Rd**	**Embakasi Bridge-Soweto**	**Kayole**	**Matopeni Twiga**	**Kangundo Rd Bridge Njiru**	**Mong'etho Chokaa Njiru**	**NEMA DW STDS**	**WHO DW STDS**
pH	pH Scale	7.52	6.94	7.19	6.83	7.09	7.11	6.75	6.94	7.09	7.22	7.72	7.08	6.5-8.5	<8
Turbidity	N.T.U	ND	17	20	22	15	8.2	26	25	22	12	11	20	NA	<1.5
Conductivity (25˚C)	µS/cm	509	1102	1244	934	885	882	1216	1186	1261	1239	1239	934	NA	250
Nitrate (NO3-N) & Nitrate (NO3-)	mgN/l	36.53	32.45	19	19.22	9.8	14.73	36.07	28.3	29.15	24.6	22.93	22.6	10	50
Total Dissolved Solids	mg/l	316	638	771	579	549	547	754	735	782	768	768	579	1200	1000
Temperature	˚C	22.2	23.0	22.7	23.1	22.6	22.2	22.7	23.2	22.8	22.9	23.0	23.0	-	-
COD	mgO_2/L	35	1411	376	642	920	350	1112	1050	880	470	750	990	-	-
BOD (20˚C)	mgO_2/L	5	370	70	250	160	120	290	320	270	180	120	210	-	-
Oil & Grease	mg/l	0.04	ND	0.06	0.02	0.03	ND	0.03	0.01	0.04	0.02	ND	0.04	-	-
Total Suspended Solids	mg/l	10	300	100	200	200	150	600	350	250	100	133	150	30	-
Total Coliforms	MPN/100mL	143	11200000	176000	24200000	10460000	9210000	1773000	12030000	24200000	24200000	17330000	24200000	-	NIL
E. Coli	MPN/100mL	2	3880000	12000	9200000	1414000	730000	148000	1120000	1590000	3800000	2310000	1720000	Nil/100mL	NIL
Cadmium	mg/l Cd	0.113	0.067	0.074	0.110	0.054	0.049	0.071	0.081	0.068	0.105	NIL	0.088	0.01	0.003
Lead	mg/l Pb	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0.05	0.01