MAPPING SPATIAL - TEMPORAL VARIATIONS OF PHOSPHATE, SULPHATE, NITRATE AND *ESCHERICHIA COLI* *(E.COLI)* POLLUTION IN NGONG RIVER, KENYA

By

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A thesis submitted to the Board of Post Graduate Studies in partial fulfilment of the requirements for the award of the Degree of Master of Science in Environmental Chemistry of the University of Nairobi.

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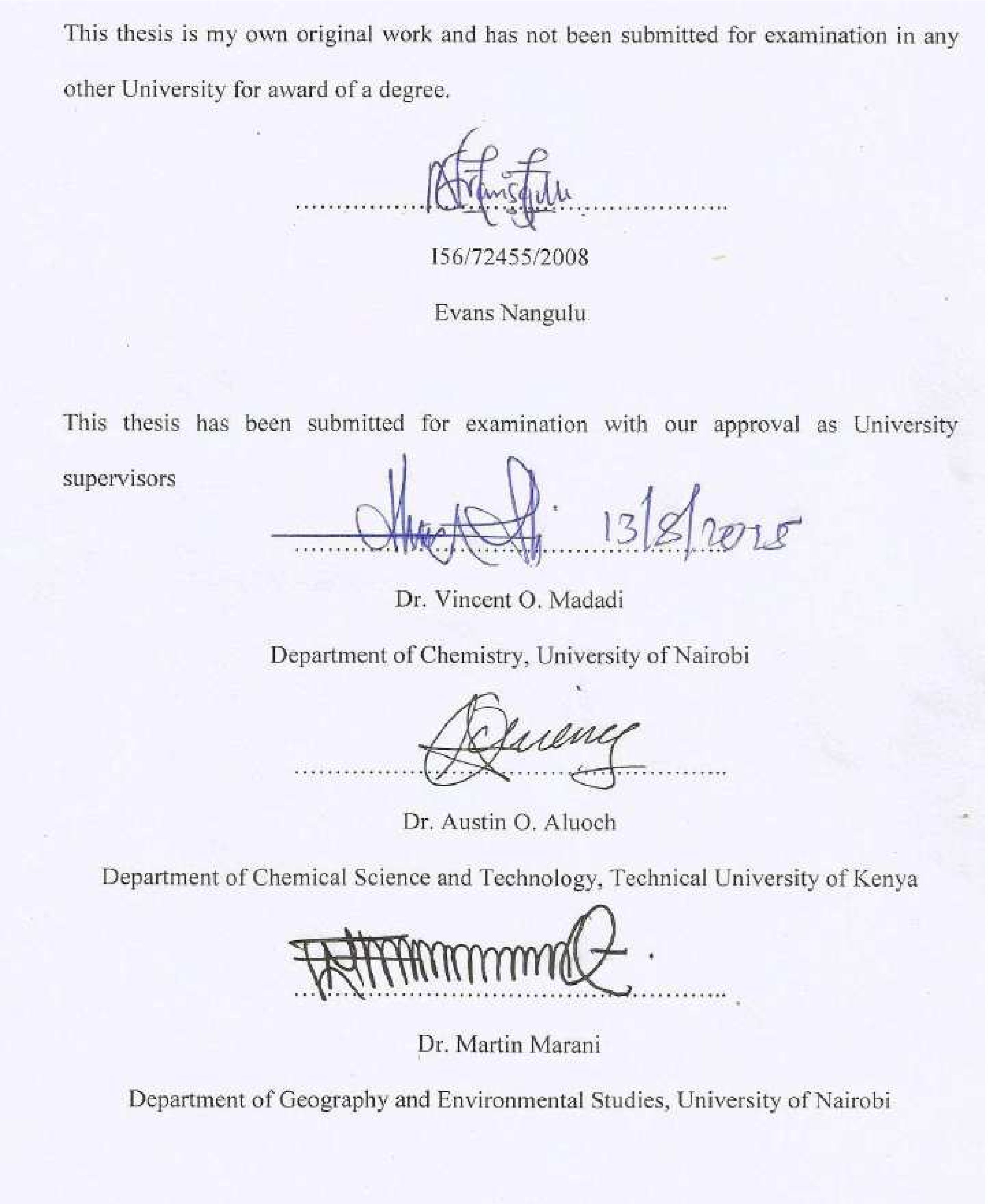
DECLARATION



This thesis is my own original work and has not been submitted for examination in any other University for award of a degree.

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To my mother Anna Nangulu, my father the late Ollis Wilberforce Nangulu and my wife Lucy for their advice, inspiration, encouragement and motivation.

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ABSTRACT

The spatial and temporal variations of phosphates, nitrates, sulphates and *E. coli* in water and sediment from Motoine-Ngong River system were investigated in this study. 13 sampling sites were selected between Motoine Dam (elevation 1,842 m) and Kangundo Road (elevation 1,526 m). Grab sampling method was used to collect water and sediments from each site between January - February 2012 (Dry season) and May- June 2012 (Wet season). Arc GIS software version 10.1 was used to generate colour-coded projection maps to establish spatial and temporal distribution of contaminants in selected sites. Statistical analysis of spatial and temporal changes in water quality was conducted at 5% confidence level ($p\leq0.05$) by Analysis of Variance (ANOVA), Pearson correlation coefficient (r) and Regression analysis using QI Microsoft excel 2010.

Phosphate concentration in water ranged from 1.59±0.01 mg/L to 11.34±0.01 mg/L, with a mean concentration of 5.50 mg/L for the dry season and a range of 0.96±0.27 mg/L to 9.96±0.54 mg/L, with a mean of 4.95 mg/L for the wet season. Sulphates levels ranged from below detectable limit to 1.15±0.02 mg/L with a mean of 0.54 mg/L in the dry season, and 0.42±0.12 mg/L to 0.79±0.02 mg/L, with a mean of 0.67 mg/L in the wet season. The concentration of nitrates ranged from below detectable limit to 13.74±0.08 mg/L, with a mean of 6.14 mg/L in the dry season and from below detectable limit to 26.65±1.36 mg/L, with a mean of 16.92 mg/L during the wet season.

E. coli levels ranged between 140 and 1,800 MPN/100 mL, with a mean of 1,661 MPN/100 mL in the dry season and between 94 and 1,800 MPN/100 mL, with a mean of 1,525 MPN/100 mL during the wet season. For sediments, phosphate levels ranged from

1,985±2 mg/Kg to 8,805±150 mg/Kg, with a mean of 4,602 mg/Kg during the dry season and from 1,866±162 mg/Kg to 9,157±540 mg/Kg, with a mean of 4,767 mg/kg in the wet season. Sulphates ranged from 1,045±104 mg/Kg to 21,033±1,197 mg/Kg, with a mean of 10,739 mg/Kg for the dry season and 18,120±364 mg/Kg to 32,373±4,283 mg/Kg, with a mean of 24,407 mg/Kg in the wet season. Nitrates ranged from below detectable limit to 4,178±20 mg/Kg, with a mean of 1,327 mg/Kg in the dry season and from below detectable limit to 3,524±39 mg/Kg, with a mean of 1,136 mg/Kg for the wet season.

Statistical data analysis revealed a positive temporal correlations for different parameters in water at $r\ (PO_4^{3-}) = 0.71$, $r\ (NO_3^{-}) = 0.16$, $r\ (SO_4^{2-}) = 0.25$ and sediments at $r\ (PO_4^{3-}) = 0.19$, $r\ (NO_3^{-}) = 0.32$, $r\ (SO_4^{2-}) = 0.21$. Weak correlations were observed for both water and sediments.

Sulphate levels in water were within the World Health Organization’s recommended standards (0 -500) mg/L for drinking water. Phosphates and Nitrates level were higher at some sampling sites than the recommended WHO standards of phosphates (0-5) mg/L and Nitrates (0-10) mg/L, respectively. There was no significant difference in *Escherichia coli* (*E. coli*) levels in both seasons. The results suggest random sources of pollution in Ngong-Motoine River system. Therefore, greater attention should be paid to the anthropogenic activities along the river system in order to restore the river water quality.

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ABBREVIATIONS AND ACRONYMS

Abs	Absorbance
APHA	American Public Health Association
$BaSO_4$	Barium Sulphate
$CaCO_3$	Calcium Carbonate
^0C	Degree Celsius
DDT	Dichloro-Diphenyl-Trichloroethane
DNRA	Dissimilatory Nitrate Reduction to Ammonium
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
g	Grams
g/Kgm	grams per kilograme
GIS	Geographical Information System
GPS	Global Positioning System
H_2S	Hydrogen Sulphide
HCl	Hydrochloric Acid
ICC	International Christian Church
IP	Inorganic phosphate
IUCN	International Union for the Conservation of Nature
JKIA	Jomo Kenyatta International Airport
KH_2PO_4	Monopotasium Phosphate
KIRDI	Kenya Industrial Research and Development Institute

KMD	Kenya Metrological Department
KNCPC	Kenya National Cleaner Production Centre
KNO_3	Potassium Nitrate
KWS	Kenya Wildlife Service
mg/Kg	Milligrams per kilogram
mg/L	Milligrams per liter
ml	Millilitres
MPN	Most Probable Number
N	Nitrogen
N_2O	Nitrous Oxide
NEMA	National Environmental Management Authority
NETWAS	Network for Water and Sanitation
nm	Nanometres
NO_3^-	Nitrate
NRB	Nairobi River Basin
NRBP	Nairobi River Basin Programme
OP	Organo Phosphate
P	Phosphorus
PET	Polyethylene Terephthalate
PO_4^{3-}	Phosphate
ppm	Part per million
RH	Relative Humidity
SO_4^{2-}	Sulphate

UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNFPA	United Nations Population Fund
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VO_3^-	Vanadate
WHO	World Health Organization
WRMA	Water Resource Management Authority

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is one of the most important resources to life. Lack of adequate quantities of safe water or poor quality water undermines the quality of life, environmental conservation and the entirety of human civilization. Additionally, water is a critical factor of crop production, pastoralism, quality human settlements and the beauty of landscapes. At 647 m^3 per capital water availability, Kenya is a water-scarce country [Mogaka *et al.*, 2006], a situation exacerbated by rapid population growth, industrialisation, agricultural intensification, desertification and environmental pollution. The problem of pollution has not been addressed with the same energy and drive as has the quest for industrialisation in Kenya. As the country industrialises, environmental degradation is increasingly becoming evident in water bodies, soil and terrestrial systems.

Kannel and co-workers [2007] noted that anthropogenic activities such as urbanization, human settlements, industrialisation, and agricultural intensification adversely affect human and ecosystem health. As a result, the impacts of such activities need to be monitored to ensure promotion of sustainable development objectives. One aspect that needs such environmental monitoring is the quality of rivers. Since the early days of human civilization, rivers have played a vital role in ecosystem wellbeing and social and economic development.

According to the United Nations Fund for Population activities [UNFPA, 2001], "human impact on the environment is a function of population size, per capita consumption and the environmental damage caused by the technology used to produce what is consumed". The unsustainable population growth in Nairobi has manifested itself through increased and unplanned industrial development with poor solid and effluent management, unprecedented sprawling of slums marked with poor sanitation, lack of water supply infrastructure and lack of waste management facilities.

The industrial development in Nairobi entails both heavy manufacturing as well as light industries such as warehouses, metal workshops and garages. Some of these developments have been uncoordinated resulting into incompatible mixed land use and encroachment into sensitive ecosystems. The legal instruments that govern the development and operation of these industrial developments have been inadequate resulting into their contribution to poor human health and environmental degradation [Franz and Fitzroy, 2006]. The sprawling informal settlements have been accompanied by urban agriculture which provides support of alternative livelihood but have also been accompanied with negative environmental activities ranging from the use of inorganic fertilizers to use of insecticides, pesticides and herbicides to control pests and diseases.

According to Hayombe (1997), the rapid population growth in Nairobi has led to fragile land zones being exploited to support settlements and industrial activities where they are increasingly vulnerable to environmental change. These fragile zones include rivers, wetlands and flood plains. Nairobi County has three major rivers: Nairobi, Ngong and Mathare. Due to the unplanned developments (settlement and industrial) and poor sanitation infrastructures in the county, its rivers have been impacted negatively by acting as pollutant sinks.

1.2 Concerns of Pollution in the Nairobi River Basin

Pollution in the Nairobi River Basin has been a concern of many international and national agencies for many years but the first major concrete effort to confront the problem happened in 1999 when the International Union for Conservation of Nature (IUCN), the University of Nairobi Department of Chemistry, the Network of Water and Sanitation (NETWAS), UNEP, UNDP, UN-HABITAT, relevant government agencies and players from the corporate sector jointly implemented a four-year programme called the Nairobi River Basin Programme (NRBP) with the funding from various bilateral donors and the United Nations [Geoffrey, 2006].

The vision of the joint effort was a restored riverine eco-system with clean water for the capital city and a healthier environment for the people of Nairobi, while the main goal was to rehabilitate, restore and manage the Nairobi River ecosystem in order to provide improved livelihoods (especially for the poor), enhanced biodiversity and a sustainable supply of water for domestic and industrial, recreational and emergency uses. NRBP was a three-phase programme coordinated by UNEP. The first two phases established benchmarks, identified interventions and mobilized the participation of Nairobi residents with messages such as “Save the Nairobi Rivers-Everyone Lives Downstream” [UNEP, 2003], implemented projects, and provided capacity building efforts among stakeholders.

1.3 The phases of Nairobi River Basin Programme

1.3.1 Phase I (October 1999 to March 2000)

According to UNEP, 2003 this phase consisted of a situational assessment of water quality, a public awareness, education campaign, community outreach through pilot Income Generation Activities and development of Environmental Management Information System.

1.3.2 Phase II (June 2001 to December 2003)

The second phase of NRBP focused on Ngong-Motoine River as a pilot initiative to establish major point sources of pollution. The seasonal monitoring and assessment conducted by NETWAS in conjunction with the University of Nairobi and Nairobi City Council focused on 20 sampling stations which developed a strategy for the other rivers in the basin. The sampling stations were marked 22 km upstream Nairobi Dam and 25 km downstream the Dam to the confluence with Athi River Basin. This phase also provided a platform for community education and information sharing amongst key stakeholders on the designing and implementation of activities aimed at restoring the ecological integrity of the entire Nairobi River Basin Rivers [UNEP 2003].

1.3.3 Phase III (January 2005 to December 2008)

Phase III of NRBP was a follow up of phase I and II which established benchmarks laid down in phases I and II as pillars to achieve its long-term vision of a restored, rehabilitated, and managed water quality and the riverine eco-system with clean water for the capital city and a healthier urban environment for the people of Nairobi. This phase aimed at bringing together United Nations agencies, government authorities, civil societies and the private sectors to become a model for environmental action at national level.

The Nairobi River Basin Program (NRBP) Phase III revealed that no consistent environmental monitoring had taken place in all the rivers under the Nairobi River Basin between 1969 and 2008. The gaps identified included a lack of reliable monitoring datasets and omissions in parameters measured between 1969 and 2004. For example, microbial parameters were ignored in monitoring of Ngong River. Total coliforms and faecal coliforms were only reported four times between 1969 and 2004, while total bacteria and clostridium were only reported twice in the same period which makes the datasets and the conclusions made from them scientifically implausible [UNEP, 2005].

This study focused on seasonal (wet and dry) variation of phosphates, nitrates, sulphates and *E. coli* pollution on part of Ngong-Motoine River system between Motoine Dam and Kangundo Road Bridge. Agricultural land use, influence of human settlement, industrial activities and a distance of at least 100 m between stations were considered when selecting sampling points.

1.4 Problem Statement

River pollution from phosphates, nitrates, sulphates, human waste and sewage discharges is a common problem across the world. In Kenya, the availability of quality water for human and industrial use is manifested through the decreasing trend of reliability of piped water for the urban population. Ngong -Motoine River system is one of the main sources of water for residents along its profile. From the source, the river is relied on heavily by urban farmers for irrigation and other domestic uses. Motoine River is the main source of water for Nairobi Dam which was commissioned in 1953 to provide portable and emergency water supply for Nairobi City.

Other than providing fresh water for domestic use, the Dam also provided recreational activities such as sport fishing, sailing, picnics and other water sports. Lately, the Dam has been infested by water hyacinth and other plant species rendering it inaccessible for water sports. Kibera slums residents who relied on Ngong-Motoine River for clean water supply have now resorted to farming using the river water despite the danger posed by heavy pollution emanating from the slum itself and other residential areas. Downstream the Dam, the river remains polluted due to informal settlements, agricultural activities, car garages and several industries. As a result of the declined water quality on Ngong-Motoine River system, there has been a change in the river hydrological system.

Previous studies on Ngong- Motoine River only pointed possible pollution sources but did not provide a solid foundation for monitoring purposes. Data on pollution levels are scanty and unreliable due to randomized study stations. These research findings established that, the natural hydrological processes along the river profile have been overtaken by man’s influence resulting into a continuous change in channel morphologies, increasing catchment imperviousness, siltation of the channels and increasing diseases outbreaks.

To restore the hydrological system and water quality of Ngong –Motoine River, this study investigated spatial and temporal variations in levels of phosphates, nitrates, sulphates and *E. coli* along the Ngong River Profile and presented data on GIS maps. The data is important for identification of hotspots and management of the River ecosystem by controlling direct waste discharge, surface run-off and infiltration.

1.5 Research Questions

This study was guided by the following research questions

i) Does the water quality of Ngong-Motoine river system vary significantly from upstream to downstream?

ii) Is there significant impact of seasonal variability on water quality within the study area?

iii) Is there any inter-relationship in water quality with respect to the studied parameters?

1.6 Objectives of the Study

1.6.1 Overall Objective

The overall objective of this study is to map spatial and temporal variations of phosphates sulphates nitrates and *E. coli* in Ngong River.

1.6.2 Specific Objectives

The specific objectives are:

i) To determine the spatial and temporal concentration variations of Phosphates (PO_4^{3-}) ,Nitrates (NO_3^-), Sulphates (SO_4^{2-}) in water and sediment and *E.coli* pollution downstream Ngong-Motoine River between Motoine Dam and Kangundo Road bridge.

ii) To investigate the locations of possible point and non-point pollution sources downstream Ngong-Motoine River.

iii) To apply GIS to establish the extent of Ngong-Motoine River Phosphates (PO_4^{3-}) Nitrates (NO_3^-), Sulphates (SO_4^{2-}) and *E. coli* spatial and temporal pollution using maps and diagrams from which inferences can be made.

iv) To determine the Ngong-Motoine River water and sediment quality conformance and violation by comparing the measured phosphates (PO_4^{3-}), nitrates (NO_3^-), sulphates (SO_4^{2-}) and *E. coli* concentrations with respect to World Health Organisation standards.

1.7 Justification of the study

Nairobi as the capital city of Kenya is a centre of industry, education and culture. The city occupies an area of about 696 km^2 [CBS, 2006] and in 1960s it was regarded as “the green city in the sun” because of its refreshing environment at that time. However, due to population growth, the city capacity and resources have been overstretched [Hayombe, 1997]. The existing facilities were not planned to cater for the increased population currently being realised with the decreasing resource base.

The city faces problems ranging from management, planning and foresight [Hagerlund, 2006]. The population of Nairobi grew tremendously from 8000 in 1901 to 118,579 in 1948 [Rakodi, 1997]. In 1962, the city had a population of 343,500 people thus between the year 1948 and 1962 censuses, the population grew at an average rate of 5.9 per cent per annum [CBS, 2006]. The 2009 census established a population of 3.8 million (CBS 2010). This increase has put pressure on the available resources.

Kenya is a signatory to the 2003 Harare declaration on urban and peri-urban agriculture in Eastern and Southern Africa that advocates for the development of policies to create an enabling environment for integrating urban agriculture into the urban economies. Ayaga and co-workers (2004) noted that there is need for the development of an appropriate policy framework for urban settlement and agriculture in Kenya. Therefore, it is important to study the effects of anthropogenic activities on river ecosystem. The data produced in this study is key to a better understanding of river pollution from point and non-point sources.

1.8 The study area ; Nairobi River Basin (NRB)

Nairobi River Basin (NRB) covers an area of about 1,078 km^2 and the main rivers include Nairobi, Ngong –Motoine and Mathare. The physiography of the area comprises of the Ngong hills in the south-west, Kikuyu highlands and the Rift Valley flanks in the west and the Athi plains in the east [Ngecu and Gaciri, 1999]. Figure 1.1 shows the main rivers and major informal settlements in the Nairobi River Basin [NEMA, 2012].

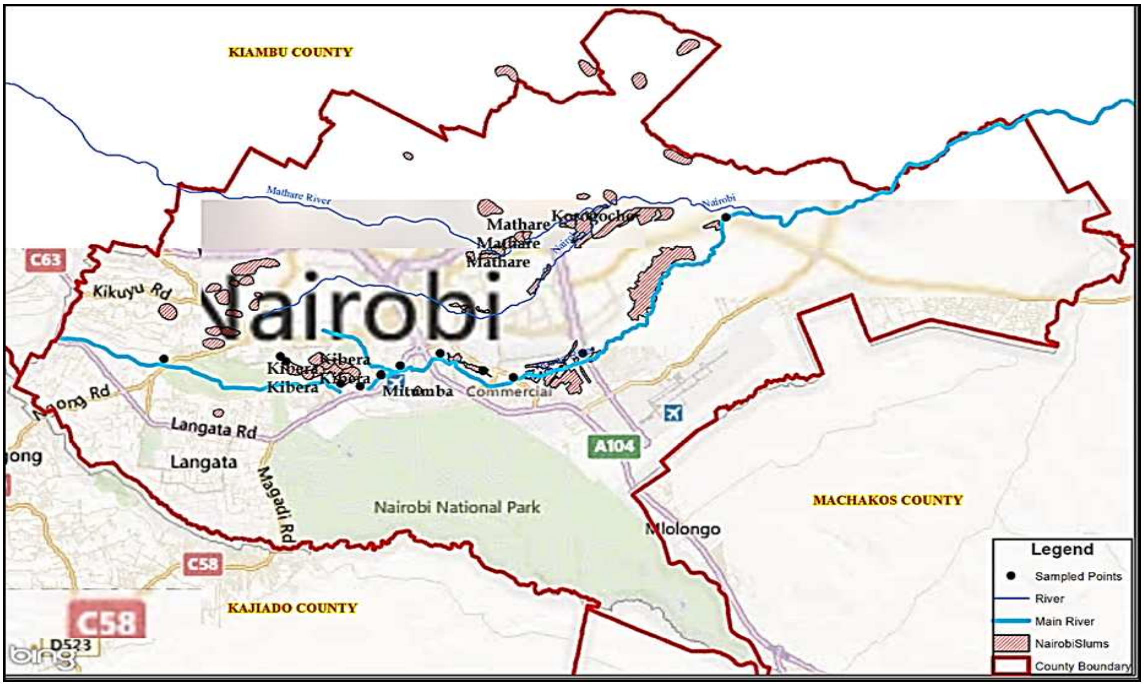


Figure 1.1: Map of Nairobi River Basin showing the three major rivers

1.9 The Ngong-Motoine River System

The sources of Ngong-Motoine River system are Kibiku, Ngong and Dagoretti forests, and Riu swamp. The Motoine tributary originates from Motoine Dam and runs through Jamhuri Park where it joins Ngong tributary within Kibera slums; the point at which it becomes Ngong-Motoine. The river flows into Nairobi Dam which is a man-made Dam commissioned in 1953 to provide portable and emergency water supply to the city of Nairobi. It leaves the Dam as Ngong River and becomes Athi River after the confluence with Nairobi River and Mathare River [UON/UNEP, 2005].

The river system is divided into four sections; the upper section; the stretch upstream of Nairobi Dam, the Dam itself and the stretch from the Dam through the industrial area to the confluence with Nairobi River. The upper section of Ngong-Motoine River system is characterised by indigenous forests, agricultural lands and wetlands. Human activities here include intensive agriculture, silviculture, animal husbandry, vegetable farming, and human settlements.

The upper catchment of Ngong-Motoine tributary consists of natural wetlands. Motoine swamp lies at an elevation of 1842 meters above sea level and Riu swamp lies at 2033 meters above sea level. The Motoine River waters are heavily used for irrigation in farm lands and for domestic purposes in heavily populated Dagoretti area. The main anthropogenic activities around the wetlands are; vegetable farming, sugarcane farming, arrow roots farming, maize farming among other crops. Other activities include bathing and washing of cloths.

Downstream, from Motoine Dam, the river flows through Jamhuri Dam a constructed reservoir and eventually Nairobi dam. Jamhuri Dam provides water to the Agricultural Society of Kenya (ASK) show grounds for crops irrigation and for livestock. Spill waters from the dam are used by Kibera informal settlement residents for bathing and cloths washing. *Typha domingesis* and *Cyperus* species are dominant around Jamhuri Dam while the Nairobi Dam is heavily infested with water hyacinth (*Eichhornia crassipes*) at the weir and *Typha domingesis* and *Cyperus* species at the Inlet of Motoine River [Krhoda, 2002].

The Nairobi Dam the source of Ngong River has a surface area of about 356,179 m^2 and a volume of 98,422 m^3. The Dam's weir has an average depth of 2.76 m at an elevation of 1718 meters above sea level [UNEP, 2003]. The Dam acts as a sink for all the waste that emanates from Kibera slums, sediments from soil erosion, raw domestic waste discharge, surface run-off from agricultural lands and waste used to reclaim land for agricultural purposes along the river and around the Dam. Coupled with animal husbandry within the slums, this has accelerated nutrients loading thus the extensive coverage of water hyacinth [Kahara, 2002].

The river leaves Nairobi Dam as Ngong River across Langata Road, through Nairobi west and to the industrial area across Mombasa Road. This zone has major industries ranging from service providers, manufacturing to automotive garage. The zone has both informal settlements (Mukuru Kwa Njenga, Kwa Ruben, Kayaba and Baraka slums) and the peri-urban residential (South B, River bank estate, Hazina Estate, Embakasi, Donholm, Umoja and Kayole).

Utilizing Ngong-Motoine River water for farming is common along the river bank in the slums. As the river flows through this section, it becomes an open sewer as a result of direct effluent discharge from some of the industries, discharge form burst sewer lines due to vandalism and blockage, oils discharge from motor vehicle garages and detergents used for cleaning. Also, the residents in the slums discharge human waste directly into the river either wrapped in polyethene bags (flying toilets) or the toilets are suspended directly above the river [Ndede 2002].

1.9.1 Environmental degradation along the River System.

Due to the nature and set up of the slums along the river system, infrastructure is not well planned. This has led to poor sanitation hence the degradation of the environment. Most industries in the industrial area section do not have wastewater treatment plants thus they channel their raw effluent to the nearby Ngong River or directly to the sewer line without pre-treatment. Vandalism of servicing manholes along the sewer lines has also impacted negatively to the general environment whereby, the sewer overflows to the river system at various points. Table 1.1 illustrates the major sources of pollution along the Ngong River [Krhoda, 2002].

Table 1.1: Sources and significance of pollutants from human activities along Ngong-Motoine River system.

Source	**Bacteria (*E.coli)***	**Nutrients (PO_4, SO_4^{2},NO_3^-)**	**Trace elements**	**Pesticides and herbicides**	**Industrial micro pollutant**	**Oils and grease**
Atmosphere		X	XXX	XXX	XXX	
Sewage	XXX	XXX	X	XXX		
Industrial Effluents		X	XXX		XXX	XX
Agricultural fields	XX	XXX	X	XXX		
Runoff and waste disposal	XX	XX	XXX	XX	XX	XX
Geological			XX			

Legend: X-Low significant; XX-Moderate significant; XXX-High significant;

1.9.2 The hydrogeology of the river system

Ngong Motoine River system flows over foundations of folded Precambrian Schist's and Gneisses of Mozambique belt [Saggerson, 1991]. The underlying geological layer beneath Ngong and Dagoretti forests are the upper Athi series which is porous and permeable allowing for percolation making it favourable as a watershed for discharge into the river and recharge of aquifers [Saggerson, 1991]. The upper Athi series is the main aquifer for the Ngong- Motoine river system. The lower Athi series constitutes of more clay and therefore forms an aquiclude (a sediment unit that does not yield much quantities of water).

The Motoine River soils are shallow, yellow- brown to yellow–red friable clay overlaying laterite horizon. Nairobi Dam settles on the middle and upper Kirichwa valley Tuffs and consists of vitreous pumice fragments that are collapsed. Below the Nairobi Dam, chances of water percolation through the Kirichwa valley Tuffs are high due to its porosity and permeability and the flow is downstream Ngong River over the underlying phonolite [Saggerson, 1991]. Downstream the spillway, the river flows over alluvial clays and swamp soils. As it cascades through Nairobi West, South B and through the industrial area and Embakasi, it flows over the impermeable Nairobi phonolite which protects the Kirichwa valley tuffs that are like a sponge and a perfect aquifer.

1.9.3 Industrialisation

Ngong–Motoine River system is heavily polluted by the industries as it cascades through the industrial area which is the home to about 80% of the Kenya’s manufacturing and service industries [UNEP, 2003]. The enterprises along the river include auto garages, chemicals, electrical and engineering, pharmaceuticals, food and beverage, printing and paper conversion, metal fabrication, wood products, clothing and textiles, body and household products, healthcare, hotels among others.

1.9.4 The River system profile

The topography of Ngong-Motoine River drainage system is divided into four sections; the upper section at the source, the stretch upstream of Nairobi Dam, the Dam itself and the stretch from the Dam through the industrial area to the confluence with Nairobi River.

The river upstream the Dam is 52.6 km^2 and the area of Ngong- Motoine River system from the source to the confluence with Nairobi River is 127 km^2 [Kahara, 2002].

Ngong –Motoine River rises in the west at an elevation 1842 m falling drastically up to 1525 m at the confluence with Nairobi River [Ndede, 2002]. The rivers longitudinal profile within the study area drops to 316 meters above sea level for the horizontal distance of about 25.4 kilometres between the 13 sampling stations selected. The uppermost point is Motoine Dam and the lowest point is Kangundo Road Bridge just before confluence with Nairobi River. Figure 1.2 depicts Ngong-Motoine River elevation profile.

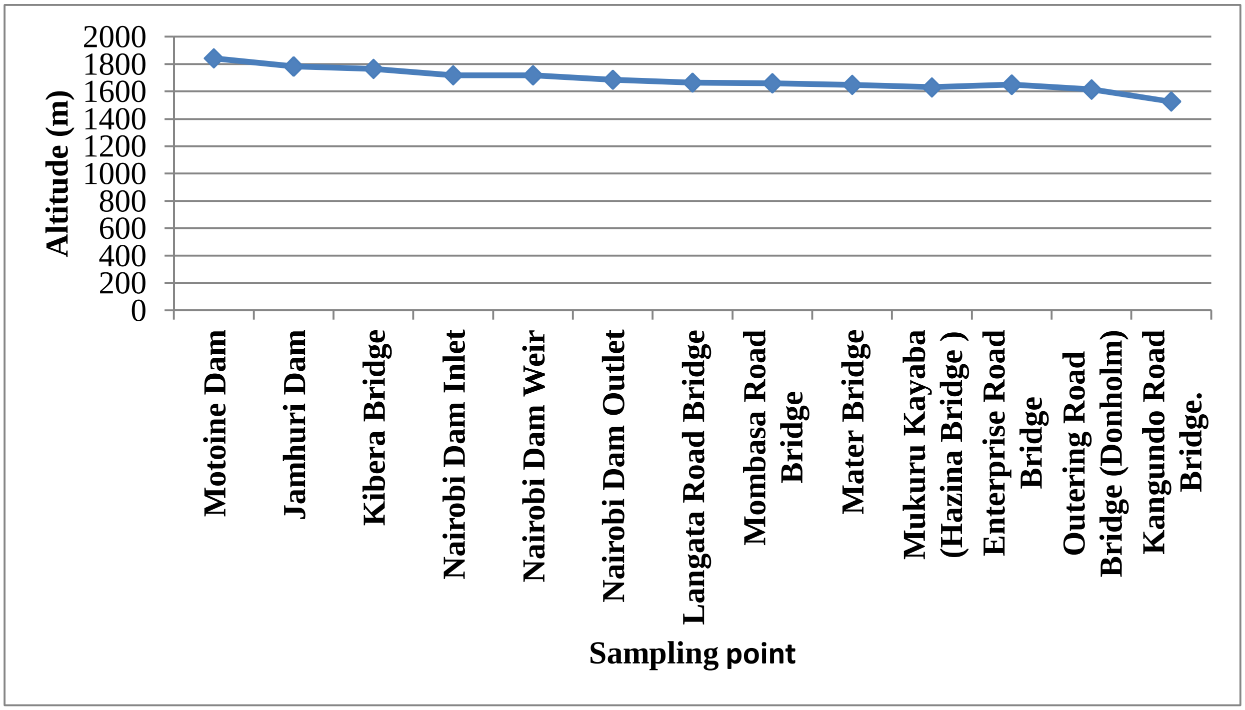


Figure 1.2: Ngong-Motoine River elevation profile

1.9.5 Social economic activities

Ngong- Motoine River system traverses trough residential areas heavily marked by slums, middle income estates and the industrial area. The slums are overcrowded and consist of permanent slum dwellers, non-resident land lords, temporary job seekers and business owners. According to Central Bureau of Statistics (CBS 2010), the 1999 and 2009 census had the biggest social group is that of the tenants or sub-tenants who expect to move out the slums upon improvement of their social economic status. Slum residents are predominantly of low income earners.

A significant part of the population work as casuals in the industrial area, employed as domestic staff and security guards. Residents in the middle class sections of Ngong Road, Langata, Nairobi West, South C, South B, Donholm, Kayole and Kangundo are employed mostly on permanent basis in Nairobi City and its environs. The industrial area section is characterized by the engineering workshops and manufacturing industries ranging from big to cottage enterprises. Farming activities along the river profile are of small scale for subsistence use and sale. These include vegetable, sugarcane, arrow root farming and small scale livestock husbandry which include, pigs, cattle, goat, sheep and chicken.

Educational facilities along the river system are majorly private owned either by the churches, NGO’s or individuals. The existing schools have been overwhelmed by the increasingly growing population in the informal settlements. The quality of education in these schools is low compared to county government schools in the surrounding area [Ndede, 2002]. There are no adequate public health facilities in the study area. Health facilities are privately owned and some are owned by Non-Governmental Organizations. Occasionally, there are mobile health clinics conducted by the ministry of health; public health department [Ndede, 2002]. The area is characterized by mixed religion consisting of dominantly Christians and Muslims.

1.9.6 Climate

This study used the Kenya Meteorological Department (KMD) 2009, 2010 and 2011 meteorological data obtained from Wilson Airport, Dagoretti and Jomo Kenyatta International Airport Meteorological Stations to describe the climate of the study area to compare the effect of climate variability in relation to the pollution characteristics. The data were obtained from The Kenya Meteorological Department (KMD) and are presented in detail in appendix 20. The study was characterized by two rains seasons (wet and dry). The wet season starts in mid- March to mid-May and the dry season from December- mid-March. The river system cuts across three distinct physiographic sections (upper, middle and lower).

The data for the upper section of the river system was collected from the Dagoretti meteorological station, for the middle from Wilson Airport metrological station and the lower part from Jomo Kenyatta international airport meteorological station. From the data obtained, the upper section of the river forms the wet part of the river with an average annual rainfall ranging from 500 – 1285 mm while the middle section ranges from 500-1096 mm annually and the lower section ranging from 300- 630 mm annually. Thus on average, Ngong–Motoine River system receives an annual rainfall ranging from 600-

1000 mm. High maximum daily temperatures were experienced in the lower section of the river system ranging from 29.1 °C to 23.5 °C .

The middle section had daily maximum temperature ranging from to 22.6 ^{o}C to 28.4 ^{o}C and minimum daily temperatures ranging from 16.5 ^{o}C- 12.4 ^{o}C. The upper section recorded the lowest temperature with the daily maximum temperatures at the height of 21.6 ^{o}C to 27.9 ^{o}C and minimum daily temperatures ranging from 10.5 ^{o}C to 15.7 ^{o}C. Daily maximum Relative humidity (RH) at 06 Z (0900hrs) in the basin ranges from 81% RH to 87% RH and daily minimum ranges from 64 % RH to 74% RH. At 012 Z (1500hrs), daily maximum relative humidity ranges from 63%-51% and daily minimum ranges from 32% to 41%. Daily evaporation in the basin ranges from 15.1 mm to 2.5 mm.

The meteorological data obtained from the Kenya Meteorological Department clearly indicates that the upper and middle sections of the river system are wet with lower temperatures and relatively lower relative humidity. The lower part of the river is relatively dry with high temperatures and high relative humidity [KMD, 2012]. This is well demonstrated by the variability in pollution concentrations downstream the river system.

CHAPTER TWO

LITERATURE REVIEW

2.1 GIS Applications in Natural Resources Management

According to Teefelen and co-workers (1992), the use of Geographical Information System (GIS) facilitates easier and quicker solutions for technically complicated time consuming geographical problems. This is a powerful computer tool that is used for storing, retrieving, transforming and displaying spatial data of many kinds and is rapidly becoming a key technology for the automated capture, management, analysis and presentation of location- referred data all over the world [Ottens, 1992].

This ability to store and retrieve data about special aspects of the earth, the way people live and the potential to use these data in models of environmental and socioeconomic process in order to learn more about the possible outcomes of natural trends, planning decisions or disaster is not only very important for industrialized countries but also for the developing world [Burrough, 1992].

There are many actual and potential applications for GIS in developing countries ranging from resource inventory and monitoring through land use planning, land evaluation, biological control and health studies, irrigation, pollution and drainage, social and economic planning, disaster avoidance, management of conservation areas and parks to tourism [Burrough, 1992]. In Kenya, the use of GIS is limited. The reasons for this include the high cost of computer hardware and software necessary to set up a GIS station and lack of trained manpower coupled with the high cost of the training courses

[Yimbo, 1992]. Acquisition of georeferenced data is also an expensive undertaking, including the data management and dissemination. Another limitation is poor consumer awareness which means less demand for the products and services of GIS. These limitations notwithstanding, GIS has been used in Kenya for several projects with good result, for instance, in compiling the National Water Master Plan.

The Kenya Wildlife Services (KWS) uses GIS for managing the large volumes of data relating to wildlife census, vegetation and land use dynamics, infrastructure, security and planning of operations [Kariuki, 1992]. The Department of Resource Surveys and Remote Sensing makes use of GIS and Remote Sensing [Ottichilo, 1986] spatial data management and handling, for natural resource inventories (forest cover, wildlife and livestock populations and environmental parameters) and information on land use, crop cover and yield, including crop production forecast. GIS has also been used to prepare the National Environment Action Plan and to monitor a development programme in Laikipia District [Hoesli, 1995].

2.2 Sources and effects of nitrates, phosphates and sulphates in the environment.

2.2.1 Nitrogen and nitrates in the environment

According to Vitousek *et al*. [1997], Nitrogen (N) is a key component to life processes and its global cycling is possibly the most altered biogeochemical cycle on earth. Human impact on the N cycle is manifested in numerous ways, including a doubling transfer of atmospheric N into biologically available N, increased global concentrations of the greenhouse gas N_2O, increased smog and acid rain, acidification of ecosystems, declines in biodiversity and increased plant uptake of CO_2 [Vitousek *et al*., 1997]. Increased global populations and relatively in-expensive synthetic N fertilizer have caused world agriculture to greatly rely on N fertilizers to increase crop yields [Pierzynski *et al*., 2005].

The manufacture of fertilizer is the greatest anthropogenic source of fixed N to the environment [Holland *et al*., 2005]. Plants take up N in the form of ammonium (NH_4^+) or Nitrate (NO_3^-) with nitrate generally being the form which becomes an environmental concern if it is not consumed by plants or microbially assimilated. Ammonium that is not used in soil biological processes is generally retained on cation exchange sites, volatized into NH_3, or nitrified into Nitrate. Since Nitrate is an anion that is highly soluble with virtually no retardation in soil water, it is a major leaching concern and the most commonly observed contaminant in groundwater [Nolan and Stoner, 2002].

