LAND USE PRACTICES AND WATER QUALITY OF RIVER SHIMICHE ECOSYSTEM

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A thesis submitted in partial fulfillment for the requirements of the award of Master of Science in Environmental Biology of Masinde Muliro University of Science and Technology

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DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

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APPROVAL

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled "Land use practices and water quality of River Shimiche ecosystem".

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DEDICATION

I dedicate this work to my mother Nipher Nakhumwa, my brother Sammy Ralph, my spouse Phitalis Were and my children Antonia Khalayi, Tonygilbert Bukosia and Zack Inguyesi.

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ABSTRACT

A majority of inland water bodies are rapidly undergoing degradation and drying up mainly due to human influences and climate change. These water bodies and especially those that supply domestic water to human populations should be given more attention for management and conservation. The main objective of the study was to determine the difference in water quality in relation to land use practices along River Shimiche in Western Kenya. The River's ecosystem drains three land use types; forested environment in the upper course, sugarcane plantations and urban settlement in the middle and small-scale mixed farming activities in the lower course. Sampling was done at each sampling station on the first day of each month from January 2014 to August 2014. The sampling stations were selected to represent the mainland uses along the course of the river determined by direct surveys and observations. Water temperature, pH, electrical conductivity and total dissolved solids were measured in-situ in triplicate, using appropriate meters. Three water samples were randomly collected at each station and taken to the laboratory for determination of total suspended solids and concentration of Escherichia coli, a coliform bacterium. Water temperature were generally low in the forest area upstream with a mean of 21.08 °C, increased to 23.18 °C in middle stream with urban settlements, and further to 24.71 °C in area of mixed small scale farming downstream. pH, Total dissolved solids, conductivity, total suspended solids and turbidity followed a similar pattern: low values in the upper stream, increased in the middle stream and increased further in area with mixed small scale farming downstream. pH values ranged from 6.44 to 7.81, TDS (25.92 – 48.81 mg l^{-1}) and turbidity (187.5-366.37 NTU). Concentration E. coli ranged from 12.97/100 ml to 178.97/100 ml, with no particular trends but higher values downstream. Statistical analyses were done using Statistical Analysis System (SAS) version 9.1. Mean, variance and standard error were used to assess the spread of the data. The mean parameters and one-way analysis of variance (ANOVA) were calculated to compare the mean values of observations based on land use. Where ANOVA showed significant differences, the means were separated through difference of the least square analysis. Pearson correlation co-efficient explored the relationships between physico-chemical parameters and E. coli concentrations in the three land use zones. The mean values of all the physico-chemical variables at the three land uses were significantly different ($p<0.05$); indicating that land use variation impacts on physical-chemical conditions in the river's ecosystem. Mixed agriculture and urban settlements areas recorded the highest concentration of E coli. Changes in riparian land uses in the watershed therefore influence the river physico-chemical conditions, which subsequently affect concentration of E. coli, a biological indicator of water quality. There is need for the establishment of effective land management schemes by different stakeholders for sustainable utilization of land along the course of River Shimiche and other similar rivers.

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ABBREVIATION AND ACRONYMS

ANOVA	-	Analysis of Variance
APHA	-	American Public Health Association
BOD	-	Biological Oxygen Demand
BOS	-	Biodegradable Organic Substances
COD	-	Chemical Oxygen Demand
DO	-	Dissolved Oxygen
EC	-	Electrical Conductivity
GPS	-	Global Positioning System
MSC	-	Mumias Sugar Company
NEMA	-	National Environment Management Authority
NTU	-	Nephelometric Turbidity Units
pH	-	Potential of Hydrogen Ions Concentration
SAS	-	Statistical Analysis System
TDS	-	Total Dissolved solids
TSS	-	Total Suspended Solids
U.S.E.P.A	-	United States Environmental Protection Agency
WARMA	-	Water Resource Management Authority
WARUAs	-	Water Resource Users Associations
WHO	-	World Health Organization

DEFINITION OF OPERATIONAL TERMS

Anthropogenic Activities: Refers to human impact on the environment including impacts on biophysical environments, biodiversity, and other resources.

Eutrophication: Refers to the ecosystem's response to the addition of artificial or natural nutrients, mainly phosphates, through detergents, fertilizers, or sewage, to an aquatic system.

Forested area:

An area characterized by growth of trees and other plants covering a relatively large area.

Mixed agricultural areas: Refers to areas charactreised by the growing of food or cash crops, feed crops, and livestock on the same farm

River ecosystem: Refers to the river viewed as a system operating in its natural environment, and includes biotic (living) interactions amongst plants, animals and micro-organisms, as well as abiotic (non living) physical and chemical interactions.

Standard laboratory procedures: Refers to a quality system of management controls for research laboratories and organizations to try to ensure the uniformity, consistency, reliability, reproducibility, quality, and integrity of chemical (including pharmaceuticals) non-clinical safety tests; from physio-chemical properties through acute to chronic toxicity tests.

Sugarcane plantation: An area under cultivation of sugarcane and related grasses such as nappier.

Water quality: Refers to the chemical, physical, biological, and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed. The most common standards used to assess water quality relate to health of ecosystems, safety of human contact and drinking water.

Physico-chemical parameters: Water quality factors that interface between chemical and physical characteristics of water.

Land use gradient: Horizontal axes along the river's course showing various land use activities.

Coliform bacteria

Coliforms are a broad class of bacteria found in our environment, including the feaces of man and other warm-blooded animals. The presence of coliform bacteria in drinking water may indicate a possible presence of harmful, disease-causing organisms. Coliform bacteria are used as water quality indicators for two main reasons:

- Coliforms may be associated with the sources of pathogens contaminating water.
- The analysis of drinking water for coliforms is relatively simple, economical and efficient.

Escherichia coli (E. coli)

E. coli is the most prevalent member of fecal coliform group. It is a member of the indigenous fecal flora of warm blooded animals. The occurrence of E. coli in water is considered a specific indicator of feacal contamination and the presence of enteric pathogens.

CHAPTER ONE

INTRODUCTION

1.1. Background to the study

Water bodies around the world are faced with problems of pollution (Maier et al., 2001). The current pollution experienced in a majority of water bodies are occasioned by industrial, domestic and agricultural activities undertaken along the riparian zones (Dynesius and Wilson, 1994).

Streams are water bodies that give rise to larger water resources such as rivers, lakes and even oceans (Petts et al., (1998). Streams are invaluable as they provide sources of water for agricultural activities such as irrigation, livestock farming, fishing and economic activities including sand harvesting. Due to rising populations along riparian areas, streams face considerable pressure which reduces the water level and quality. The rise in population that accelerates agricultural activities along the riparian zone increases siltation. However there are few studies on the water level and quality among a majority of streams in East Africa (Andrea et al., 2009).

In Kenya, Rivers Nzoia, Lusumu, Isiukhu and Yala are among the major inflows of Lake Victoria (Enanga et al., 2010). Consequently, these rivers form part of the Lake Victoria basin. These rivers are of economic importance to people around them and they also provide habitat for aquatic flora and fauna (Townsend et al., 1997). However, little is known about the tributaries of these big rivers like River Shimiche which discharges its waters into River Nzoia, which eventually drain into Lake Victoria. Recent studies reveal notable influences of land use activities on water quality and stream fauna in small local rivers of Kenya, including River Njoro (Makoba, et al., 2008), Rivers Kibos, Kisat and Kisian (Kobingi, et al., 2009; Triest, et al., 2012) and River Isiukhu (Onyando, et al., 2013, 2016 a,b).

Continued degradation of River Shimiche is a major challenge to the survival of flora and fauna in River Nzoia and the Lake Victoria at large. In a preparatory measure to mitigate on the current pressure on aquatic water bodies and life forms, the present study endeavors to establish the likely effects of human activities on the water quality of River Shimiche. Information generated by this study will be invaluable to stakeholders including the water management authorities in devising ways of sustainable utilization of the River Shimiche and other aquatic ecosystems.

1.2. Problem statement

River Shimiche is an important source of water to the people living in the rural part of Mumias Sub-County. It drains into the more extensive River Nzoia which is the source of water used by thousands of other people living in the region and more so for the daily operations of the Mumias Sugar factory.

River Shimiche is in proximity to various sources of pollution; such as industrial effluents from Mumias Sugar factory, domestic waste from Shibale residential area and the Mumias Sugar Company nucleus estates, run- off from sugarcane plantations, waste oil from sugar cane transporting Lorries and tractors fleet and car washing points. The changes in the hydrology and biophysical composition of River Shimiche watershed pose grave danger to human health and aquatic life forms. Organisms respond to various water pollutants either acutely or chronically. Acute effects occasionally result in death of some of the organisms such as fish on exposure to high concentrations of pollutant. Chronic effects may occur following exposure to low concentrations of a pollutant, the effects of which appear over time such as cancers (Dudley and Blair, 1992). The impacts of human settlement and socioeconomic activities on River Shimiche have not been studied and documented. This study was therefore designed to determine the extent to which land use practices near the river have influenced the quality of water in River Shimiche.

1.3. Justification

Pollution of inland waters by agricultural, industrial and municipal wastes is a global problem and a common phenomenon in developing countries. These anthropogenic activities within the landscape facilitate the transfer of nutrients into aquatic ecosystems sometimes leading to eutrophication which has adverse effects on aquatic ecosystem. River Shimiche is an important source of water to the people living in the vicinity of its course and in the rural part of Mumias Sub-County. The river is of great importance to the area for agricultural activities; a variety of food crops are grown along the river valley. Such crops include maize, sorghum, millet and sweet potatoes. The river also provides water for domestic purposes such as drinking and non-drinking purposes such as sand harvesting, bathing, swimming and fishing.

Currently there is increasing public concern about the environment and especially the quality and quantity of the water resources including River Shimiche. Many rivers have reduced in volume and more degraded by siltation and pollution. Water resources management is of critical importance to reducing the vulnerability of poor people to water related hazards such as drought and floods that can devastate livelihoods and throw people into poverty, destroy infrastructure and reduce the benefits of major investments. The water resources in Mumias region include River Nzoia on which Mumias Sugar Factory greatly depends for its operations and the neighboring River Shimiche relied upon by the company residents and the riparian community for their daily activities including domestic uses. Government water regulatory authorities such as Water Resources Management Authority (WARMA), National Environment Management Authority (NEMA) and the local Water Resource Users Associations (WRUAs) have given little or no attention to River Shimiche in terms of pollution level monitoring. River Shimiche receives surface runoffs from Shibale residential estates, waste waters from the Mumias Sugar Company estates, waste oil from the cane transportation fleet and the neighboring Total and Magharibi petrol stations and car wash ventures. The situation exacerbates during the rainy season, since storm waters accelerate discharge of such wastes into River Shimiche. These activities could have adverse impacts on aquatic life forms and human health. This may, in the long run cause ecological imbalance of River Shimiche and its catchment.