Other than inorganic fertilizers, Nitrate has other numerous anthropogenic sources including septic drain fields, animal feeding operations and atmospheric deposition. Due to the wide variety and non-point of nitrate, it is a problematic surface and ground water contaminant. Korum [1992] noted that ‘‘Nitrate can follow a number of fates after it exits the root zone, including microbial assimilation, gentrification and Dissimilatory Nitrate Reduction to Ammonium (DNRA)”. Figure 2.1 Illustrates microbial transformation of nitrogen [Pett-Ridge *et al*., 2006].

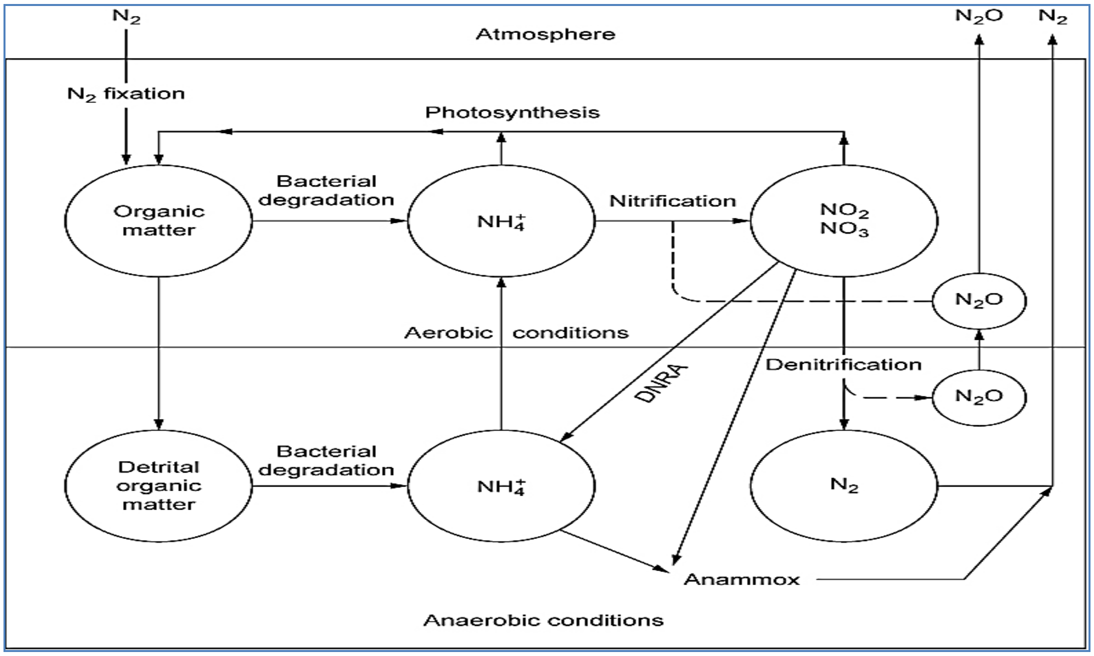


Figure 2.1: Microbial transformations in the nitrogen cycle

2.2.2 Health Effects of Nitrates

Among infants, high level of nitrates causes a condition called methemoglobinemia or blue baby syndrome which is associated with lack of oxygen in the body [Carlson *et al.*, 1970]. Thousands of cases of this condition have been reported worldwide since its initial diagnosis in 1945 [Fan *et al.*, 1987].

Nabukeera and Mworonzi [2012] reported a case of methemoglobinemia on a three and a half year old Ugandan child as a case report “sudden onset of methaemoglobinaemia” in the Pan African Medical Journal. In Kenya, no case of blue baby syndrome has been documented. Overall, the major health effects of high levels of nitrate in drinking water include methemoglobinemia, cancer, disruption of thyroid function and birth defects [Bouchard *et al.*, 1992].

2.2.3 Phosphorus and phosphate in the environment

According to McKelvie [2000], phosphorus is a trace element and the eleventh most abundant on the earth's crust, found commonly as part of a phosphate molecule (PO_4^{-3}). On earth, total phosphorus concentrations in soils range from 200 to 5000 mg P/kg soil, averaging to 600 mg P/kg soil [Kuo, 1996]. Major sources of phosphorus in the environment are; weathering, non-point sources (fertilizers from farm lands) and surface runoff, and point sources such as municipal and domestic sewers discharge and industrial effluent.

In water bodies, the predominant species of P is orthophosphate (o-PO_4^-), which is found in its mono- or diprotonated forms (HPO_4^{2-}, $H_2PO_4^-$) [Spivakov *et al.*, 1999]. Other than the mono and deprotonated forms of Phosphates, polyphosphates and organically bound phosphates (OP) found in natural waters are either dissolved or in particulate form [Spivakov *et al.*, 1999]. The polyphosphate and o-PO_4 are referred to as inorganic phosphorus (IP). Figure 2.2 shows a simplified phosphorus cycle [Spivakov *et al.*, 1999].

Håkanson and Jansson [1996] suggested that, as large amounts of P entering water bodies eventually settle down in sediments. Later, Kuo [1996] noted that, once the P reaches the bottom of a water body, physiochemical and biological reactions/processes in sediments act in concert and regulate P solubility, which in turn affects surface water.

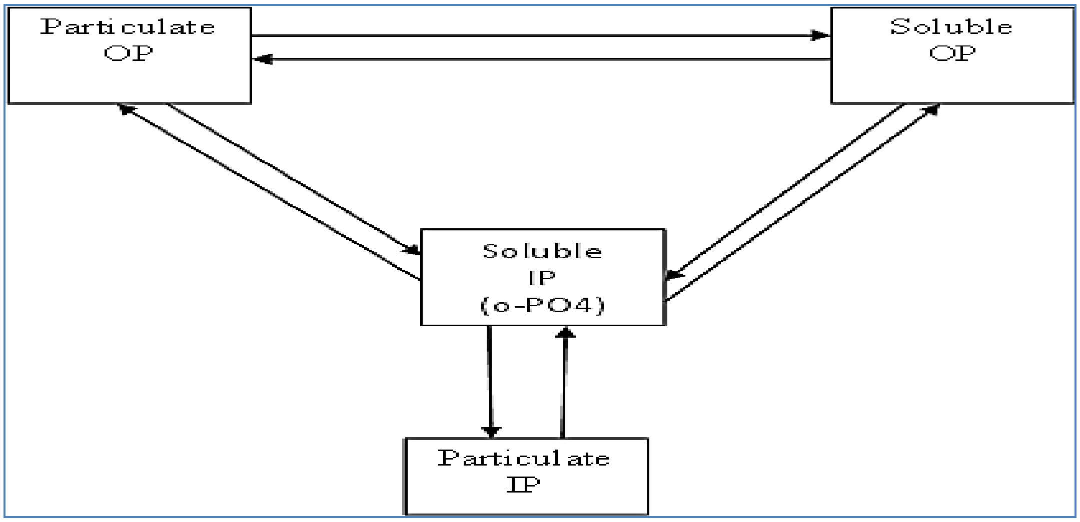


Figure 2.2: Simplified phosphorus cycle

2.2.4 Health Effects of phosphates

High levels of Phosphates in water for drinking courses digestive problems. According to the World Health Organization [2006] maximum safe limits for phosphates in drinking water is 5 mg/L, while for the USEPA [2002] water quality criteria for phosphates should not exceed 0.1 mg/L for streams which do not empty into reservoirs, and no more than 0.05 mg/L for streams discharging into reservoirs, and no more than 0.025 mg/L for reservoirs.

2.2.5 Sulphur and sulphates in the environment

Sulphur is the 14th most abundant element in the earth's crust tied up in rocks and buried deep in the oceanic sediments. It is also found in the atmosphere as a result of natural sources (volcanic eruptions, bacterial processes, evaporation from water and decaying organisms) and anthropogenic sources (industrial processes where sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) gases are emitted) [Greenwood & Earnshaw, 1984].

Volcanic and sedimentary deposits such as, barite ($BaSO_4$), pyrite (FeS_2), epsomite ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$) are the principle natural sources of sulphur [Greenwood & Earnshaw, 1984]. Sulphate is produced in the environment from oxidation of elemental sulphur, sulphide minerals or organic sulphur. According to Drever [1988], sulphur dioxide in the air can react with atmospheric water to produce sulphuric acid, resulting in acid rain which can lead to increased soil acidity and elevated levels of sulphate in ground water. Figure 2.3 illustrates the flow of sulphur compounds in the environment [Bickle *et al*., 1994].

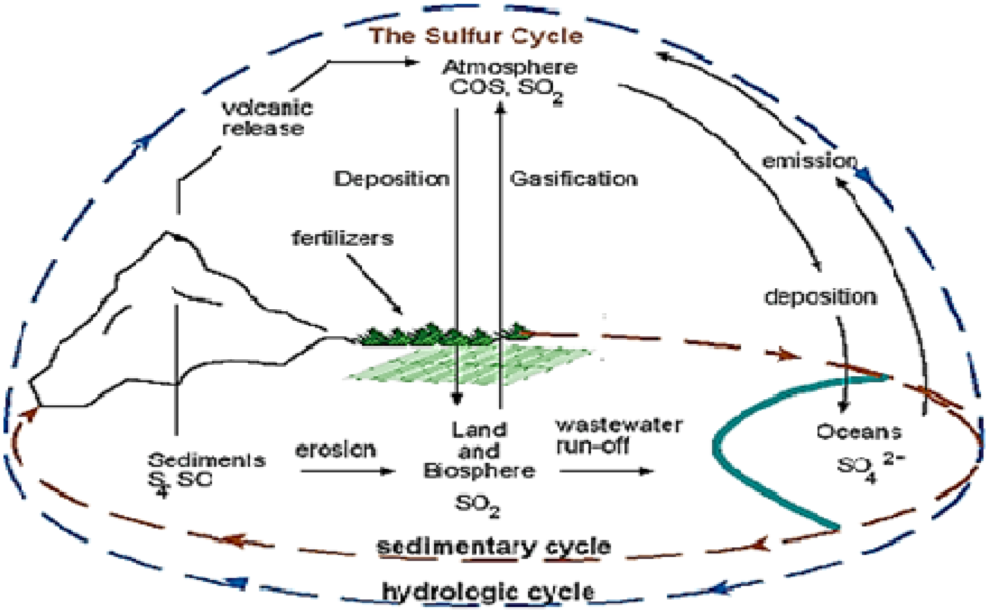


Figure 2.3: The flow of sulphur compounds in the environment.

2.2.6 Health effects of sulphates

According to the USEPA [1979], sulphates have a maximum contaminant level of 250 mg/L based on aesthetic effects (i.e. taste and odour). Backer [2000] reported the occurrence of osmotic diarrhoea and loose stools as a result of high intake of sulphates consumed in water. Osmotic diarrhoea and loose stools have been reported with high intakes of sulphate consumed in water [Backer, 2000]. Laxative effects have been reported to be experienced by people consuming drinking water containing sulphate in concentration exceeding 600 mg/L [Chien *et al*., 1968], although it is also reported that humans can adapt to higher concentrations with time [USEPA, 1979].

2.3 Combined effects of Nitrates and Phosphates on the Environment

2.3.1 Eutrophication

Khan and Ansari [2005] defined eutrophication "as the sum of the effects of excessive growth of phytoplankton's leading to imbalanced primary and secondary productivity and a faster rate of succession from existence to higher serial stage, as caused by nutrient enrichment through runoffs that carry down over used fertiliser from agro ecosystems and/or discharged human waste settlements". The word eutrophication is borrowed from the Greek words *eu* meaning "well" and *trophic* meaning "nourishment".

Rapid urbanization, industrialisation coupled with increased agricultural production has greatly increased nutrient input in water bodies. Water eutrophication can be greatly accelerated by human activities that increase the rate of nutrient input in a water body [Lui and Qui, 2007]. Western [2001] noted that, "influence of the human activities, excessive nitrogen, phosphorus and other nutrients are loaded into water bodies like lakes, rivers and reservoirs, which cause negative ecological consequences on aquatic ecosystem structures, processes and functions resulting in the fast growth of algae and other plankton, and deteriorate water quality."

Water eutrophication is caused by the autotrophy algae blooming in water, which composes its bioplasm by sunlight energy and inorganic substances through photosynthesis. According to Mainstone [2002], the process of eutrophication can be described as follows:

$$\mathbf{106CO_2 + 16NO_3^{-} + HPO_4^{2-} + 18H^{+} \xrightarrow{\text{Energy +Microelements}} C_{106}H_{263}O1_{10}N_{16}P\ (Bioplasm\ of\ algae + 138O_2} \text{...............}\textbf{Equation 2.1}$$

From the above equation, inorganic nitrogen and phosphorus are the major control factors for the propagation algae in water bodies.

2.3.1.1 Impacts of eutrophication on river ecosystem

Eutrophication is one of the main causes of stream and rivers impairment and imposes severe threats to ecosystem structure and function [Welch and Crook, 1987]. The direct impact of nutrient enrichment is to increase autotrophic production and change species including proliferation of filamentous green algae that alters the flow environment, physical benthic habitat used by stream invertebrate organisms and releases toxins that render the organic matter in water to be decomposed into harmful gases [Welch and Crook, 1987].

Allan [2004] noted that nutrient enrichment in streams and river as a result of land use change accelerates litter breakdown rates by bacteria and fungi. As nutrient concentrations increase and destabilize the primary producer assemblage and water chemistry, macro invertebrates and fish may shift from sensitive species to more tolerant, often non-native species. Changes in the food web may also cause changes in ecosystem function and further alter stream physical habit and water chemistry, e.g. decreasing dissolved oxygen.

Sand-Jensen and co-workers [1997] found that excessive eutrophication can break out the intrinsic equilibrium of the aquatic ecosystem and lead to the damage of the water ecosystem. As a result, it affects the water quality and reduces transparency consequently limiting the growth of submerged aquatic plants, decreasing available habitat and shelter for fish and their food organisms. Also, eutrophicated river systems accumulate large amounts of organic carbon causing a shift in organic matter biochemical composition [Dell'Anno *et al*., 2002].

2.3.1.2 Health effects of eutrophication

Eutrophication causes a shortage in supply of drinking water by degrading water quality. When the accumulated algae, periphytons and macrophytes die, they produce toxin which are harmful to human health [Carmichael, 2001]. These toxins include Cyanobacteria toxins (cytotoxins and biotoxins) which are responsible for; lethal, acute, chronic and sub-chronic poisons of wildlife/domestic animals and humans.

The biotoxins include the neurotoxins; anatoxin-a, anatoxin-a(s) and saxitoxins plus the hepatotoxins; microcystins, nodularins and cylindrospermopsins [Carmichael 2001]. Yu and Len [2004] detected Cyanotoxins in Yangtze River as well as many reservoirs and lakes in Yellow River basin in China. Also, increased nitrite concentrations in the eutrophic water are dangerous to human health as products of nitrite nitrification process are strongly carcinogenic [Dell'Anno *et al*., 2002].

2. 4 Summary of literature review and gaps identified.

In summary, the deterioration of surface and ground water quality is attributed to both natural processes and anthropogenic activities including; hydrological features, geology, climate change, seasonal variation of climatic features, agricultural land use, human settlement, industrialisation and sewer discharges [Ravichandran, 2003; Gantidis *et al*., 2007; Kundewicz *et al*., 2007; Arain *et al*., 2008]. As a consequence, pollution has become a growing concern to human society and natural ecosystems. This has led to the increasing need for better understanding of the spatial and temporal variability of pollutants within aquatic systems.

Caccia and Boyer (2005) and Zhang *et al.,* (2007) noted that research on spatial and temporal variations of river water quality has been conducted in many basins worldwide and the results show that water quality issues such as eutrophication in river systems are highly dependent on land use patterns, influence from water shade run-off discharges, industrial effluent discharges, human waste disposal, urbanization and sewer systems malfunction.

In Kenya, several studies have been conducted on the effects of human and industrial activities on several basins. According to Geoffrey [2006], In addition to Nairobi River Basin Programme phase I, II and from 2007, the World Bank under the Ministry of Environment and Mineral Resources has been implementing a Programme within the Lake Victoria basin (Lake Victoria Environmental Management Programme phase I and II) in the East Africa community aimed at reducing environmental stress in targeted pollution hotspots and selected degraded sub-catchments as a means of improving livelihoods of communities who depend on the natural resources within the basin with a focus on restoring the water quality in lake Victoria. These studies have been marked with almost similar challenges.

The pilot study on Ngong-Motoine river system under the second phase of Nairobi River Basin programme to establish major point source of pollution by NETWAS in conjunction with the University of Nairobi and Nairobi City Council did not achieve its objective as a result of gaps ranging from lack of reliable monitoring pollution loading datasets, inconsistency of sampling points location, omission of some of the parameters over years.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Design

Experimental study design was applied for this research. Field samples were collected and subjected to treatment, transportation, storage and systematic analytical procedures under controlled conditions to minimize on errors on obtained results.

3.1.1 Field Methods

This study was designed to collect water and sediment samples from selected sites along Ngong-Motoine River system during the dry and wet seasons. The goal was to determine the temporal and spatial variations of phosphates, nitrates and sulphates concentrations in water and sediments and Escherichia coli (E. coli) pollution in water. Selection of the study sites was done with consideration of the river profile, the use of water for agricultural activities and influence of human settlement and industrial activities along the river.

Based on these facts, thirteen sampling points (at least 100 meters from each other) were located using a 12 channel Global Positioning System Navigator (Germin 12x GPS). Water and sediment samples were collected between 16th to 18th January 2012 and 2nd to 5th May 2012 and the analytical research results for each parameter (mean value per sampling point) were used as input data in ArcGIS. 10.1 and respective colour coded maps developed. Table 3.1 summarises the characteristics of the sampling points.

Table 3.1: Location of Sampling Points

Sampling site	Altitude (m)	Latitude	Longitude	Location	Sampling site justification
Motoine Dam	1842	1.30855 S	36.72348 E	Southern Bypass Off Ngong Road	This point provided the influence of surface run-off from agricultural fields, animal husbandry, human settlement from the larger Dagoretti and Ngong areas to the water and sediments quality.
Jamhuri Dam	1782	1.30746 S	36.76965 E	Jamhuri Park (ASK Show Ground)	This point provided the influence of surface run-off from human settlement in Jamhuri area and Ngong Road and the Nairobi international trade fair grounds (animal husbandry and garden farming) to the water and sediments quality change.
Kibera bridge	1765	1.30957 S	36.77187 E	Next to Jamhuri Park (ASK Show Ground)	This point provided the influence of human activities and domestic waste effluents discharge from Kibera slum to the water and sediments

					quality change. The slum residents at this point utilize this water for bathing, washing clothes and animal husbandry etc.
Nairobi Dam inlet	1718	1.31983 S	36.80119 E	Adjacent to Kibera slums and Ng`eno estate	This point provided the effects of domestic waste effluents discharged from Kibera slums and agricultural farm lands that use such water to the water and sediments quality change. It also helped to determine the effects of nutrient loading to the Dam.
Nairobi Dam weir	1718	1.31873 S	36.79346 E	Next to Nairobi Dam estate and Kibera slums	This point assisted in the evaluation of the rate and effects of nutrient loading to the Dam and their contribution to eutrophication.
Nairobi Dam outlet	1685	1.31509 S	36.80941 E	At the spill way Next to Nyayo High rise Estate	This point evaluated the effect of eutrophication and its power to reduce or increase pollutants concentration from water and sediments.
Langata Road	1664	1.31518 S	36.80945 E	Across Langata	This point provided the influence of human

bridge				Road next to shell petrol station near Mbaghathi Road round about.	settlement to the water and sediments quality from Kenyatta market, Ngumo estate, Highrise estate Mbaghathi area and the rate of water pollution by use of organic and inorganic fertilizer for flowers and tree nurseries that are located along the river at this point.
Mombasa Road Bridge	1659	1.31138 S	36.81705 E	Next to International Christian Church (ICC)	This point evaluated the influence of human settlement from Mbaghathi area, Nairobi west and pollution from garages lined up along the river to the water and sediments quality.
Mater Bridge	1648	1.30814 S	36.83294 E	South B next to Mater Hospital	This point evaluated the influence of waste effluents discharged from car garages that are lined up along this section to the water and sediments quality.
Mukuru	1630	1.31607 S	36.86185 E	Inside Mukuru	This point evaluated the influence of domestic

kayaba (Hazina Bridge)				Kayaba slums towards Hazina south B	waste effluents discharged from Mukuru slums Hazina and South B estate to the water and sediments quality.
Enterprise Road bridge	1649	1.24841 S	36.946 E	On enterprise Road near Road A	This point evaluated the influence of industrial waste effluents discharged from industries to the water and sediments quality.
Jogoo Road Bridge (Donholm)	1614	1.30607 S	36.88941 E	Outering Road at Donholm	This point evaluated the influence of domestic waste effluents discharged from Sinai slums and industrial effluent discharged from industries to the water and sediments quality.
Kangundo Road Bridge.	1526	1.30607 S	36.88943 E	Along Kangundo Road near Njiru town	This point evaluated the influence of domestic waste effluents discharged from the expansive Donholm estate, Baraka slums, Kayole estate and Komarock estate and agricultural farm lands along the river to the water and sediments quality. .

3.1.2 Water sample collection and storage.

Grab water sampling method was used during sample collection. Water Samples were collected in 5 litres new Polyethylene Terephthalate (PET) pre-cleaned with tap water and later soaked in 10% HNO_3 for 3 days (72 hours) and finally rinsed with deionizer water. During sampling, the bottles were rinsed with the sample three times then direct immersed in the middle of the river at each sampling site using a tree branch.

The samples were preserved following the standard methods of water sampling and preservation techniques [APHA, 1998; Hutton, 1996]. Samples were tightly capped, labelled to show the site name, sample location and GPS co-ordinate reference number; date and time of sampling and preserved using icebox and transported to the Kenya Industrial Research and Development institute laboratories within 6-9 hours after sample collection. The samples were stored in the refrigerator below 4 ^{o}C.

3.1.3 Sediment sample collection and storage

Sediments samples were collected by grab method using a shovel by scooping from the bed of the river, put into pre-cleaned dried polythene bags and transported to the laboratory together with the water samples. Sediment samples collected from each site were at least 3 kg. Following collection, sediment samples were labelled to show the site name, sample location and GPS co-ordinate reference number, date and time of sampling. In the laboratory all the sediments were kept in the refrigerator below 6 ^{o}C.

3.2 Laboratory methods

3.2.1 Laboratory equipments, chemicals and reagents

Several instruments and equipment's were used in this study for both water and sediment analysis including , Cary 50 UV-Visible spectrophotometer and UV-VIS quartz cell for colorimetric analysis of samples, Kern-ABJ 0.1 mg-320 mg analytical balance for all weighing, Nabatherm muffle furnace (30-1100 ^{o}C) for ashing, Compilac sand bath for digestion of samples, drying oven for drying glassware and sediment samples, incubator 37±1 ^{o}C for microbiological incubation, Autoclave, Platinum crucibles, water bath 45.5± 0.05 ^{o}C, Petri dishes, measuring cylinders 50-100 ml Pyrex beakers, conical flasks 50-1000 ml, wash bottles, filter funnels, Whatman filter papers (No. 41), ash less filter paper, volumetric flasks 25-1000 ml, graduated pipettes 1-25 ml, graduated measuring cylinders 25-1000 ml, Durham tubes , test tubes and desiccators.

Analytical grade chemical and reagents used in this study include; anhydrous KH_2PO4 for the preparation of stock solution for phosphates analysis, dry KNO_3 for the preparation of stock solution for nitrates analysis, phenolphthalein indicator, 1:1 hydrochloric acid (HCl) for digestion of both sediments and water for analysis of phosphates and sulphates in both water and sediment samples, ammonium molybdate for complexion of phosphates, 10% barium chloride ($BaCl_2$) for precipitations of sulphates, 1 N hydrochloric acid (HCl) for acidifying the sample for nitrates analysis and distilled water, MacConkey broths (lactose) and bromocresol purple indicator.

3.2.2 Quality Control and assurance

To ensure quality and control, each procedure in this study was standardised and done the same way each time for every sample to ensure reproducibility. Quality assurance and control measures were undertaken to demonstrate the accuracy and precision of the results obtained. This was performed by validating analytical methods as per the Standard for Examination of Water and Wastewater [APHA, 1998] for each parameter, using analytical grade reagents, ensuring cleanliness of glassware and apparatus used and regular analysis of procedural blanks for each parameter. Samples were analysed in triplicates to test the precision of the results and by regular analyses of procedural blanks.

3.2.3 Samples analysis

All the samples were analysed using the American Public Health Association; Standard Methods for the Examination of Water and Wastewater [APHA, 1998] in which phosphates were analysed by vanadomolybdophosphoric acid colorimetric method, Sulphates were analysed by gravimetric method with ignition of residue, nitrates were analysed by ultraviolet spectrophotometric screening method and *E. coli* pollution in water was determined by multiple tube formation microbiological MPN method.

3.3 Analysis of water samples

3.3.1 Phosphates analysis in water

Phosphate analysis in water samples was carried out by the conversion of the phosphorus into dissolved orthophosphates and calorimetric analysis of the dissolved phosphates. Total reactive phosphate in the samples was determined in triplicate per sample. This analysis was based on the fact that, in a dilute orthophosphate solution, ammonium molybdate reacts under acid conditions to form a heteropoly acid, molybdophosphoric acid and in the presence of vanadium, yellow Vanadomolybdophosphoric acid is formed. The intensity of the yellow colour formed is proportional to phosphate concentration.

3.3.1.1 Preparation of standard phosphate solution

Standard phosphate solution was obtained by making standards of anhydrous KH_2PO_4 (219.5 g) in 1000 ml distilled water; (1 ml=50.0µg PO_4^{3-}P). This was followed by dilution of 2,4,6,8 and 10 ml of stock solution to 50 ml by distilled water to make 2, 4, 6, 8 and 10 ppm working solutions. These solutions were reads using the Cary 50 UV-Visible spectrophotometer at 430 nm. Appendix 2 shows the phosphates calibration curve obtained by plotting the resultant absorbance against concentration (ppm).

3.3.1.2 Procedure

Each water sample was filtered and 50 ml of filtrate was added with 0.5% (1 drop) phenolphthalein indicator solution then digested by adding 20 ml of 1:1 hydrochloric acid solution and put on a hot sand bath for 40 minutes. The digested samples were then filtered and 35 ml of the filtrate was transferred into a 50 ml volumetric flask and 10 ml of ammonium molybdatemetavanadate (vanadate-molybdate reagent) was added and the solution diluted to the mark with deionised water. A blank was prepared by substituting the samples with 35 ml deionised water and 10 ml molybdatemetavanadate. The blank was used to set the UV spectrophotometer to zero and the absorbance of the samples were read against a series of freshly prepared standards after allowing for the colour to develop in 10 minutes using Cary 50 UV-Visible spectrophotometer at 430 nm.

3.3.1.3 Calculation of phosphate concentration in water

Phosphorus (mg/L) in water samples were calculated using the following formula below [APHA, 1998].

mg/LP= ppm x 1st Volume made x 2nd Volume made/Volume of sample taken x Aliquot taken…………………………………………………………..Equation 3.1

Phosphates (mg/L) were calculated using the following formula

Mg/LPO$_4$ =mg/L P x final vol. x Gravimetric Factor (P to PO$_4$) / Aliquot taken……………………………………………………………………Equation 3.2

Where

mg/LPO$_4$ = milligrams per liter of reactive phosphates

Final volume = 50 ml of the sample made after digestion

mg/LP = Concentration of phosphorus read on the UV spectrophotometer

The gravimetric Factor (GF) for P to PO$_4$ is given as Relative Molecular Mass for PO$_4$ / Relative Molecular Mass P= 3.0661

Aliquot taken = 35 ml of the sample taken from the 50 ml final volume.

3.3.2 Sulphates analysis in water

Sulphates analysis in water was carried out by gravimetric method with ignition of residue in duplicates. The analysis was based on the principle that sulphate is precipitated in a hydrochloric acid (HCl) solution as barium sulphate ($BaSO_4$) by the addition of barium chloride ($BaCl_2$).

3.3.2.1 Procedure

50 ml of each sample was filtered, 20 ml 1:1 HCl was added, placed on the sand bath and allowed to boil. After boiling, the samples were filtered, 20 ml of 10% barium chloride was added and returned to the sand bath to boil overnight to form precipitate. The formation of a white precipitate confirmed the presence of barium sulphates ($BaSO_4$). The precipitate was filtered using an ashless Whatman filter paper number 41 then washed several times with deionised water until free from chlorides.

Platinum crucibles for each sample were washed then put in a muffle furnace at 750 ^oC to dry then cooled and weighed using a Kern analytical balance. The weights of empty platinum crucibles were taken. The ashless filter paper containing $BaSO_4$ precipitates for each sample were then put on a cool pre-weighed platinum crucible then ignited at 750 ^oC for one hour in a muffle furnace. The crucibles were removed and allowed to cool then weighed until constant weight obtained.

3.3.2.2 Calculation of sulphates concentration in water

The following formula was used to calculate mg/L SO_4^{2-}

mg/L SO_4^{2-} = wt. of $BaSO_4$ x Gravimetric Factor (0.4116) x 1000/Volume of sample taken…………………………………………………………………....Equation 3.3

4.3.3 Nitrates analysis in water

Nitrates in all samples were analysed in duplicate using the Ultraviolet spectrophotometric screening method in which measurements of UV absorption at 220 nm enables rapid determination of NO_3^- because dissolved organic matter also may absorb at 220 nm and NO_3^- does not absorb at 275 nm, a second measurement made at 275 nm may be used to correct the NO_3^- value**.**

3.3.3.1 Calculation of Nitrates concentration in water

The concentration of nitrates in water samples were determined by taking absorbance's at 220 nm minus twice absorbance at 275 nm then multiplied by the mean transmittance as illustrated in Table 3.2 . The nitrates calibration curve is presented in appendix 3.

Table 3.2: Nitrates calibration curve data

Concentration (ppm)	Absorbance	transmittance	Mean transmittance
2	0.1214	16.47	16.23
4	0.2454	16.30	
6	0.3813	15.74	
8	0.4886	16.37	
10	0.6141	16.28	

3.3.3.2 Preparation of standard nitrate solution

Standard nitrate solution was prepared by drying KNO_3 in an oven at 105 ^oC for 24 hours. 0.7218 g of the dry KNO_3 was dissolved in distilled water and diluted to 1000 ml (1 ml = 100 ppm NO_3) to make a stock solution. Out of the stock solution, 2,4,6,8 and 10 ml were taken and made to 100 ml each to make working solutions of 2,4,6,8 and 10 ppm. These solutions were read using the Cary 50 UV-Visible spectrophotometer. The calibration curve presented in appendix 3 was obtained by plotting the resultant absorbance against concentration (ppm).

The curve generated obeys the Beer-Lambert Law which is the linear relationship between absorbance and concentration of an absorbing species. The general Beer-Lambert law is usually written as:

$A = \varepsilon l C$ ……………………………………….………...………..…..Equation 3.4

Where

A is absorbance (no units, since $A = \log_{10} P_0 / P$)

P_0 is the radiant power of monochromatic radiation directed at a sample solution

P is the radiant power for the beam of radiation leaving the sample.

ε (epsilon) is the molar absorptivity (a constant that indicates how well the species absorbs light of a particular wavelength, in units of M^{-1} cm^{-1}).

l is the path length that the light must travel through the solution (1.00 cm for the cuvet),

C is the concentration of the compound in solution (in mol/L).

Transmittance, $T = P / P_0$ = Concentration (ppm)/Absorbance

3.3.3.3 Procedure

All the samples were filtered to remove possible interferences from suspended particles then 50 ml of the filtrate taken from each sample and treated with 1 ml of 1 N HCl to prevent interference from hydroxide or carbonate concentrations up to 1000 mg $CaCO_3$/L by shaking thoroughly. A blank was also prepared in the same way by taking 50 ml of distilled water and adding 1 ml of 1 N HCl. The samples were then read using a Cary 50 UV-Visible spectrophotometer at 220 nm first then at an advanced reading of 275 nm. The concentration of nitrates in the samples nitrates were determined by taking absorbance’s at 220 nm minus twice abs at 275 nm then multiplied by the mean transmittance from the calibration curve.

3.3.4 Escherichia Coli (*E. coli*) analysis in water

Water samples were analysed for *E.coli* as per APHA, (1998) Standard for Examination of Water and Wastewater. Multiple fermentation tube technique in which fermentation tubes containing double and single strength MacConkey broths (lactose) inverted with Durham tubes inoculated with measured volumes of water samples was employed. Using this method, the coliform bacteria present in the water sample multiply and are detected by formation of acid and gas.

This is followed by a confirmatory test for *E. coli* in which positive tubes are inoculated into a single strength MacConkey broth. From the number of tubes inoculated and the number with a positive reaction, the Most Probable Number (MPN) of bacteria present in the original water sample were determined statistically using the MPN index which was determined by comparing the pattern of positive results (the number of tubes showing growth at each dilution) with statistical table (Appendix 11). The tabulated value is reported as MPN per 100 ml of sample.

3.3.4.1 Procedure

Double strength medium was prepared by taking 80 g of MacConkey broth to I L of deionised water and single strength medium was prepared by taking 40 g of MacConkey broth to I L of deionised water. 10 ml of double strength medium was distributed into 5 test tubes and incorporated with inverted Durham tubes then plugged with cotton wool for each sample. five ml single strength MacConkey broth was also distributed in 10 test tubes then incorporated with inverted Durham tubes and plugged by cotton wool for each sample then all sterilised by autoclaving at 121 ^{o}C for 15 minutes then left to cool. Each water sample was mixed thoroughly (shaken) and from each, 10 ml was added into the prepared 10 ml double strength tube in the first row for each sample. In the second row of 5 ml single strength for each sample, 1 ml of each sample was added and to the third row of 5 ml single strength MacConkey broth for each sample, 0.1 ml of respective sample was added. A test tube of 5 ml single strength MacConkey broth was prepared as a control. All the tube on a rack were incubated in a water bath at 37 ^{o}C for 24hrs and the results for the tubes with and without acid and gas production were recorded as positive and negative respectively in all dilutions.

From each presumptive positive tube, a confirmatory test for *E. coli* was carried out by preparing 5 ml of single strength MacConkey broth, incorporating them with inverted Durham and carefully labelling and autoclaving at 121 ^{o}C for 15 minutes then allowed to cool. A wire loop was also sterilized using a Bunsen burner then used to pick a loop full of the culture from each positive tube, then cultured in the 5 ml single strength medium MacConkey broth. The wire loop was sterilized between successive transfers by heating in a flame until it is red hot and allowed to cool. The tubes were then incubated at 44 ^{o}C for 24 hours and then positive tubes were determined by the production of gas and acid which is present when the Bromocresol purple indicator changes the colour thus showing formation of lactose.

The results obtained were compared to the pattern of positive results with a most probable number table by comparing the pattern of positive results (the number of tubes showing growth at each dilution) with statistical tables. The tabulated value is reported as MPN per 100 mL of sample.

3.4. Analysis of sediment samples

3.4.1 Phosphates in sediment

Approximately one gram (crushed fine powder) of each sample was weighed on a fisher analytical balance in triplicate. To each 20 ml 1:1 hydrochloric acid was added and then put on a hot sand bath to digest. The sample was allowed to cool then filtered using a Whatman filter paper number 41 and washed thoroughly using distilled water to 100 ml. From the 100 ml. filtrate, an aliquot of 20 ml was taken and to it, 10 ml of molybdatemetavanadate was added and made to 50 ml by diluting with deionised water. A stable orange yellow coloured complex of vanado-molybdiphosphoric acid ($H_2PO_4.VO_3.11Mo.nH_2O$) was formed. A blank made in the same way was used to zero the spectrophotometer. The samples were then read after 10 minutes using a Cary 50 UV-Visible spectrophotometer at 430 nm.

3.4.1.1 Calculation of phosphate concentration in sediments

Phosphates (mg/L) in sediments were calculated using the following formula

% P= ppmP x 1st Volume made x 2nd Volume made x 100 x 10^6/ weight of sample taken x Aliquot taken………………..…………………………………..…Equation 3.5

% PO_4 =ppmP x final vol. x 2nd volume x Gravimetric Factor (P to PO_4) x 100 x10^6 / Aliquot taken x wt. of sample taken …………………………………….....Equation 3.6

Mg/Kg PO_4 = % (w/w) PO_4 x 10,000……………….……………………….…...Equation 3.7

3.4.2 Nitrates in sediments

Each sample was mixed thoroughly to homogenize them then part of it was taken on a Petri dish in the oven for drying. The samples were then cooled grounded to fine powder and a concentration of 10% was prepared by weighing approximately 10 g from each sample and leaching in 100 ml deionised water over night to with constant stirring. The supernatant was decanted and filtered then 50 ml of the filtrate was taken and treated with 1 ml of 1 N HCl and the samples were read a Cary 50 UV-Visible spectrophotometer at 220 nm and 275 nm. The concentration of nitrates in the samples were determined by taking absorbance's at 220 nm minus twice abs at 275 nm then multiplied by the mean transmittance from the calibration curve.

3.4.2.1 Calculation of Nitrates concentration in sediments

The concentration of nitrates in sediment samples were determined by taking absorbance at 220 nm minus twice absorbance at 275 nm then multiplied by the mean transmittance from the calibration curve.

$mLNO_3^-$ = Abs at 220nm - 2(Abs at 275 nm) x Calibration curve mean transmittance……………………………………………………………..Equation 3.8

$mg/KgNO_3^-$= $mLNO_3^-$ / Wt. of dry sediment sample taken X 1000 g/kg……………………………………………………………………...Equation3.9

3.4.3 Sulphates in sediments

Approximately one gram (ground fine powder) of each sample was weighed on a fisher analytical balance in duplicate. To each, 20 ml 1:1 hydrochloric acid was added and then put on a hot sand bath to digest. The samples were allowed to cool then filtered using an ash less Whatman filter paper number 41 and washed thoroughly using distilled water and made to the mark in 50 ml volumetric flask. 20 ml of 10% barium chloride was added and then returned to the sand bath to boil then left for overnight to precipitate. The formation of a white precipitate confirmed the presence of barium sulphates. The precipitate was filtered using an asheless filter paper then washed several times with deionised water until free from chlorides.

Platinum crucibles for each sample were washed then put in a muffle furnace at 750 ^{o}C to dry then cooled and weighed using a fisher analytical balance. The weights of empty platinum dishes were taken. The ashless filter paper containing $BaSO_4$ precipitates for each sample were then put on a cool pre-weighed platinum crucible then ignited at 750 ^{o}C for one hour in a muffle furnace. The crucibles were removed and allowed to cool then weighed until constant weight obtained.

3.4.3.1 Calculation of sulphates concentration in sediments

The following formula was used to calculate % SO_4^{2-} and mg/Kg SO_4^{2-}

% SO_4^{2-}=wt. of $BaSO_4$ x 0.4116 x 100/Weight of sample taken………....Equation 3.10

mg/Kg SO_4^{2-} =% (w/w) SO_4^{2-} x 10,000…………………………….…………Equation3.11

3.5 Data analysis

Water and sediments analytical results obtained were analysed in three stages; the first stage was to determine seasonal (temporal) variability in both water and sediments. The data was grouped according to dry and wet season. The second stage was to determine the variability of parameters in both water and sediments as water moves from upstream to downstream (spatial variability). The third stage was to determine temporal inter-parameter correlation in both water and sediments.

Water quality criteria standards and the related legislation were used to interpret water quality characterization. The most common national requirements are suitability of water quality for drinking and domestic purpose. In Kenya, water quality standards are based on the standards of World Health Organization (2006) guidelines for drinking water. The obtained analytical results evaluated the average mean values for each parameter and compared with the WHO allowable limits. Deviations from guidelines were discussed and interpreted in relation with the corresponding activities along the river profile.

3.6 Statistical analysis

The data were statistically analysed using Microsoft Excel QI wizard. Descriptive and inferential methods were used to interpret the obtained results.

3.6.1 Descriptive statistics

This study considered the central tendency of the obtained data (mean) and dispersions (variance and standard deviation) to display the variability of parameters in water and sediments in time and space. The results obtained have been presented as mean ± standard deviation (Mean ±SD).

3.6.2 Inferential statistics

Inferential statistics was used to test the hypothesis of the study and make inferences on spatial-temporal variability for parameters analysed in water and sediment samples. The null and alternative hypotheses were formulated as follows:

H_0: $\mu0=\mu1$: There is no significant difference in temporal and spatial parameter variation for water and sediments samples respectively.

H_1: $\mu0\neq\mu1$: There is significant difference in temporal and spatial parameter variation for water and sediment samples respectively.

One Way Analysis of Variance (ANOVA) at 0.05 significant level ($p<0.05$) was used to test the hypothesis of the means of samples to determine if the sites were significantly different from one another with respect to study variables.

3.6.3 Regression and Correlation Analysis

Regression and correlation analysis were conducted to determine the seasonal spatial and temporal correlations for the parameters analysed at 95% confidence limit and significant level of 0.05 ($p\leq0.05$).

3.6.4 Interpretation and Presentation of Results

After the descriptive, inferential and correlation analysis of the data, the results were presented in mathematical equations, tabular forms, graphical expressions; GIS map, objects and photo plates for easy interpretation. The results were triangulated with secondary research done by other scholars in areas of nutrient temporal-spatial variability in river water and sediments to compare the relevance of the study findings.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Resultant data on spatial and temporal variations of phosphates (PO_4^{3-}), nitrates (NO_3^-), sulphates (SO_4^{2-}) in water and sediment and *E.coli* pollution in water in a section of the Ngong-Motoine River showed changes in the levels along the river profile and seasonal differences. The data obtained suggests the likelihood of mixed sources of pollution including both point and non- point sources.

4. 1 Water analysis results

4.2.1 Spatial and temporal variations in phosphates levels in water

Phosphate levels a long Ngong- Motoine River system were significantly above the guideline limit of 0.5 mg/L (WHO, 2006) with increasing concentrations from upstream to downstream. In the dry season, increases in concentration were observed at Nairobi Dam Inlet at 7.17±0.01 mg/L with a peak of 11.34±0.01 mg/L at Nairobi Dam weir, with significant increase from Mukuru Kayaba Hazina Bridge at 7.67±0.01 mg/L, Enterprise Road Bridge at 7.68±0.02 mg/Land Kangundo Road Bridge at 7.64±0.04 mg/L (Appendix 4).

The sharp increase in phosphate levels observed at Kibera Bridge to Nairobi Dam inlet may be due to sewers discharges and use of phosphorus based detergents from Kibera slums (Plate 4) Ngeno estate and the larger Langata estates. Nairobi Dam weir had the highest levels of phosphate suggesting the potential cause of eutrophication which has entirely covered the Dam thus acting as a sink, hence leading to P accumulation (Plate 7).

The water hyacinth (*E. crassipes*) that has invaded Nairobi Dam significantly absorbs phosphates as it is evident in the results of water quality which had a concentration level in the range of 3.6±0.01 mg/L to 4.65±0.01 mg/L between Nairobi Dam outlet and Mombasa Road Bridge. The high level of phosphate at Langata Road Bridge (4.1±2.88 mg/L) as compared to Nairobi Dam outlet could be attributed to flowers and tree nurseries which are lined up from Mbagathi Road Bridge to Langata Road Bridge where the trees and flower venders use phosphate fertilizer and manure to grow flowers and tree seedlings.

The increase in levels of phosphate from Mukuru Kayaba all through to Kangundo Road Bridge could be attributed to informal settlement and industrial discharges which exhibit high levels of both raw sewage discharges (from both the slum and burst sewer lines) and industrial phosphates present in detergents heavily used for cleaning purposes. On the other hand, the high level of phosphate at Motoine Dam (3.07±0.00 mg/L) could be due to farming activities taking place in Karen and Dagoretti region whereby farmers apply phosphates fertilizers in their farms.

The steady increase in phosphate from Kibera Bridge to Kangundo Road Bridge could also be attributed to farming activities whereby farmers apply phosphate fertilizers in their farms, hence surface run-off from the farms could increase phosphate load in the river water. Jamhuri Dam had the lowest level at 1.59±0.01 mg/L which could also be attributed to the annual scattered farming activities around the Jamhuri show ground in the month of October.

Temporal variations showed that in the wet season, phosphate levels were above the guideline limit of 0.5 mg/L (WHO, 2006) with varying trends from upstream with a peak of 9.96±0.54 mg/L at Outer ring Road (Donholm) Bridge. This was closely followed by a high of 9.77±0.81 mg/L at Enterprise Road Bridge. Nairobi Dam weir recorded 8.82±0.54 mg/L whereas the inlet registered 4.79±0.54 mg/L (Figure 4.1). The observed increase could be as a result of reduced water flow rate due to eutrophication at the Dam. Nairobi Dam outlet at 5.56±0.27 mg/L depicted the effect of increased volumetric flow from the Dam thus washing out accumulated phosphates as a result of reduced resident time.

The varying trends from Motoine Dam to Nairobi Dam inlet and Nairobi Dam outlet to Mukuru Kayaba (Hazina Bridge) are linked to heavy surface runoff thus diluting the phosphate concentration in the river water. Surface runoff, informal settlement and industrial discharge also contributed to the generally high levels of phosphates downstream. Generally, the levels were exceptionally high in regions where farming is practiced heavily during rain seasons that is a round Karen, Dagoretti, and Kibera and between Outerring Road (Donholm) and Kangundo Road Bridge. Figure 4.1 below shows the spatial-temporal variation of phosphates in water.

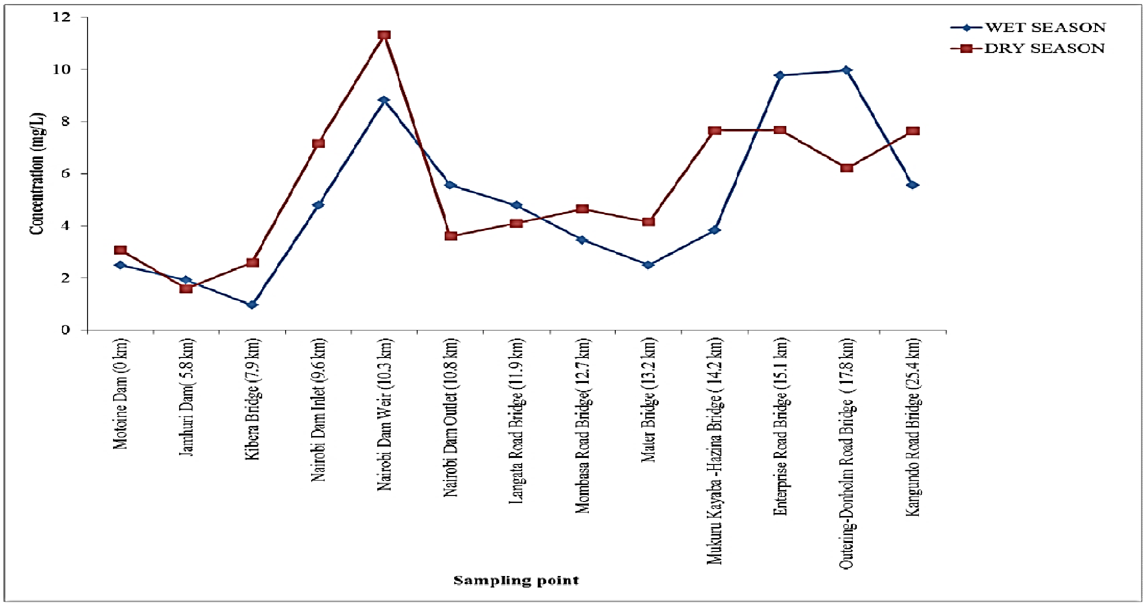


Figure 4.1: Temporal variation of phosphates in water

Seasonal water phosphates concentrations ANOVA test showed no significant difference in variations hence accepted the null hypothesis since there was a similarity in the mean values because $p>0.05$ at $p=0.63$ (Appendix 12a). Regression analysis for seasonal phosphates levels showed a strong positive correlation at $r= 0.71$ and $p=0.01$ thus the results are significant at $p<0.05$ (Appendix 13a).

The resultant seasonal positive coefficient of determination ($R^2 = 0.50$) indicated that, 50% of the total variation in the dry and wet season can be explained by a linear relationship as shown in Figure 4.2. This depicts that the sources of phosphates pollution is influenced by season and other several factors such as human activities and other uncontrolled factors which change the water quality in the river system.

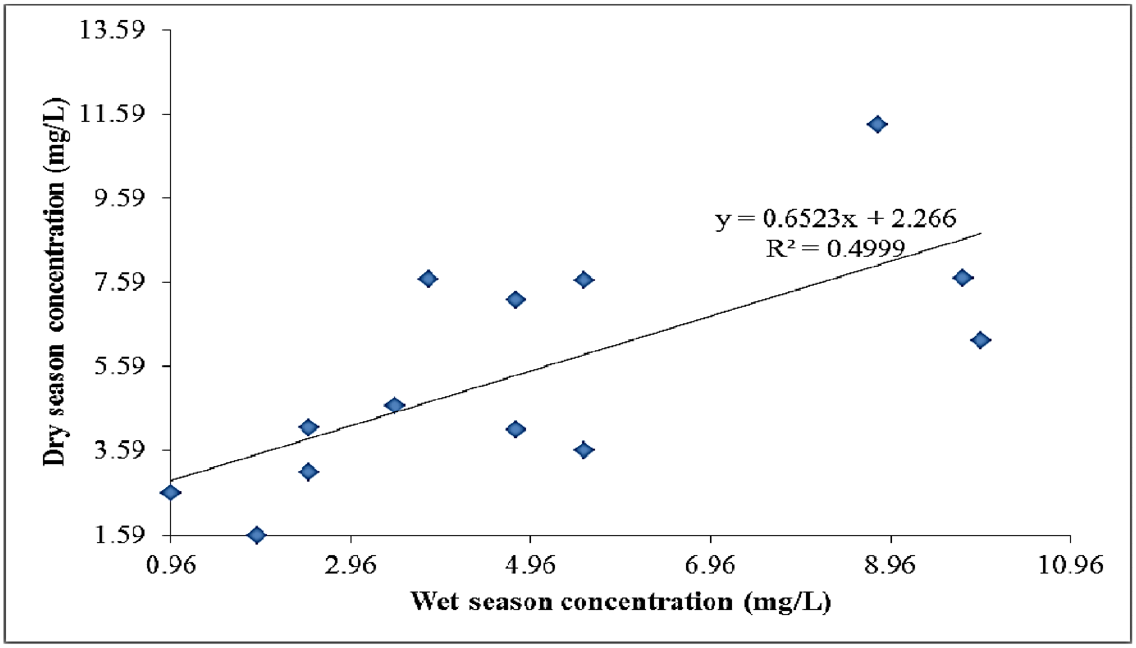


Figure 4.2: A scatter plot of dry season vs wet season phosphate levels in water

Regression analysis for river distance from the source and phosphate levels variations for both the dry and wet seasons showed a strong positive correlations at r=0.49 and p= 0.09 for the dry season (Appendix 16a) and r=0.48, and p=0.09 for the wet season (Appendix 16b) thus results not significant at $p < 0.05$. The positive correlation with a coefficient of determination ($R^2 = 0.23$) for both the dry and wet seasons indicated that, only 23% of the total variation can be explained by a linear relationship (Figure 4.3). The results indicated that the spatial variations were as result of various activities as the river flows downstream irrespective of the season.

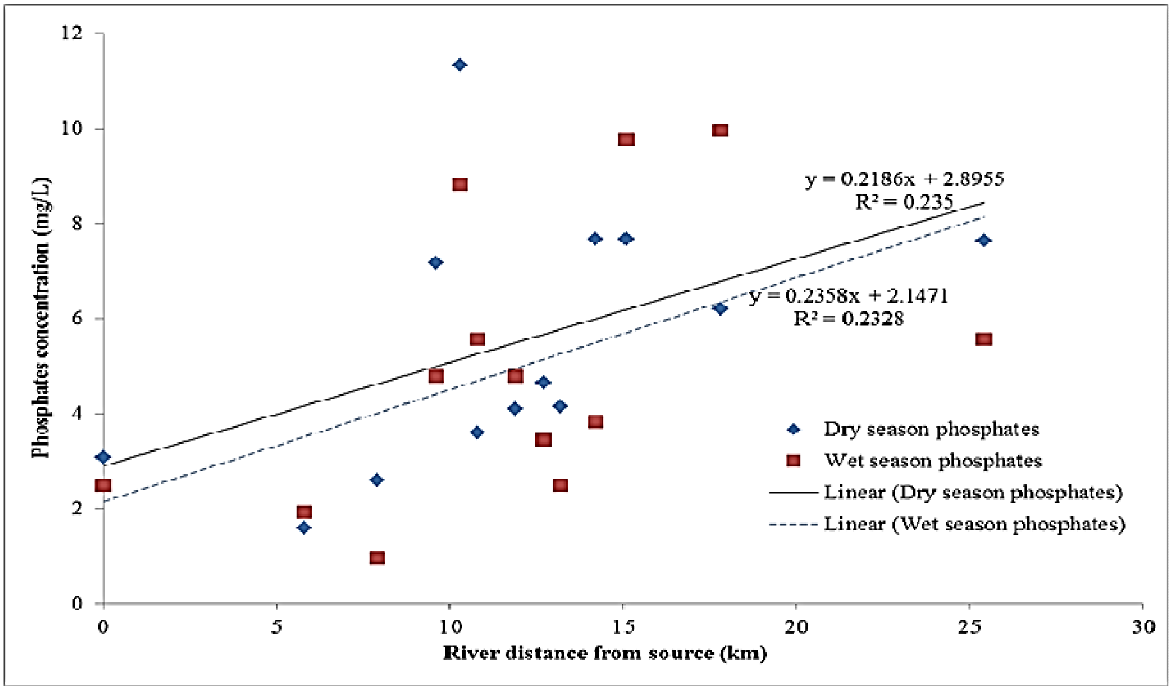


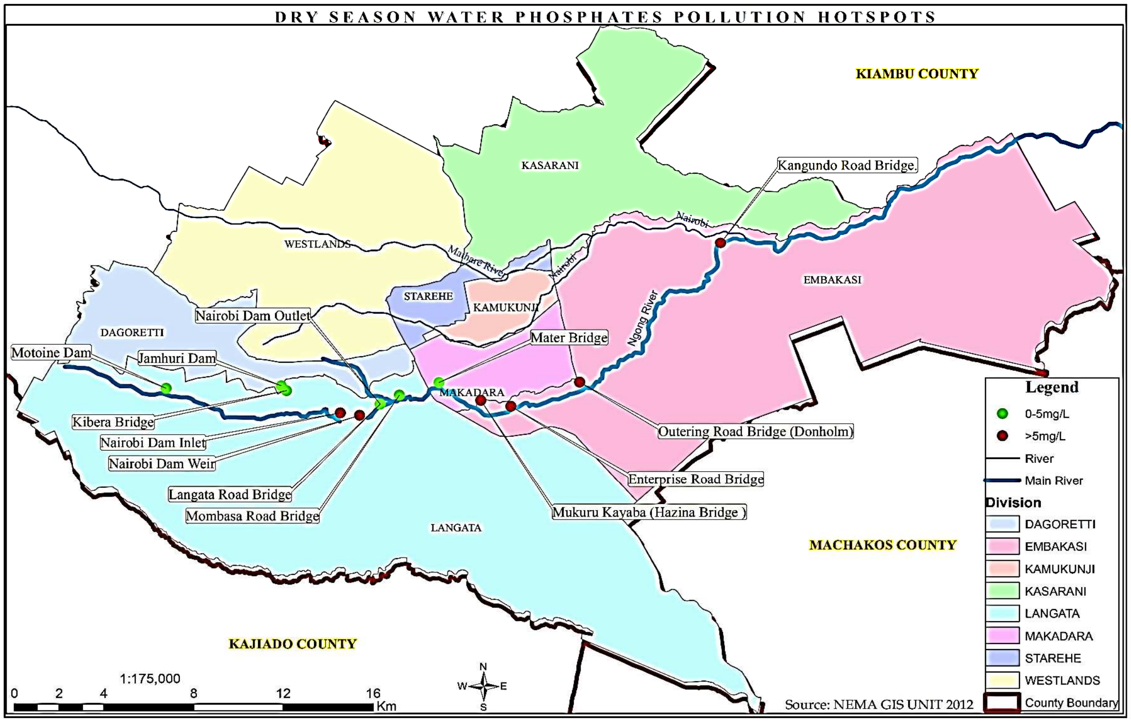
Figure 4.3: Water phosphates spatial variations scatter plot

4.2.2 Phosphates pollution hotspots projection maps

Phosphates pollution intensities were colour coded using green and red colours based on WHO guideline limits to indicate pollution hotspots for any station having levels above 5 mg/L as indicated below;

- 🟢 Pollution levels for PO_4^{3-} between 0 - 5 mg/L
- 🔴 Pollution levels for PO_4^{3-} > 5 mg/L

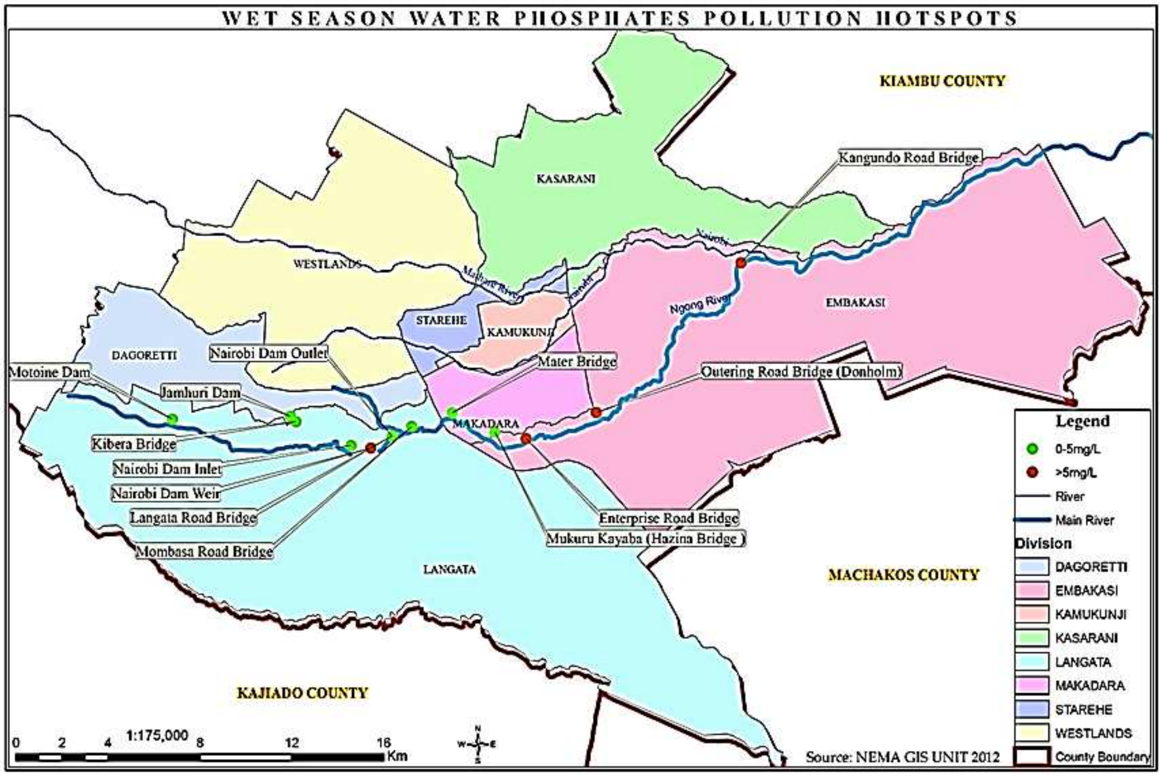
Projection map generated from the resultant data indicated that the Nairobi Dam inlet, the Dam weir, Mukuru Kayaba (Hazina Bridge), Enterprise Road Bridge, Outering Road Bridge and Kangundo Road Bridge had values above the World Health Organisations limits of 5 mg/L, therefore they were considered hotspots along the river system for the dry season (Figure 4.4).



Source: NEMA GIS UNIT 2012

Figure 4.4: Dry Season water phosphates pollution hotspots

The wet season projection map indicated that Langata Road Bridge, Enterprise Road Bridge, Outering Road Bridge and Kangundo Road Bridge having levels above World Health Organisations limits to be pollution hotspots along the river system for the wet season. These points were colour coded red as shown in Figure 4.5.



Source: NEMA GIS UNIT 2012

Figure 4.5: Wet season water phosphates pollution hotspots

4.2.3 Spatial and temporal variations in Sulphate levels in water

The mean concentrations of sulphates at all sampling sites in both dry and wet season were lower than the WHO (2006) safe limit for drinking water (250 mg/L) at 0.54 mg/L and 0.67 mg/L, respectively. However, detectable levels of 1.15±0.02 mg/L for the dry and 0.77±0.07 mg/L for the wet season were obtained (Appendix 2).

The dry season had high levels of 1.15±0.02 mg/L at Nairobi Dam weir and 1.07±0.00 mg/L at Mukuru Kayaba Hazina Bridge giving a clear indication of pollution by the effluents from informal settlements Kibera and Mukuru Kayaba slums. Jamhuri Dam, Kibera Bridge, Nairobi Dam outlet and Langata Road Bridge did not contain sulphates but there were variations from Mombasa Road Bridge to Kangundo Road Bridge as indicated shown in Figure 4.6 giving an indication of some industrial pollution at the river flows through the industrial area.

The wet season had relatively low and uniform concentrations for all the sampling sites this could be attributed to the fact that sulphate easily precipitates and settles to the bottom sediment of the river as reported by Mathuthu and co-workers [1997].

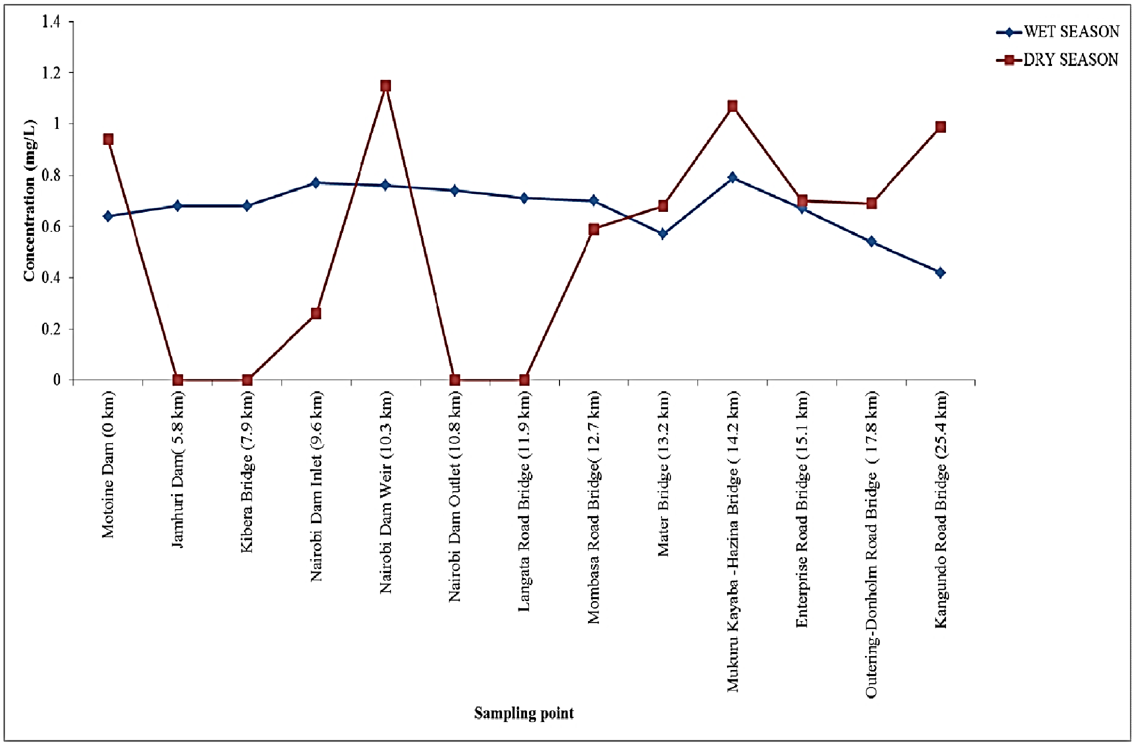


Figure 4.6: Sulphates temporal variation in water

The ANOVA test for the dry and wet season retained the null hypothesis for sulphates in water since $p>0.05$ indicated that the means are the same (no seasonal significant difference) at $p=0.34$ (Appendix 12b). Regression analysis showed a weak negative correlation at $r= 0.25$ and $p=0.42$ thus $p>0.05$, hence the results were not significant at $p<0.05$ (Appendix 13b). The resultant seasonal low coefficient of determination (R^2 =

0.06) indicated that, only 6% of the total variation in the dry and wet season can be explained by a negative linear relationship as shown in Figure 4.7. This depicts that there is no or negligible relationship between the wet and dry season sulphate concentration, hence the pollution is as a result to other human and natural activities.

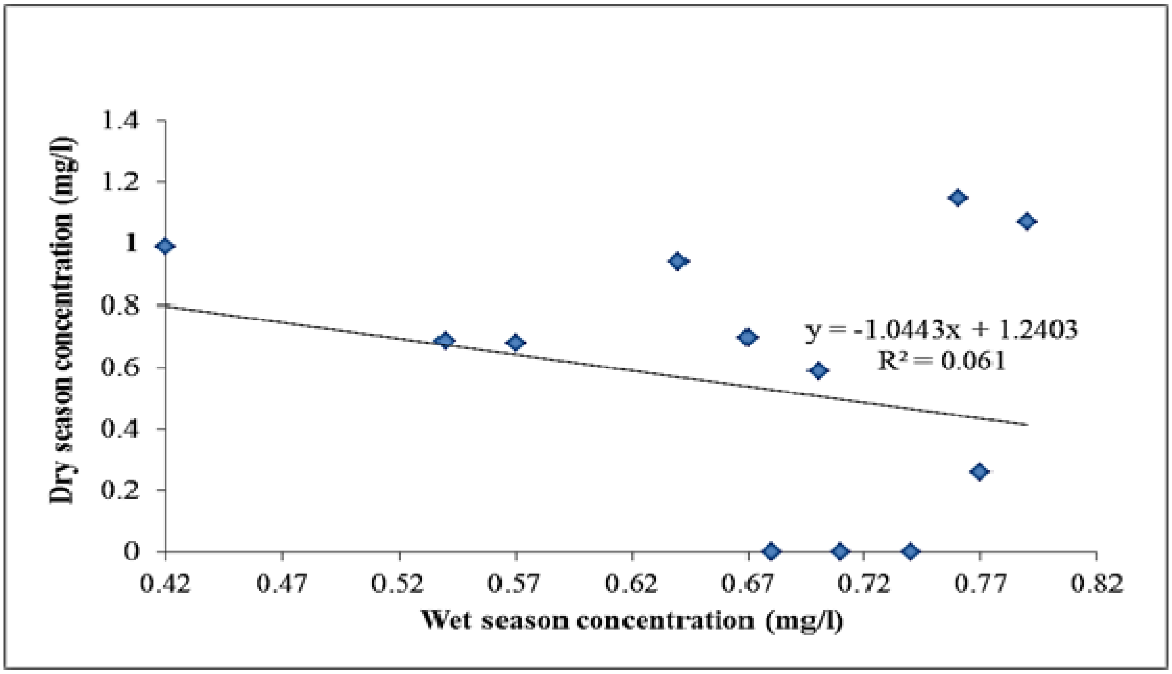


Figure 4.7: A scatter plot of dry season vs wet season sulphate levels in water

Spatial variation for sulphates in the dry seasons showed a weak positive at r=0.31 and p=0.31 thus results not significant at $p<0.05$ (Appendix 16c) and a strong positive correlation respectively at r=0.55 and p=0.05 for the wet thus results significant at $p<0.05$ (Appendix 16d). the weak positive and strong negative coefficients of determination (R^2 = 0.10, R^2 = 0.30) for the dry and wet seasons respectively as shown in Figure 4.8 indicated that, the variation in pollution as the river flows downstream are seasonally influenced with respect to various point and non-points sources.

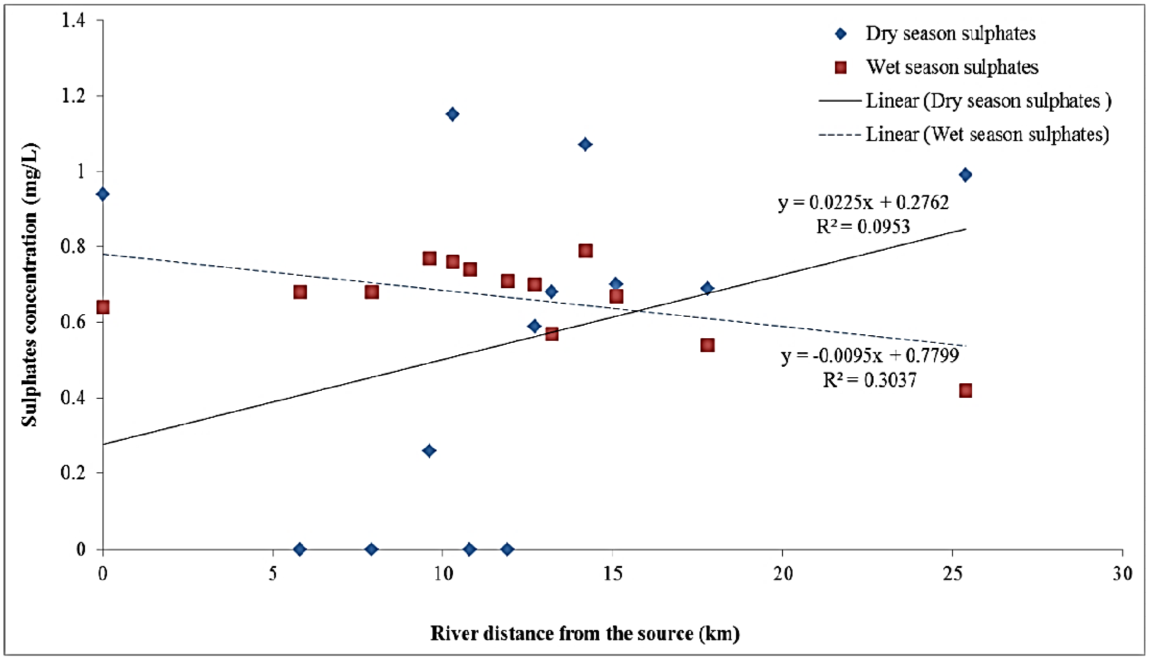


Figure 4.8: Water sulphates spatial variations scatter plot

4.2.4 Spatial and temporal variations in Nitrates levels in water

Nitrate concentrations in the dry season were within the WHO guideline standards of 10 mg/L for drinking water for all the stations apart from Nairobi Dam inlet, weir and outlet where the levels were in the range of 10.06±0.08 to 13.74±0.02 mg/L as illustrated in Figure 4.9. The high level at the outlet could be due to leaching from the Dam sediments and as a result of wash out from the Dam. Human waste from Kibera slums could also be a contributing factor since people in this slum lack toilets and the pit latrines available have been directed to Ngong-Motoine River. Jamhuri Dam had a significant level of 8.37±0.34 mg/L which could be attributed to surface runoff from agricultural trade fair ground that the park usually host every October of the year and contributions from horse riding fields present at the park.

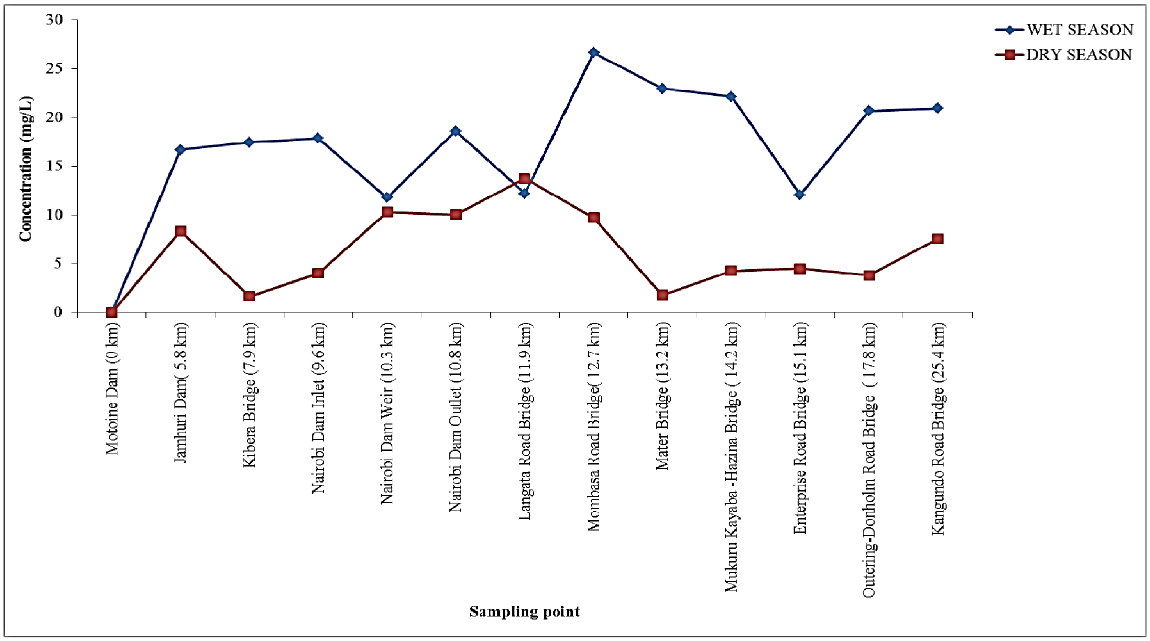


Figure 4.9: Nitrates spatial and temporal variation in water

Nitrates in the wet season were high with a mean concentration of 16.92 mg/L, whereas Motoine Dam recorded a below detectable limit. This is attributed to the fact the nitrates dissolve in water thus heavy surface runoff in the region diluted the Dam water. The nitrate levels from Jamhuri Dam had varying trends with the highest levels of 26.65±1.36 mg/l obtained at Mombasa Road Bridge (Appendix 4). The close range concentration levels experience between Jamhuri Dam and Nairobi Dam weir and between Mombasa Road Bridge and Kangundo Road are directly linked to farming activities along the river profile where nitrate fertilizers are heavily applied and other anthropogenic activities.

Consequently, the high level of nitrate observed during the rainy season is in agreement with [Wolfhard and Reinhard, 1998] who concluded that nitrates are usually built up during dry seasons. This is because initial rains flush out deposited nitrate from near-surface soils and nitrate level reduces drastically as rainy season progresses.

The ANOVA test for seasonal nitrates in water showed that the mean values for the two seasons were different at $p<0.05$ ($p=0.00$) (Appendix 12c) thus there is a significant seasonal difference, hence rejecting the null hypothesis. Regression analysis for seasonal nitrates showed a weak positive correlation at ($r= 0.16$ and $p=0.61$ thus the relationship is negligible implying that the results are not significant at $p<0.05$ (Appendix 13c).

The resultant weak coefficient of determination ($R^2 =0.02$) as shown in Figure 4.10 indicates that only 2% of the total variations can be explained by a linear relationship for the dry and wet season hence nitrates pollution in the river system is a contribution of various factors.

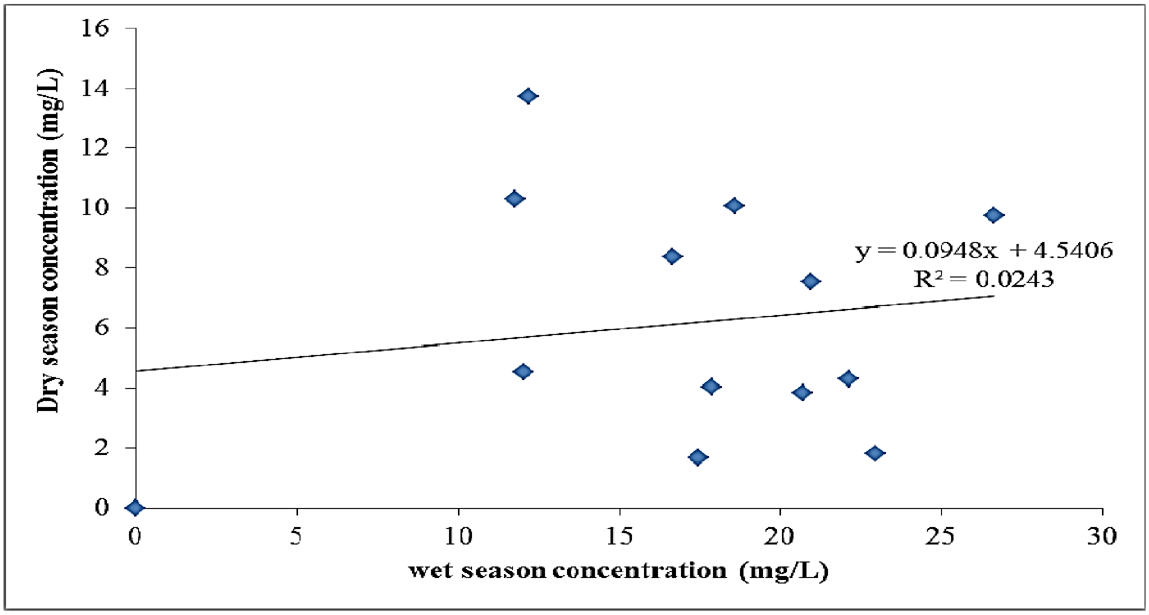


Figure 4.10: A scatter plot of dry season vs wet season nitrates levels in water

Analysis of spatial variations showed a weak positive correlation at $r= 0.22$ and $p=0.48$ in the dry season suggesting that the results were not significant at $p<0.05$ (Appendix 16e). The wet season had a moderate positive correlation at $r= 0.60$ and $p=0.03$ thus results were significant at $p<0.05$ (Appendix 16f). The variation in correlation and coefficient of determinations at R^2= 0.35 (35%) for the wet season and R^2=0.05(5%) for the dry season (Figure 4.11) showed that various factors contributed to nitrates as the river flows downstream. The dry season had a weak linear relationship between the pollution levels in different sites as the river flows downstream.