This study aims at assessing the extent to which land use activities along the river and its catchment has impacted on the quality of the river water. There are glaring gaps in the management of the small water resources such as small rivers and streams in Kenya as much as these water resources which give rise to big rivers and lakes may be degraded with time. This study therefore aims to document the impacts human settlement and their economic activities have on the quality of river Shimiche waters.

This will in turn provide useful information which will benefit environmentalists interested in environmental management and sustainable development, including WARMA, NEMA and the local WRUAs.

1.4. Research objectives

1.4.1 The general objective

To determine effects of land use practices on the water quality of River Shimiche ecosystem.

1.4.2. The specific objectives

(i) To determine the difference in physico-chemical parameters along the land use gradient of River Shimiche ecosystem.

(ii) To assess the concentration of E. coli bacteria along the land use gradient of River Shimiche.

(iii) To determine the relationship between E. coli concentration and physico-chemical parameters with respect to area of research.

1.5. Research hypotheses

Ho_1: There is no difference in physico-chemical parameters along the land use gradient of River Shimiche.

H_{O2}: There is no difference in the concentration of E. coli bacteria along the land use gradient of River Shimiche

Ho_3: There is no relationship between E. coli concentration and physico-chemical parameters with respect to area of research.

1.6. Limitation of the study

Transport network within the river watershed was poorly developed. For instance, most roads became impassable even by motor cycles during the rainy season. This delayed sampling for laboratory analyses.

1.7. Assumptions of the study

The water samples that were collected from each of the sampling stations within a particular land use were a good representative of the river water within that land use area.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter presents a review of literature and information on previous similar studies. It also gives some findings that have been obtained from related research topics elsewhere in the world and therefore clearly brings out the knowledge gap that the study is expected to fill.

2.2. River and water quality

A river is defined as large natural stream of water emptying into an ocean, lake or other body of water and usually fed along its source by converging tributaries. Rivers drain water that falls in upland areas. Many landscape factors can affect water quality of a river e.g., channel slope, vegetation on the banks and conditions of riparian zone. Shifts in the prevailing riparian vegetation can be expected to change the physical-chemical and biological nature of streams (Townsend et al., 1997).

Moving water dilutes and decomposes pollutants more rapidly than standing water, but many rivers and streams around the world are significantly polluted beyond their self-cleansing abilities. A primary reason for this is that normally all three major sources of pollution (industry, agriculture and domestic) are concentrated along rivers in addition to freshwater because they provide transportation and convenient places to discharge waste. Agricultural activities have tended to be concentrated near rivers, because river flood plains are exceptionally fertile due to many nutrients that are deposited in the soil when the river overflows (Tabacchi et al., 1998).

According to Oxford dictionary of Geography (Mayhew, 2009), Water quality is defined as a measure of the condition of water relative to the requirements of one or more biotic species and/or human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed. Water quality is, basically, the physical, chemical and biological characteristics of water. The most common standards used to assess water quality relate to drinking water and safety of ecosystems. The characteristics of surface soil, control water movement and retention and secondarily control the main water supply for riparian plants and animal communities. Therefore, some researchers argue that analysis of land use and land cover and water quality should be conducted during storm seasons because landscape has large influence on the water course. Streams surrounded by agricultural activities are greatly disturbed by human activities. Such agricultural activities, which tends to modify the hydrology of lotic systems through a combination of irrigation impoundments, makes most of the large rivers in the world to be greatly affected by human activities (Dynesius and Wilson, 1994 and Petts et al., 1998). Human factors e.g., wastewater effluents and non-point pollution greatly affect rivers. In the United States, for example, eutrophication occurs in large rivers because the large rivers integrate impacts of such large land areas.

Many major cities are located on large rivers making their watershed a home of large human populations. Increased human activities results into increased dissolved ions concentrations and suspended materials in water involving sediments and nutrients. This makes larger rivers to be more susceptible to high turbidity than smaller streams in the basin. For example, in River Njoro Watershed, water resources have become degraded due to high population growth and change in land use upsetting environmental stability in terms of sedimentation and increased nutrient deposition (Shivoga et al., 2005).

Land cover classification using Landsat Images showed a decrease of about 20% of forested areas between 1986 and 2003 in the watershed (Shivoga et al., 2005).

The forested and large-scale farm areas have been converted mainly into small-scale mixed agriculture and human settlement. These changes impacted negatively on the ecological integrity and hydrologic processes in the watershed but little is known about the influence of specific land uses on the water quality of the river (Maier et al., 2001)

Water quality standard vary significantly due to different environmental conditions, ecosystem and intended human uses. Toxic substances and high concentration of certain micro-organisms can present a health hazard for non-drinking purposes such as irrigation, swimming and fishing. These conditions may also affect wildlife which uses the water for drinking or as a habitat e.g., in case of Murray-Darling River systems in Australia (Maier et al., 2001).

In a study conducted on the River Njoro watershed in Kenya, it was found that the mid-stream portion of the river near Egerton University, with industrial, human settlement and agricultural land uses accounted for the highest cover and lower phosphorus loss from the sub-watershed (Shivoga et al., 2005). There was significant decrease in nutrient levels downstream indicating natural purification as the river flows through an area of large scale farming with dense riparian vegetation. In their study, Shivoga et al., (2005) observed that small scale farms and bare lands contributed over 55% nutrients load into the river. Increased erosion, nutrient and sediment loadings, human and animal pollution, along with damage to the integrity of the riparian corridor and changes in the hydrologic regime of the river were also observed. Within the same watershed, land use had significant effects on riparian soil properties (Enanga et al., 2010). The phosphorus of the surface and sub-surface soils within riparian buffers generally increased with more intensive land use in the adjacent areas.

Andrea et al., (2009) noted that in order to achieve the water quality objective by European Water Framework Directive, there is need to combine limitation of pollution sources and quality standards in the receiving natural water bodies. This could be achieved by proper management of the catchments of the rivers and streams. The shading effect of riparian vegetation is stimulated in their model by reduction of the light intensity reaching the stream which directly affects the algal growth and influences water temperature through a heat balance model. Restriction of riparian buffers is an example of water course management practices that can be used to control water quality of streams.

Enanga et al., (2010) stated that several spatial and temporal patterns observed in stream water chemistry in most catchments are controlled by land use history and hydrology which also controls the storage and transport of constituents. Studies within the Saginaw river basin revealed that nitrogen concentration, alkalinity and TDS were more sensitive to agricultural land use during summer and underlying geology during autumn (Maier et al., 2001).

Raburu et al., (2009) observed high amounts of nutrients and suspended solids in downstream River Nyando which drains an area of vast and varied land use activities ranging from forested upper reaches to the urban-industrial middle and lower reaches. This was probably due to high effluent loads, both domestic and industrial, entering the river and high inputs of phosphorus and nitrogenous fertilizers used within the catchment. Similar trends showing increase in nutrients and other pollutants down river have been observed in other rivers in Kenya including River Njoro (Makoba, et al., 2008), Kibos, Kisat and Kisian (Kobingi, et al., 2009; Triest, et al., 2012) and River Isiukhu (Onyando, et al., 2013, 2016 a,b).

Previous research on the physical-chemical quality of water bodies and its relationship with land use within Costilla, La Mancha, Spain, showed that agricultural fertilizer runoff and urban wastewater discharge are major contributors to river contamination (Tabacchi et al., 1998). Use of mixture of new techniques and social organization gives a balanced attention to improving resource management and farmers livelihoods. However, Osbourne and Wiley (1998) found that urban land use determined concentrations of soluble reactive phosphorus in an East Illinois watershed while agriculture was only a secondary predictor of Nitrogen and phosphorus. They noted that median nitrate concentrations were correlated with agricultural practices during high flow spring periods and was correlated with urban land cover during low-flow in summer and autumn.

In India, for example, the most successful watershed and catchment management programs involve multiple stakeholders-community groups, NGOs and Government agencies.

2.3. Aspects of water quality

Common parameters used to assess water quality include: suspended sediment, turbidity, dissolved oxygen, water temperature, and key nutrients. Forest watersheds often yield high-quality water because of erosion protection provided by forest vegetation, the forest floor, and forest soils. However, forests are subject to human and natural disturbances that can cause major changes in water quality (Brookes et al., 1992). Some of the parameters that are basic to life within aquatic systems include plant nutrients, turbidity, electrical conductivity, pH, temperature, total solids, total dissolved solids and total suspended solids. Impairment of these can be observed as impacts to the flora and or fauna within a given water body.

2.3.1. Biodegradable Organic Substances (BOS)

Human and animal wastes as well as effluents from industries processing plant or animal products contain a mixture of complex organic substances such as carbohydrates, proteins and fats as their major pollution load (Danida, 1998). These substances are readily biodegradable and when introduced into the environments are quickly decomposed through the action of natural microbial populations. Some of the organic matter is oxidized to carbon dioxide and water while the rest is assimilated and used for the synthesis of new microbial cells. In due course, these organisms will also die and become food for other decomposers. Eventually, virtually all of the organic carbon will be oxidized (Lamb, 1985).

When a biodegradable organic waste is discharged into an aquatic ecosystem such as stream, estuary or lake, oxygen dissolved in the water is consumed due to the respiration of microorganisms that oxidize the organic matter. The more biodegradable a waste is, the more rapid is the rate of its oxidation and the corresponding consumption of oxygen. Because of this relationship and its significance to water quality (dissolved oxygen levels in the water), the organic content of waste waters is usually measured in terms of the amount of oxygen consumed during its oxidation, termed the Biochemical Oxygen Demand (BOD).

In an aquatic ecosystem, a greater number of species of organisms are supported when the dissolved oxygen (DO) concentration is high. Oxygen depletion due to waste discharge has the effect of increasing the numbers of anaerobic bacteria at the expense of others.

When oxygen demand of a waste is so high as to eliminate all or most of the dissolved oxygen from a stretch of a water body, organic matter degradation occurs through the activities of anaerobic organisms, which do not require oxygen (Meertens et al., 1995).

Not only does the water then become devoid of aerobic organisms, but anaerobic decomposition also results in the formation of a variety of foul smelling volatile organic acids and gases such as hydrogen sulphide, methane and mercaptans (certain organic sulphur compounds). The stench from these can be quite unpleasant and is frequently the main cause of complaints from residents in the vicinity.

Chemical Oxygen Demand (COD) is the measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. It does not differentiate between biologically available and inert organic matter. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements usually take five days (BOD_5).

2.3.2. Plant Nutrients

The availability of plant nutrients, particularly nitrogen and phosphorous are important determinants of the biological productivity of aquatic ecosystems. Nutrients deficient aquatic environments are called “oligotrophic” and those rich in nutrients, “eutrophic.” Young lakes are generally oligotrophic (Nyanda, 2000), but they naturally accumulate nutrients over time, derived from drainage and sediment run off from its catchments. When human activities greatly accelerate nutrient enrichment of water bodies, the process is called “cultural eutrophication.” Sewage, animal wastes and many industrial effluents contain high levels of nitrogen and phosphorous. Another major source is fertilizer run off from urban and agricultural catchments. While in the long term, cultural eutrophication accelerates the natural succession progress of aquatic ecosystems towards a terrestrial system; in the short term problems arise due to cyclic occurrences of alga blooms and decay. In warm weather, nutrients stimulate rapid growth of algae and floating aquatic weeds. The water often becomes opaque and has unpleasant tastes and odours (Katima and Masanja, 1994). When these organisms die they become food for decomposing bacteria. Depletion of dissolved oxygen leads to anaerobic conditions and a general decline in the ecological aesthetic qualities of the water body.

According to Perry et al, (2007), nitrogen, phosphorous, or both may cause aquatic biological productivity to increase, resulting in low dissolved oxygen and eutrophication of lakes, rivers, estuaries, and marine waters. Besides adding to nutrient-content of the water, addition of some forms of nitrogen and phosphorous will increase BOD and COD, Chennakrishnan et al. (2008). Increased nitrogen levels adversely affect cold-water fish more than they do warm water fish. The study carried out by Barnes et al, (1998) on sedimentation and Georgia's fishes revealed that nitrogen concentrations of 0.5 mg/liter are toxic to rainbow trout.

In the natural world phosphorous is never encountered in its pure form, but only as phosphate. Phosphorous is one the key elements necessary for growth of plants and animals. Phosphorous in its pure form has a white color. When white phosphorous occurs in nature, this can be a serious danger to our health because it is extremely poisonous. White phosphorous enters the environment when industries use it to make other chemicals and when the military uses it as ammunition.

Through discharge of wastewater, white phosphorous ends up in surface waters near the factories that use it. Phosphorous is generally the limiting nutrient in fresh water systems and any increase in phosphorous usually results in more aquatic vegetation. Phosphates can be found commonly in plants. Concentrated phosphoric acids are used in fertilizers for agriculture and farm production. Phosphates are used for special glasses, sodium lumps, in steel production, in military applications (incendiary bombs and smoke screening), and in other applications such as pyrotechnics, pesticides, toothpaste and detergents.

There can be more phosphate in rivers and lakes, resulting in excessive algae growth (EPA, 1986). Phosphates enter waterways from human and animal waste, industrial effluents, and fertilizer runoff. These phosphates become detrimental when they over fertilize aquatic plants and cause stepped up eutrophication.

If too much phosphate is present in the water, the algae and weeds will grow rapidly, may choke the waterway, and use up large amounts of precious oxygen (in the absence of photosynthesis and as the algae and plants die and are consumed by aerobic bacteria). The result may the death of many aquatic organisms (EPA, 1986) such as the zooplankton and fish.

Little attention has been given to management strategies to minimize the non-point movement of phosphorous in the landscape because of the easier identification and control of point source inputs of phosphorous to surface waters and lack of direct human health risks associated with eutrophication.

Organic phosphates are important in nature; their occurrence may result from the breakdown of organic pesticides which contain phosphates (Barnes et al., 1998). Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate (USEPA, 2006). Though total phosphate loading is a problem in the entire Lake Victoria, it is evidently an acute one in Murchison bay. Therefore efforts should be made to minimize the loading of total phosphorous whenever possible using properly designed sedimentation basins to treat urban storm water and reducing phosphorous levels.

According to Githui (2009), there has been an increase of population over the last three decades within an estimated population density of 221persons/km^2 in 2002 within the River Nzoia basin. She also reports that the forest cover has decreased markedly from 12.3 to 7%, especially for the regions in the Northwest and south of the catchment. This could be attributed to the cutting of trees for various uses such as firewood, timber and clearing for agricultural purposes.

From the past research, the main anthropogenic activities increasing sediment supply to water course include, changes in agricultural practices e.g increased areas of arable cultivation, leading to grater areas of bare land exposed soil susceptible to erosion by rainfall Githui (2009), and mechanized farm practices which compact the soil and increase run off and soil erosion.

2.3.3. Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a water sample (Smith and Davies-Calley, 2001). Turbidity in water is caused by the presence of suspended matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms.

Waters with turbidity in excess of 50 NTU are quite cloudy, and waters with turbidities exceeding 500 NTU are downright muddy. Suspended sediment is a ubiquitous water pollutant, with a multitude of environmental impacts on water bodies, including transport of other pollutants such as absorbed nutrients and toxic materials. Effects on aquatic organisms include benthic smothering once sediment settles out of the water column (Smith and Davies-Calley, 2001). However, the most visually and ecologically significant, impact of suspended sediment is optical/increased light attenuation through water, decreasing algal growth, and low algal productivity can reduce the productivity of aquatic invertebrates, a food source of many fish.

High turbidity levels affect fish feeding and growth. Light attenuation by suspended particles in water has two main types of environmental impact: reduced penetration of light into water for photosynthesis and reduced visual range of sighted animals. High turbidity also due to total suspended solids supports high numbers of foreign micro biota in the water body, accelerating microbial pollution.

2.3.3.1. Factors affecting Turbidity

(a) Soil erosion

Eroded soil particles can be carried by storm water to surface water. This will increase the turbidity of the water body.

(b) Flooding

As flood waters recede, they will bring along inorganic and organic particles from the land surface, and contribute this to the river.

(c) Decaying Plants and Animals

As animals and plants present in water body die and decompose, suspended organic particles are released and can contribute to increased turbidity.

(d) Urban Run-off

Because of the large amount of pavement in urban areas, natural settling areas of soil particles and debris from streets have been removed and sediment is carried through storm drains to rivers and streams contributing to turbidity (Ahearn et al., 2005).

(e) Algal Blooms

Algal blooms greatly contribute to turbidity of water bodies. According to USEPA, (2006) turbidity level for drinking water should not be more than 5 Nephelometric Units (NTUs).

2.3.4. Electrical Conductivity (EC)

Electrical conductivity is a function of Total Dissolved Solids (TDS) known as ions concentration, which determines the quality of water (Mogere, (2000). Electrical conductivity or Total Dissolved Solids is a measure of how much total salt (inorganic ions as sodium, chloride, magnesium and calcium) is present in the water (Mosley et al., 2004), the more ions the higher the conductivity. Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems. If the conductivity of a stream suddenly increases, it indicates that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. All natural waters contain some dissolved solids due to the dissolution and weathering of rock and soil. Some but not the entire dissolved solids act as conductors and contribute to conductance. Waters with high TDS are unpalatable and potentially unhealthy.

According to Nadia (2006) discharge of wastewater with a high TDS level would have adverse impact on aquatic life, render the receiving water unfit for drinking and domestic purposes, reduce crop yield if used for irrigation and exacerbate corrosion in water networks.

2.3.4.1. Factors influencing electrical conductivity of stream water

Agricultural runoffs from farms contain agrochemicals such as fertilizers which contain phosphate and nitrate, herbicides and pesticides, this adds to dissolved solids in the stream water (Moxon, 1998).

Road runoffs from roads can contain fluids from automobiles and salts from chemicals used in road defrosting such as sodium chloride.

Geology and the nature of the soil in the surrounding is another important factor. Some rocks and soils release ions very easily when water flows over them. For instance, rocks containing calcium carbonate such as calcareous shales, calcium and carbonate ions will dissolve into the water. Therefore, conductivity increases in such waters. However, some rocks such as quartz (SiO_2) do not dissolve easily when water flows over them, therefore conductivity of such waters decreases.

2.3.5. pH

pH is a measure of the acid balance of a solution and is defined as the negative of the logarithm to the base 10 of the hydrogen ion concentration (UNEP &WHO, 1996). In waters with high algal concentrations, pH varies diurnally, reaching values as high as 10 during the day when algae are using carbon dioxide in photosynthesis.

pH drops during the night when the algae respire and produce carbon dioxide. As reported in Salequzzaman et al., (2008), pH changes can tip the ecological balance of the aquatic system and excessive acidity can result in the release of hydrogen sulfide.

The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. According to Mosley et al., (2004), water with a pH >8.5 indicates that the water is hard. Most metals become more water soluble and more toxic with increase in acidity. Toxicity of cyanides and sulfides also increase with a decrease in pH (increase in acidity). The content of toxic forms of ammonia to the non-toxic form depends on pH dynamics.

2.3.5.1. Factors influencing pH

The concentration of Carbon (IV) Oxide; can add up to water body from a variety of sources such as respiratory activities by aquatic organisms, released from bacteria in the water and atmospheric carbon (IV) Oxide. The dissolved carbon (IV) oxide forms a weak carbonic acid which then lowers the pH of the water.

pH is a function of air pollution. Fumes from car exhaust and industrial emissions increase the concentration of oxides of nitrogen (NO_2, NO) and sulphur (IV) Oxide (SO_2) in the air. These air pollutants react with atmospheric moisture to form nitric acid (HNO_3) and sulphuric acid (H_2SO_4) forming acid rain. When the acid rain falls on to the earth it lowers the pH of the streams.

According to USEPA (2006), the pH levels of drinking water should range between 6.5 and 8.5.

Extreme pH values such as greater than 9.5 or less than 4.5 are unsuitable for most aquatic organisms, for example, high pH levels (9-14) can harm fish by distorting the cellular membranes and eventually killing the fish. At very low pH levels below 5, the larval stages of aquatic insects may die.

2.3.6. Temperature

Temperature is a measure of the average energy (kinetic) of water molecules. It is measured on a linear scale of degrees Celsius or degrees Fahrenheit. Temperature affects water chemistry and the functions of aquatic organisms. Temperature affects the amount of oxygen that can be dissolved in water, rate of photosynthesis by algae and other aquatic plants, metabolic rates of organisms and sensitivity of organisms to toxic wastes, parasites and diseases and timing of reproduction, migration and aestivation of aquatic organisms.

Respiration of organisms is enzyme controlled and therefore temperature related, the rate of respiration can increase by 10% or more per 1^0c temperature rise. Increased temperature lowers the concentration of dissolved oxygen available in water which in turn increases oxygen demand which adds to physiological stress of organisms (Giller, et al., 1998).