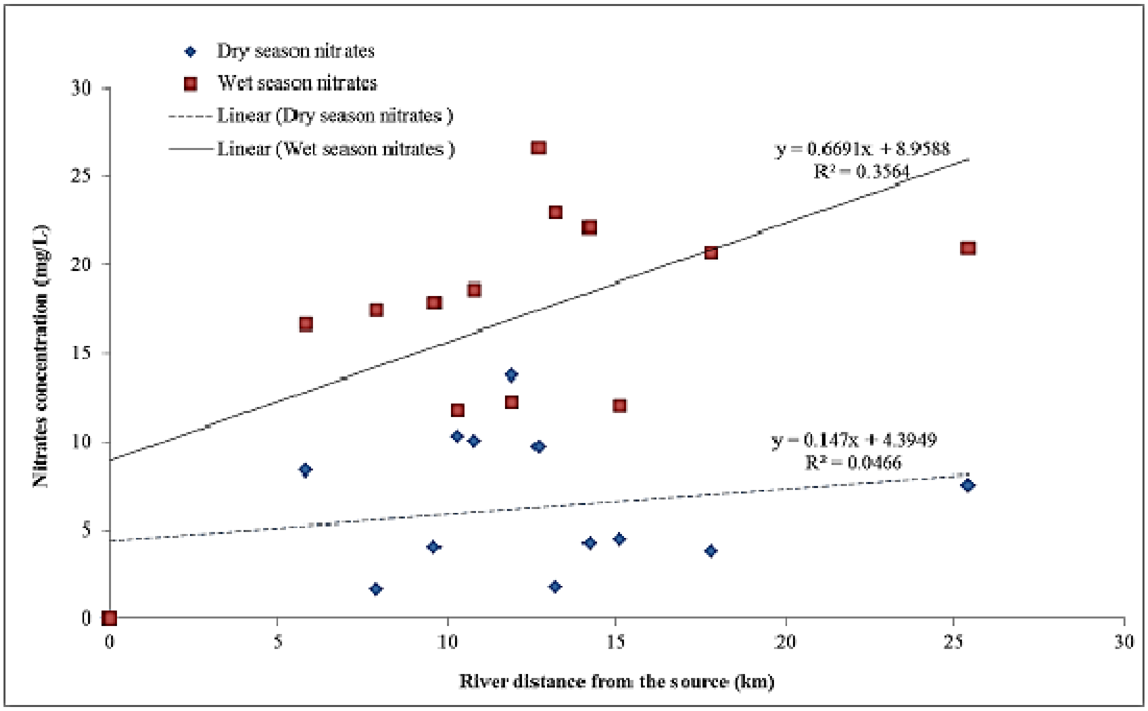
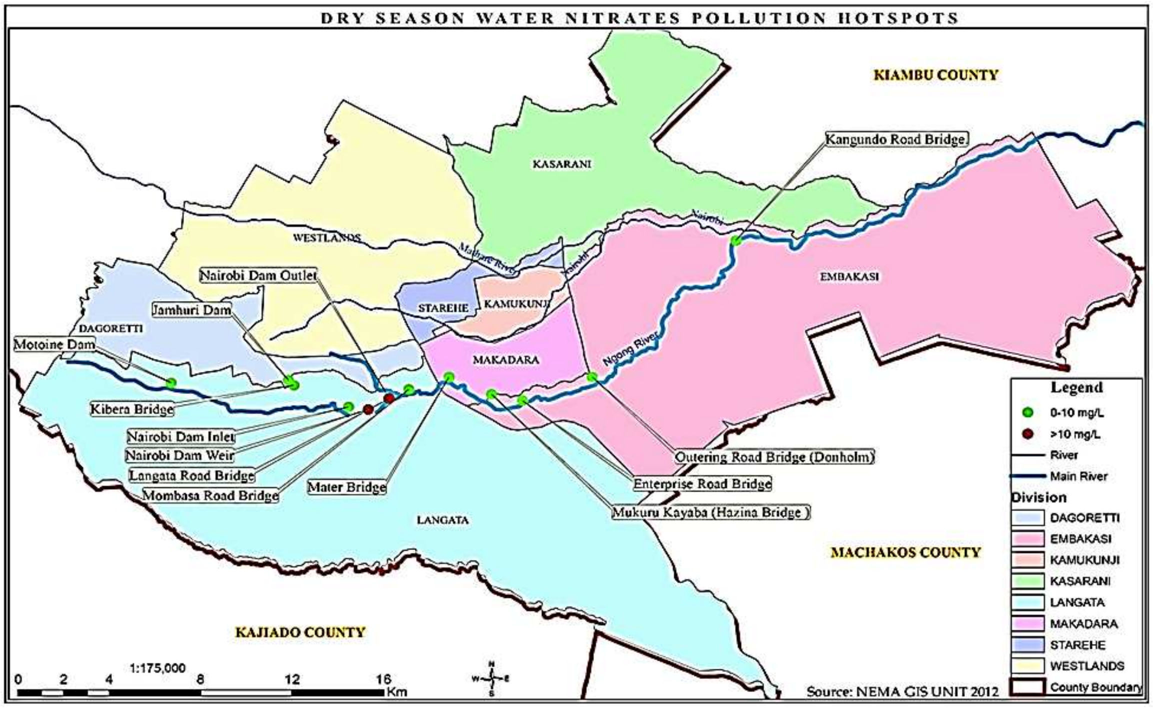


Figure 4.11: Water nitrates spatial variations scatter plot

Nitrates pollution intensities were colour coded using green and red colours based on WHO guideline limits to indicate pollution hotspots for any station having levels above 10 mg/L as indicated below;

- ● Pollution levels for NO_3^- between 0 - 10 mg/L
- ● Pollution levels for NO_3^- > 10 mg/L

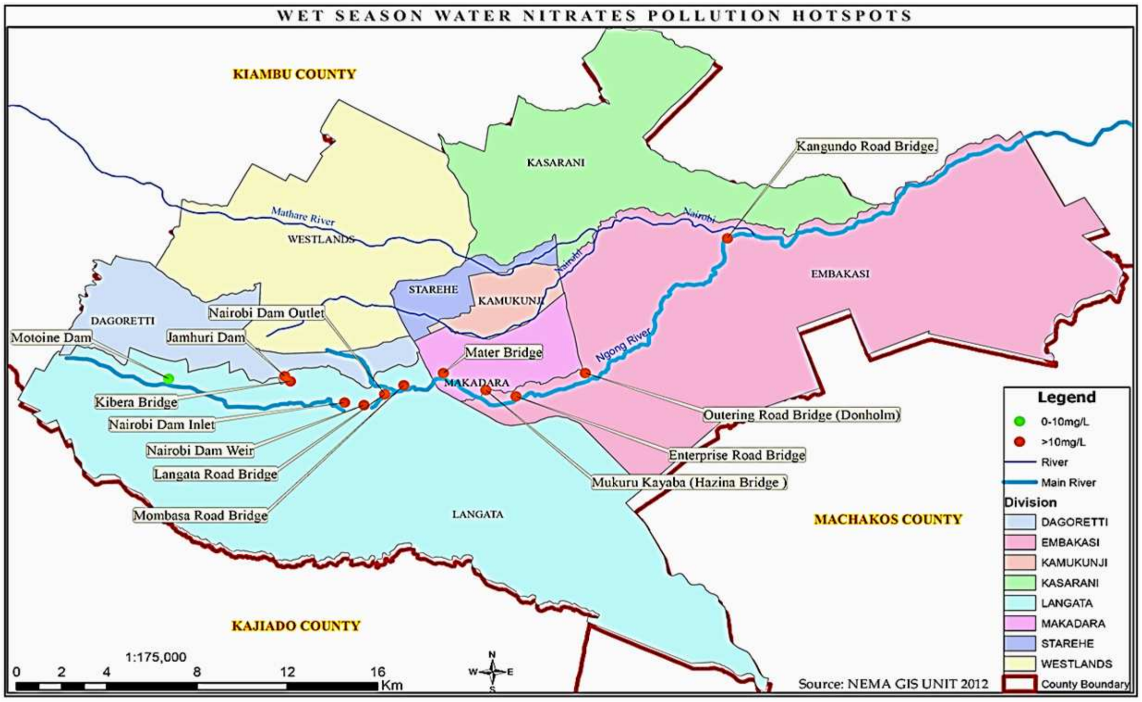
Nairobi Dam weir and Langata Road Bridge were the only two stations indicated to be nitrates pollution hotspots for the dry season as shown in Figure 4.12 since the levels were above the World health organisation limit of 10 mg/L.



Source: NEMA GIS UNIT 2012

Figure 4.12: Dry season water nitrates pollution hotspots

Motoine Dam was the only site with nitrate levels <10 mg/L in the wet season as shown in Figure 4.13. All other sites had nitrate concentration above 10 mg/L suggesting that they are hot spots during the wet season. This could be as a result of runoff and increased discharges experienced during the wet season.



Source: NEMA GIS UNIT 2012

Figure 4.13: Wet season water nitrates pollution hotspots

4.2.5 Spatial and temporal variations in Escherichia coli (E. coli) in water

Escherichia coli (*E. coli)* pollution in Motoine /Ngong River was higher than the World Health Organization's guidelines of 0 MPN/100 mL in drinking water in both seasons. The lowest pollution levels were established at Motoine Dam in both seasons at 140 MPN/100 mL in the dry and 94 MPN /100 mL during the wet season.

In both seasons, MPN count increased sharply downstream to +1800 MPN/100ml of sample at all stations and no dilution effects seem to take place as shown in Figure 4.14. This may infer that there is human waste or several sewage discharges into the river channel.

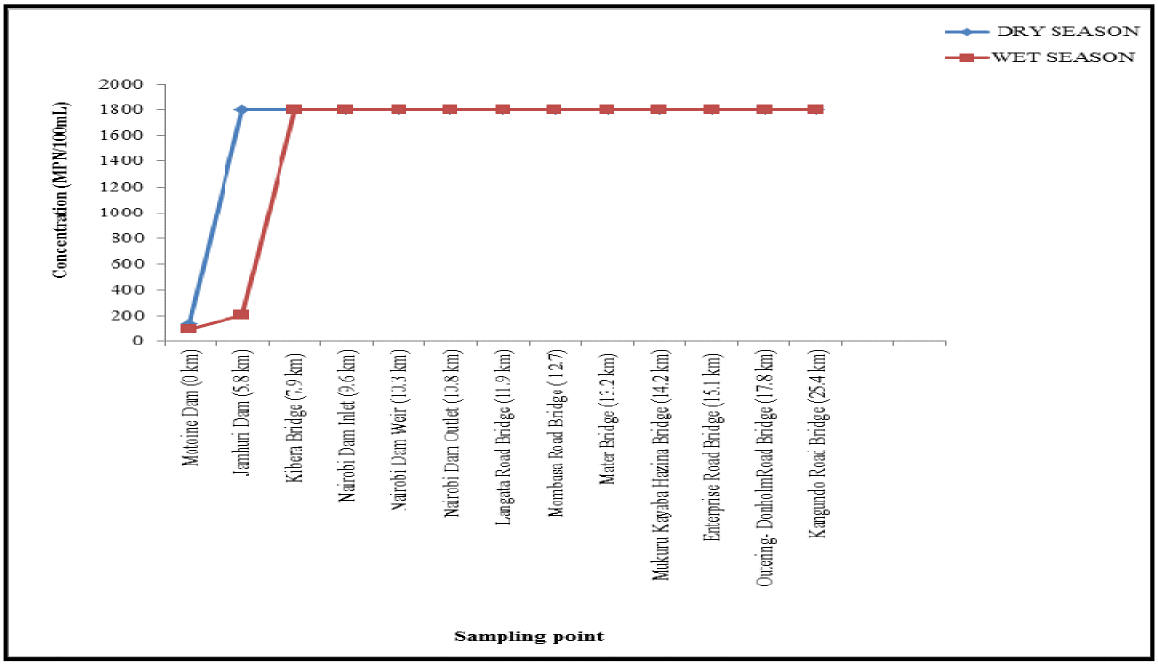


Figure 4.14: ***E.coli*** **spatial and temporal variation in water**

ANOVA test of *E. coli* pollution in water showed that the mean values in both seasons were similar thus the null hypothesis was retained since p=0.53 (and p<0.05) (Appendix 12d). Regression analysis showed a strong positive correlation at r=0.71, p= 0.01 thus the results were significant at p<0.05 (Appendix 14).

The obtained coefficient of determination (R^2 =0.50) as shown in Figure 4.14 indicates that 50 % of the total variation in the dry and wet season is explained by a linear relationship with a positive gradient. Therefore *E.coli* pollution in the river system is uniformly distributed emanating from various factors.

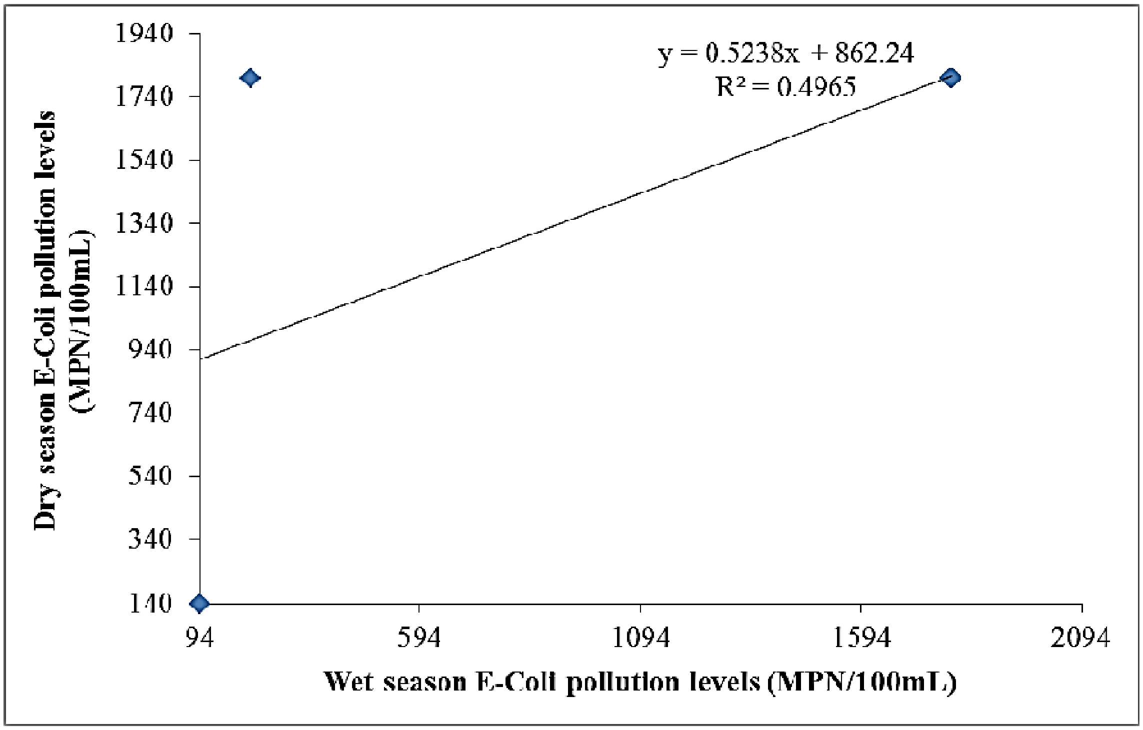


Figure 4.15: A scatter plot of dry season vs wet season *E-Coli* levels in water

Spatial variations for *E. coli* in water for both seasons showed moderate correlations at r=0.59 and p=0.03 for the dry season and r= 0.67 and p=0.01 for the wet season, suggesting that the results are significant at $p<0.05$ (Appendix 16g &16h). Both seasons indicated a moderate spatial linear relationship at 45% of the sites for the wet season and 35% for the dry season as the river flows downstream (Figure 4.16). This suggests relatively uniform distribution of the pollution levels.

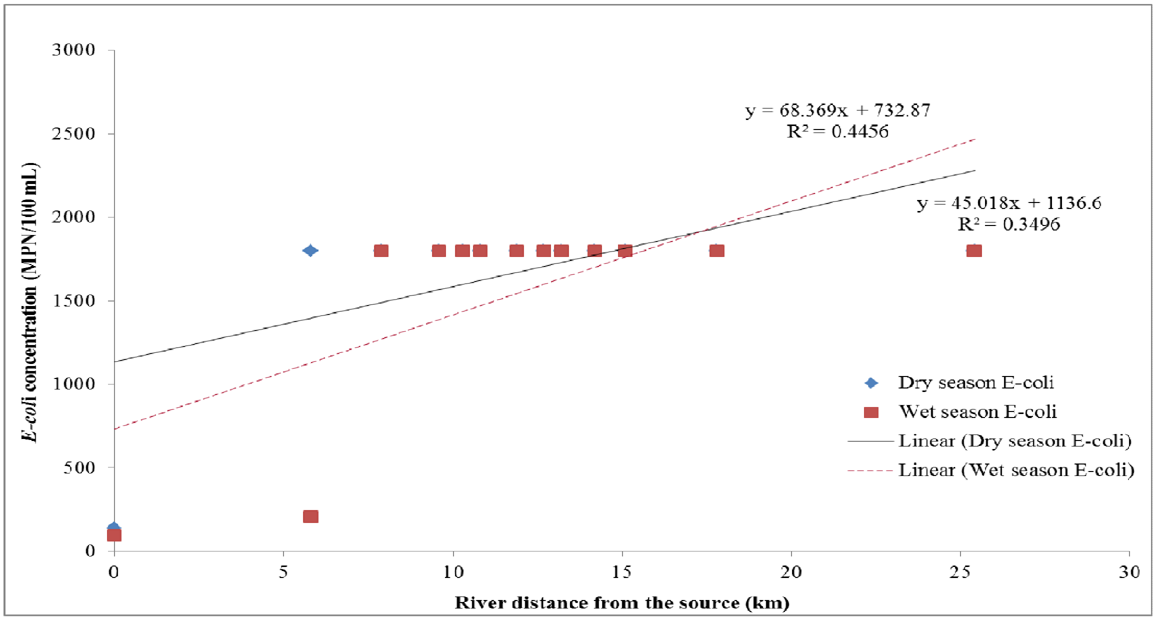


Figure 4.16: Water E-coli spatial variations scatter plot

4.2.6 *E. coli* pollution hotspots projection maps

E.coli pollution hotspots were colour coded using red colours based on WHO guideline limits to indicate pollution hotspots for stations having levels above 0 MPN/100mL as indicated below;

- ● Pollution levels for *E.coli* above 0 MPN/100mL

Pollution projection map for both seasons indicated that all the stations were pollution hotspots for *E.coli* as the levels were above the recommended WHO, 2006 guideline values of Zero MPN/100mL as shown in Figures 4.17.

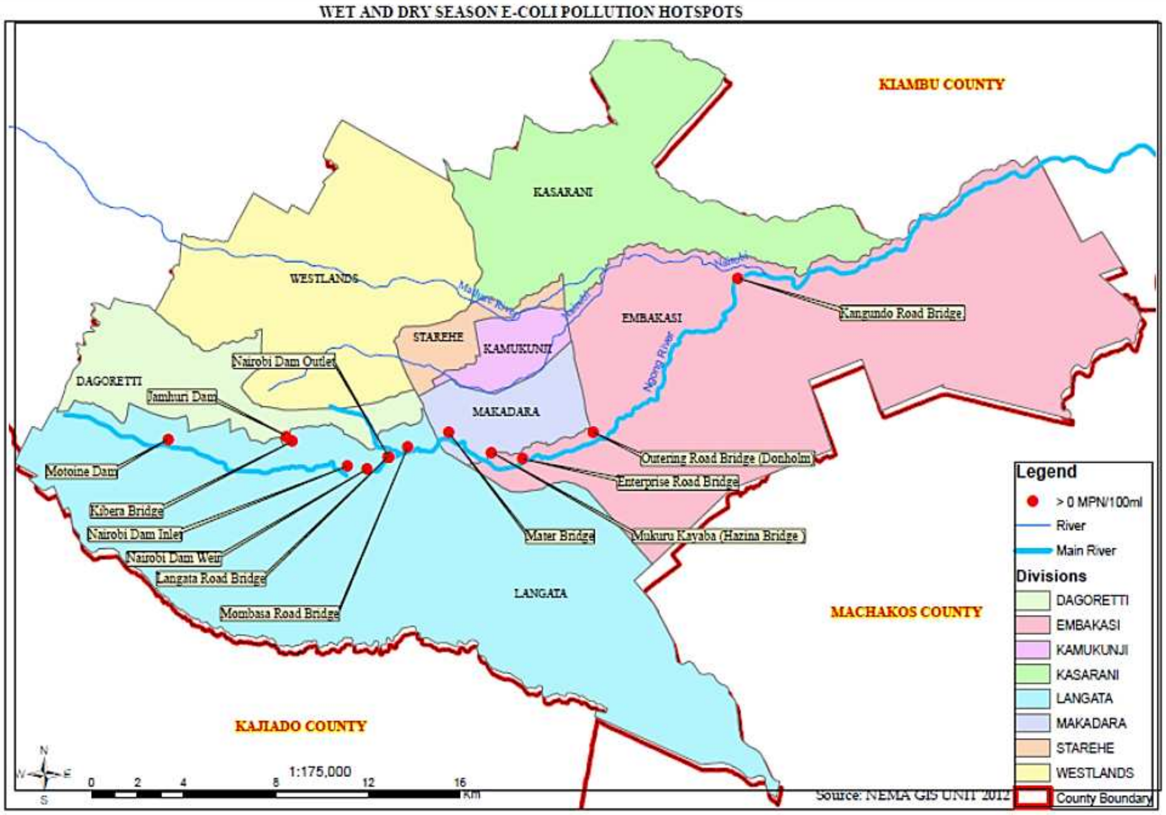


Figure 4.17: Wet and dry season E. coli pollution hotspots

4.3 Sediments analysis results

4.3.1 Spatial and temporal variations in Phosphate levels in sediments

Sediments were found to have higher deposition of phosphate in the entire Motoine/Ngong River as compared to the World Organizations Health guidelines. High concentration levels were established during the wet season with a peak of 9,157±539 mg/Kg at Nairobi Dam weir with a corresponding 7,510±56 mg/Kg in the dry season. During the dry season the highest levels were obtained at Enterprise Road Bridge at 8,805±150 mg/Kg as illustrated in appendix 7. In the wet seasons, the concentration levels had increasing trends from upstream up to mid-stream at Nairobi Dam weir having the highest concentration (Figure 4.18).

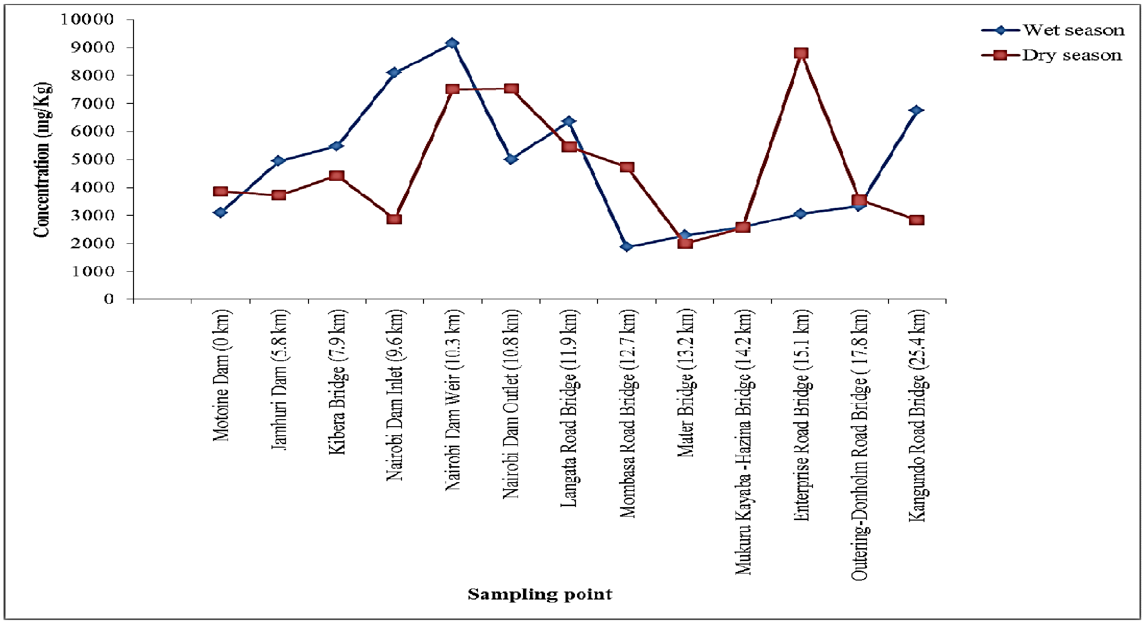


Figure 4.18: Phosphates seasonal spatial and temporal variation in sediments

From the results analysis, Nairobi Dam weir acts as a sink for phosphates in sediments with a substantial release as noticed at the outlet. Langata Road Bridge had a significant amount at 6,348±128 mg/Kg. This is attributed to the flower and tree nurseries that are lined up from Mbaghathi Road Bridge up to Nairobi west having constant irrigation. A similar trend is experienced form Mater Bridge up to Outering Road Bridge with a sharp increase at Kangundo road. The dry season had varying levels with a peak at enterprise road with Nairobi Dam weir and outlet having significant amounts of 7510±56 mg/Kg and 7,536±218 mg/Kg, respectively (Figure 4.18). The observed trends in both seasons could be due to high domestic effluent and agricultural activities over long period of time as evident by the high population in the informal settlements of Kibera and Mukuru slums coupled with farming along the river profile.

Phosphates temporal variations in sediments ANOVA test showed a similarity in mean values (no significant difference in distribution) hence accepted the null hypothesis with $p > 0.05$ at $p = 0.85$ as illustrated in appendix 12e. Regression analysis showed a weak positive correlation at $r = 0.19$ and $p = 0.53$ (Appendix 15a) therefore results not significant at $p < 0.05$.

The resultant weak coefficient of determination ($R^2 = 0.04$) as shown in Figure 4.19 indicates that only 4% of the total variation is explained by a linear relationship hence the distribution and accumulation of pollutants is random in nature for the dry and wet season.

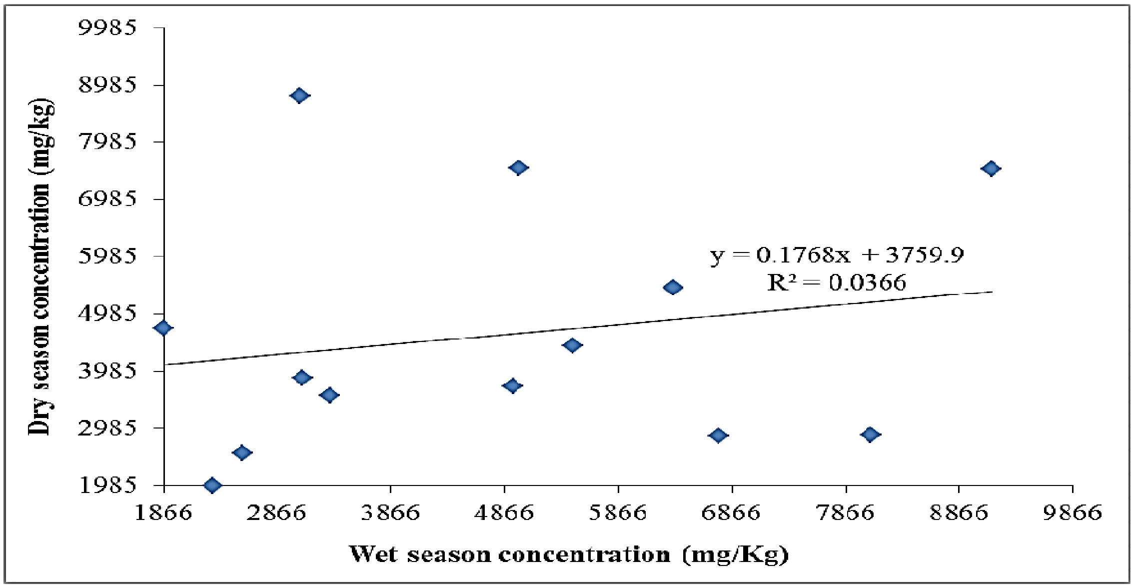
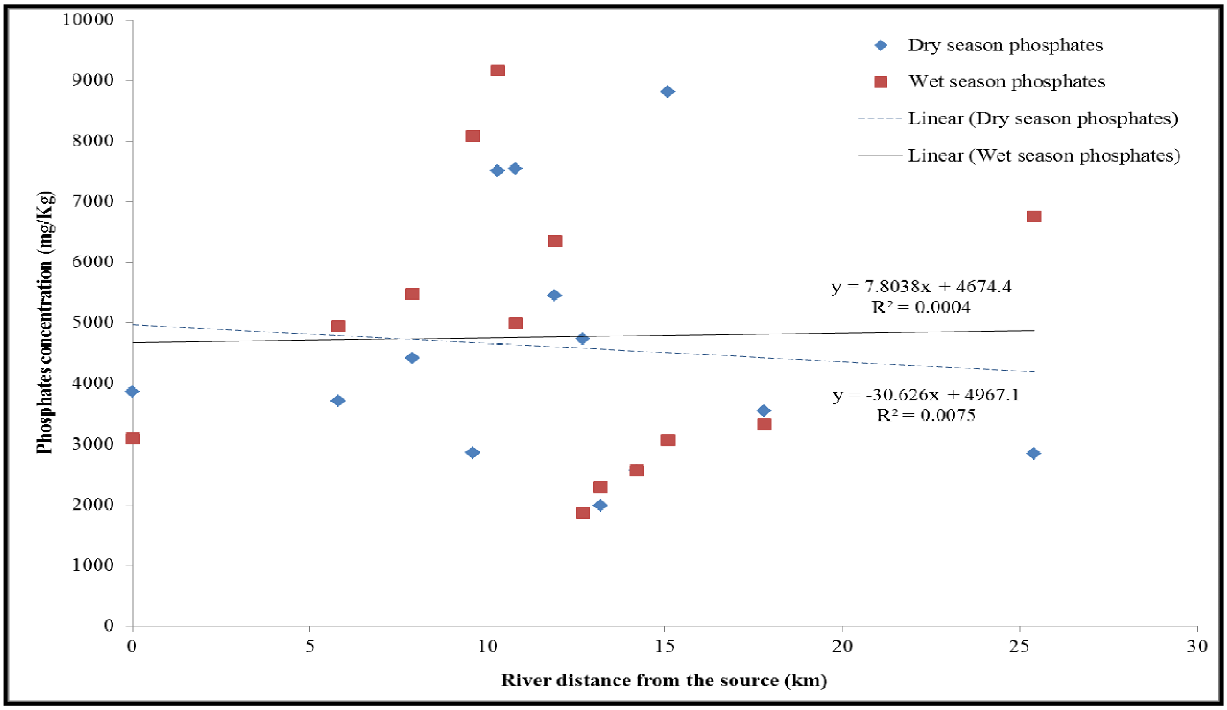


Figure 4.19: A scatter plot of dry season vs wet season phosphate levels in sediments

Spatial analysis for both seasons shows a random nonlinear relationship at $r = 0.09$, $p = 0.78$ for the dry season and $r = 0.02$ and $p = 0.95$ for the wet season hence results not significant at $p < 0.05$ as illustrated in appendix 17a and 17b. Both the wet and dry season had weak very weak linear relationships at 0% and 1%, respectively (Figure 4.20) indicating nonlinear relationships.

Figure 4.20: Sediments phosphates spatial variation scatter plot

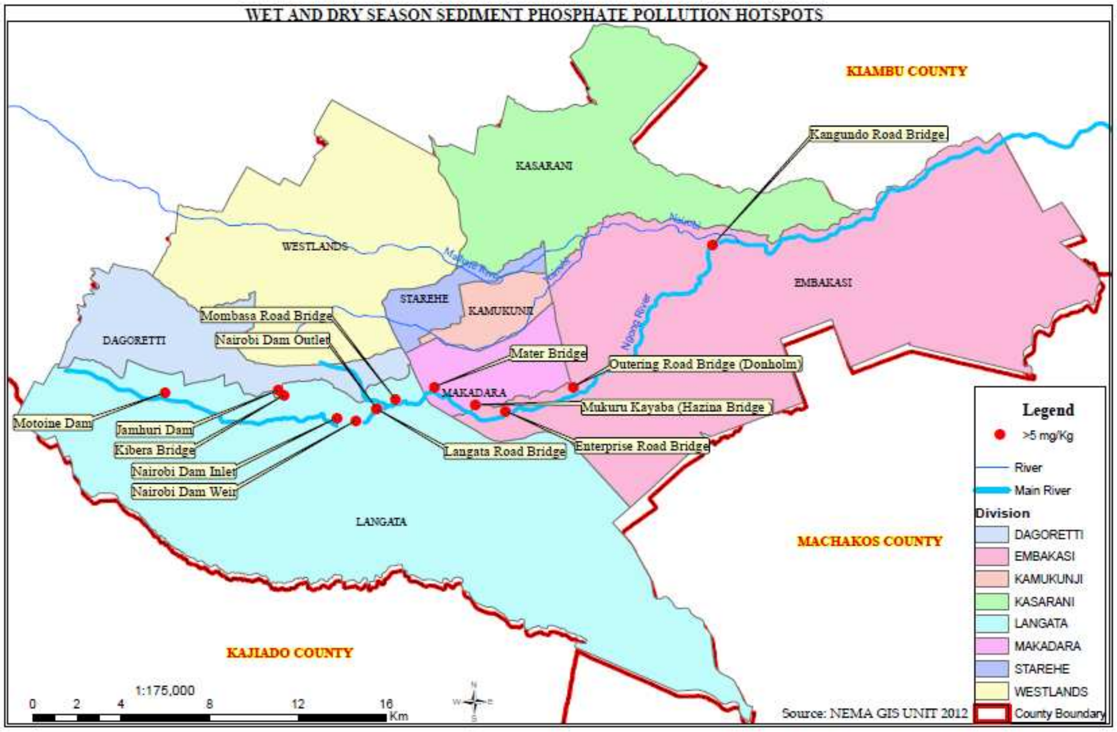


4.3.2 Dry and wet seasons sediments phosphates pollution hotspots projection maps

Phosphates pollution hotspots were colour coded using green and red colours based on WHO guideline limits to indicate pollution hotspots for any station having levels above 5 mg/Kg as indicated below;

- ● Pollution levels for PO_4^{3-} between 0 - 5 mg/Kg
- ● Pollution levels for PO_4^{3-}> 5 mg/Kg

Pollution projection maps for both seasons indicated that all the stations were phosphates pollution hotspots as the levels were above the recommended WHO 2006 guideline values of 5 mg/Kg as shown in Figures 4.21. The results revealed high concentrations of phosphorus in sediments compared to the WHO limit guideline values. The results suggest that sediments in Ngong/Motoine River are acting as sink to phosphorus load. The threat is that the sediments will continue to replenish the water column with phosphorus over a long time and therefore high chances of sustained eutrophication in the river.



Source: NEMA GIS UNIT 2012

Figure 4.21: Wet and dry season sediment phosphates pollution hotspots

4.3.2 Spatial and temporal variations in sulphates levels in sediments

Sulphates in sediments were exceptionally higher in the wet season as compared to the dry season. The concentrations were comparable across all sites with Enterprise Road Bridge recording the least concentration at 18,120±364 mg/Kg followed by Nairobi Dam weir at 20,199±872 mg/Kg (Figure 4.22. and Appendix 7).

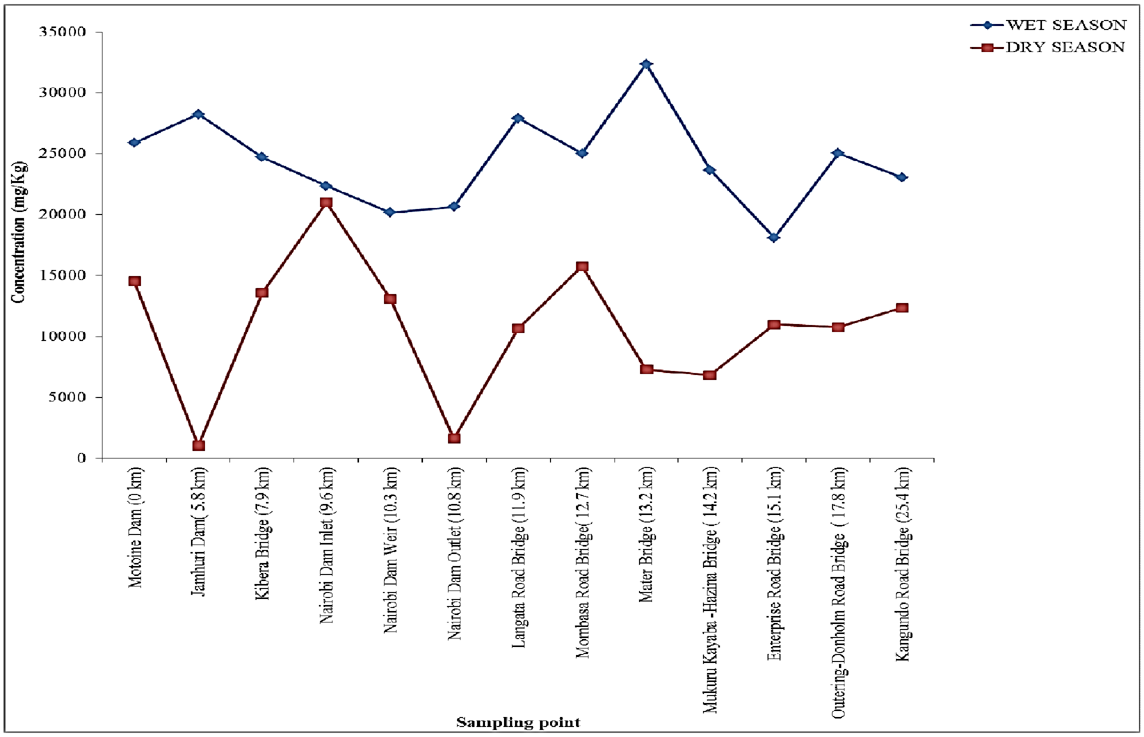


Figure 4.22: Sulphates seasonal spatial and temporal variation in sediments

This could be due to the fact that that the sulphate in the sediments was used up as a source of oxygen by bacteria and was converted to hydrogen sulphide (H_2S) under anaerobic conditions which was evident with a pungent smell from the samples collected at the Dam weir and through Mukuru slums downstream, also high sulphate levels observed could be a result of sulphates occurring naturally in surface water which arises from the leaching of sulphur compounds either as sulphate minerals such as gypsum or sulphite as pyrite or from sedimentary rocks.

Abdul-Razak and co-workers (2009) found that, when sulphates are added to water, they tend to accumulate to increasing concentration ultimately accounting for high levels recorded in the wet season.

The levels were low during the dry season with relatively varying trends. Jamhuri Dam recorded the lowest level at 14,551±6,314 mg/Kg with a peak at Nairobi Dam inlet at 21,033±1,197 mg/Kg (Figure 4.22). The low levels in the dry season can be linked to the fact that during the dry season, the river sulphate in the sediments was used up as a source of oxygen by bacteria and was converted to hydrogen sulphide (H_2S) under anaerobic conditions [Peirce *et al.*, 1998].

ANOVA test for temporal variations of sulphates in sediments showed a difference in mean values between the two seasons with $p< 0.05$ at $p= 0.00$ thus rejecting the null hypothesis (Appendix 12f). Regression analysis showed a weak positive correlation at $r= - 0.21$, and $p=0.49$ thus results not significant at $p<0.05$ as illustrated in appendix 15b.

The resultant weak coefficient of determination with a negative correlation as shown in figure 4.23 indicates that only 5% of the total variation has a linear relationship between the dry and wet season thus the pollutant distribution is random in nature.