2.3.6.1. Factors Influencing Water Temperature

(a) Industrial Effluents

Industrial effluents discharged in a water body increases water temperature. This in turn causes an increase in the rate of respiration by the aquatic plants and animals, resulting into an increase in oxygen demand.

(b) Vegetation Cover

Natural vegetation growing along the banks of a river provides shade, preventing the sun from heating up the water and this therefore lowers the water temperatures.

(c) Rate of Water Flow

Rate of water flow or velocity is low during dry seasons due to less water volume in the stream. This makes the water to be heated up more quickly hence raising the water temperature. Rapid temperature changes adversely affect the aquatic organisms, Dara, (1997).

2.3.7. Total Solids (TS)

The term "total solids" refers to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. Total solids (also referred to as total residue) are the term used for material left in a container after evaporation and drying of a water sample. Total Solids includes both total suspended solids, the portion of total solids retained by a filter and total dissolved solids, the portion that passes through a filter (APHA, 1998).

2.3.7.1. Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micrometers). TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells (Stapp and Mitchell, 1992). However, if TDS concentrations are too high or too low, the growth of many aquatic lives can be limited, and death may occur.

Similar to TSS, high concentrations of TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature.

TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.

2.3.7.1.1. Factors affecting Total Dissolved Solids

a) Geology and Soil in the Watershed

Some rock and soil release ions very easily when water flows over them; for example, if acidic water flows over rocks containing calcite ($CaCO_3$), such as calcareous shales, calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will dissolve into the water. Therefore, TDS will increase. However, some rocks, such as quartz-rich granite, are very resistant to dissolution, and don't dissolve easily when water flows over them. TDS of waters draining areas where the geology only consists of granite or other resistant rocks will be low (Shehata and Badr, (2010).

b) Urban Runoff

During storm events, pollutants such as salts from streets, fertilizers from lawns, and other material can be washed into streams and rivers. Because of the large amount of pavement in urban areas, natural settling areas have been removed, and dissolved solids are carried through storm drains to creeks and rivers.

c) Fertilizer Runoff

Fertilizer can dissolve in storm water and be carried to surface water during storms, and contribute to TDS.

d) Wastewater and Septic System Effluent

The effluent from Wastewater Treatment Plants (WWTPs) adds dissolved solids to a stream. The wastewater from our houses contains both suspended and dissolved solids that we put down our drain. Most of the suspended solids are removed from the water at the WWTP before being discharged to the stream, but WWTPs only remove some of the TDS. Important components of the TDS load from WWTPs include phosphorus, nitrogen, and organic matter.

e) Soil Erosion

Soil erosion is caused by disturbance of a land surface. Soil erosion can be caused by building and road Construction, forest fires, logging, and mining. The eroded soil particles may contain soluble components that can dissolve and be carried by storm water to surface water. This will increase the TDS of the water body.

f) Decaying Plants and Animals

As plants and animals decay, dissolved organic particles are released and can contribute to high TDS concentration

2.3.7.2. Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life.

High TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down. Reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from the water. Low dissolved oxygen can lead to fish kills. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (because warmer waters can hold less DO), and can harm aquatic life in many other ways, as discussed under temperature. (Stapp and Mitchell, 1992).

The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. When suspended solids settle to the bottom of a water body, they can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae. Settling sediments can fill in spaces between rocks which could have been used by aquatic organisms for homes. (Stapp and Mitchell, 1992).

High TSS in a water body can often mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water. In the water, the pollutants may be released from the sediment or travel farther downstream (USEPA, 2006).

High TSS can cause problems for industrial use, because the solids may clog or scour pipes and machinery.

2.3.7.2.1. Factors that affect Total Suspended Solids

a) High flow rates

The flow rate of the water body is a primary factor in TSS concentrations. Fast running water can carry more particles and larger-sized sediment. Heavy rains can pick up sand, silt, clay, and organic particles (such as leaves, soil, and tire particles) from the land and carry it to surface water. A change in flow rate can also affect TSS; if the speed or direction of the water current increases, particulate matter from bottom sediments may be re-suspended.

a) Soil Erosion

Soil erosion is caused by disturbance of a land surface. The eroded soil particles can be carried by storm water to surface water. This will increase erosion can be caused by building and road construction, forest fires, logging, and mining. The TSS of the water body.

b) Urban Runoff

During storm events, soil particles and debris from streets and industrial, commercial, and residential areas can be washed into streams. Because of the large amount of pavement in urban areas, infiltration is decreased, velocity increases, and natural settling areas have been removed. Sediment is carried through storm drains directly to creeks and rivers.

c) Wastewater and Septic System Effluent

The effluent from Wastewater Treatment Plants (WWTPs) can add suspended solids to a stream. The wastewater from our houses contains food residue, human waste, and other solid material that we put down our drains. Most of the solids are removed from the water at the WWTP before being discharged to the stream, but treatment can't eliminate everything, (Keith et al, 2004).

d) Decaying Plants and Animals

As plants and animals decay, suspended organic particles are released and can contribute to the TSS concentration.

e) Bottom-Feeding Fish

Bottom-feeding fish (such as carp) can stir up sediments as they remove vegetation, these sediments can contribute to high TSS.

2.3.8. Biological components

2.3.8.1. Micro-organisms and water quality

Many serious human diseases such as cholera, typhoid, bacterial and amoebic dysentery, enteritis, polio and infectious hepatitis are caused by water-borne pathogens. In addition, malaria, yellow fever and filariasis are transmitted by insects that have aquatic larvae.

In most developed nations, the spread of water-borne infectious diseases has been largely arrested through the introduction of water and sewage treatment facilities and through improved hygiene. But in many developing countries, such diseases are still a major cause of death, especially among the young (Lamb, 1985). A strong correlation exists between the infant mortality rates of various countries and the percentage of the population with access to clean water and sewage disposal facilities.

Biological assessment studies to generate information on water quality degradation and particularly on its impact on biodiversity have been carried out in many countries. Biological parameters have been identified as good indicators of ecosystem integrity (Nderitu, 2003). The use of genera abundances to infer environment conditions have been examined with notable success. A cost effective and ecologically relevant way to assess urban impacts on rivers is to look directly into responses of biological assemblages such as fish or aquatic insects (Dix, 1981).

Bacteria of the coliform group are considered the primary indicators of fecal contamination and are some of the most frequently applied indicators of water quality. They are the principal indicator of suitability of water for domestic uses. The density of coliform group is the criteria for the degree of contamination and has been the basis of bacteriological water quality standards. In ideal situation, all samples taken from the distribution system should be free from coliform organisms. The coliform group is made up of a number of bacteria including the genera Klebsiela, Escherichia, Serratia.

2.7.8.2. Erwinia and Enterobacteria

Total Coliform bacteria, are all gram negative Asporogeneous rods and have been associated with feaces of warm blooded animals and with soil. The fecal Coliform bacteria which comprise a portion of the total Coliform group are able to grow at 44.5^{o}C and ferment lactose, producing acid and gas. Use of fecal Coliform bacteria has proven to be of more sanitary significance than the total use of Coliform bacteria because they are restricted to intestinal tract of warm blooded animals and are now used to define water quality for swimming. Arguments have been advanced for the use of Escherichia coli as the indicator of choice for fresh fecal pollution. Enterococci were recognized as early as 1890 as being indicators of recent fecal pollution from warm blooded animals. Ideally, a microbiological indicator organism should fulfill all the following criteria; (Scarpino, 1974): It should be applicable to all types of water, it should be present with a survival time equal to that of the hardiest enteric pathogen and the indicator should not reproduce in contaminated waters thus resulting in inflated values.

Microorganisms are always present in water. The pathogenic ones were often and are still the cause of serious epidemics. Bacteriological analysis of water is a rather difficult and prolonged process. The re -known bacteriologist Robert Koch proposed in 1892 a rapid method that is now widely used for estimating bacteriological contamination of water by the quantity of cells of E. coli bacterium. This bacterium is a normal component of intestinal flora. It does not cause any diseases, but its quantity in water is an indicator of the presence of other harmful microorganisms. If E. coli is absent or present in water only in small quantities, then there should be no contamination with other microorganisms. It is established that water is harmless for drinking, if there are not more than 3 cells of E. coli in 1 liter. The cell number per liter of water is called the coli-index. Another characteristic of water decontamination is coli-titer i.e. the volume of water (cm^3) containing 1 cell of E. coli. Water of good quality should have coli-titer not less than 300 ml; this corresponds to coli-index of not more than 3 cells per litre (APHA, 1998).

Another aspect of the interaction of water and microorganisms is their use for biochemical purification of waste water in filtration and purification beds, in biological filters and aeration tanks, and also in the silt places and in biological ponds (Brookes, 1992). Coliform bacteria are a commonly used bacterial indicator of water pollution, although not an actual cause of disease. Other microorganisms sometimes found in surface waters which have caused human health problems include Burkholderia pseudomallei, Cryptosporidium parvum, Giardia lamblia, Salmonella, Novovirus and other viruses, and parasitic worms (helminths).

High levels of pathogens may result from inadequately treated sewage discharges. This can be caused by a sewage plant designed with less than secondary treatment (more typical in less-developed countries). In developed countries, older cities with aging infrastructure may have leaky sewage collection systems (pipes, pumps, valves), which can cause sanitary sewer overflows. Some cities also have combined sewers, which may discharge untreated sewage during rain storms. Pathogen discharges may also be caused by poorly managed livestock operations, Meynendonckx et al. (2006).

The presence of fecal Coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of man or other animals. Fecal Coliform bacteria can enter rivers through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and from untreated human sewage. Individual home septic tanks can become overloaded during the rainy season and allow untreated human wastes to flow into drainage ditches and nearby waters. Agricultural practices such as allowing animal wastes to wash into nearby streams during the rainy season, spreading manure and fertilizer on fields during rainy periods, and allowing livestock watering in streams can all contribute fecal Coliform contamination, (Allan, 1995).

At the time this occurs, the source water may be contaminated by pathogens or disease producing bacteria or viruses, which can also exist in fecal material. Some waterborne pathogenic diseases include ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. The presence of fecal Coliform tends to affect humans more than it does aquatic creatures, though not exclusively. While these bacteria do not directly cause disease, high quantities of fecal Coliform bacteria suggest the presence of disease causing agents. The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. During high rainfall periods, the sewer can become overloaded and over flow, bypassing treatment. As it discharges to a nearby stream or river, untreated sewage enters the river system. Runoff from roads, parking lots, and yards can carry animal wastes to streams through storm sewers. Drinking water should not contain pathogenic micro-organisms. The most common being Coliform bacteria that are normally present in fecal matter mainly from pesticides and nutrients, atmospheric deposition, leaching and corrosion of building materials and consume (Meynedonckx et al., 2006).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study area

The study made use of primary data which was generated out of field measurements and tests performed in the laboratory. Sampling stations were identified and their locations determined using a Geographical Positioning System (GPS) model Garmin tino 130. The coordinates of the sampling sites are given in Table 3.1 and their positions shown in Figures 3.1 and 3.2. Images of photographs of some of the land use practices and other features in the riparian area of River Shimiche also showing direction of flow taken during sampling are presented in Plates 3.1 to 3.5.