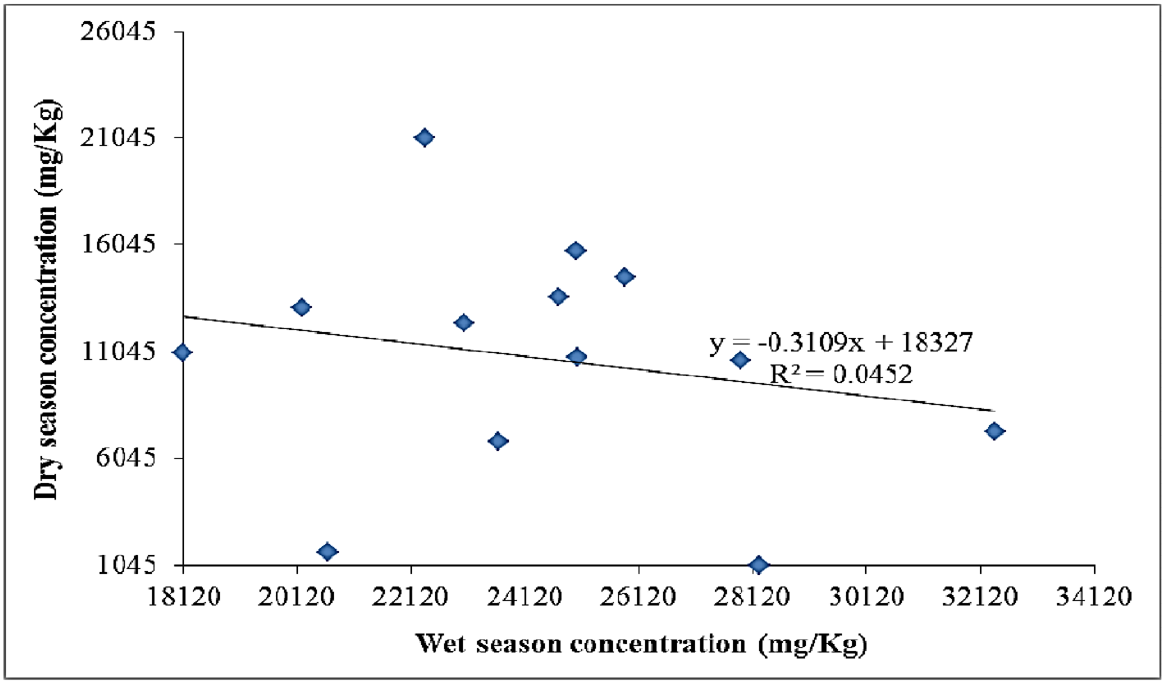


Figure 4.23: A scatter plot of dry season vs wet season sulphates levels in sediments

Spatial variations for sulphates in both seasons showed weak positive correlations at r=0.00 and p=0.99 for the dry season and r=0.19 and p= 0.54 for the wet season hence no linear correlations and results not significant at $p<0.05$ (Appendix 17c&17d) depicting the existence of a seasonal random nonlinear relationship pollutant distribution. The spatial variation analyses for both the seasons indicated weak negative relationships at 0% for the dry season and 4% for the wet season (Figure 4.24) indicating random pollutions distribution.

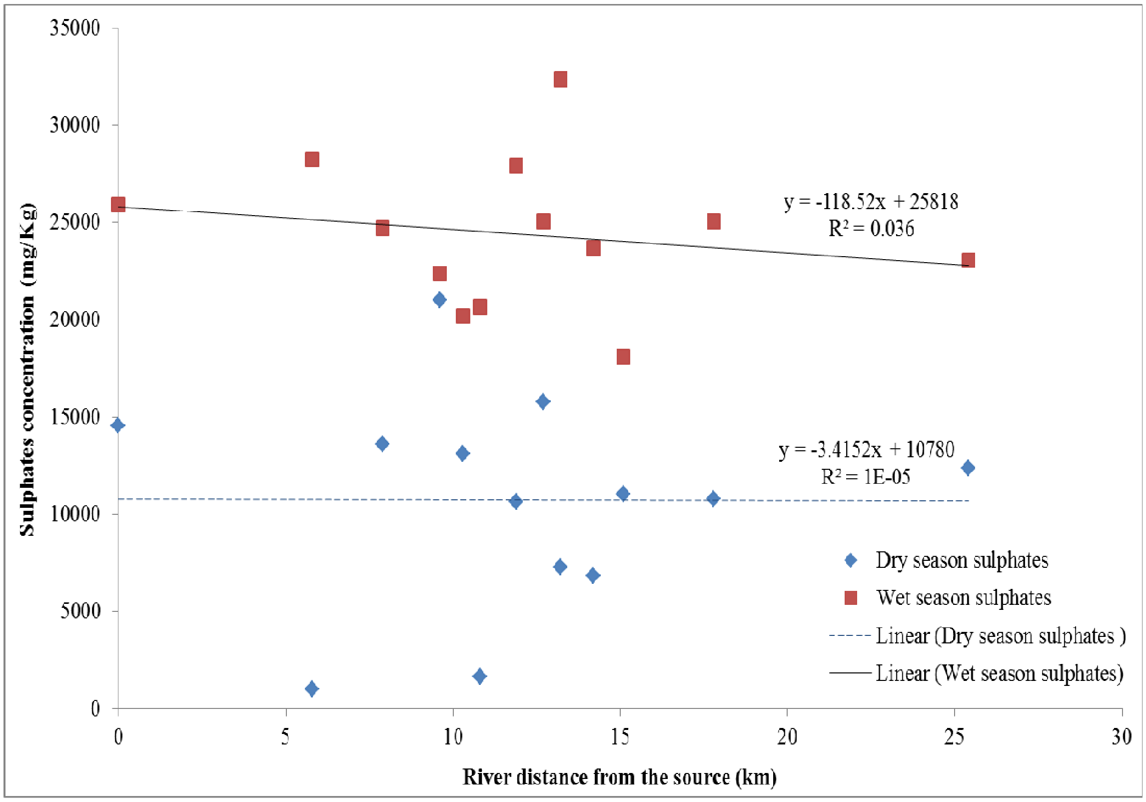


Figure 4.24: Sediments sulphates spatial variation scatter plot

4.3.3 Dry and wet seasons sediments sulphates pollution hotspots projection map

Sulphates pollution hotspots were colour coded using green and red colours based on WHO guideline limits to indicate pollution hotspots for any station having levels above 500 mg/Kg as indicated below;

- ● Pollution levels for SO_4^{2-} > 500 mg/Kg

Pollution projection maps for both seasons indicated that all the stations were sulphate pollution hotspots as the levels were above the recommended WHO, 2006 guideline values of 500 mg/Kg as shown in Figures 4.25.

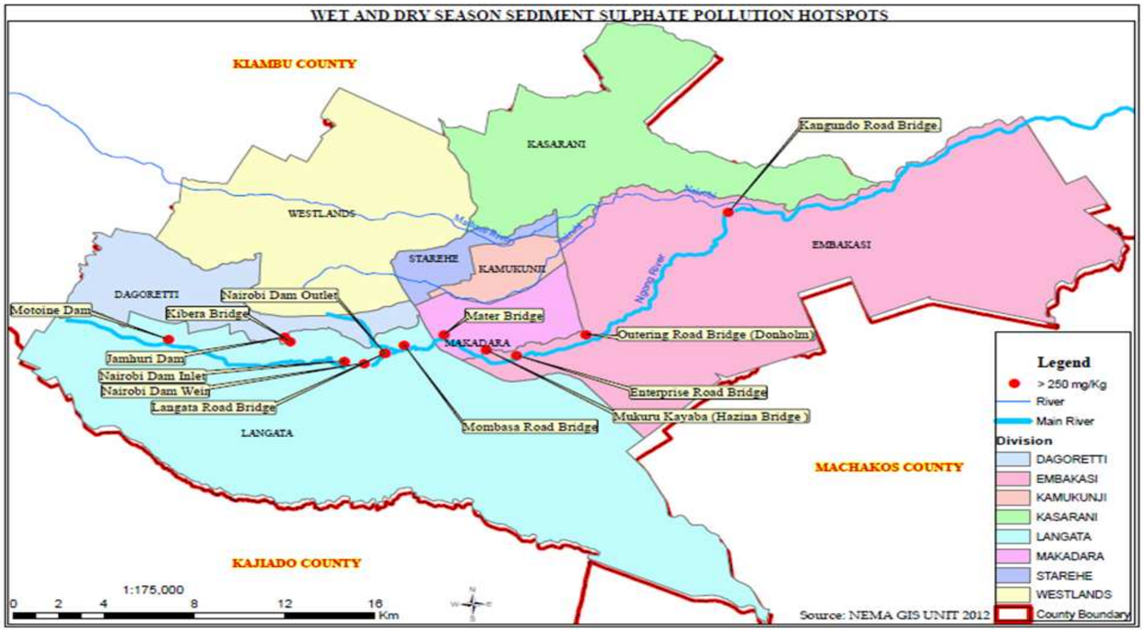


Figure 4.25: Dry season sediment sulphates pollution hotspots

4.3.4 Spatial and temporal variations in nitrate levels in sediments

High concentrations of nitrates were obtained during the dry season at seven stations; Kibera Bridge, Nairobi Dam inlet, the Dam Weir, Langata Road Bridge, Mukuru Kayaba, Outering Road Bridge and Kangundo Road Bridge at 2298±8.38 mg/Kg, 4178±19.74 mg/Kg, 1124±0.69 mg/Kg, 3897±99.16 mg/Kg 893±34.54 mg/Kg, 756±1.03 mg/Kg and 4110±366.10 mg/Kg respectively (Figure 4.25).

During this season, the nitrate values in the streams were as high as 4178±19.74 mg/Kg at Nairobi Dam inlet depicting the heavy contribution from agricultural field at this point and animal and human waste emanating from Kibera slums occurring all-round the year. Motoine Dam, Jamhuri Dam, Mombasa Road Bridge, Mater Bridge, Mukuru Kayaba, Enterprise Road Bridge and Outering Road Bridge did not have detectable limits in the dry season as illustrated in Figure 4.26 (Appendix 7 gives detailed seasonal variations in pollution levels).

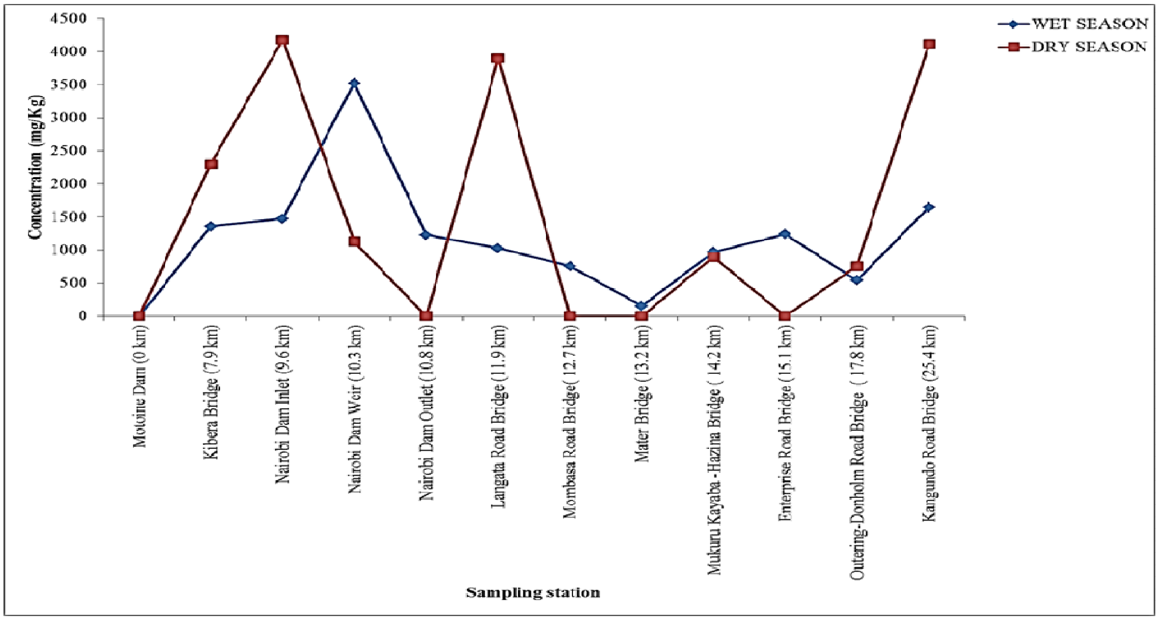


Figure 4.26: Nitrates seasonal spatial and temporal variation in sediments

From Figure 4.26, the wet season recorded considerable amounts at all stations with a peak of 3,524±38.79 mg/Kg at Nairobi Dam weir which acts as a sink to nitrates facilitating eutrophication. The concentration trends varied with a mean of 1,136 mg/Kg. the reduced concentrations experienced in the wet season could be attributed to the leaching effect of nitrate and dilution from the heavy down pore.

Nitrates in sediments ANOVA test showed similar mean values indicating no significant difference for the two seasons at $p=0.72$ hence $p>0.05$ thus accepting the null hypothesis (Appendix 12g). Regression analysis showed a moderate positive correlation at $r=0.32$, and $p= 0.29$ hence results not significant at $p<0.05$ (Appendix 15c). The resultant linear relationship for the wet and dry season nitrates variation (Figure 4.27). The data indicates that only 10% of the total variations have a seasonal relationship, hence random distribution of the pollutant for both the dry and wet season.

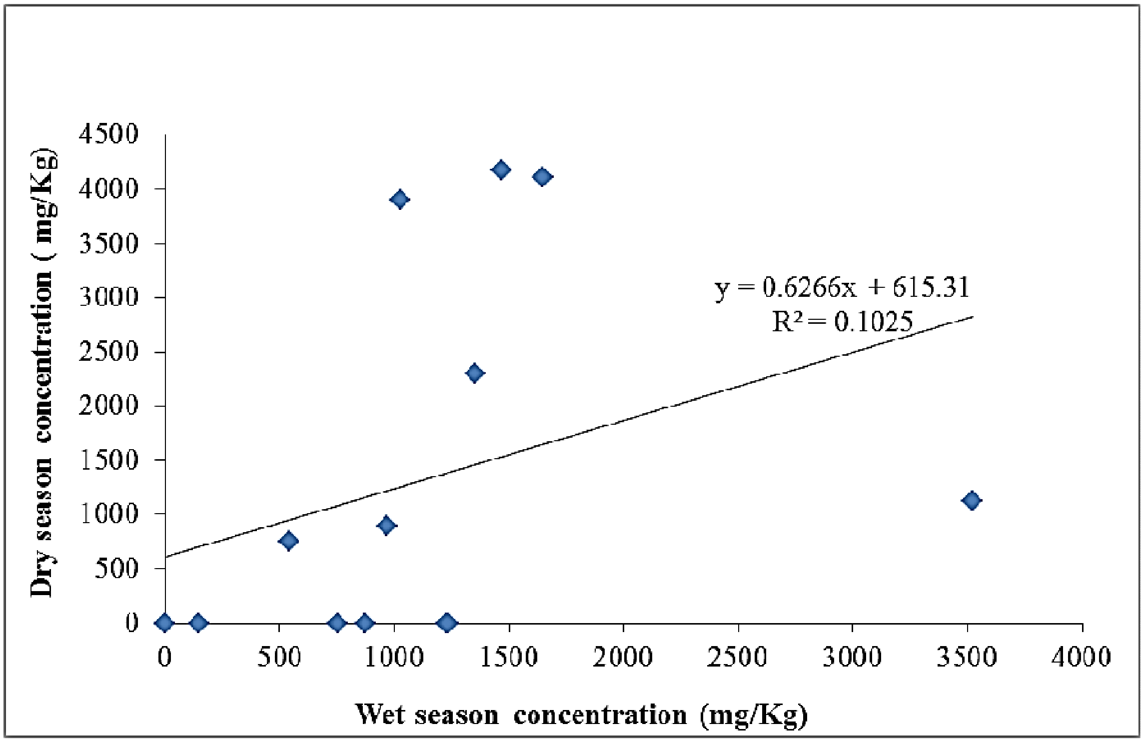


Figure 4.27: A scatter plot of dry season vs wet season nitrates levels in sediments

Spatial variations for the dry seasons showed a moderate positive linear relationship at r= 0.34, and p=0.26 hence results not significant at $p<0.05$ (Appendix 17e) and a random nonlinear relationship in the wet season at r=0.18, and p=0.56 hence results not significant at $p<0.05$ (Appendix 17f). The variation obtained indicates a random distribution in pollutants as the river flows downstream with weak positive linear relationships at 11% for the dry season and 3% for the wet season as shown in Figure 4.28.

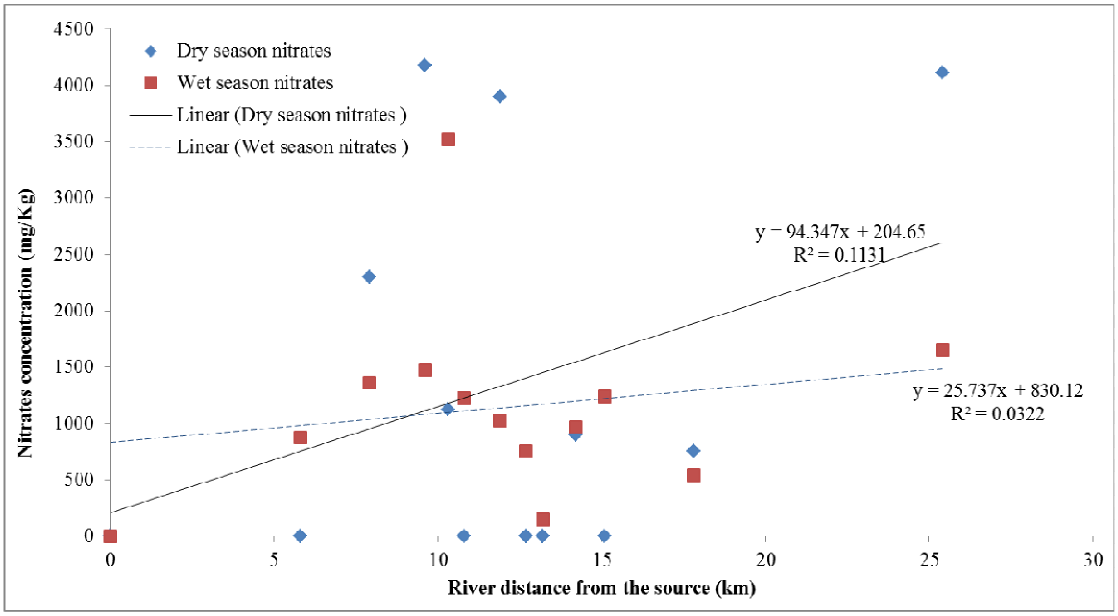


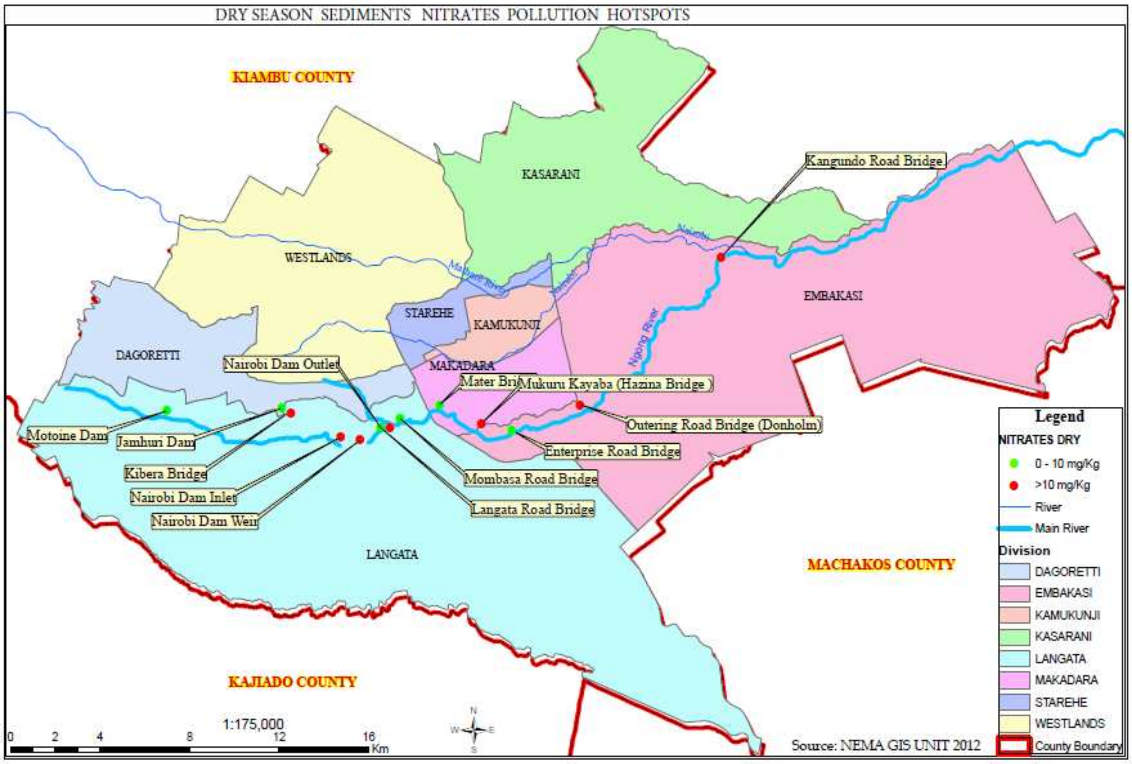
Figure 4.28: Sediments nitrates spatial variation scatter plot

4.3.5 Dry and wet seasons sediments nitrates pollution hotspots projection maps

Nitrates sediment pollution hotspots were colour coded using green and red colours based on WHO guideline limits to indicate pollution hotspots for any station having levels above 10 mg/Kg as indicated below;

- 🟢 Pollution levels for NO_3^- between 0 - 10 mg/Kg
- 🔴 Pollution levels for NO_3^- > 10 mg/Kg

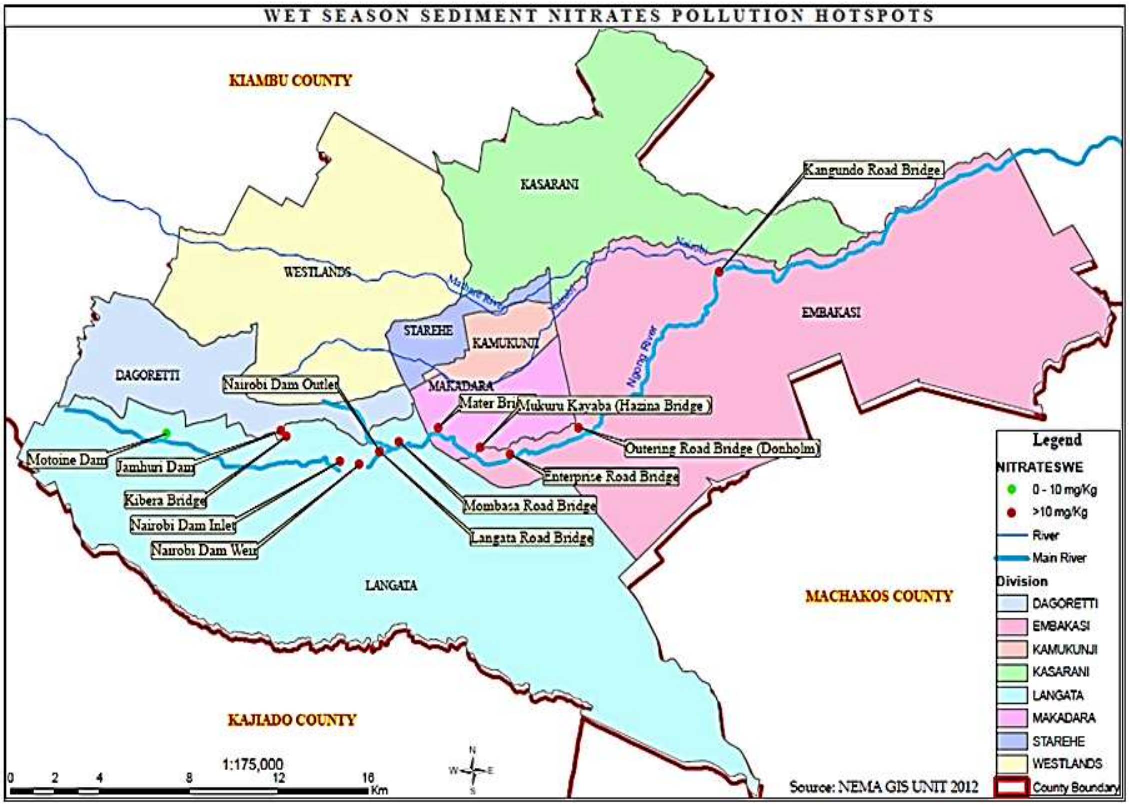
Kibera Bridge, Nairobi Dam inlet, the Dam Weir, Langata Road Bridge, Mukuru Kayaba, Outering Road Bridge and Kangundo Road Bridge were identified as pollution hotspots for the dry season as shown in Figure 4.29.



Source: NEMA GIS UNIT 2012

Figure 4.29: Dry season sediment nitrates pollution hotspots

All the stations except Motoine Dam were found to be pollution hotspots during the wet season since the concentration levels were above the recommended WHO, 2006 guideline values of 10 mg/Kg as shown in Figure 4.30.



Source: NEMA GIS UNIT 2012

Figure 4.30: Wet season sediment nitrates pollution hotspots

4.4 Inter-parameter correlation between different variables in water

Regression analysis for inter–parameter nutrients relationship in water indicated that only phosphates had a strong positive correlation with sulphates in the dry season at r=0.47 and p=0.01) thus results significant at $p<0.05$ (Table 4.1). The resultant coefficient of determination indicated that 69% of the total variations had a linear relationship with a positive gradient indicating that an increase in either pollutant caused an increase of the other.

All other parameters had very weak positive correlations in both seasons as shown in Table 4.1 depicting random nonlinear relationships at $p>0.05$. Thus, the results were not significant at $p<0.05$ suggesting that the concentration of respective nutrients were independent of each other. Inter-parameter regression analysis for sediment samples indicated that phosphates and nitrates had a strong positive correlation in the dry season at $r= 0.79$ with 63% of coefficient of determination hence a relatively strong linear relationship.

Sulphates had a moderate positive correlation with nitrates at $r=0.60$ in the dry season and indicated that 37% of the total variations had a linear relationship. Sulphates and nitrates in the wet season showed a strong positive relationship at $r=0.49$ with only 24% showing linear relationship. The other parameters showed very weak positive correlations in both seasons and $p>0.05$, hence results not significant at $p<0.05$ (Table 4.1).

The seasonal strong, moderate to weak correlation coefficients between phosphates, sulphates and nitrates in both water and sediments indicate the contribution and accumulation of various factors along the river system both temporally and spatially. Scatter plots for inter-parameter linear relationships for both the dry and wet seasons are provided in appendix 19.

Table 4.1: Summary of inter-variable regression statistics

	INTER-VARIABLE REGRESSION STATISTICS FOR WATER SAMPLES			
	DRY SEASON		**WET SEASON**	
	Phosphates	**Sulphates**	**Phosphates**	**Sulphates**
Sulphates	R=0.47 R^2=0.67 **P=0.01**[a]		R=0.10 R^2=0.01 **P=0.75**[b]	
Nitrates	R=0.14 R^2=0.03 **P=0.65**[b]	R=0.26 R^2=0.07 **P=0.39**[b]	R=0.06 R^2=0.00 **P=0.84**[b]	R=0.13 R^2=0.02 **P=0.67**[b]
NUTRIENT REGRESSION STATISTICS FOR SEDIMENT SAMPLES				
	DRY SEASON		**DRY SEASON**	
	Phosphates	**Sulphates**	**Phosphates**	**Sulphates**
Sulphates	R=0.12 R^2=0.01 **P=0.70**[b]		R=0.33 R^2=0.11 **P=0.26**[b]	
Nitrates	R=0.25 R^2=0.06 **P=0.40**[b]	R=0.49 R^2=0.24 **P=0.09**[b]	R=0.79 R^2=0.63 **P=0.00**[a]	R=0.60 R^2=0.37 **P=0.03**[a]

[a] $p<0.05$ and **[b]** $p>0.05$
Correlation at 95% confidence limit and $p \leq 0.05$
Where, **R** is the correlation coefficient
$\mathbf{R^2}$ is the coefficient of determination
P (Alpha) is the test of statistical significance.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study demonstrates effects and influences of natural phenomena and anthropogenic factors on Ngong–Motoine River systems using spatial and temporal pollution Arc-GIS maps and diagrams. The spatial and temporal pollution variations for PO_4^{3-}, SO_4^{2-}, NO_3^- in water and sediments and *E. coli* in water strongly indicate that the river system receives pollutants from various activities from many point and non-point sources. The observed pollution within the study area could be arising from surface run-off from farm lands, raw sewerage, human waste from the informal settlements and domestic and industrial discharges.

In both the dry and wet seasons, phosphate levels were higher than the 2006 World Health Organization guideline limit of 0.5 mg/L. There were elevated levels of phosphates, in both seasons, from Nairobi Dam inlet all through to Kangundo Road Bridge with varying trends which was attributed to discharges from the Kibera, Mukuru (Kayaba, Kwa Njenga and Kwa Ruben) informal settlements and industrial activities which exhibit high levels of raw sewage, vandalised sewer lines and raw industrial effluent.

The river profile seasonal averages for phosphates were 5.50 mg/L for the dry season and 4.95 mg/L for the wet season. Temporal variations indicated a build-up of phosphates levels at Nairobi Dam weir at 11.34 ±0.01 mg/L and 8.82±0.54 mg/L for the dry and wet seasons, respectively. This was attributed to the accumulation of the nutrients as a result of eutrophication which has entirely covered the Dam acting as a sink. The results obtained indicate that a significant self-cleaning at the Dam outlet which had reduced levels of 3.6±0.01 mg/L (Dry) and 5.56±0.27 mg/L (Wet) as a result of absorption by the existing several plant species at the Dam weir.

Irrigation and surface runoff from agricultural field along the river also contributes to increased phosphate levels. Overall, the upper section of the river system was less polluted probably due to low population density with minimal agricultural activities than the middle and the lower section. Pollution intensities increased downstream indicating the influence of informal settlements with poor sanitation infrastructure, encroachment of the river banks for agricultural activities and industrial activities which are heavily concentrated downstream.

Nitrates levels in water were within the WHO limits of 10 mg/L in all sampling point except the Nairobi Dam weir, the Dam outlet and Langata Road bridge that had 10.32±0.19 mg/L, 10.06±0.08 mg/L and 13.74±0.02 mg/L, respectively, for the dry season with an average concentration of 6.14 mg/L. The high levels at Langata Road Bridge were attributed to accumulation in the Dam weir as a result of pollution from human waste from Kibera slums, agricultural activities with subsequent wash out and contribution from inorganic nitrate containing fertilizers used by tree seedlings vendors lined up along the river.

All the sampling stations except at Motoine Dam (0±0.18 mg/L) had the nitrate levels higher than the WHO limits of 10 mg/L in the wet season with an average concentration of 16.92 mg/L along the river profile. The high levels observed along the river system in the wet season are directly linked to the effect of surface runoff from non-point sources, farming activities along the river, discharges from the informal settlements and industrial effluent.

Sulphates concentration levels in water were within the WHO limits of 0-500 mg/L for drinking water and water for domestic purposes. The average concentrations in the dry and wet seasons were 0.54 mg/L and 0.67 mg/L, respectively. A high concentration of 1.15±0.02 mg/L was observed at Nairobi Dam weir and 1.07±0.00 at Mukuru Kayaba (Hazina Bridge) giving a clear indication of pollution by discharges emanating from Kibera and Mukuru informal settlements. Contribution from the industrial activities is depicted by the varying trends in small concentrations observed as the river cascades through the industrial area.

The wet season showed low and relatively uniform concentrations of sulphate measured from all stations could be because sulphates easily precipitates and settles to the bottom sediments of the river. However, the general low concentration of sulphate in the entire stream for both seasons could be attributed to the fact that, the sulphate in both water and sediments was used up as a source of oxygen by bacteria and was converted to H_2S under anaerobic conditions.

Spatial and temporal *E. coli* pollution for both seasons were higher than the recommended WHO, USEPA and NEMA limit guidelines of 0 MPN/100ml for drinking water. The most probable number count increased sharply from 140 MPN/100 mL and 94 MPN/100 mL (dry and wet) to +1800 MPN/100 mL of sample for all stations suggesting heavy human and domestic waste discharges to the river coupled with sewer discharges into the river channel.

Sediment pollution by phosphates and sulphates were high in both seasons, but exceptionally high in the wet season. Nairobi Dam weir had the highest concentration of phosphates in sediments at 9,157±539 mg/Kg that could be attributed to application of phosphate fertilizers during the rainy season on farmlands along the river profile. Surface run-off and the use of detergents from the settlements and industries along the river system coupled with biomass decay in the sediments could also account for increased phosphate levels in all stations.

High levels of sulphates along the river system in the wet season could be explained by the leaching effect from sulphur compounds either as sulphate minerals such as gypsum or sulphite as pyrite or from sedimentary rocks and the fact sulphates in rainy season tends to accumulate and precipitate to progressively high concentrations. Jamhuri Dam and Motoine Dam had the highest concentration levels. This could also be attributed by the geology of the upper section of the river system which is characterised by the Precambrian Schist’s and Gneisses of Mozambique belt in Ngong hills.

The relatively high levels of phosphates in both the dry and wet season could be attributed to the discharges from settlements, contamination from burst sewer lines, overflows from irrigation fields along the river system and accumulation of due to eutrophication of the river channel. While for sulphates, relatively high concentrations observed could be due to precipitations and settlement in the river sediments.

Nitrates were high in the dry season at an average of 1,338 mg/Kg with a peak at Nairobi Dam inlet at 4,178±19 mg/Kg. The high levels of nitrates could be as a result of application of animal manure and inorganic fertilizers by tree seedlings vendors along the river profile. Minimum detectable limits between Mombasa Road Bridge and Mater Bridge could be linked to the absence of agricultural and informal settlements along the river stretch in the midstream, whereas elevated levels at Kangundo Road Bridge could be as a result of cumulative effect of farming activities, animal husbandry and human waste discharges from informal settlements.

The wet season had relatively distributed high nitrate levels with an average of 1,136 mg/Kg and a pick at the Nairobi Dam weir at 3,524±50 mg/Kg. This could be attributed to the fact that the Dam acts as a sink for nitrates emanating from use of nitrates containing fertilizers in agricultural farms and animals pen surface run-off. Human waste discharge from Kibera slums also formed a basis for nitrate accumulation in the Dam. Observed varying trends along the system are attributed to the distribution due to leaching effect from the top sediments.

There was no significant difference in *Escherichia coli* during in both seasons, although the parameters were higher than the recommended standard of 0 Coliform MPN/100 ml of water. All the Sediments samples had all the parameters above the World Health Organizations standards for drinking water quality.

5.2 Recommendations

Based on the findings of this study, the following recommendations could be suggested:

1) The National Environemnt Management Authority (NEMA) of Kenya, Water Resources Management Authority (WRMA) should establish a mechanisms for protection , prevention and monitoring of Ngong-Motoine River system (including its tributaries) pollution from phosphates, nitrates and sulphates and *E. Coli* to prevent the deterioration of its water quality.

2) Relevant authorities to monitor the water quality and pollution intensity from point sources and develop pollution inventory of effluent characteristics from industries and informal settlements.

3) Soil type, water retention capacity, soil particle size were not considerd in this study. It is therefore suggested that future studies need to consider the use of such variables so as to to get more insight into their influence on measured levels. Subsequently, more studies should be carried out on soils from the riparian land and biota to establish possible contribution to the degradation of the river water quality.

4) This study only considered thirteen stations along a 52.4 km stretch of Ngong River. These points can not adequately adivise on the magnitude of pollution from the point and non-point sources. It is recommended that more permanent sampling stations be established along the river system for effective monitoring. This will also aid in the development of a water quality monitoirng network that will acquire fundamental information for understanding the current baselines and predict short and long -term pollution trends.

5) Regulation and laws should be enforced to control industrial effluent treatment and discharge to water bodies and farming activities on the riverine and additional studies should be done to determine the effects of use of Ngong-Motine River water for its users i.e for domestic purposes and agriculture.

6) Data on diseases out break for the water users was unavailable. It is highly reccomended that such a survey be carried out to establish the frequency of water related disease out breaks. Since residents along the river system use these river waters for crop irrigation and fishing, there is need for a detailed analysis of the crops and fish species present for the levels of phosphates, nitates and sulphates and their effects to human health.

7) This study considered two seasons the (dry and wet) for the year 2012. The data obtained is inadequate for the development of predictions models, therefore, more data need to be collected during the dry period, long rains and short rains for over time to compare the pollution levels and there infleuce due to climate variability.

8) Geographic Information System (GIS) application on water resources managemnt in Kenya is limited due to high associated costs and lack of trained pesonel. This coupled with the high cost for the acquisition of georeferenced data has negativley impacted on development for GIS based prediction models for rivers polltuion levels. Thus there is need for the government to subsidise on equipments importation costs.

9) Due to the eutrophic nature of Nairobi Dam, residents in Kibera informal settlements have started reclaiming the Dam for agricultural practices. There is need for the county government of Nairobi to secure the Dam area and restrict access.

10) The Nairobi dam was in 1953 a recreational centre with a variety of water sports activities. Feasibility studies on the reclamation of the the Dam and the entire river should be carried out to establish a programme of activities geared to words the water quality restoration.

11) There are no proper waste management facilities in the informal settlemnts resulting to direct disposal of unseggregated solid waste into the river. This has resulted in a continous water pollution and the detororation of the riverine. There is need for the county governemnt of Nairobi to formulate and implement an integrated solid waste management strategy and improve on the sanitation infrastructure in the informal settlements. This will go alongway in reducing comunicable dieseses outbreaks and restore the water quality in the river.

12) A strategy to expand the coverage of the sewer system in new upcoming residential in the river basin should be developed and implemented and at the same time, efforts should be made to improve the efficiency and effectiveness in the maintenance of the exisitng sewer system that has been greatly vandalized resulting to surface overflows ending up to the river.

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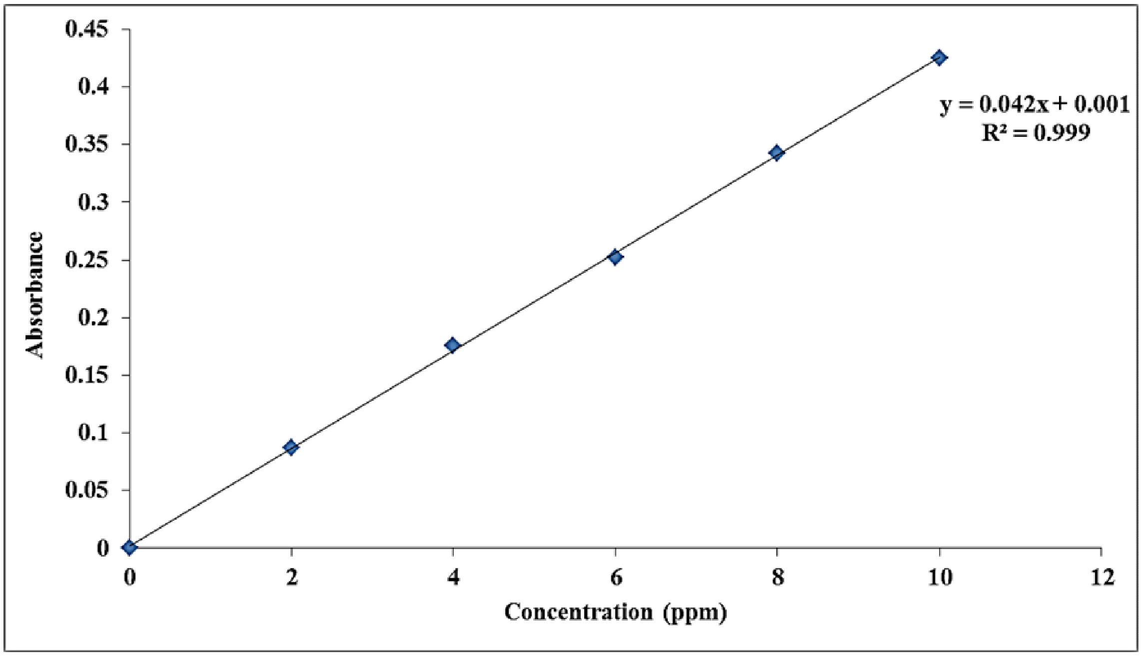
APPENDICES

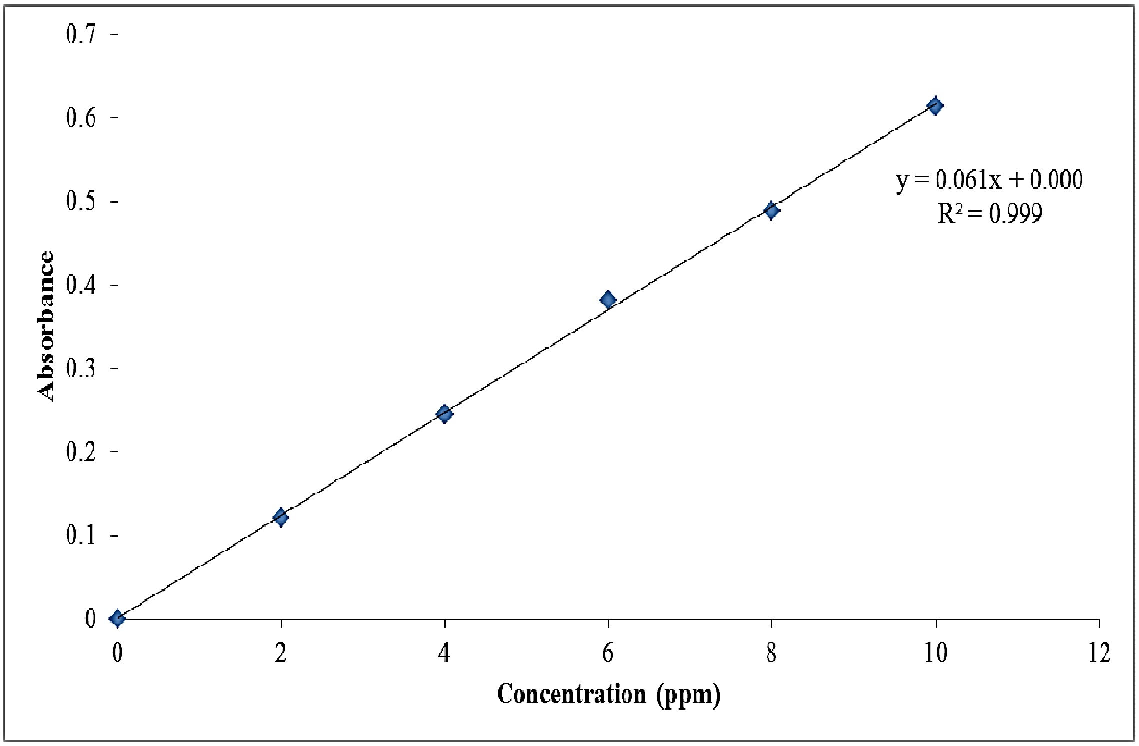
Appendix 1: Geographical Information System coordinates for the study area.

Sampling point	Latitudes	Longitudes	Altitude (masl)	Distance (km)
Motoine Dam	-1.30855	36.72348	1842	0
Jamhuri Dam	-1.30746	36.76965	1782	5.8
Kibera Bridge	-1.30957	36.77187	1765	7.9
Nairobi Dam Inlet	-1.31873	36.79346	1718	9.6
Nairobi Dam Weir	-1.31983	36.80119	1718	10.3
Nairobi Dam Outlet	-1.31509	36.80941	1685	10.8
Langata Road Bridge	-1.31518	36.80945	1664	11.9
Mombasa Road Bridge	-1.31138	36.81707	1659	12.7
Mater Bridge	-1.30614	36.83294	1648	13.2
Mukuru Kayaba (Hazina Bridge)	-1.31346	36.84978	1630	14.2
Enterprise Road Bridge	-1.31607	36.86185	1649	15.1
Outering Road Bridge (Donholm)	-1.30607	36.88941	1614	17.8
Kangundo Road Bridge.	-1.24841	36.946	1526	25.4

Appendix 2: Phosphates Calibration Curve.



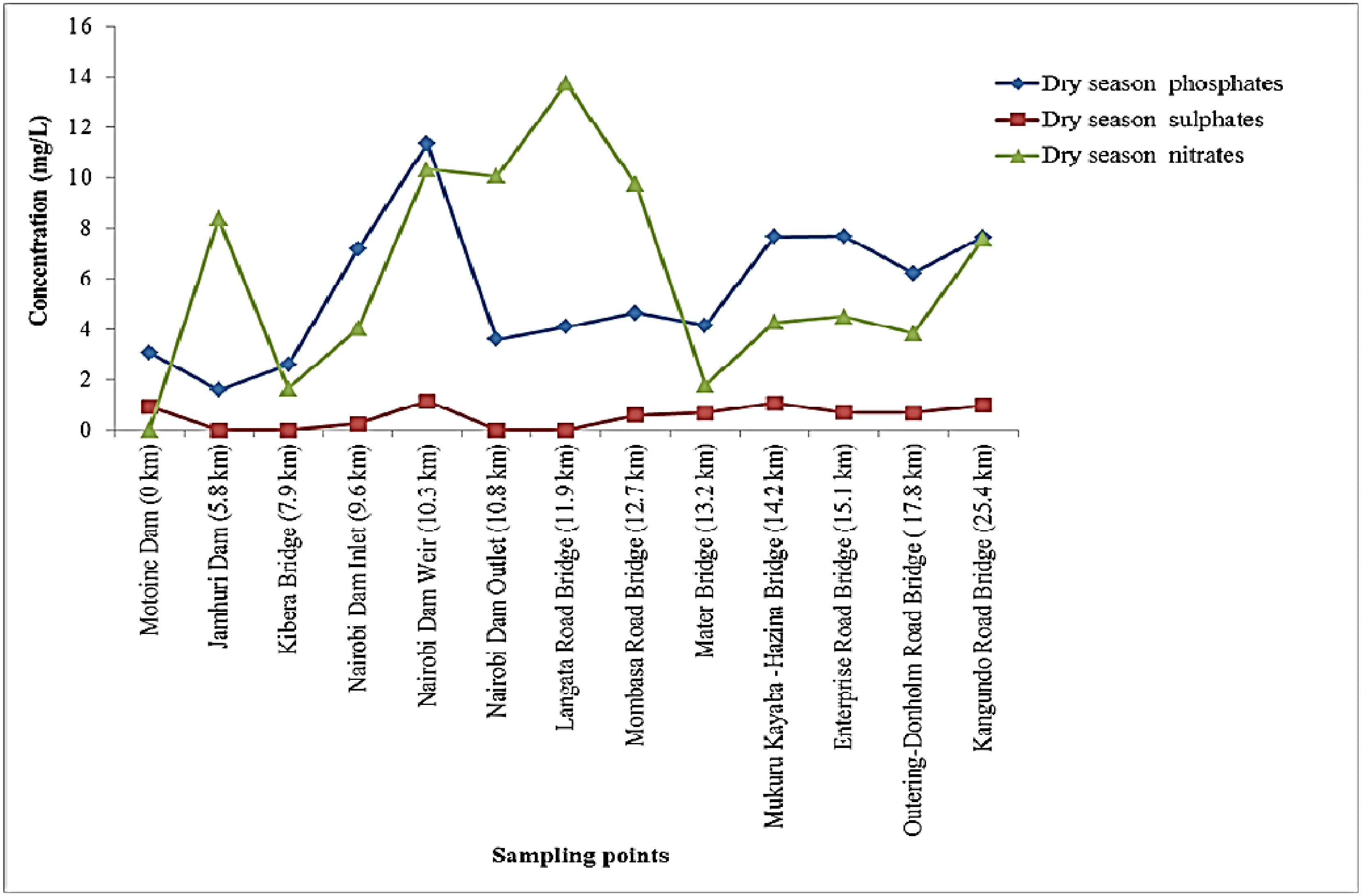
Appendix 3: Nitrates Calibration Curve.



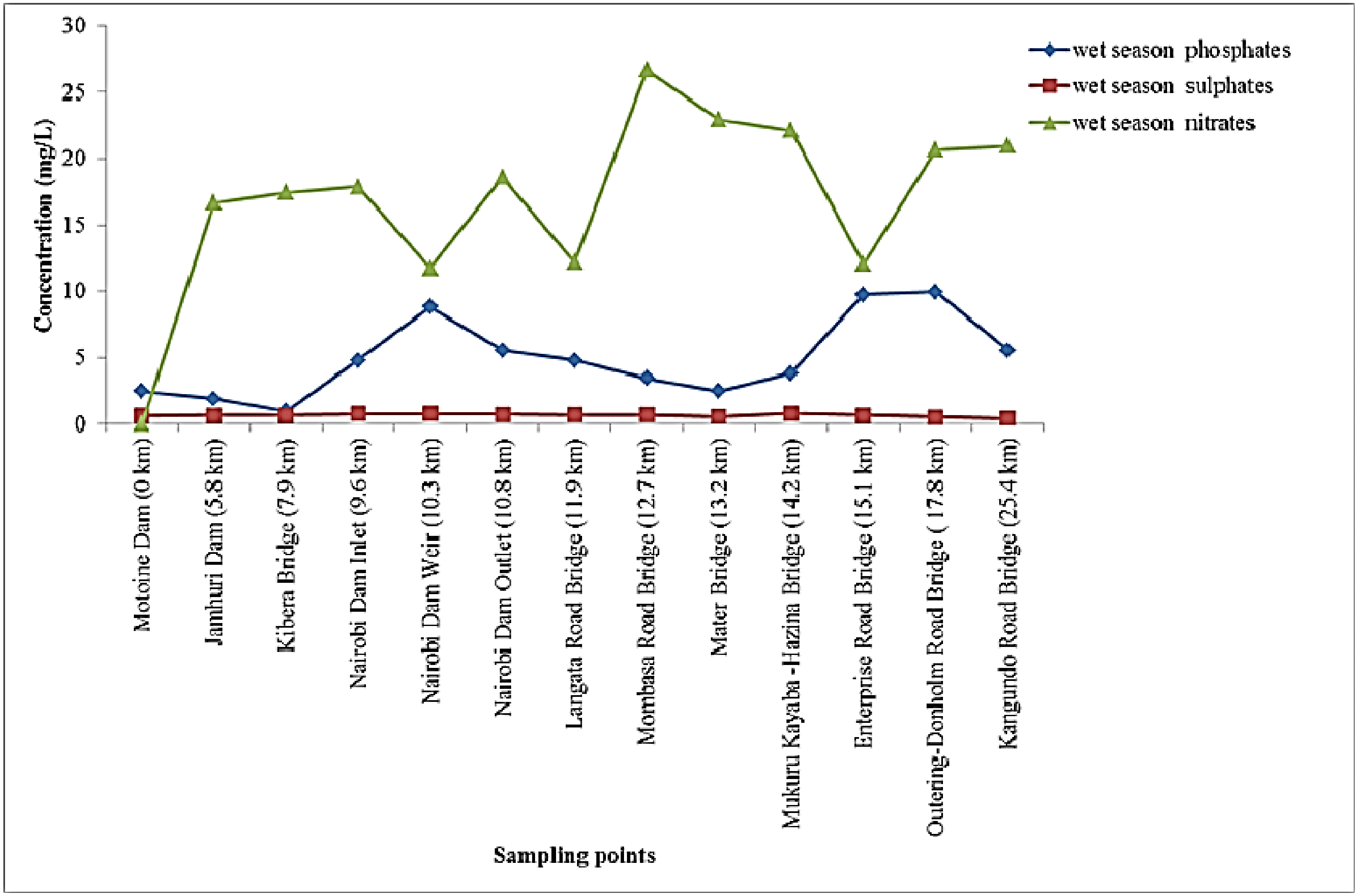
Appendix: 4: Temporal variations of Phosphates, Sulphates and Nitrates in water.

SAMPLING POINT	DRY SEASON			WET SEASON		
	Pollution Concentration levels (mg/L)			Pollution Concentration levels (mg/L)		
	PO_4^{3-}	SO_4^{2-}	NO_3^-	PO_4^{3-}	SO_4^{2-}	NO_3^-
Motoine Dam	3.07±0.00	0.94±0.02	0±1.10	2.49±0.27	0.64±0.02	0±0.18
Jamhuri Dam	1.59±0.01	0±0.00	8.37±0.34	1.92±0.00	0.68±0.01	16.67±2.38
Kibera Bridge	2.59±0.02	0±0.00	1.65±0.22	0.96±0.27	0.68±0.00	17.45±0.05
Nairobi Dam Inlet	7.17±0.01	0.26±0.026	4.03±2.48	4.79±0.54	0.77±0.07	17.87±2.48
Nairobi Dam Weir	11.34±0.01	1.15±0.016	10.32±0.19	8.82±0.54	0.76±0.03	11.77±0.22
Nairobi Dam Outlet	3.6±0.01	0±0.00	10.06±0.077	5.56±0.27	0.74±0.10	18.59±0.48
Langata Road Bridge	4.1±2.88	0±0.00	13.74±0.02	4.79±0.27	0.71±0.08	12.21±0.04
Mombasa Road Bridge	4.65±0.01	0.59±0.026	9.74±1.28	3.45±0.54	0.7±0.04	26.65±1.36
Mater Bridge	4.15±0.03	0.68±0.19	1.79±0.94	2.49±0.27	0.57±0.11	22.95±0.37
Mukuru Kayaba (Hazina Bridge)	7.67±0.01	1.07±0.00	4.28±0.12	3.83±0.54	0.79±0.02	22.12±0.48
Enterprise Road Bridge	7.68±0.02	0.7±0.01	4.51±0.52	9.77±0.81	0.67±0.09	12.06±0.10
Outering Road Bridge (Donholm)	6.21±0.11	0.69±0.00	3.82±2.85	9.96±0.54	0.54±0.13	20.68±0.34
Kangundo Road Bridge	7.64±0.04	0.99±0.00	7.56±0.65	5.56±0.27	0.42±0.12	20.95±0.27

Appendix 5: Phosphates, Sulphates and Nitrates dry season spatial variation in water.



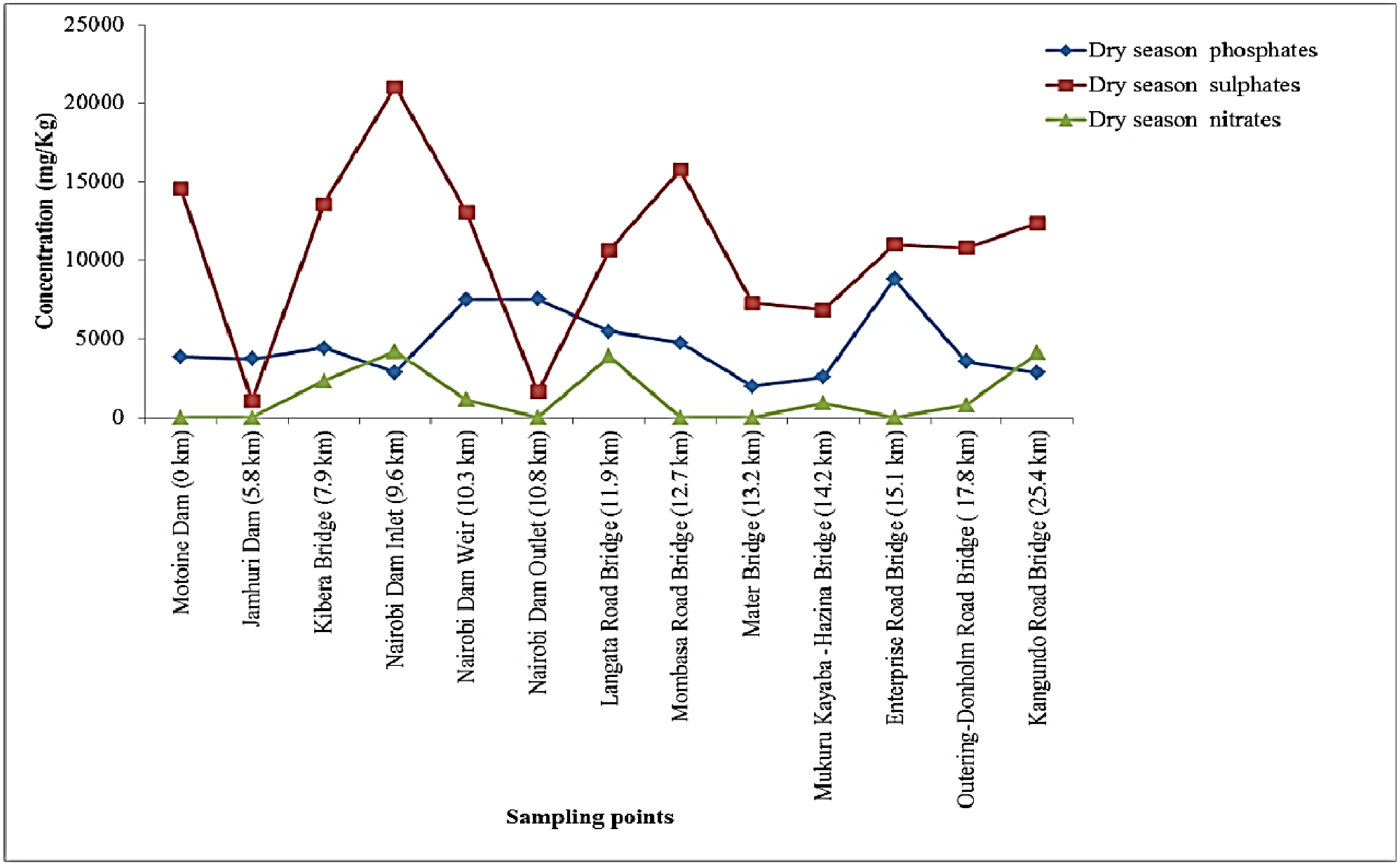
Appendix 6: Phosphates, Sulphates and Nitrates wet season spatial variation in water.



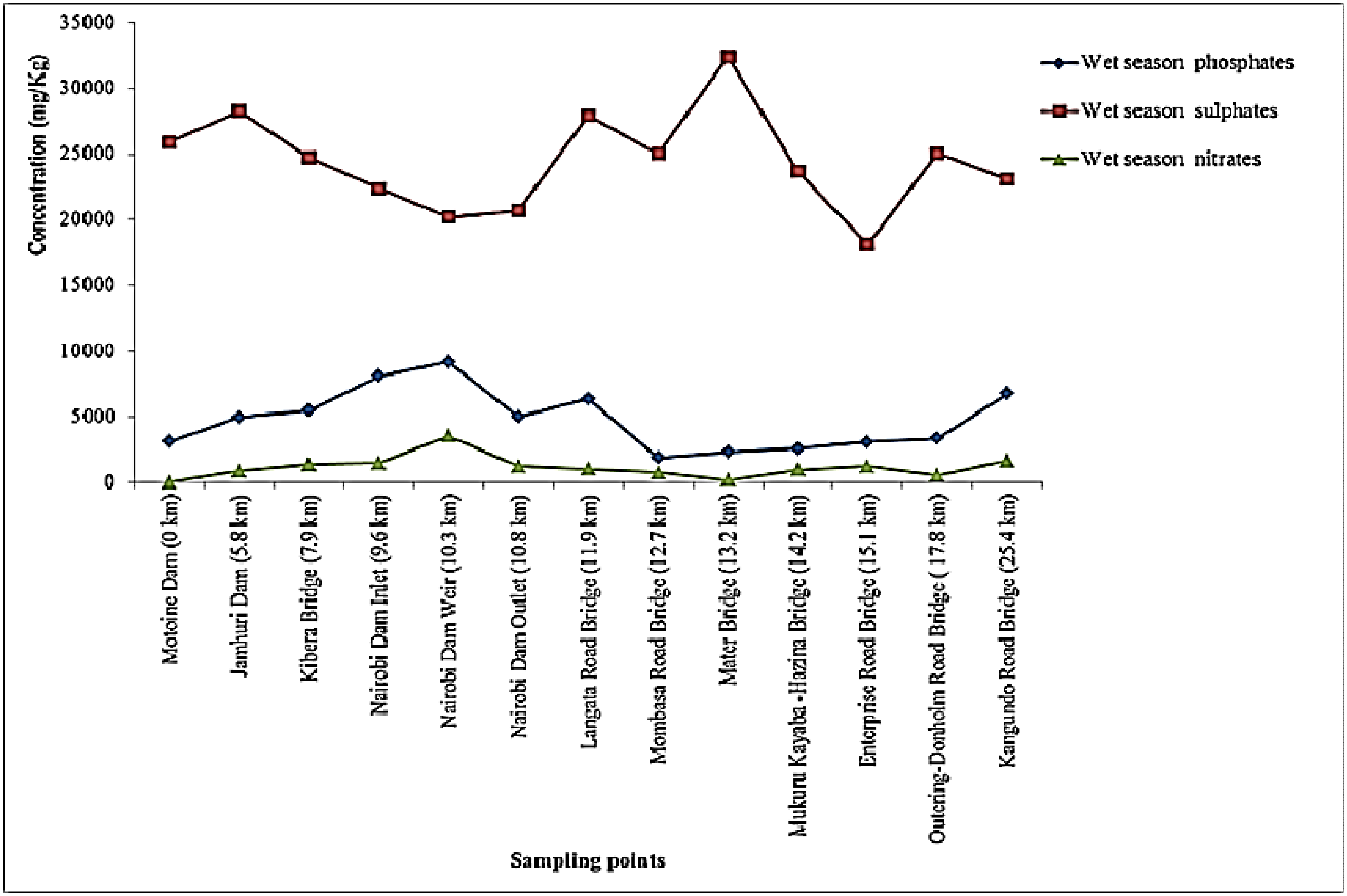
Appendix 7: Temporal variations of Phosphates, Sulphates and Nitrates in sediments.

SAMPLING POINT	DRY SEASON			WET SEASON(mg/Kg)		
	Pollution Concentration levels (mg/Kg)			Pollution Concentration levels (mg/Kg)		
	PO_4^{3-}	SO_4^{2-}	NO_3^{-}	PO_4^{3-}	SO_4^{2-}	NO_3^{-}
Motoine Dam	3,864±0.79	14,551±6,314.60	0±103.17	3,093±1,240.42	25,888±3,028.29	0±154.24
Jamhuri Dam	3,717±75.76	1,045±104.10	0±150.57	4,945±1106.42	28,247±3,584.45	874±14.11
Kibera Bridge	4,419±43.62	13,585±266.50	2,298±8.38	5,472±1529.54	24,717±1,233.19	1,355±50.04
Nairobi Dam Inlet	2,861±123.67	21,033±1,197.09	4,178±19.74	8,087±510.42	22,360±2,411.19	1,470±8.38
Nairobi Dam Weir	7,510±56.60	13,085±1,411.30	1,124±0.69	9,157±539.95	20,199±872.32	3,524±38.79
Nairobi Dam Outlet	7,536±218.73	1,635±253.64	0±10.10	4,998±476.85	20,667±5,980.16	1,226±18.13
Langata Road Bridge	5,450±138.87	10,649±7,096.37	3,897±99.16	6,348±128.34	27,919±4,283.61	1,026±35.12
Mombasa Road Bridge	4,731±25.53	15,766±23.67	0±63.35	1,866±161.97	25,026±3,872.48	754±30.76
Mater Bridge	1,985±2.18	7,280±170.24	0±21.81	2,295±108.66	32,373±3,720.74	150±46.14
Mukuru Kayaba (Hazina Bridge)	2,560±89.52	6,847±308.00	893±34.54	2,565±185.52	23,667±2,006.41	968±45.91
Enterprise Road Bridge	8,805±150.34	11,002±6,149.36	0±14.57	3,065±55.43	18,120±364.19	1,238±0.45
Outering Road Bridge (Donholm)	3,554±36.53	10,776±103.23	756±1.03	3,327±973.20	25,053±5,243.01	541±109.25
Kangundo Road Bridge	2,843±43.51	12,361±1,345.64	4,110±366.10	6,757±1,569.60	23,065±4,202.50	1,647±56.35

Appendix 8: Phosphates, Sulphates and Nitrates dry season spatial variation in sediments.



Appendix 9: Phosphates, Sulphates and Nitrates wet season spatial variation in sediments.



Appendix 10: Temporal variations of *E. coli* pollution in water.

SAMPLING POINT	**DRY SEASON**				**WET SEASON**			
	No of Tubes Giving Positive Reaction				**No of Tubes Giving Positive Reaction**			
	10ml	**1 ml**	**0.1 ml**	**MPN/ 100 mL**	**10ml**	**1 ml**	**0.1 ml**	**MPN/ 100 mL**
Motoine Dam	5	3	2	140	5	2	2	94
Jamhuri Dam	5	5	5	+1800	5	3	4	210
Kibera Bridge	5	5	5	+1800	5	5	5	+1800
Nairobi Dam Inlet	5	5	5	+1800	5	5	5	+1800
Nairobi Dam Weir	5	5	5	+1800	5	5	5	+1800
Nairobi Dam Outlet	5	5	5	+1800	5	5	5	+1800
Langata Road Bridge	5	5	5	+1800	5	5	5	+1800
Mombasa Road Bridge	5	5	5	+1800	5	5	5	+1800
Mater Bridge	5	5	5	+1800	5	5	5	+1800
Mukuru Kayaba (Hazina Bridge)	5	5	5	+1800	5	5	5	+1800
Enterprise Road Bridge	5	5	5	+1800	5	5	5	+1800
Outering Road Bridge (Donholm)	5	5	5	+1800	5	5	5	+1800
Kangundo Road Bridge	5	3	2	+1800	5	2	2	+1800

Appendix 11: MPN index table.

MPN index and 95 per cent confidence limits for various combinations of positive results when five tubes are used per dilution (10 ml, 1.0 ml, 0.1 ml portions of sample).

Combination of Positives	**MPN Index/ 100 mL**	**Confidence Limits**		**Combination of Positives**	**MPN Index/100 mL**	**Confidence Limits**	
		Low	**High**			**Low**	High
0-0-0	1.8	—	6.8	4-0-3	25	9.8	70
0-0-1	1.8	0.090	6.8	4-1-0	17	6.0	40
0-1-0	1.8	0.090	6.9	4-1-1	21	6.8	42
0-1-1	3.6	0.70	10	4-1-2	26	9.8	70
0-2-0	3.7	0.70	10	4-1-3	31	10	70
0-2-1	5.5	1.8	15	4-2-0	22	6.8	50
0-3-0	5.6	1.8	15	4-2-1	26	9.8	70
1-0-0	2.0	0.10	10	4-2-2	32	10	70
1-0-1	4.0	0.70	10	4-2-3	38	14	100
1-0-2	6.0	1.8	15	4-3-0	27	9.9	70
1-1-0	4.0	0.71	12	4-3-1	33	10	70
1-1-1	6.1	1.8	15	4-3-2	39	14	100
1-1-2	8.1	3.4	22	4-4-0	34	14	100
1-2-0	6.1	1.8	15	4-4-1	40	14	100
1-2-1	8.2	3.4	22	4-4-2	47	15	120
1-3-0	8.3	3.4	22	4-5-0	41	14	100
1-3-1	10	3.5	22	4-5-1	48	15	120
1-4-0	10	3.5	22	5-0-0	23	6.8	70
2-0-0	4.5	0.79	15	5-0-1	31	10	70

2-0-1	6.8	1.8	15	5-0-2	43	14	100
2-0-2	9.1	3.4	22	5-0-3	58	22	150
2-1-0	6.8	1.8	17	5-1-0	33	10	100
2-1-1	9.2	3.4	22	5-1-1	46	14	120
2-1-2	12	4.1	26	5-1-2	63	22	150
2-2-0	9.3	3.4	22	5-1-3	84	34	220
2-2-1	12	4.1	26	5-2-0	49	15	150
2-2-2	14	5.9	36	5-2-1	70	22	170
2-3-0	12	4.1	26	5-2-2	94	34	230
2-3-1	14	5.9	36	5-2-3	120	36	250
2-4-0	15	5.9	36	5-2-4	150	58	400
3-0-0	7.8	2.1	22	5-3-0	79	22	220
3-0-1	11	3.5	23	5-3-1	110	34	250
3-0-2	13	5.6	35	5-3-2	140	52	400
3-1-0	11	3.5	26	5-3-3	170	70	400
3-1-1	14	5.6	36	5-3-4	210	70	400
3-1-2	17	6.0	36	5-4-0	130	36	400
3-2-0	14	5.7	36	5-4-1	170	58	400
3-2-1	17	6.8	40	5-4-2	220	70	440
3-2-2	20	6.8	40	5-4-3	280	100	710
3-3-0	17	6.8	40	5-4-4	350	100	710
3-3-1	21	6.8	40	5-4-5	430	150	1100
3-3-2	24	9.8	70	5-5-0	240	70	710
3-4-0	21	6.8	40	5-5-1	350	100	1100
3-4-1	24	9.8	70	5-5-2	540	150	1700
3-5-0	25	9.8	70	5-5-3	920	220	2600
4-0-0	13	4.1	35	5-5-4	1600	400	4600
4-0-1	17	5.9	36	5-5-5	1600	700	—
4-0-2	21	6.8	40				

Source APHA 1998

Appendix 12: ANOVA tables of means for parameters in water and sediments.

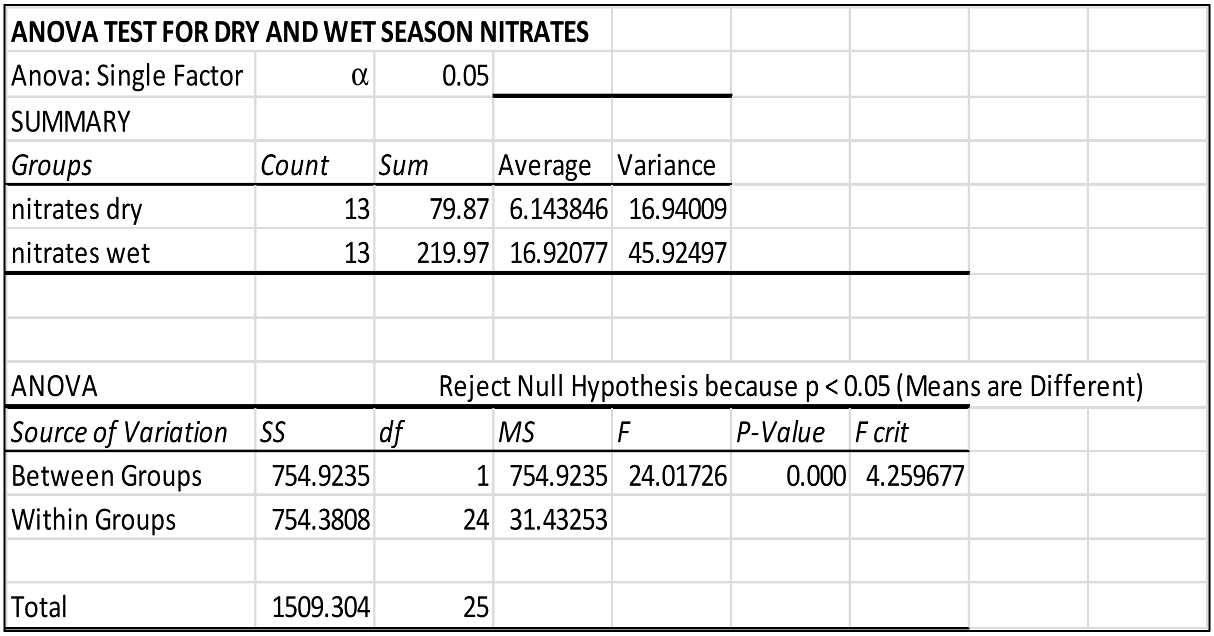
Appendix 12a: ANOVA table of means for dry and wet season phosphates in water.

ANOVA TEST FOR DRY AND WET SEASON PHOSPHATES IN WATER							
Anova: Single Factor	α	0.05					
SUMMARY							
Groups	*Count*	*Sum*	Average	Variance			
phosphates dry	13	71.46	5.496923	7.434623			
phosphates wet	13	64.39	4.953077	8.73444			
ANOVA		Accept Null Hypothesis because p > 0.05 (Means are the same)					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*	
Between Groups	1.922496	1	1.922496	0.237799	0.630	4.259677	
Within Groups	194.0288	24	8.084531				
Total	195.9513	25					

Appendix 12b: ANOVA table of means for dry and wet season sulphates in water.

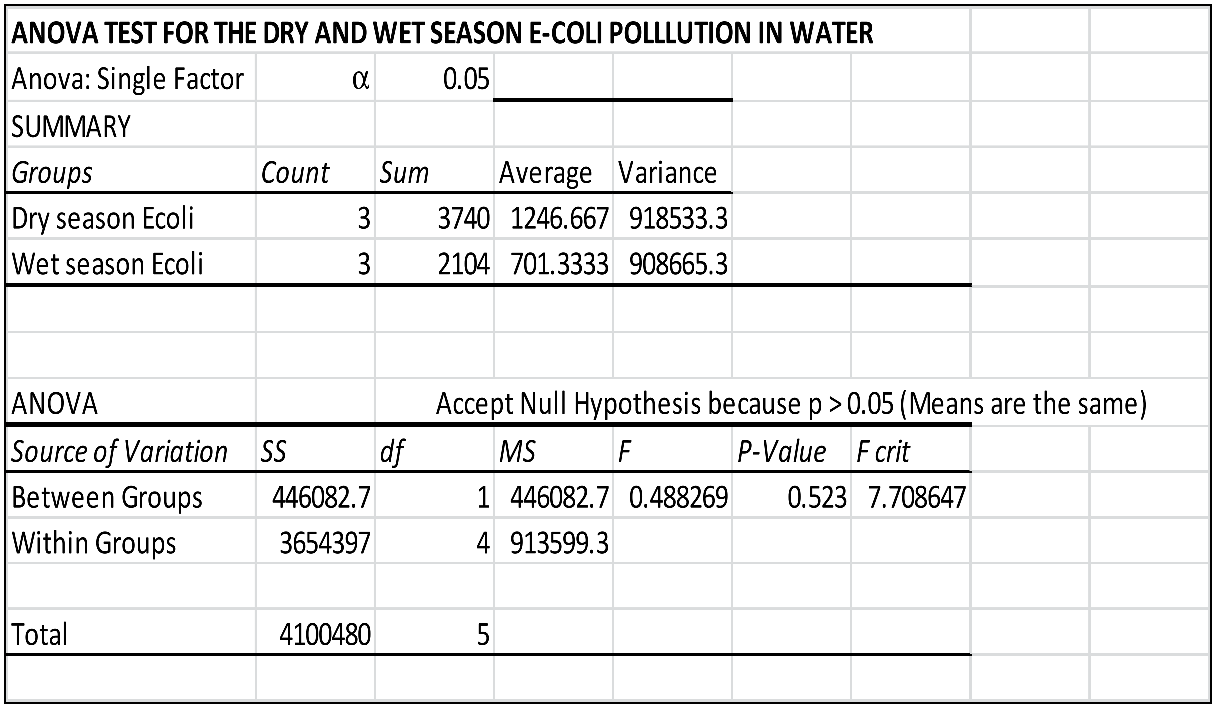
ANOVA TEST FOR DRY AND WET SEASON SULPHATES IN WATER							
Anova: Single Factor	α	0.05					
SUMMARY							
Groups	*Count*	*Sum*	Average	Variance			
sulphates dry	13	7.07	0.543846	0.194192			
sulphates wet	13	8.67	0.666923	0.010856			
ANOVA		Accept Null Hypothesis because p > 0.05 (Means are the same)					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*	
Between Groups	0.098462	1	0.098462	0.960372	0.337	4.259677	
Within Groups	2.460585	24	0.102524				
Total	2.559046	25					

Appendix 12c: ANOVA table of means for dry and wet season nitrates in water.



ANOVA TEST FOR DRY AND WET SEASON NITRATES						
Anova: Single Factor	α	0.05				
SUMMARY						
Groups	*Count*	*Sum*	Average	Variance		
nitrates dry	13	79.87	6.143846	16.94009		
nitrates wet	13	219.97	16.92077	45.92497		
ANOVA		Reject Null Hypothesis because p < 0.05 (Means are Different)				
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*
Between Groups	754.9235	1	754.9235	24.01726	0.000	4.259677
Within Groups	754.3808	24	31.43253			
Total	1509.304	25				

Appendix 12d: ANOVA table of means for dry and wet season *E.coli* in water.



ANOVA TEST FOR THE DRY AND WET SEASON E-COLI POLLLUTION IN WATER						
Anova: Single Factor	α	0.05				
SUMMARY						
Groups	*Count*	*Sum*	Average	Variance		
Dry season Ecoli	3	3740	1246.667	918533.3		
Wet season Ecoli	3	2104	701.3333	908665.3		
ANOVA		Accept Null Hypothesis because p > 0.05 (Means are the same)				
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*
Between Groups	446082.7	1	446082.7	0.488269	0.523	7.708647
Within Groups	3654397	4	913599.3			
Total	4100480	5				

Appendix 12e: ANOVA table of means for dry and wet season phosphate sediments.

ANOVA TEST FOR DRY AND WET SEASON PHOSPHATES IN SEDIMENTS						
Anova: Single Factor	α	0.05				
SUMMARY						
Groups	*Count*	*Sum*	Average	Variance		
phosphates dry	13	59835	4602.692	4589087		
phosphates wet	13	61975	4767.308	5373692		
ANOVA		Accept Null Hypothesis because p > 0.05 (Means are the same)				
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*
Between Groups	176138.5	1	176138.5	0.035359	0.852	4.259677
Within Groups	1.2E+08	24	4981389			
Total	1.2E+08	25				

Appendix 12f: ANOVA table of means for dry and wet season sulphates in sediments.

ANOVA TEST FOR DRY AND WET SEASON SULPHATES IN SEDIMENTS						
Anova: Single Factor	α	0.05				
SUMMARY						
Groups	*Count*	*Sum*	Average	Variance		
sulphates dry	13	139615	10739.62	30504188		
sulphates wet	13	317301	24407.77	14282236		
ANOVA		Reject Null Hypothesis because p < 0.05 (Means are Different)				
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*
Between Groups	1.21E+09	1	1.21E+09	54.22714	0.000	4.259677
Within Groups	5.37E+08	24	22393212			
Total	1.75E+09	25				

Appendix 12g: ANOVA table of means for dry and wet season nitrated in sediments.

ANOVA TEST FOR DRY AND WET SEASON NITRATES IN SEDIMENTS						
Anova: Single Factor	α	0.05				
SUMMARY						
Groups	*Count*	*Sum*	Average	Variance		
nitrates dry	13	17256	1327.385	2878517		
nitrates wet	13	14773	1136.385	751107.8		
ANOVA		Accept Null Hypothesis because p > 0.05 (Means are the same)				
Source of Variation	*SS*	*df*	*MS*	*F*	*P-Value*	*F crit*
Between Groups	237126.5	1	237126.5	0.130662	0.721	4.259677
Within Groups	43555502	24	1814813			
Total	43792629	25				

Appendix 13: Regression analysis for dry and wet season variables in water

Appendix 13a: Regression analysis for dry and wet season phosphates in water

REGRESSION ANALYSIS FOR DRY AND WET SEASON PHOSPHATES IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.707							
R Square	0.500	Goodness of Fit < 0.80						
Adjusted R Square	0.454							
Standard Error	2.183							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	52.39578281	52.39578281	10.9954438	0.007			
Residual	11	52.41749412	4.765226738					
Total	12	104.8132769					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	0.740501153	1.407294726	0.526187684	0.609	-2.356933654	3.837935961	-3.63028	5.111286
phosphates dry	0.766351595	0.231111568	3.315937847	0.007	0.257678464	1.275024727	0.048564	1.484139
y = 0.741 +0.766*phosphates dry								

Appendix 13b: Regression analysis for dry and wet season sulphates in water.