Table 3.1: Location of the sampling stations on River Shimiche and the predominant land use. (Source: Field Data 2014).

Station code	Name	Position			Land use
		Latitude	Longitude	Altitude (m a.s.l.)	
1a	Upper stream	0°35´50´´N	34°38´46´´E	1300	Forest
1b	Upper stream	0°35´46´´N	34°38´46´´E	1298	Forest
1c	Upper stream	0°35´40´´N	34°38´46´´E	1298	Forest
2a	Middle stream	0°21´35´´N	34°28´46´´E	1298	Urban settlement
2b	Middle stream	0°21´49´´N	34°28´46´´E	1280	Urban settlement
2c	Shibale Bridge	0°21´26´´N	34°28´60´´E	1272	Urban settlement
3a	Lower stream	0°21´11´´N	34°28´46´´E	1272	Mixed farming
3b	Lower stream	0°21´31´´N	34°28´64´´E	1270	Mixed farming
3c	R. Nzoia confluence	0°21´09´´N	34°28´46´´E	1270	Mixed farming

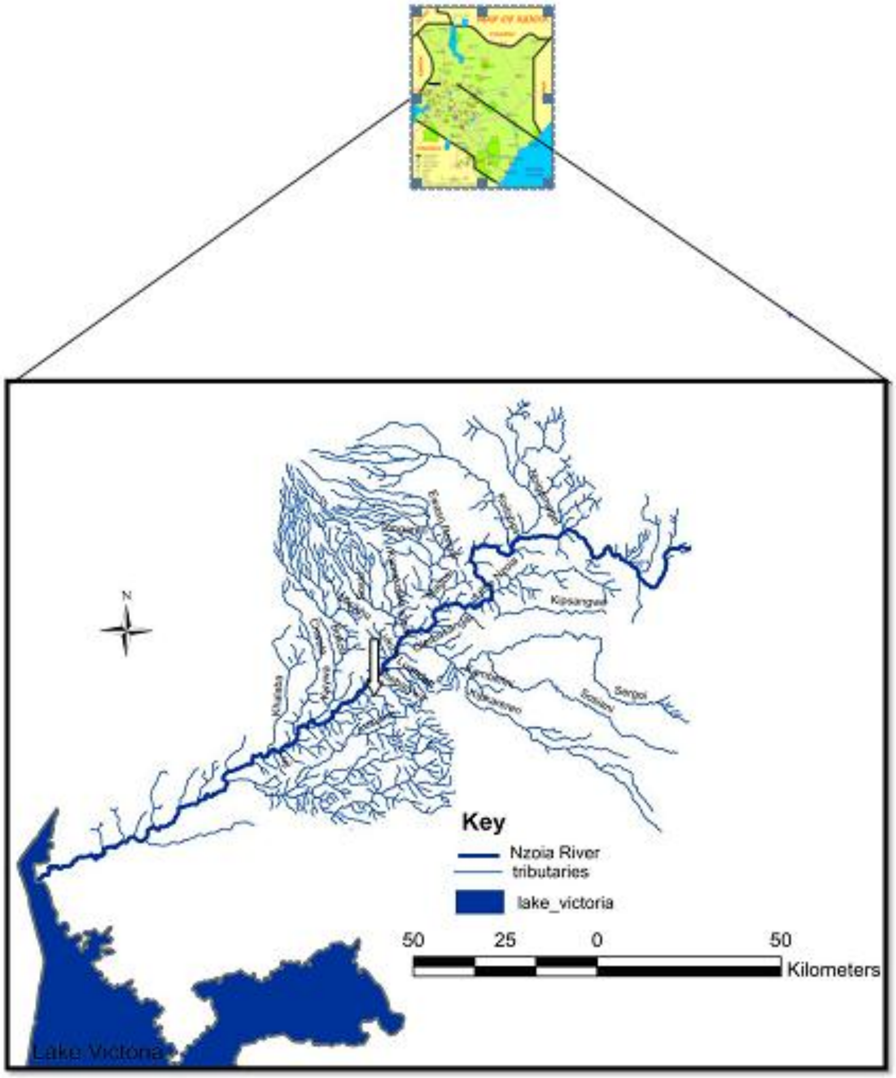

Figure 3.1: Map of Kenya showing position of River Shimiche in relation to River Nzoia and Lake Victoria.(arrow pointing at position of River Shimiche)

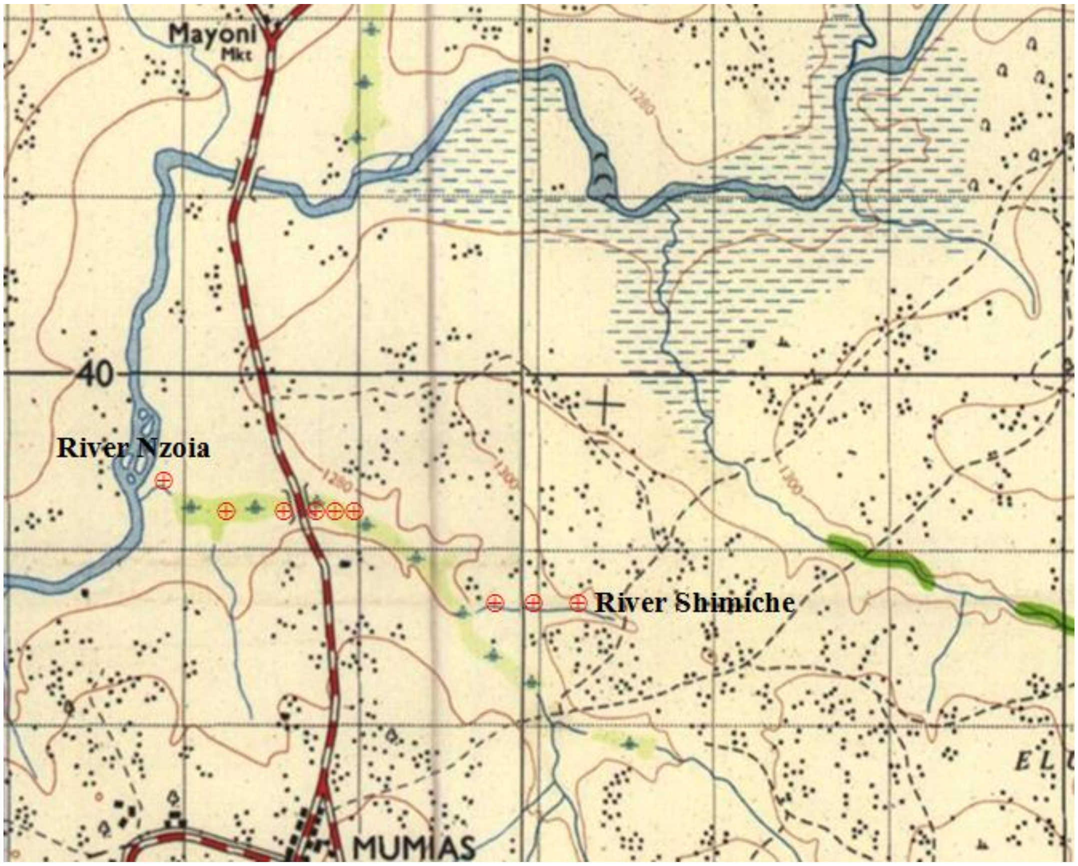

Figure 3.2: Map showing the sampling stations **(+)** along River Shimiche,

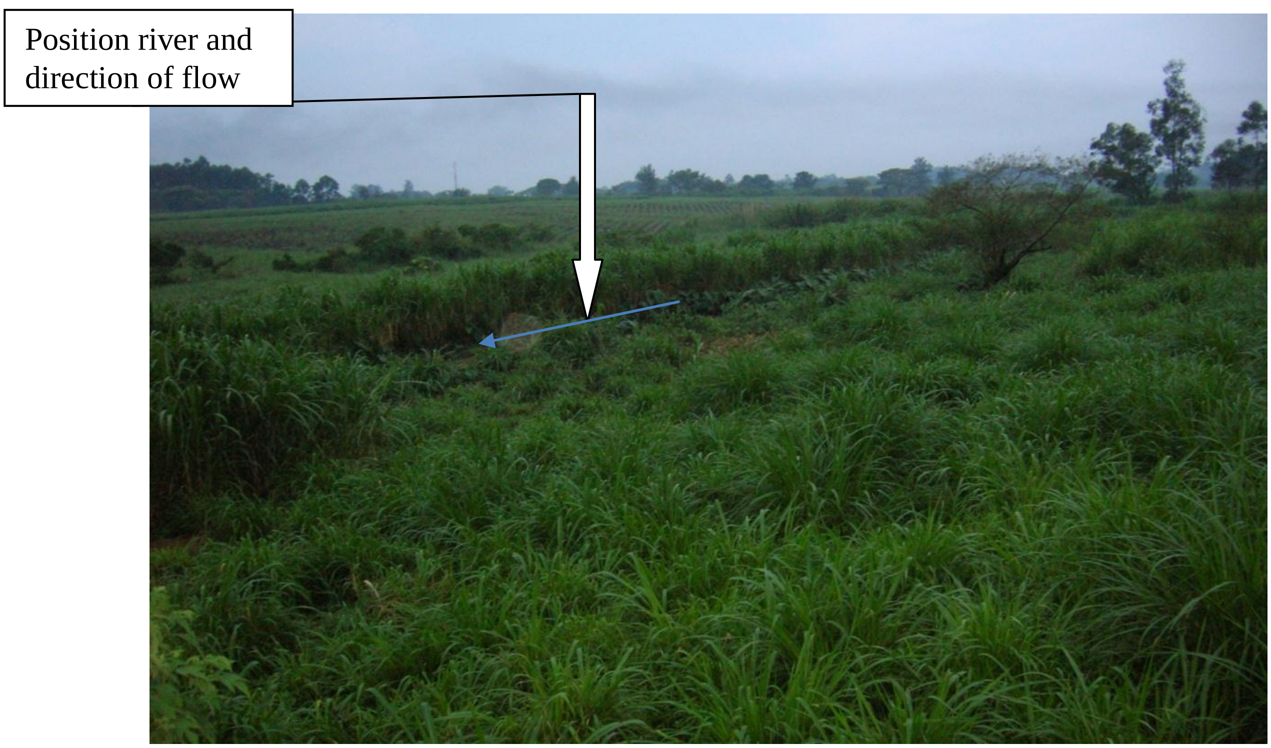

Plate 3.1: Sugarcane farms in the riparian area of upper River Shimiche (arrow indicate position and direction of flow of water).