REGRESSION ANALYSIS FOR DRY AND WET SEASON SULPHATES IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.247							
R Square	0.061	Goodness of Fit < 0.80						
Adjusted R Square	-0.024							
Standard Error	0.105							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	0.007942537	0.007942537	0.714172968	0.416			
Residual	11	0.122334386	0.011121308					
Total	12	0.130276923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	0.698673467	0.04761334	14.67390153	0.000	0.593877211	0.803469722	0.550796	0.846551
sulphates dry	-0.058381198	0.069083017	-0.84508755	0.416	-0.210431893	0.093669498	-0.27294	0.156177
y = 0.699 -0.058*sulphates dry								

Appendix 13c: Regression analysis for dry and wet season nitrates in water.

REGRESSION ANALYSIS FOR DRY AND WET SEASON NITRATES IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.156							
R Square	0.024	Goodness of Fit < 0.80						
Adjusted R Square	-0.064							
Standard Error	6.991							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	13.4131105	13.4131105	0.274405612	0.611			
Residual	11	537.6865818	48.88059835					
Total	12	551.0996923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	15.34258909	3.582817682	4.282269	0.001	7.456860541	23.22831764	4.215051	26.47012759
nitrates dry	0.256871689	0.490365319	0.523837391	0.611	-0.822415101	1.33615848	-1.26611	1.779851493
y = 15.343 +0.257*nitrates dry								

Appendix 14: Regression analysis for dry and wet season *E-Coli* in water.

REGRESSION ANALSIS FOR DRY AND WET SEASON E-COLI POLLUTION IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.705							
R Square	0.497	Goodness of Fit < 0.80						
Adjusted R Square	0.451							
Standard Error	458.993							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	2285448.231	2285448.231	10.84821754	0.007			
Residual	11	2317425	210675					
Total	12	4602873.231					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	-38.70481928	497.8291904	-0.077747187	0.939	-1134.41948	1057.009841	-1584.87	1507.456
Dry season Ecoli	0.947891566	0.287792496	3.293663241	0.007	0.314464553	1.58131858	0.054064	1.841719
y = -38.705 +0.948*Dry season Ecoli								

Appendix 15: Regression analysis for dry and wet season variables in sediments

Appendix 15a: Regression analysis for dry and wet season phosphates in sediments

REGRESSION ANALYSIS FOR THE DRY AND WET SEASON PHOSPHATES IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.191							
R Square	0.037							
Adjusted R Square	-0.051							
Standard Error	2196.147							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	2015370.516	2015370.5	0.4178613	0.531			
Residual	11	53053674.25	4823061.3					
Total	12	55069044.77					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	3759.894	1439.052671	2.6127564	0.024	592.560451	6927.2276	-709.525	8229.31
WET SEASON	0.1767871	0.27348556	0.6464219	0.531	-0.4251506	0.7787247	-0.67261	1.02618
y = 3759.894 +0.177*WET SEASON								

Appendix 15b: Regression analysis for dry and wet season sulphates in sediments.

REGRESSION ANALYSIS FOR DRY AND WET SEASON SULPHATES IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.213							
R Square	0.045	Goodness of Fit < 0.80						
Adjusted R Square	-0.042							
Standard Error	3856.902							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	7754216.092	7754216.092	0.521267562	0.485			
Residual	11	163632620.2	14875692.75					
Total	12	171386836.3					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	25970.87124	2414.847613	10.75466257	0.000	20655.82748	31285.915	18470.82	33470.92
sulphates dry	-0.145545436	0.201589656	-0.721988616	0.485	-0.589241277	0.298150404	-0.77164	0.480553
y = 25970.871 -0.146*sulphates dry								

Appendix 15c: Regression analysis for dry and wet season nitrates in sediments.

REGRESSION ANALYSIS FOR DRY AND WET SEASON NITRATES IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.320							
R Square	0.102	Goodness of Fit < 0.80						
Adjusted R Square	0.021							
Standard Error	857.577							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	923467.4531	923467.4531	1.255668843	0.286			
Residual	11	8089825.624	735438.6931					
Total	12	9013293.077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	919.3482428	306.734265	2.99721403	0.012	244.2306773	1594.465808	-33.309	1872.006
nitrates dry	0.163506771	0.14591441	1.120566305	0.286	-0.15764868	0.484662222	-0.28968	0.616689
y = 919.348 +0.164*nitrates dry								

Appendix 16: Regression analysis for River distance from the source and parameters in water.

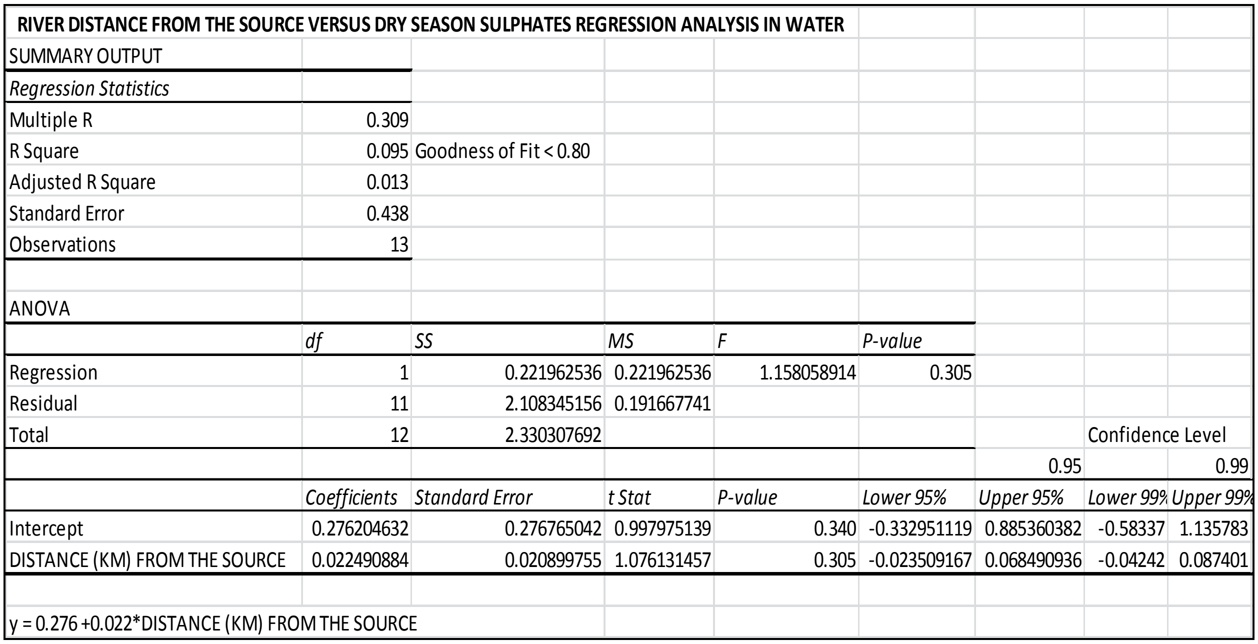
Appendix 16a:Regression analysis for river distance from the source and dry season phosphates concentration in water.

RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON PHOSPHATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.485							
R Square	0.235	Goodness of Fit < 0.80						
Adjusted R Square	0.166							
Standard Error	2.491							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	20.96949356	20.96949356	3.37989751	0.093			
Residual	11	68.24598336	6.204180305					
Total	12	89.21547692					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	2.89552016	1.57463147	1.838855767	0.093	-0.570220339	6.361260659	-1.99498	7.786021
DISTANCE (KM) FROM THE SOURCE	0.218605287	0.118907404	1.838449757	0.093	-0.043108143	0.480318718	-0.1507	0.587909
y = 2.896 +0.219*DISTANCE (KM) FROM THE SOURCE								

Appendix 16b: Regression analysis for river distance (km) from the source and wet season phosphates concentration in water.

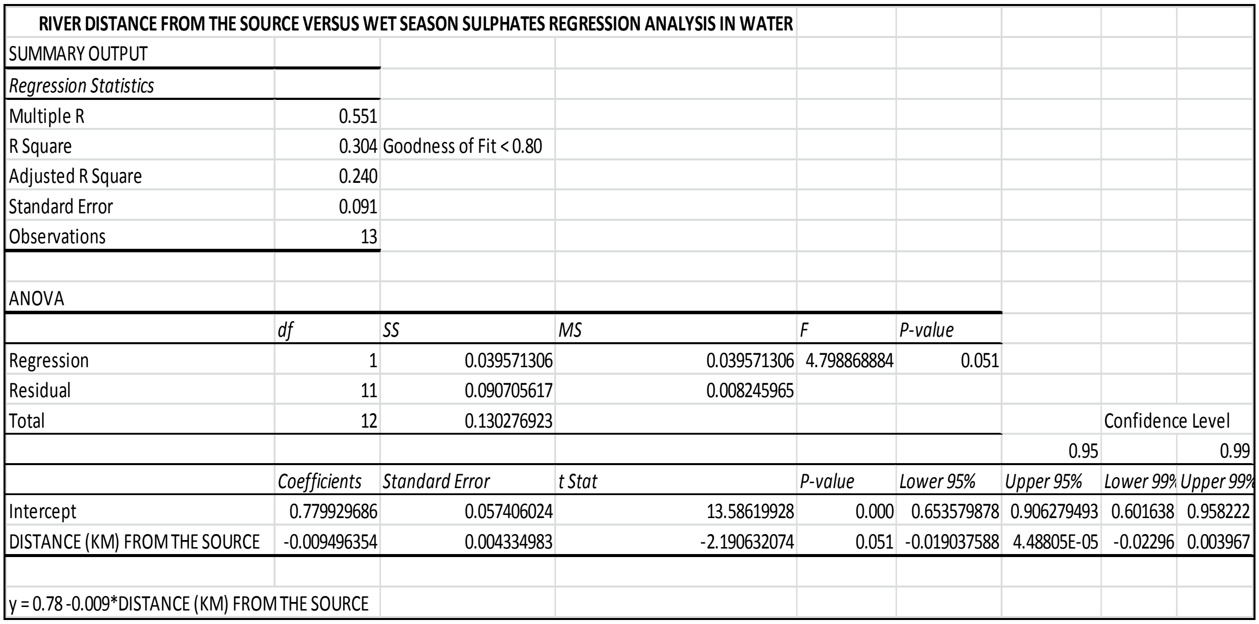
RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON PHOSPHATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.482							
R Square	0.233	Goodness of Fit < 0.80						
Adjusted R Square	0.163							
Standard Error	2.704							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	24.39656599	24.39656599	3.337145013	0.095			
Residual	11	80.41671093	7.310610085					
Total	12	104.8132769					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	2.147139366	1.709281264	1.256165039	0.235	-1.61496333	5.909242062	-3.16156	7.455836
DISTANCE (KM) FROM THE SOURCE	0.235793072	0.129075406	1.826785432	0.095	-0.048299982	0.519886126	-0.16509	0.636676
y = 2.147 +0.236*DISTANCE (KM) FROM THE SOURCE								

Appendix 16c: Regression analysis for river distance (km) from the source and dry season sulphates concentration in water.



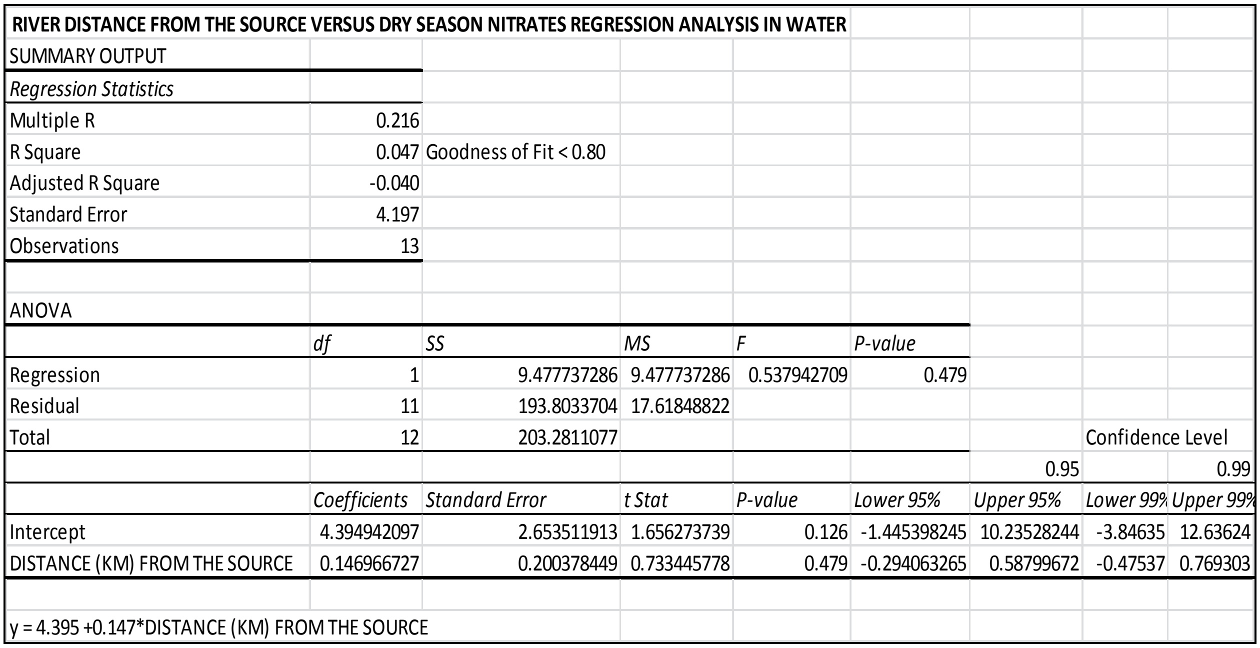
RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON SULPHATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.309							
R Square	0.095	Goodness of Fit < 0.80						
Adjusted R Square	0.013							
Standard Error	0.438							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	0.221962536	0.221962536	1.158058914	0.305			
Residual	11	2.108345156	0.191667741					
Total	12	2.330307692					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	0.276204632	0.276765042	0.997975139	0.340	-0.332951119	0.885360382	-0.58337	1.135783
DISTANCE (KM) FROM THE SOURCE	0.022490884	0.020899755	1.076131457	0.305	-0.023509167	0.068490936	-0.04242	0.087401
y = 0.276 +0.022*DISTANCE (KM) FROM THE SOURCE								

Appendix 16d: Regression analysis for river distance (km) from the source and wet season sulphates concentration in water.



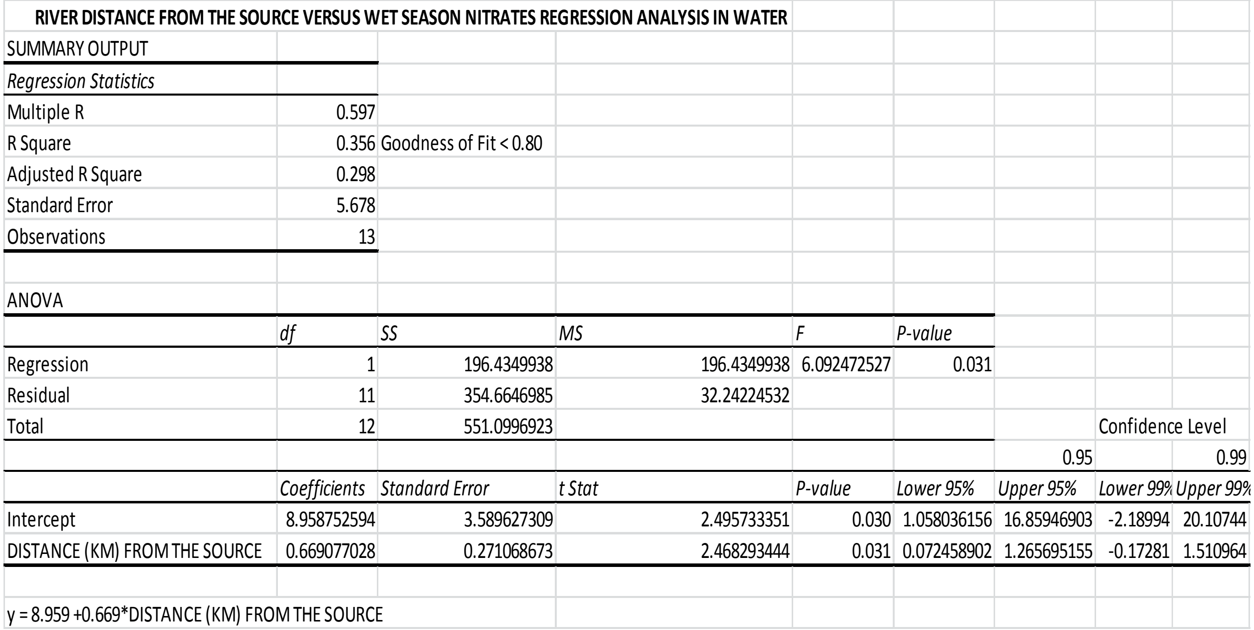
RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON SULPHATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.551							
R Square	0.304	Goodness of Fit < 0.80						
Adjusted R Square	0.240							
Standard Error	0.091							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	0.039571306	0.039571306	4.798868884	0.051			
Residual	11	0.090705617	0.008245965					
Total	12	0.130276923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	0.779929686	0.057406024	13.58619928	0.000	0.653579878	0.906279493	0.601638	0.958222
DISTANCE (KM) FROM THE SOURCE	-0.009496354	0.004334983	-2.190632074	0.051	-0.019037588	4.48805E-05	-0.02296	0.003967
y = 0.78 -0.009*DISTANCE (KM) FROM THE SOURCE								

Appendix 16e: Regression analysis for river distance (km) from the source and dry season nitrates concentration in water.



RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON NITRATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.216							
R Square	0.047	Goodness of Fit < 0.80						
Adjusted R Square	-0.040							
Standard Error	4.197							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	9.477737286	9.477737286	0.537942709	0.479			
Residual	11	193.8033704	17.61848822					
Total	12	203.2811077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	4.394942097	2.653511913	1.656273739	0.126	-1.445398245	10.23528244	-3.84635	12.63624
DISTANCE (KM) FROM THE SOURCE	0.146966727	0.200378449	0.733445778	0.479	-0.294063265	0.58799672	-0.47537	0.769303
y = 4.395 +0.147*DISTANCE (KM) FROM THE SOURCE								

Appendix 16f: Regression analysis for river distance (km) from the source and wet season nitrates concentration in water.



RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON NITRATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.597							
R Square	0.356	Goodness of Fit < 0.80						
Adjusted R Square	0.298							
Standard Error	5.678							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	196.4349938	196.4349938	6.092472527	0.031			
Residual	11	354.6646985	32.24224532					
Total	12	551.0996923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	8.958752594	3.589627309	2.495733351	0.030	1.058036156	16.85946903	-2.18994	20.10744
DISTANCE (KM) FROM THE SOURCE	0.669077028	0.271068673	2.468293444	0.031	0.072458902	1.265695155	-0.17281	1.510964
y = 8.959 +0.669*DISTANCE (KM) FROM THE SOURCE								

Appendix 16g: Regression analysis for river distance (km) from the source and wet season *E.coli* pollution in water.

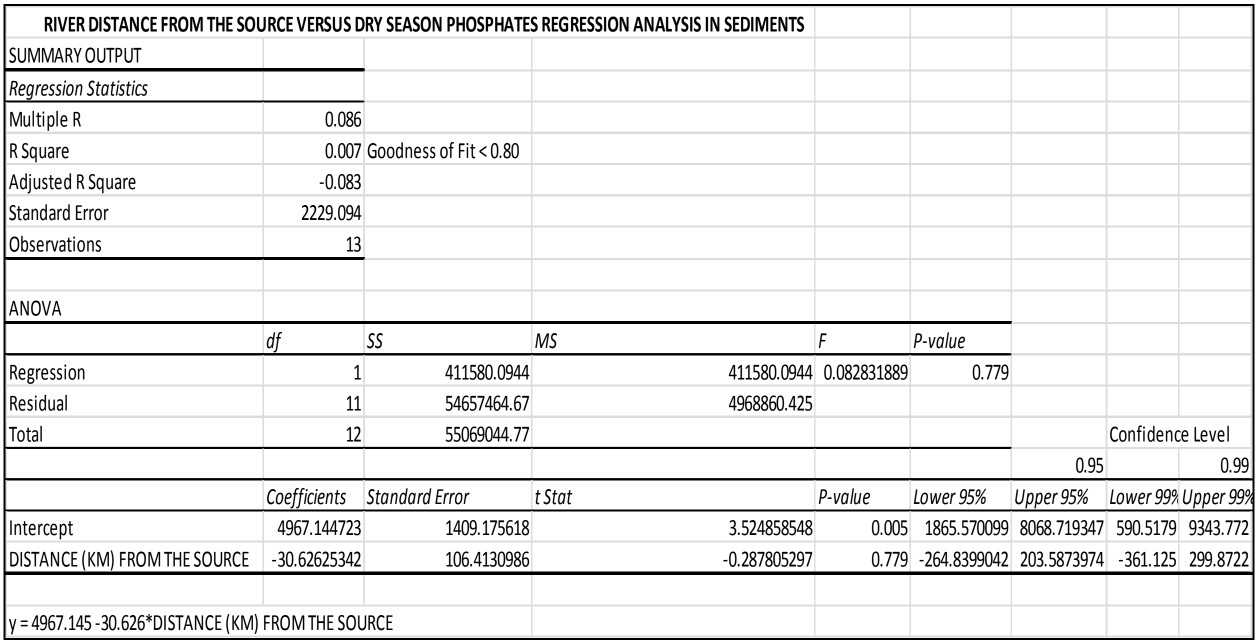
RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON *E.COLI* REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.668							
R Square	0.446	Goodness of Fit < 0.80						
Adjusted R Square	0.395							
Standard Error	481.642							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	2051103.009	2051103.009	8.841757341	0.013			
Residual	11	2551770.222	231979.1111					
Total	12	4602873.231					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	732.868193	304.481676	2.406936938	0.035	62.70854248	1403.027843	-212.793	1678.529
DISTANCE (KM) FROM THE SOURCE	68.3691887	22.99276129	2.973509264	0.013	17.7624623	118.9759151	-3.04188	139.7803
y = 830.12 +25.737*DISTANCE (KM) FROM THE SOURCE								

Appendix 16h: Regression analysis for river distance (km) from the source and dry season *E.coli* pollution in water.

RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON *E.COLI* REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.591							
R Square	0.350	Goodness of Fit < 0.80						
Adjusted R Square	0.290							
Standard Error	387.807							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	889290.1459	889290.1459	5.913045637	0.033			
Residual	11	1654340.623	150394.6021					
Total	12	2543630.769					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	1136.590737	245.1618253	4.636083679	0.001	596.9931977	1676.188276	375.1655	1898.016
DISTANCE (KM) FROM THE SOURCE	45.01823154	18.51325636	2.431675479	0.033	4.27082902	85.76563406	-12.4804	102.5168
y = 830.12 +25.737*DISTANCE (KM) FROM THE SOURCE								

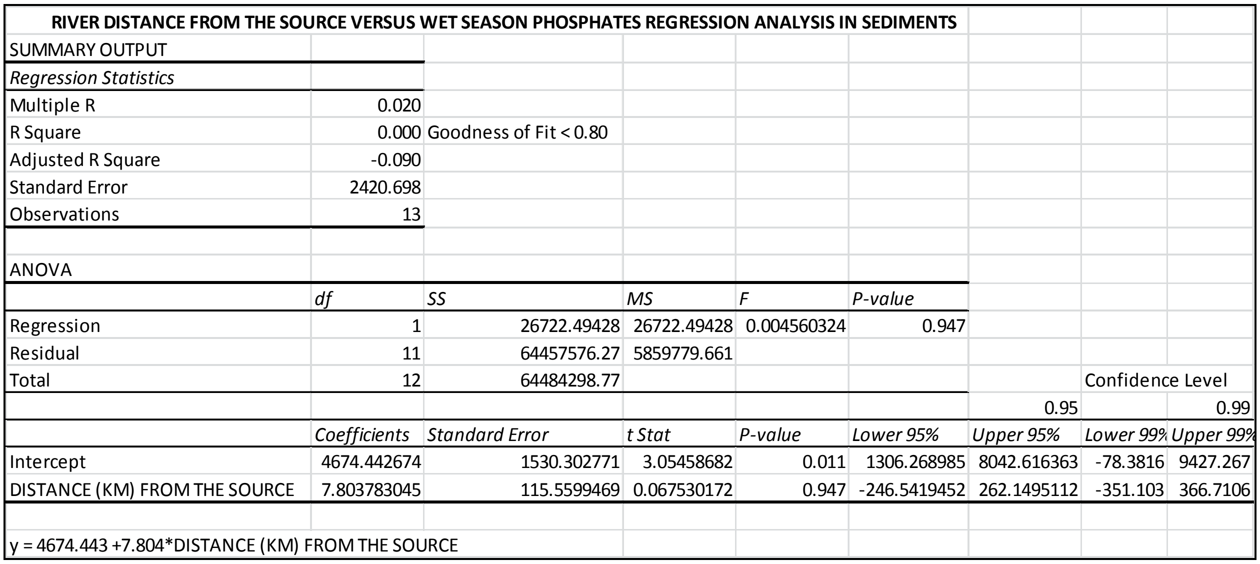
Appendix 17: Regression analysis for River distance from the source and parameters in sediments.

Appendix 17a: Regression analysis for river distance (km) from the source and dry season phosphates concentration in sediment.



RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON PHOSPHATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.086							
R Square	0.007	Goodness of Fit < 0.80						
Adjusted R Square	-0.083							
Standard Error	2229.094							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	411580.0944	411580.0944	0.082831889	0.779			
Residual	11	54657464.67	4968860.425					
Total	12	55069044.77					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	4967.144723	1409.175618	3.524858548	0.005	1865.570099	8068.719347	590.5179	9343.772
DISTANCE (KM) FROM THE SOURCE	-30.62625342	106.4130986	-0.287805297	0.779	-264.8399042	203.5873974	-361.125	299.8722
y = 4967.145 -30.626*DISTANCE (KM) FROM THE SOURCE								

Appendix 17b: Regression analysis for river distance (km) from the source and wet season phosphates concentration in sediment.



RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON PHOSPHATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.020							
R Square	0.000	Goodness of Fit < 0.80						
Adjusted R Square	-0.090							
Standard Error	2420.698							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	26722.49428	26722.49428	0.004560324	0.947			
Residual	11	64457576.27	5859779.661					
Total	12	64484298.77					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	4674.442674	1530.302771	3.05458682	0.011	1306.268985	8042.616363	-78.3816	9427.267
DISTANCE (KM) FROM THE SOURCE	7.803783045	115.5599469	0.067530172	0.947	-246.5419452	262.1495112	-351.103	366.7106
y = 4674.443 +7.804*DISTANCE (KM) FROM THE SOURCE								

Appendix 17c: Regression analysis for river distance (km) from the source and dry season sulphates concentration in sediment.

RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON SULPHATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.004							
R Square	0.000	Goodness of Fit < 0.80						
Adjusted R Square	-0.091							
Standard Error	5768.607							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	5118.053692	5118.053692	0.000153802	0.990			
Residual	11	366045137	33276830.64					
Total	12	366050255.1					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	10780.25654	3646.764343	2.956115484	0.013	2753.782341	18806.73074	-545.888	22106.4
DISTANCE (KM) FROM THE SOURCE	-3.415223336	275.3833436	-0.012401706	0.990	-609.529876	602.6994294	-858.703	851.8722
y = 10780.257 -3.415*DISTANCE (KM) FROM THE SOURCE								

Appendix 17d: Regression analysis for river distance (km) from the source and wet season sulphates concentration in sediment.

RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON SULPHATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.190							
R Square	0.036	Goodness of Fit < 0.80						
Adjusted R Square	-0.052							
Standard Error	3875.596							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	6164156.937	6164156.937	0.410389945	0.535			
Residual	11	165222679.4	15020243.58					
Total	12	171386836.3					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	25818.19585	2450.051478	10.53781771	0.000	20425.66891	31210.72279	18208.81	33427.58
DISTANCE (KM) FROM THE SOURCE	-118.5232452	185.0142495	-0.640616847	0.535	-525.7368627	288.6903723	-693.142	456.0952
y = 25818.196 -118.523*DISTANCE (KM) FROM THE SOURCE								

Appendix 17e: Regression analysis for river distance (km) from the source and dry season nitrates concentration in sediment.

RIVER DISTANCE FROM THE SOURCE VERSUS DRY SEASON NITRATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.336							
R Square	0.113	Goodness of Fit < 0.80						
Adjusted R Square	0.032							
Standard Error	1668.867							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	3905922.061	3905922.061	1.402426562	0.261			
Residual	11	30636287.02	2785117.001					
Total	12	34542209.08					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	204.6543282	1055.014537	0.193982472	0.850	-2117.417011	2526.725668	-3072.02	3481.325
DISTANCE (KM) FROM THE SOURCE	94.34708295	79.66882514	1.184240922	0.261	-81.0028189	269.6969848	-153.089	341.783
y = 204.654 +94.347*DISTANCE (KM) FROM THE SOURCE								

Appendix 17f: Regression analysis for river distance (km) from the source and wet season nitrates concentration in sediment.

RIVER DISTANCE FROM THE SOURCE VERSUS WET SEASON NITRATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.180							
R Square	0.032	Goodness of Fit < 0.80						
Adjusted R Square	-0.056							
Standard Error	890.487							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	290648.0543	290648.0543	0.366532008	0.557			
Residual	11	8722645.023	792967.7293					
Total	12	9013293.077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	830.1196199	562.9430715	1.474606691	0.168	-408.9097264	2069.148966	-918.273	2578.512
DISTANCE (KM) FROM THE SOURCE	25.73655424	42.51032716	0.60541887	0.557	-67.828045	119.3011535	-106.292	157.7654
y = 830.12 +25.737*DISTANCE (KM) FROM THE SOURCE								

Appendix 18: Inter-correlation between parameters.

Appendix 18a: Dry season inter-correlation between phosphates and nitrates in water.

DRY SEASON PHOSPHATES VERSUS NITRATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.139							
R Square	0.019	Goodness of Fit < 0.80						
Adjusted R Square	-0.070							
Standard Error	4.257							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	3.911631128	3.911631128	0.21582011	0.651			
Residual	11	199.3694766	18.12449787					
Total	12	203.2811077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	4.992837721	2.744582354	1.819161197	0.096	-1.047947312	11.03362275	-3.5313	13.51698
Phosphates (mg/L)	0.209391403	0.450726291	0.464564431	0.651	-0.782650474	1.20143328	-1.19048	1.60926
y = 4.993 +0.209*Phosphates (mg/L)								

Appendix 18b: Wet season inter-correlation between phosphates and nitrates in water.

WET SEASON PHOSPHATES VERSUS NITRATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.064							
R Square	0.004	Goodness of Fit < 0.80						
Adjusted R Square	-0.086							
Standard Error	7.064							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	2.27043451	2.27043451	0.045505554	0.835			
Residual	11	548.8292578	49.89356889					
Total	12	551.0996923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	17.64975897	3.939065153	4.480697394	0.001	8.97993502	26.31958291	5.415785	29.88373
Phosphates (mg/L)	-0.147179167	0.689944466	-0.213320309	0.835	-1.665736698	1.371378364	-2.29001	1.995655
y = 17.65 -0.147*Phosphates (mg/L)								

Appendix 18c: Dry season inter-correlation between sulphates and nitrates in water.

DRY SEASON SULPHATES VERSUS NITRATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.262							
R Square	0.069	Goodness of Fit < 0.80						
Adjusted R Square	-0.016							
Standard Error	4.149							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	13.94526258	13.94526258	0.810189366	0.387			
Residual	11	189.3358451	17.21234956					
Total	12	203.2811077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	7.474247805	1.873142417	3.990218649	0.002	3.351489142	11.59700647	1.65663	13.29187
Sulphates (mg/L)	-2.446283092	2.717774655	-0.900105197	0.387	-8.428064777	3.535498592	-10.8872	5.994599
y = 7.474 -2.446*Sulphates (mg/L)								

Appendix 18d: Wet season inter-correlation between sulphates and nitrates in water.

WET SEASON SULPHATES VERSUS NITRATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.131							
R Square	0.017	Goodness of Fit < 0.80						
Adjusted R Square	-0.072							
Standard Error	7.017							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	9.508211273	9.508211273	0.193116634	0.669			
Residual	11	541.591481	49.23558918					
Total	12	551.0996923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	22.61836207	13.11051416	1.725207859	0.112	-6.237685046	51.47440918	-18.1004	63.33708
Sulphates (mg/L)	-8.543103448	19.44042805	-0.439450378	0.669	-51.3311971	34.2449902	-68.9213	51.8351
y = 22.618 -8.543*Sulphates (mg/L)								

Appendix 18e: Dry season inter-correlation between phosphates and sulphates in water.

DRY SEASON PHOSPHATES VERSUS SULPHATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.688							
R Square	0.474							
Adjusted R Square	0.426							
Standard Error	0.334							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	1.104054558	1.104054558	9.903828014	0.009			
Residual	11	1.226253134	0.111477558					
Total	12	2.330307692					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	-0.067651544	0.215246946	-0.314297347	0.759	-0.541406877	0.406103789	-0.73617	0.600864
Phosphates (mg/L)	0.111243634	0.035348714	3.147034797	0.009	0.033441638	0.189045629	0.001457	0.22103
y = -0.068 +0.111*Phosphates (mg/L)								

Appendix 18f: Wet season inter-correlation between phosphates and sulphates in water.

WET SEASON PHOSPHATES VERSUS SULPHATES REGRESSION ANALYSIS IN WATER								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.099							
R Square	0.010	Goodness of Fit < 0.80						
Adjusted R Square	-0.080							
Standard Error	0.108							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	0.001270213	0.001270213	0.108307088	0.748			
Residual	11	0.12900671	0.011727883					
Total	12	0.130276923					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	0.684165773	0.060392177	11.32871515	0.000	0.551243487	0.817088059	0.496599	0.871732
Phosphates (mg/L)	-0.003481209	0.010577954	-0.329100422	0.748	-0.026763128	0.01980071	-0.03633	0.029372
y = 0.684 -0.003*Phosphates (mg/L)								

Appendix 18g: Dry season inter-correlation between phosphates and sulphates in sediments.

DRY SEASON PHOSPHATES VERSUS SULPHATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.118							
R Square	0.014	Goodness of Fit < 0.80						
Adjusted R Square	-0.076							
Standard Error	5728.216							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	5113230.17	5113230.17	0.155831982	0.701			
Residual	11	360937024.9	32812456.81					
Total	12	366050255.1					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	12142.12499	3891.891241	3.11985208	0.010	3576.130119	20708.11985	54.66381	24229.59
Phosphates (mg/L)	-0.304715047	0.771908108	-0.394755597	0.701	-2.003673338	1.394243245	-2.70211	2.092682
y = 12142.125 -0.305*Phosphates (mg/Kg)								

Appendix 18h: Wet season inter-correlation between phosphates and sulphates in sediments.

WET SEASON PHOSPHATES VERSUS SULPHATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.332							
R Square	0.110	Goodness of Fit < 0.80						
Adjusted R Square	0.029							
Standard Error	3723.155							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	18906113.2	18906113.2	1.363892045	0.268			
Residual	11	152480723.1	13861883.92					
Total	12	171386836.3					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	26989.12176	2439.643834	11.0627303	0.000	21619.50189	32358.74164	19412.06	34566.18
Phosphates (mg/L)	-0.541469672	0.46364346	-1.167857887	0.268	-1.561942046	0.479002703	-1.98146	0.898517
y = 26989.122 -0.541*Phosphates (mg/Kg)								

Appendix 18i: Dry season inter-correlation between phosphates and nitrates in sediments.

DRY SEASON PHOSPHATES VERSUS NITRATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.252							
R Square	0.063	Goodness of Fit < 0.80						
Adjusted R Square	-0.022							
Standard Error	1715.003							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	2188626.743	2188626.743	0.744118346	0.407			
Residual	11	32353582.33	2941234.758					
Total	12	34542209.08					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	2244.964791	1165.215265	1.926652403	0.080	-319.656716	4809.586299	-1373.97	5863.898
Phosphates (mg/L)	-0.199357271	0.231105921	-0.862622945	0.407	-0.708017974	0.309303433	-0.91713	0.518413
y = 2244.965 -0.199*Phosphates (mg/Kg)								

Appendix 18j: Wet season inter-correlation between phosphates and nitrates in sediments.

WET SEASON PHOSPHATES VERSUS NITRATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.791							
R Square	0.625	Goodness of Fit < 0.80						
Adjusted R Square	0.591							
Standard Error	554.092							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	5636097.763	5636097.763	18.3575629	0.001			
Residual	11	3377195.314	307017.7558					
Total	12	9013293.077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	-273.0192273	363.0755848	-0.751962508	0.468	-1072.143201	526.1047469	-1400.66	854.6233
Phosphates (mg/L)	0.29563937	0.0690009	4.284572662	0.001	0.143769413	0.447509327	0.081336	0.509943
y = -273.019 +0.296*Phosphates (mg/Kg)								

Appendix 18k: Dry season inter-correlation between sulphates and nitrates in sediments.

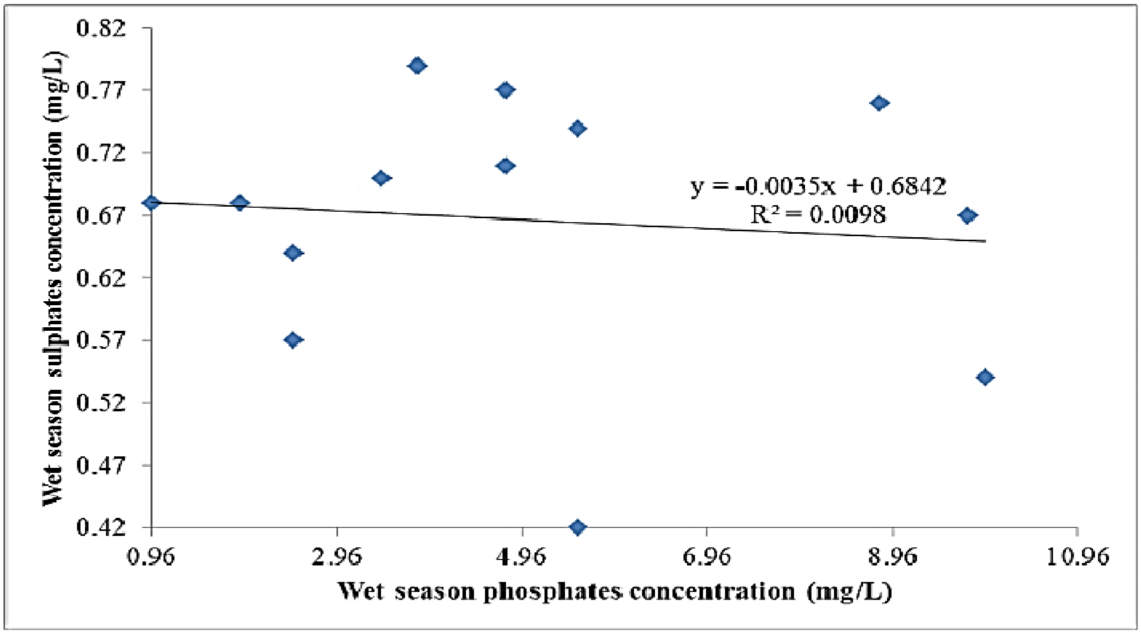
DRY SEASON SULPHATES VERSUS NITRATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.490							
R Square	0.240	Goodness of Fit < 0.80						
Adjusted R Square	0.170							
Standard Error	1545.240							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	8276768.542	8276768.542	3.466321223	0.090			
Residual	11	26265440.53	2387767.321					
Total	12	34542209.08					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	-287.5270684	967.4914428	-0.297188229	0.772	-2416.961377	1841.90724	-3292.37	2717.314
Sulphates (mg/L)	0.150369601	0.080765455	1.861805904	0.090	-0.027393967	0.32813317	-0.10047	0.401211
y = -287.527 +0.15*Sulphates (mg/kg)								

Appendix 18l: Wet season inter-correlation between sulphates and nitrates in sediments.