Plate 3.2: River Shimiche flowing through sugarcane plantations (arrow indicates direction of flow).

Plate 3.3: Pipes abstracting water from River Shimiche for irrigation of vegetable farms in the riparian area.

Plate 3.4: Sand harvesting activities in River Shimiche,

Plate 3.5: Confluence of River Shimiche and River Nzoia.

3.2. Research design

The study was conducted using purposive and experimental sampling design. Three landuse practices were identified along the river course i.e. from the upper course; the bridge area (Mumias-Bungoma road), and the mouth of the river. The river's upstream is mainly dominated by forests; along the river towards the Mumias-Bungoma road at the middle stream is dominated by the urban Shibale residential estates, Magharibi and Total Petrol Stations and a Nursing Home. The lower course of the river is characterized by mainly mixed small scale agricultural activities and non-agricultural activities such as sand harvesting, swimming and fishing.

Nine sampling stations were identified based on the prevailing human activities along the 46 km stretch of the river course. For each land use practice identified, 3 sampling stations were selected purposefully. The stations were coded 1a, 1b, 1c; 2a, 2b and 2c and 3a, 3b and 3c. (Table 3.1 and Figures 3.1 and 3.2.). Station 1a is near the source of the River, Station 1b and 1c were 50 m and 100 m below the source of the river respectively. Site 2a was 50 m before the bridge, while Station 2b was at the bridge i.e. along the Mumias-Bungoma road. Station 2c was at 50 m after the bridge while Station 3a was 100 m before the mouth of River Shimiche (confluence of River Shimiche with River Nzoia). Stations 3b and 3c were 50 m before the mouth and at the mouth of River Shimiche discharging into River Nzoia respectively.

3.3. Sampling

Sampling was done once per month from 1st January 2014 to 1st August 2014. At each sampling station, Water temperature, Total dissolved solids (TDS), Electrical conductivity (EC) and pH were measured in-situ using H12211 PH/ORP meter and turbidity using a portable turbidity meter, TN-100 Eutech instruments. Three triplicate water samples were collected just below the water surface using 1 litre sampling bottles (washed in dilute hydrochloric acid and thoroughly rinsed with distilled water) for the laboratory analysis of Total Suspended Solids (TSS) and E. coli concentration. The sample bottles were labeled to show the sampling station, date and time of collection, stored in ice cool box and transported to the laboratory. In the laboratory, the samples were stored at 4°C in the refrigerator and analyzed within 24 hours. A total of 216 data sets were collected during the study period for analysis of each physical-chemical parameter and E. coli concentration.

3.4. Laboratory analysis of water samples

3.4.1 Analysis of TSS

TSS analysis was done according to standard methods as outlined in APHA (1998). 100ml of the water sample was filtered through a pre-weighed GF/C Filter paper of pore size 0.45µm. the filter paper and its contents were dried in an even at 105°C for 1 hour, and cooled in desiccator for 1 hour . The filter paper and its contents were weighed again and TSS determined using the formula:

$$\text{TSS}(\text{mgL}^{-}1) = \frac{(\text{Weight of filter paper} + \text{sediments}) - (\text{Weight of filter paper}) \times 10^{6}}{\text{volume of water sample filtered}}$$

3.4.2. Determination of the concentration of E. coli bacteria

E. coli concentration was determined using membrane filtration method. 10ml of water sample was passed through a membrane filter with a pore size 0.45 µm to retain the E. coli present. The filter was then placed on an absorbent pad in a petri-dish saturated with MUG (4-MethylUmbelliferyl-D-Glucoronide) which produced a flurogenic product when hydrolyzed by the glucorinadase. The petri-dish and pad were then incubated upside down for 24 hours at 44.5 °C temperature. After incubation, the colonies that had grown were identified and counted using a colony counter under a dissecting microscope (Leica Zoom Model 2000, Leica Microsystems Wetzar, and Germany).

3.5. Determination of land use practices along River Shimiche

Land use activities along River Shimiche were determined by observation by the researcher. Photographs were taken at each sampling zone to indicate the dominant landuse practice. For instance at the upper course, middle and the mouth of the river, the following activities were dominant; Forested area, sugar cane plantations, urban settlement, and on the lower course, human settlement and mixed agricultural and non–agricultural activities such as sand harvesting and swimming were observed.

3.6. Data analysis

All the statistical analyses were done using Statistical Analysis System (SAS), version 9.1. For every physico-chemical parameter at different stations, descriptive statistics including the mean, range, standard deviation and standard error were calculated at 95% confidence interval.

One way analysis of variance (ANOVA) was calculated to test for any significant differences between the means of physicochemical parameters at different stations on the basis of land use practices. Significant differences revealed in the means were separated using t-test in the differences of the Least Significance Difference (LSD).

Pearson correlation coefficient was performed to explore the relationships between different physico-chemical parameters and E. coli bacteria concentrations.

CHAPTER FOUR

RESULTS

4.1. Introduction

This chapter presents results on differences in physical-chemical parameters, E. coli concentration and the relationship between E. coli concentration and physico-chemical parameters a long River Shimiche; during the study period from January to August 2014.

4.2. Water quality parameters in River Shimiche along landuse gradients

This objective sought to investigate the differences in water quality with respect to land use gradient along River Shimiche. Measurements on the physico-chemical parameters were done both in-situ and in the laboratory set up. At each site, water temperature, pH, Total Dissolved Solids (TDS), Electrical conductivity, and turbidity were determined in-situ at the time of sampling using appropriate meters. Field coordinates for sampling sites were also taken as shown in Table 3.1.

Mean (±S.E) values of all the physico-chemical parameters of water in River Shimiche varied spatially with land use patterns along the stream. A summary of the mean values and standard error of the physico-chemical variables measured in the 9 sampling stations in is given in Table 4.1.

Table 4.1: Summary of mean (±S.E) values for physico-chemical parameters and concentration of E. coli in the different land use areas on River Shimiche.

Physico-chemical parameter	n	forest	urban settlement	mixed small scale farming	f-values p-values
Temperature (°C)	72	21.08±0.11	23.81±0.13	24.71±0.17	F=185.581 P=0.000
pH	72	6.44±0.02	7.46±0.1	7.81±0.01	F=1850.695 P=0.000
TDS (mg l^{-1})	72	25.92±0.64	42.42±0.43	48.81±0.65	F=406.447 P=0.000
Electrical conductivity (µS cm^{-1})	72	46.23±1.21	59.05±0.75	67.12±1.26	F=92.7 P=0.000
Total Suspended Solids(mg l^{-1})	72	161.5±6.01	384.20±8.53	415.14±11.26	F=243.55 P=0.000
Turbidity (NTU)	72	187.54±5.18	266.33±2.5	366.37±2.95	F=577.519 P=0.000
E.coli concentration/ 100ml	72	12.97±0.34	118.51±1.16	178.97±1.05	F=8172.148 P=0.000

S.E. - Standard Error

4.2.1. Variations in water temperature

Lower water temperatures were recorded upstream in River Shimiche and they increased gradually downstream (Figure 4.1). Overall, the lowest temperatures with a mean value of 21.08 °C were recorded at the area with forest. Temperature increased downstream in the area with urban settlement to 24.71 °C at the mixed small scale farming area downstream near the confluence with River Nzoia.

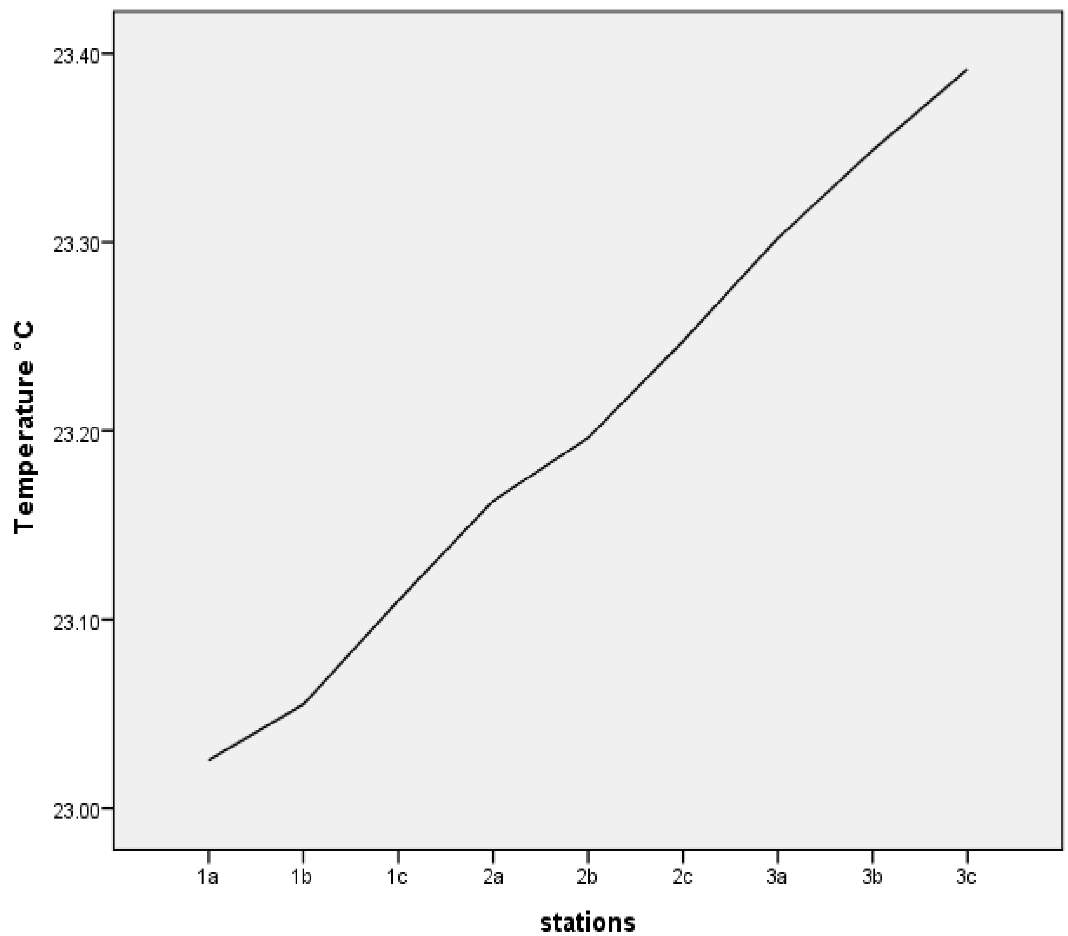

Figure 4.1: Variation in mean water temperature in River Shimiche along land use gradients.