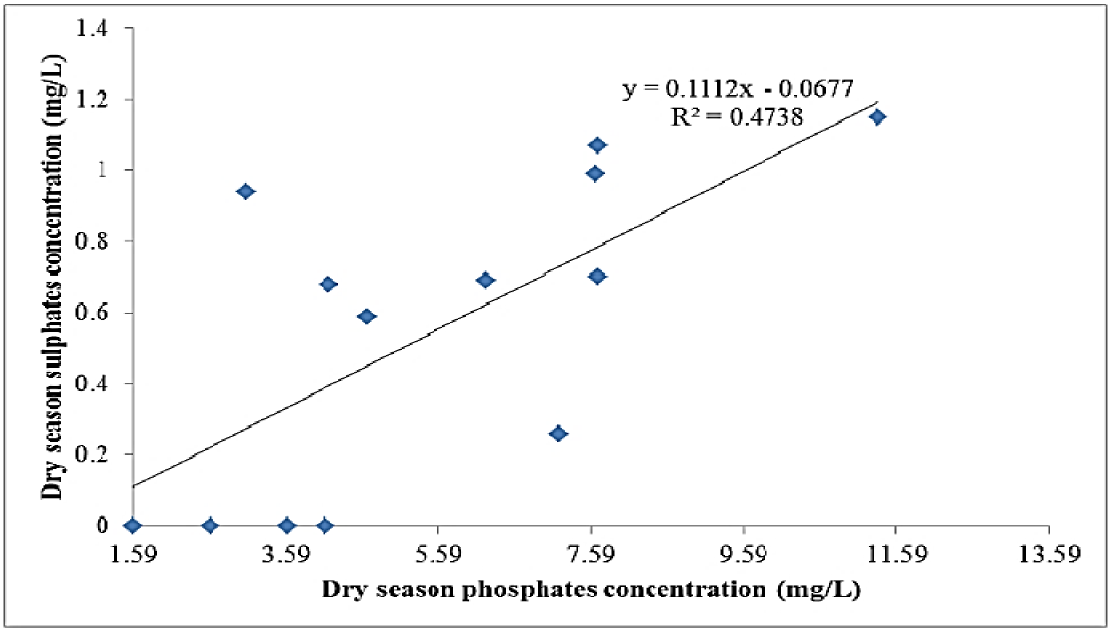
WET SEASON SULPHATES VERSUS NITRATES REGRESSION ANALYSIS IN SEDIMENTS								
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.604							
R Square	0.365	Goodness of Fit < 0.80						
Adjusted R Square	0.308							
Standard Error	721.175							
Observations	13							
ANOVA								
	df	*SS*	*MS*	*F*	*P-value*			
Regression	1	3292261.182	3292261.182	6.330129541	0.029			
Residual	11	5721031.895	520093.8086					
Total	12	9013293.077					Confidence Level	
						0.95		0.99
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*Upper 99%*
Intercept	4519.263881	1359.356065	3.324562266	0.007	1527.341354	7511.186408	297.367	8741.161
Sulphates (mg/L)	-0.138598462	0.055087379	-2.515974869	0.029	-0.259844966	-0.017351958	-0.30969	0.032492
y = 4519.264 -0.139*Sulphates (mg/Kg)								

Appendix 19: Inter-parameter Scatter plots.

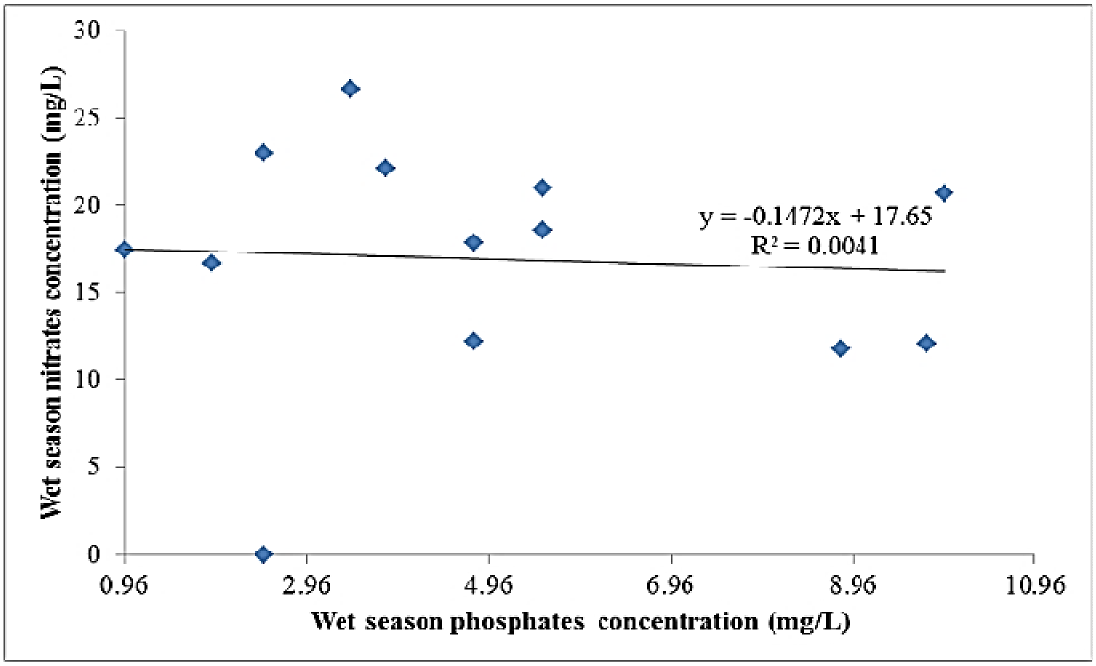
Appendix 19a: Scatter plot of wet season's sulphates versus phosphates concentration in water.



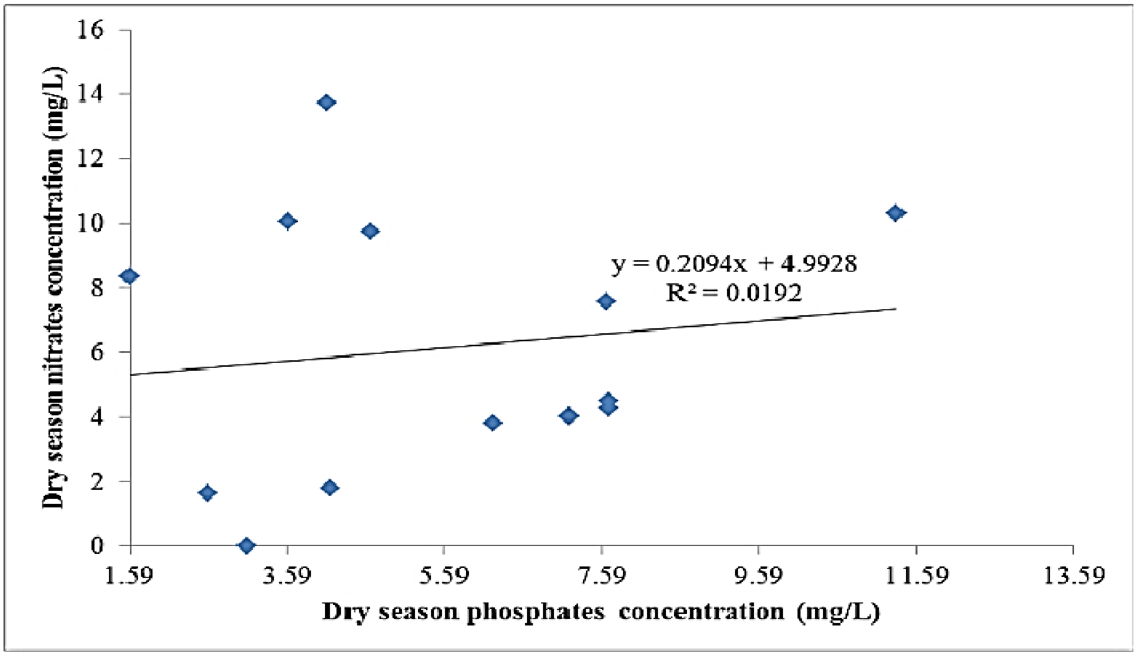
Appendix 19b: Scatter plot of dry season's sulphates versus phosphates concentration in water.



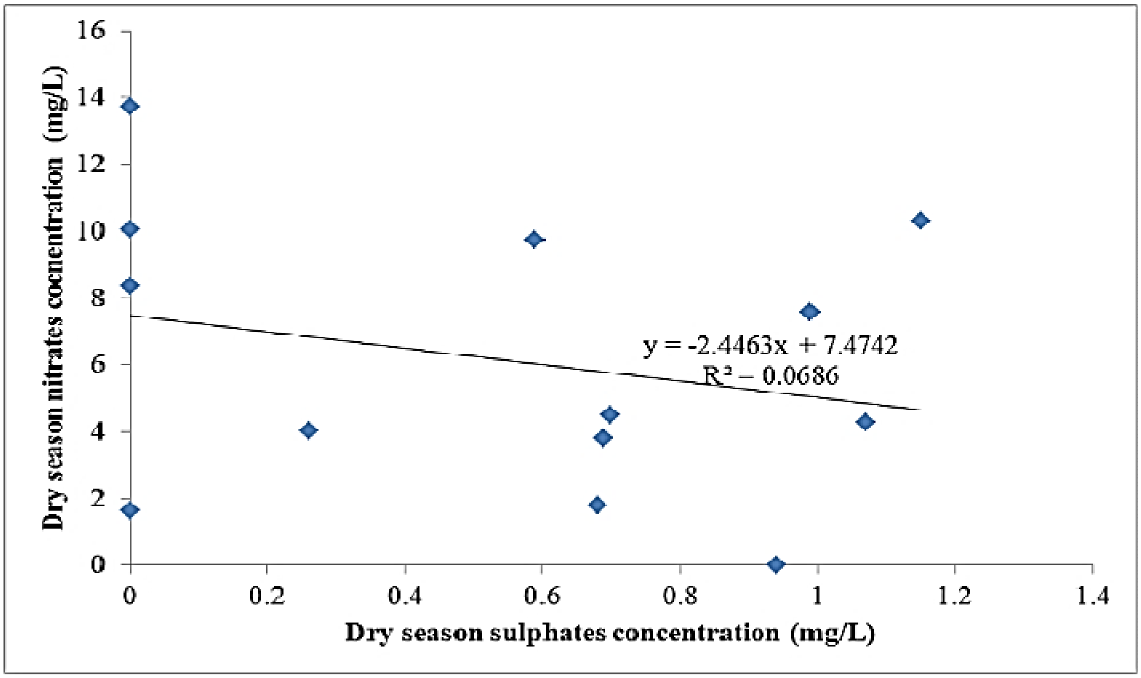
Appendix 19c: Scatter plots of wet season's nitrates versus phosphates concentration in water.



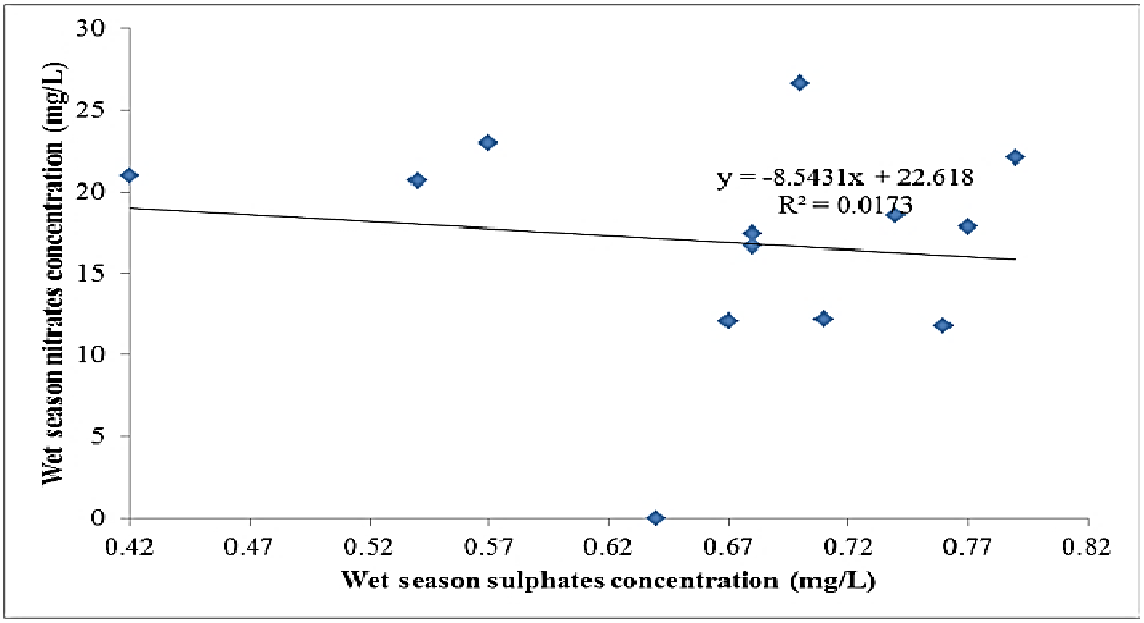
Appendix 19d: Scatter plots of dry season's nitrates versus phosphates concentration in water.



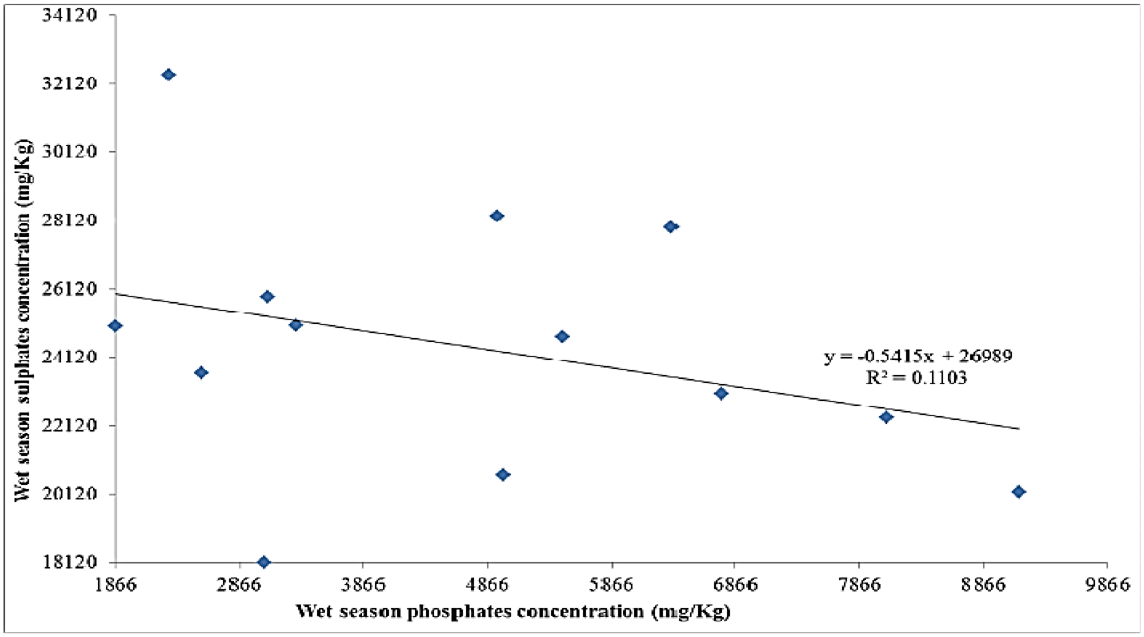
Appendix 19e: Scatter plots of dry season's nitrates versus sulphates concentration in water.



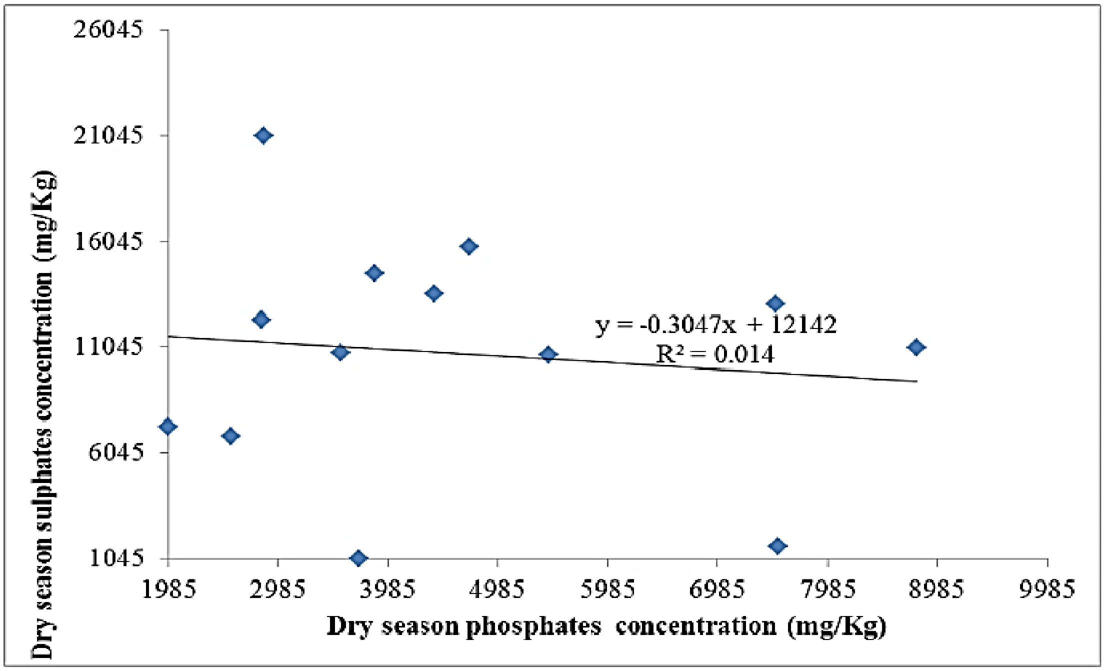
Appendix 19f: Scatter plots of wet season's nitrates versus sulphates concentration in water.



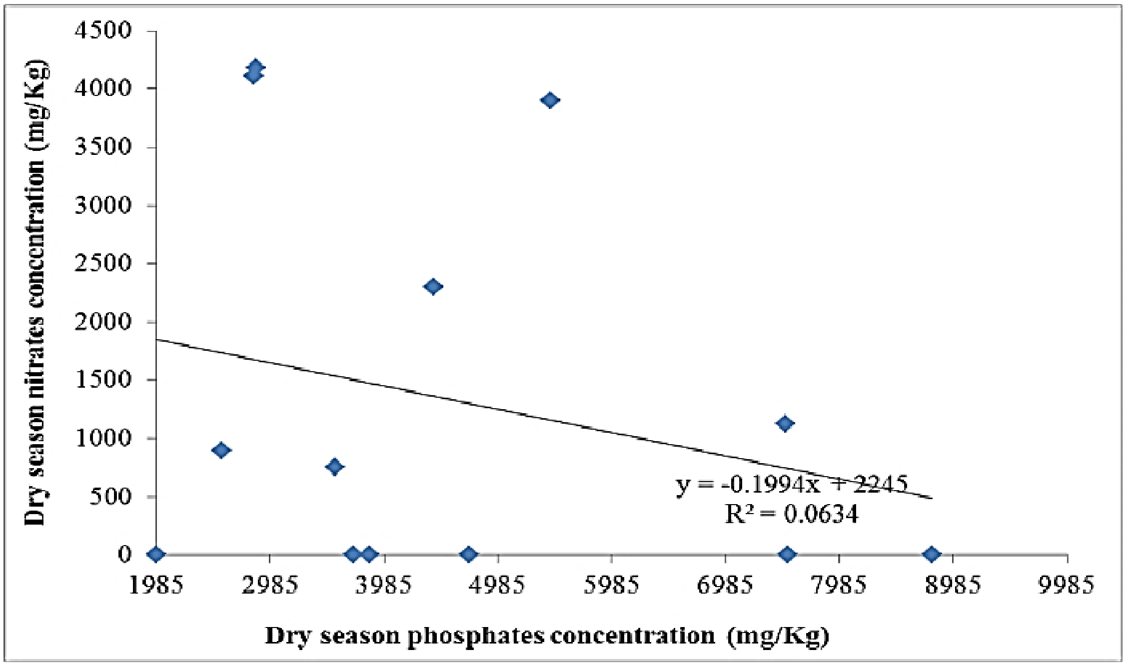
Appendix 19g: Scatter plots of wet season's sulphates versus phosphates concentration in sediments.



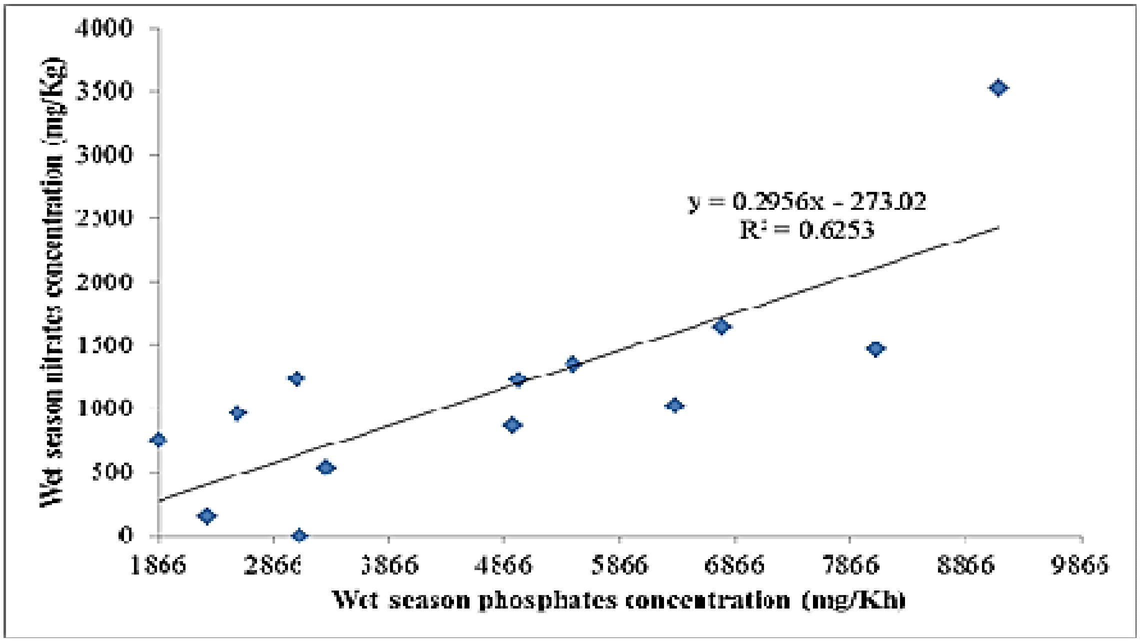
Appendix 19h: Scatter plots of dry season's sulphates versus phosphates concentration in sediments.



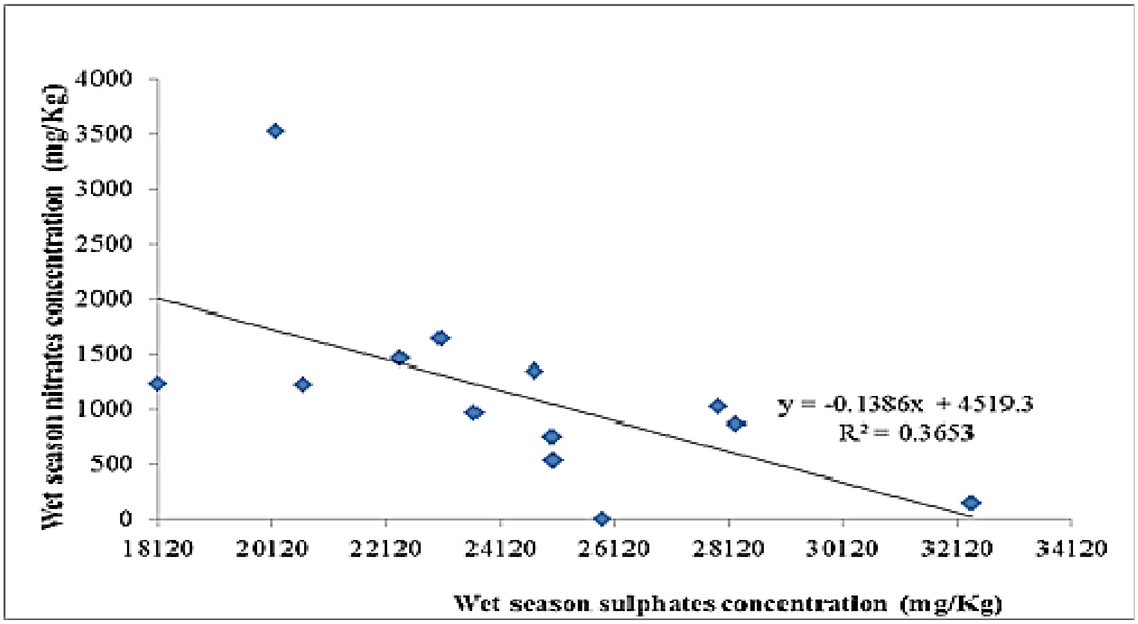
Appendix 19i: Scatter plots of dry season's nitrates versus phosphates concentration in sediments.



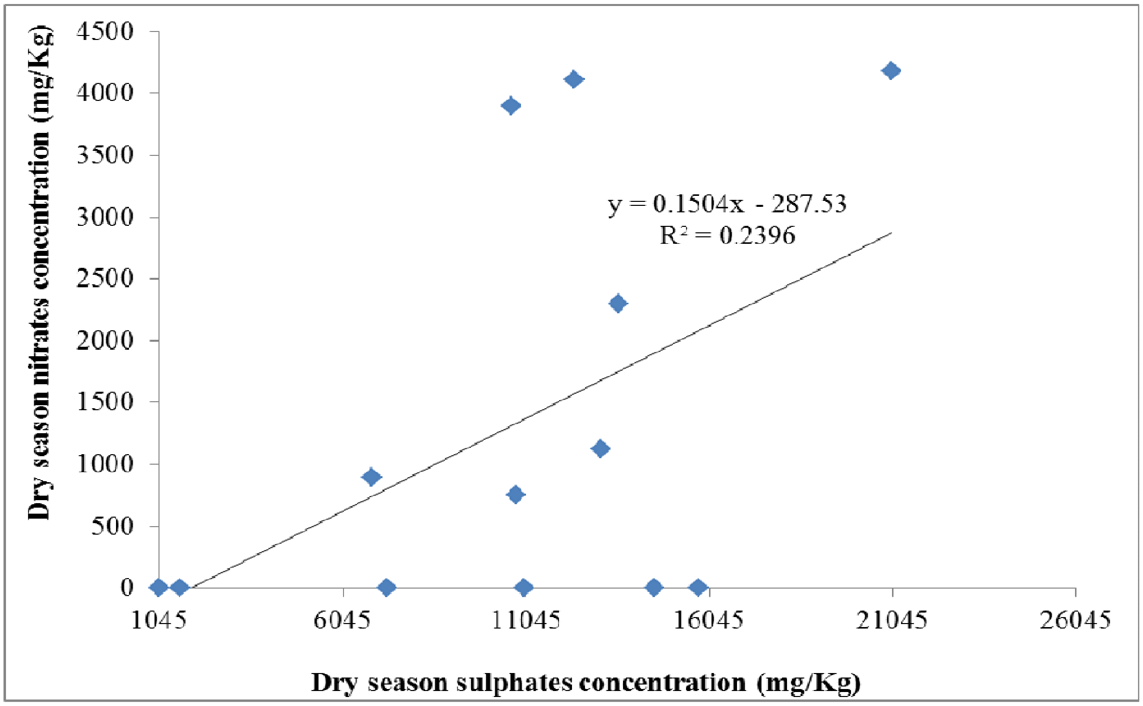
Appendix 19j: Scatter plots of wet season's nitrates versus phosphates concentration in sediments.



Appendix 19k: Scatter plots of wet season's nitrates versus sulphates concentration in sediments.



Appendix 19l: Scatter plot of dry season's nitrates versus sulphates concentration in sediments.



Appendix 20: Study area Climatic Conditions.

Appendix 20a: Station No. 9136164; Station Name: Dagoretti metrological station; Year of Record: 2009.

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	25.6	13.4	68	40	64.5	5.9
Feb	25.6	14.3	78	42	20.1	5.9
Mar	27.4	15	73	35	37.9	6.5
Apr	25.3	15.7	83	49	79.3	4.7
May	23.6	15	86	57	158.1	3.5
Jun	23.3	13.4	83	55	101.5	3.8
Jul	21.7	10.8	83	51	13.2	2.9
Aug	22.1	12.3	84	54	3.6	3.3
Sep	25.6	13.4	76	42	9.1	5.1
Oct	24.4	14.4	80	49	98.2	4.2
Nov	24.1	15.1	83	52	79.4	4.6
Dec	24.3	14.9	82	51	121.1	4.2
Total	293	167.7	959	577	786	54.6
Max.	27.4	15.7	86	57	158	6.5
Min.	21.7	10.8	73	35	3.8	2.9
Ave.	24.4	13.9	79.9	48.1	65.5	4.5

Source: Kenya Meteorological Department, 2012

Appendix 20b: Station No. 9136164; Station Name: Dagoretti metrological station; Year of Record: 2010

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	24.4	14.2	74	50	75.1	4.8
Feb	25.5	15.8	81	51	107.3	4.9
Mar	24.5	15.3	83	57	212	4.4
Apr	24.3	15.8	87	59	157.3	3.9
May	23.4	15	84	63	354.7	3.4
Jun	21.7	13.2	86	62	37.7	2.5
Jul	21.6	11.5	85	57	2.5	2.7
Aug	22.1	12.2	85	56	35.3	2.9
Sep	24.2	12.3	81	47	28.9	4
Oct	25.4	14.2	76	41	99.2	5.1
Nov	22.9	14.9	85	56	109.9	3.8
Dec	24.3	14	75	47	65.1	5.1
Total	284.3	168.4	982	646	1285	47.5
Max.	25.5	15.8	87	63	354	5.1
Min.	21.6	11.5	74	41	2.5	2.5
Ave.	23.7	14.0	81.8	53.8	107.1	3.9

Source: Kenya Meteorological Department, 2012

Appendix 20c: Station No. 9136164; Station Name: Dagoretti metrological station; Year of record 2011.

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	25.8	13.3	69.0	35	14.2	7.5
Feb	26.8	13.3	64.0	33	125.8	8
Mar	26.0	14.9	77.0	42	128.5	11
Apr	24.9	15.8	84.0	49	49.4	9.5
May	23.9	15.0	87.0	57	85.1	5.1
Jun	23.6	13.6	87.0	55	125.8	8.6
Jul	23.5	11.4	82.0	49	8.7	5.5
Aug	21.6	12.7	87.0	58	41.8	4.5
Sep	23.9	13.6	81.0	49	31.8	6.5
Total	196.07948	110.0559831	637	378	579.3	59.7
Max.	26.8	15.8	87	58	128.5	11
Min.	21.6	11.4	64	33	8.7	4.5
Ave.	16.3	9.1	53.1	31.5	48.3	4.9

Source: Kenya Meteorological Department, 2012

Appendix 20d: Station No. 9136130; Station Name: Wilson Airport; Year of Record: 2009

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(% RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	26.4	14.6	67	37	59.4	7.3
Feb	26.7	15	73	37	15.3	7.5
Mar	28.4	15.7	71	33	19.4	7.9
Apr	26.9	16.2	79	44	83.1	5.8
May	24.7	15.6	84	53	111.5	4.4
Jun	24.5	13.9	81	47	52	4.5
Jul	23	11.8	80	46	11.4	4
Aug	23.3	12.8	80	48	0.1	4.1
Sep	26.5	13.9	73	36	6.9	6.3
Oct	25.5	14.8	79	45	84.6	5.4
Nov	25.2	15.7	81	49	91.3	5.5
Dec	25.3	15.6	80	49	175.9	5.3
Total	306.4	175.6	928	524	710.9	68
Max.	28.4	15.7	84	53	175	7.9
Min.	23	12.8	67	33	0.1	4
Ave.	25.5	14.6	77.3	43.7	59.2	5.7

Source: Kenya Meteorological Department, 2012

Appendix 20e: Station No. 9136130; Station Name: Wilson Airport Metrological; Year of Record: 2010.

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	25.4	15	73	47	73.5	5.9
Feb	26.3	16.2	79	48	116.6	6.5
Mar	25.4	15.6	81	53	256.7	5.5
Apr	25.2	16	85	57	106.6	4.4
May	24.4	15.7	84	58	186.9	4
Jun	22.7	13.9	86	58	48.5	2.9
Jul	22.6	12.4	84	51	1	3
Aug	23.1	12.9	83	52	23.9	3.6
Sep	25.2	13.1	78	43	34.8	5.5
Oct	26.6	15	77	39	117.6	6.1
Nov	24.2	15.6	83	53	79	4.6
Dec	25.7	15.1	73	43	50.6	5.9
Total	296.8	176.5	966	602	1095.7	57.9
Max.	26.3	16.2	86	58	256	6.5
Min.	22.6	12.4	73	39	1	3
Ave.	24.7	14.7	80.5	50.2	91.3	4.8

Source: Kenya Meteorological Department, 2012

Appendix 20f: Station No. 9136130; Station Name: Wilson Airport Metrological station; Year of Record: 2011.

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum(Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	27.0	14.7	67.0	35.0	10.4	9.5
Feb	27.9	14.4	63.0	34.0	77.8	11.0
Mar	27.3	16.0	76.0	40.0	144.6	10.0
Apr	25.9	16.5	82.0	45.0	46.8	7.0
May	24.9	15.5	85.0	52.0	45.4	6.0
Jun	24.8	14.3	84.0	50.0	102.2	7.0
Jul	24.4	12.6	86.0	49.0	10.7	6.0
Aug	22.6	13.4	86.0	52.0	71	6.0
Sep	24.9	14.2	80.0	47.0	33.4	9.0
Total	204.7	117.	629	357	508.9	62.5
Max.	27.9	16.5	86	52	144.6	11
Min.	22.6	12.6	63	34	10.7	6
Ave.	17.1	9.8	52.4	29.8	42.4	5.2

Source: Kenya Meteorological Department, 2012

Appendix 20g:Station No. 9136130; Station Name: JKIA Metrological Station; Year of record 2009

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	27.8	13.9	69	39	52.4	8.3
Feb	28.3	14.1	79	37	34.1	8.1
Mar	29.1	14.4	74	31	27.1	9.2
Apr	27.4	15.4	79	43	84.5	7.1
May	25.4	15.2	83	54	140	7
Jun	25	13.7	82	48	36.6	5.1
Jul	23.6	10.5	77	45	5	5
Aug	23.9	12.6	78	48	0.6	5.1
Sep	27.3	13.3	72	36	2.3	7.3
Oct	26.6	14.4	78	44	65.6	6.1
Nov	25.2	15.1	81	46	48.6	6.6
Dec	27.7	15.1	79	50	112.7	6
Total	317.3	167.7	931	521	609.5	80.9
Max.	29.1	15.4	83	54	140	9.2
Min.	23.6	10.5	72	31	0.6	5
Ave.	26.4	13.9	77.6	43.4	50.8	6.7

Source: Kenya Meteorological Department, 2012

Appendix 20h:Station No. 9136130; Station Name: JKIA Metrological Station; year of record 2010

	TEMPERATURE		**RELATIVE HUMIDITY**		**PRECIPITATION**	**EVAPORATION**
Month	**Daily Maximum (Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	26.1	14.3	76	47	68.9	6
Feb	27.3	15.5	79	48	96.7	5.9
Mar	26	15	84	55	132.1	5.2
Apr	25.8	15.5	86	57	45.6	4.5
May	24.9	14.6	85	58	81.1	4
Jun	23.5	12.5	84	58	26.6	3
Jul	23.6	11.1	80	51	1.3	3.8
Aug	24	12	80	51	6.6	4.1
Sep	26.4	11.3	77	42	13.9	4
Oct	28.2	13.5	72	37	34.9	6.7
Nov	26.1	15.1	83	52	67.5	4.5
Dec	27.2	14.7	71	41	55.7	6.4
Total	309.1	165.1	957	597	630.9	58.1
Max.	28.2	15.5	86	58	132	6.7
Min.	23.5	11.1	71	37	1.3	3
Ave.	25.8	13.8	79.8	49.8	52.6	4.8

Source: Kenya Meteorological Department, 2012

Appendix 20i: Station No: 9136130: Station Name: JKIA Metrological Station. Year of record 2011

	TEMPERATURE		RELATIVE HUMIDITY		PRECIPITATION	EVAPORATION
Month	**Daily Maximum(Degree)**	**Daily Minimum (Degree)**	**At 06Z(%RH)**	**At 12Z(%RH)**	**Daily total(mm)**	**Daily total(mm)**
Jan	28.4	13.9	66.0	32	1.8	11
Feb	28.9	13.8	66.0	32	74.8	11.5
Mar	28.3	14.6	76.0	38	92.7	15.1
Apr	27.1	15.2	81.0	45	17.8	8
May	26.1	15.2	81.0	47	44.5	10.6
Jun	25.4	14.2	81.0	49	29.6	7.7
Jul	25.8	12.0	78.0	43	2.9	10
Aug	23.7	13.3	81.0	51	42.2	7.4
Sep	26.0	14.4	75.0	44	27.8	9.5
Total	213.7	112.1	610	337	306.3	81.3
Max.	28.9	15.2	81	51	92.7	15.1
Min.	23.7	12	66	32	1.8	7.7
Ave.	17.8	9.3	50.8	28.1	25.5	6.8

Source: Kenya Meteorological Department, 2012

Appendix 21: Study sites photo plates

Plate 1: Motoine Dam. Notice brown water as a result of soil erosion from agricultural fields in Ngong and Dagoretti region.

Plate 2: Jamhuri Dam. The Dam is invested with water reeds on the sides and water at the Dam is relatively clear. The Nairobi show ground treats water from this Dam for domestic use.

Plate 3: Clear water from Jamhuri Dam outlet entering Kibera Bridge. Residents of Kibera slum utilise these water for washing cloths and general cleaning.

Plate 4: Jamhuri Dam outlet just after Kibera Bridge. Here, clear water just before the Bridge is contaminated with solid wastes dumped by Kibera residents and a stream of sewerage from the slums at the bridge.

Plate 5: Ngong-Motoine River traversing Kibera slums

Plate 6: Agricultural activities at the inlet of Nairobi dam. River water is heavily Used for irrigation for crops at the point.

Plate 7: Heavily eutrophicated Nairobi dam. The dam here has been rehabilitated and residents from Kibera slums use it for arrowroots farming.

Plate 8: Ngong River crossing Langata Road. Water here is black in colour and also used for Watering trees and flower nurseries.

Plate 9: Ngong River crossing Nairobi West. Notice the direct sewer discharge at the Nairobi West mall.

Plate 10: Ngong River across the Mater Hospital Bridge. Notice the direct sewer discharge from some section of industrial area.

Plate 11: Ngong River at Hazina -Mukuru Kayaba Bridge. Water here is heavily polluted by domestic solid and human waste. Notice the suspension and close proximity of pit latrines directly to the river.

Plate 12: Ngong River at Outering Road Bridge. The river water here is mixed with effluent from several industries and gain pollution from the Mukuru Kwa Ruben and Sinai slums. The water here is also used for irrigating crops.

Plate 13: Ngong River across Kangundo Road Bridge. Water here is heavily polluted With solid and human waste for the populated Kayole and Komarocks estates.