4.2.2. Variations in pH

The pH values in River Shimiche showed a narrow range and very close to neutral (Figure 4.2). The pH was lower and slightly acidic upstream in the area with forest which registered a mean of pH 6.44. The pH also increased gradually downstream to the highest mean of pH was 7.81 in the mixed small scale farming area.

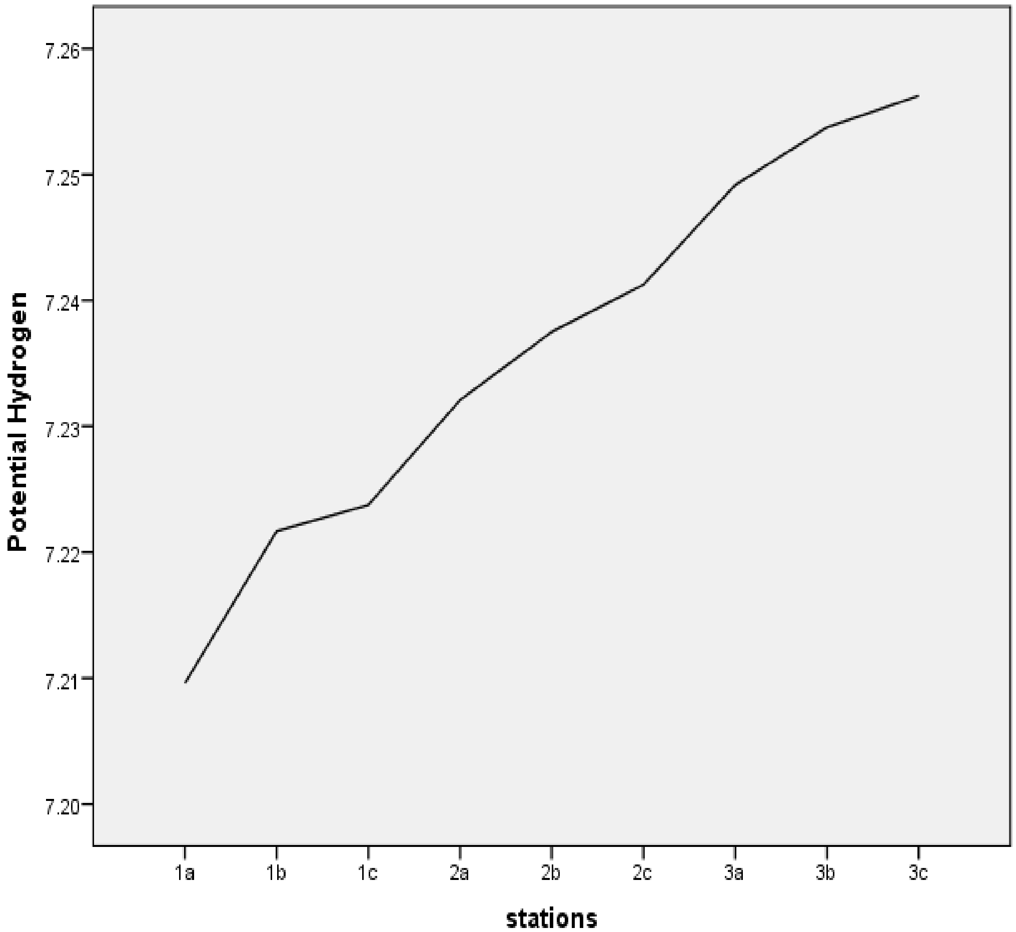

Figure 4.2: Variation in mean pH in River Shimiche along land use gradients.

4.2.3. Variations in Total Dissolved Solids

Total dissolved solids (TDS) followed almost similar patterns as for temperature and pH: low values upstream increasing gradually downstream (Figure 4.3). The lowest mean value, 25.92 mg l^{-1} was recorded in forest area upstream as opposed to the highest mean value of 48.81 mg l^{-1} observed in the mixed small scale farming area downstream.

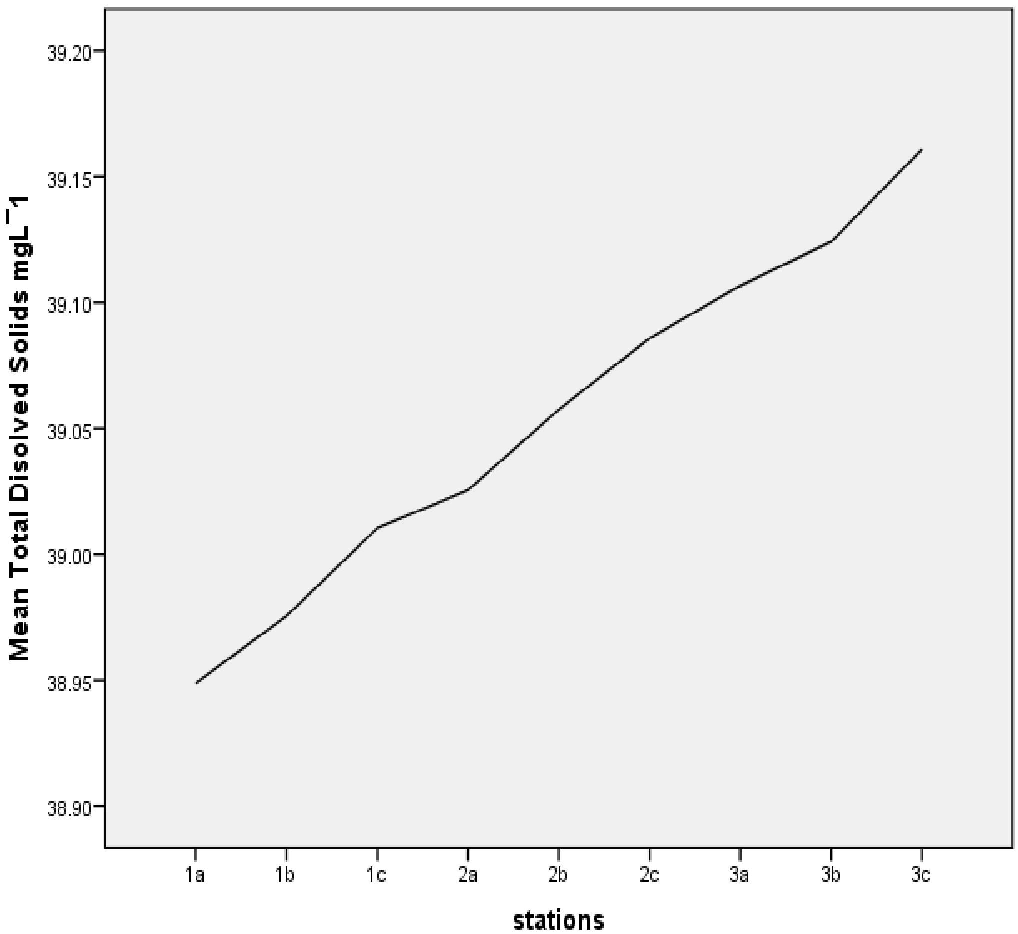

Figure 4.3: Variation in mean TDS in River Shimiche along land use gradients.

4.2.4. Variations in Electrical Conductivity (EC)

Electrical conductivity was low upstream in the forested area and varied little in the middle stream (Figure 4.4). Higher values of EC were recorded downstream in the the mixed small scale farming area.

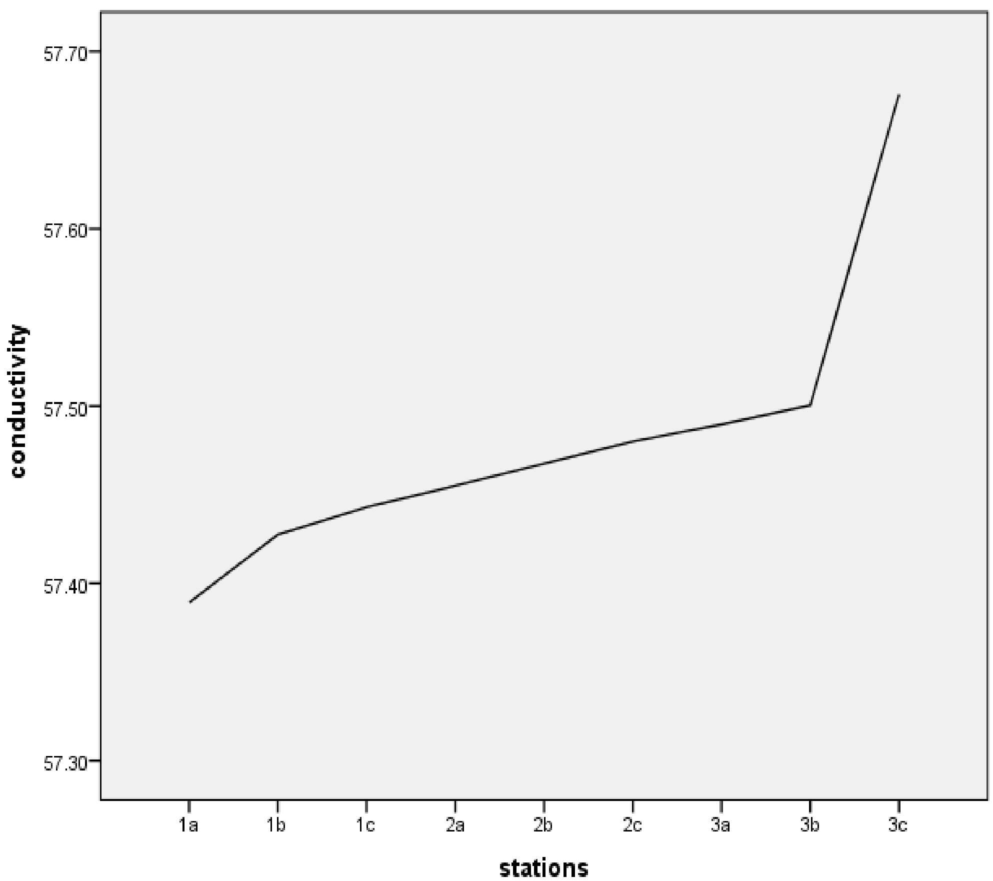

Figure 4.4: Variation in Electrical conductivity (μS cm^{-1}) in River Shimiche along land use gradients.

4.2.5. Variations in concentration of E. coli

Concentrations of E. coli showed great variations along the course of the river but were generally low upstream in the forested area, increased substantially but with no particular patterns in the urban settlement area in middle stream and decreased slightly downstream in the mixed small scale farming area (Figure 4.5).

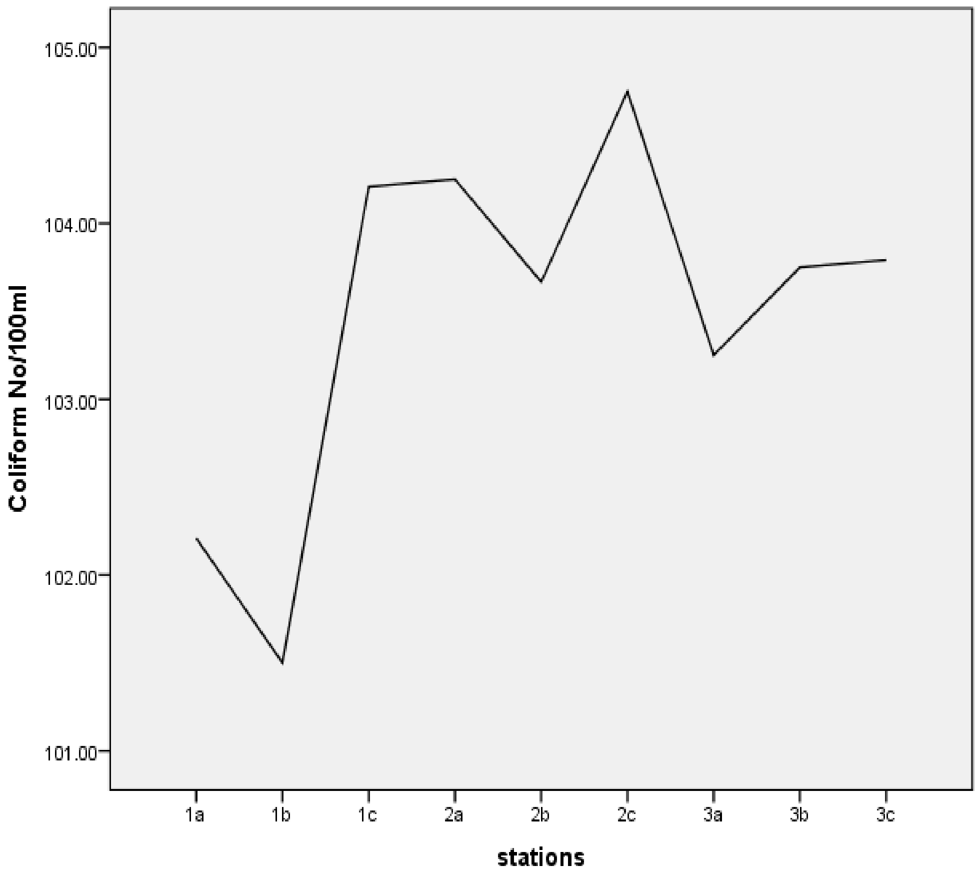

Figure 4.5: Variation in mean values E. coli concentrations in River Shimiche along land use gradients.

4.2.6. Variations in Total Suspended Solids

Total suspended solids (TSS) followed almost similar patterns as for temperature, pH and TDS: low values upstream increasing gradually downstream (Figure 4.6). TSS in the three land use categories were significantly different along the land-use gradient of River Shimiche.

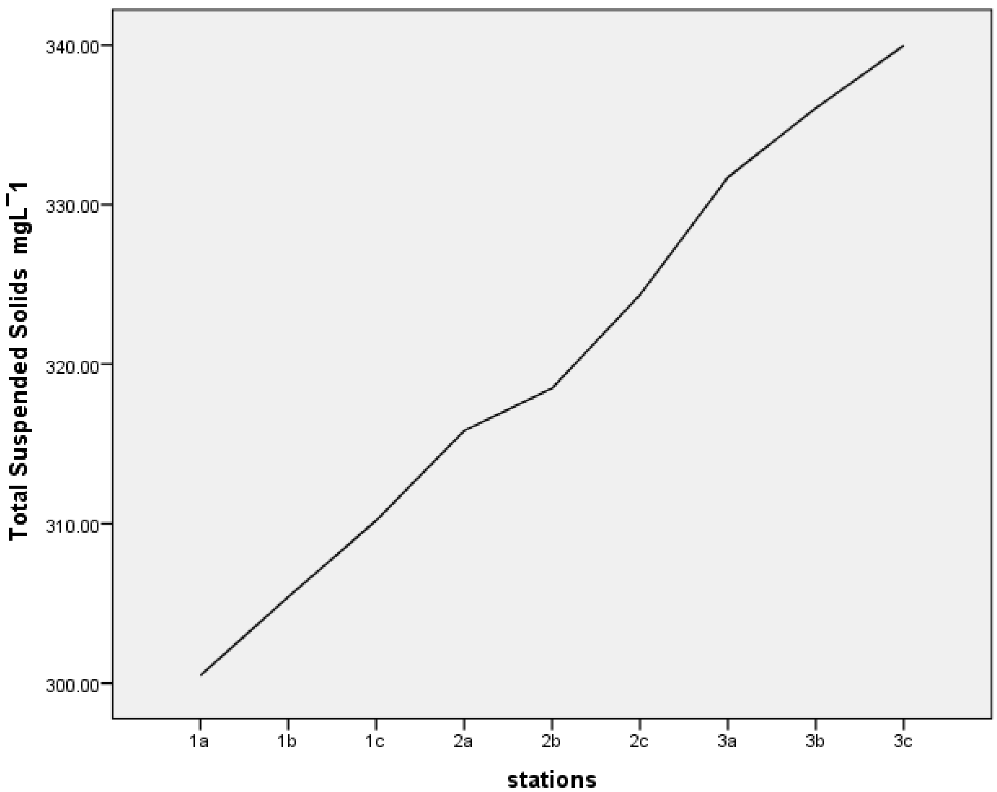

Figure 4.6: Mean values of TSS in River Shimiche along land use gradients.

4.2.6. Variations in Turbidity

Turbidity was low upstream in the forested area and it increased sharply in the middle stream area with urban settlement and remained high in mixed small scale farming area downstream (Figure 4.7).

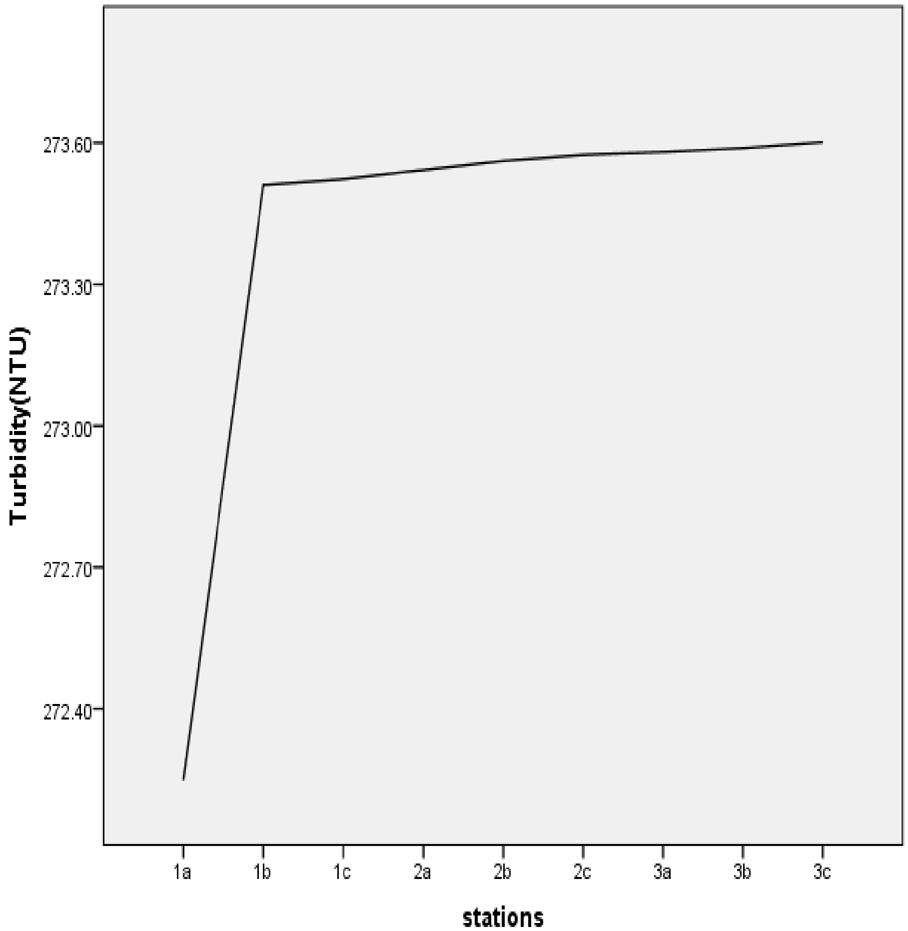

Figure 4.7: Variation in mean Turbidity in River Shimiche along land use gradients.

4.3. Relationship between concentration of E. coli and physico-chemical parameters.

The study also sought to establish the relationship between E. coli concentrations and physico-chemical parameters with respect to land use practices along River Shimiche. The results are shown in the Table 4.2. There were weak correlations between the concentration of E. coli and all the physico-chemical parameters measured in this study: r = -0.491 to -0.118 to for temperature, r = -0.066 to 0.256 for pH, -0.046 to -0.538 to -

0.082 for TDS, r = -0.307 to 0.43 for conductivity, r = -0.298 to 0.06 for TSS and r = -0.081 to - 0.0369 for turbidity.

Table 4.2: Correlation between E. coli and physico-chemical parameters in River Shimiche.

Land use	**Parameter**	**Statistics**	**Temp(^{0}c)**	**pH**	**TDS**	**Conductivity**	**TSS**	**Turbidity**
Forest	E. coli	R	-0.333	0.256	-0.538	-0.307	0.063	-0.06
		S	0.005	0.03	0.00	0.009	0.598	0.619
Urban settlement	E. coli	R	-0.118	-0.066	-0.082	-0.067	0.031	-0.081
		S	0.324	0.582	0.493	0.576	0.796	0.498
Mixed agricultural areas	E. coli	R	-0.491	0.197	-0.046	0.431	- 0.298	-0369
		S	0.000	0.097	0.7	0.000	0.06	0.001

4.4. Assesment of concentration of E. coli bacteria

The study finally assessed the concentration of E. coli bacteria along the land use gradient of River Shimiche. The results are shown in the Figures 4.8 to Figure 4.13.

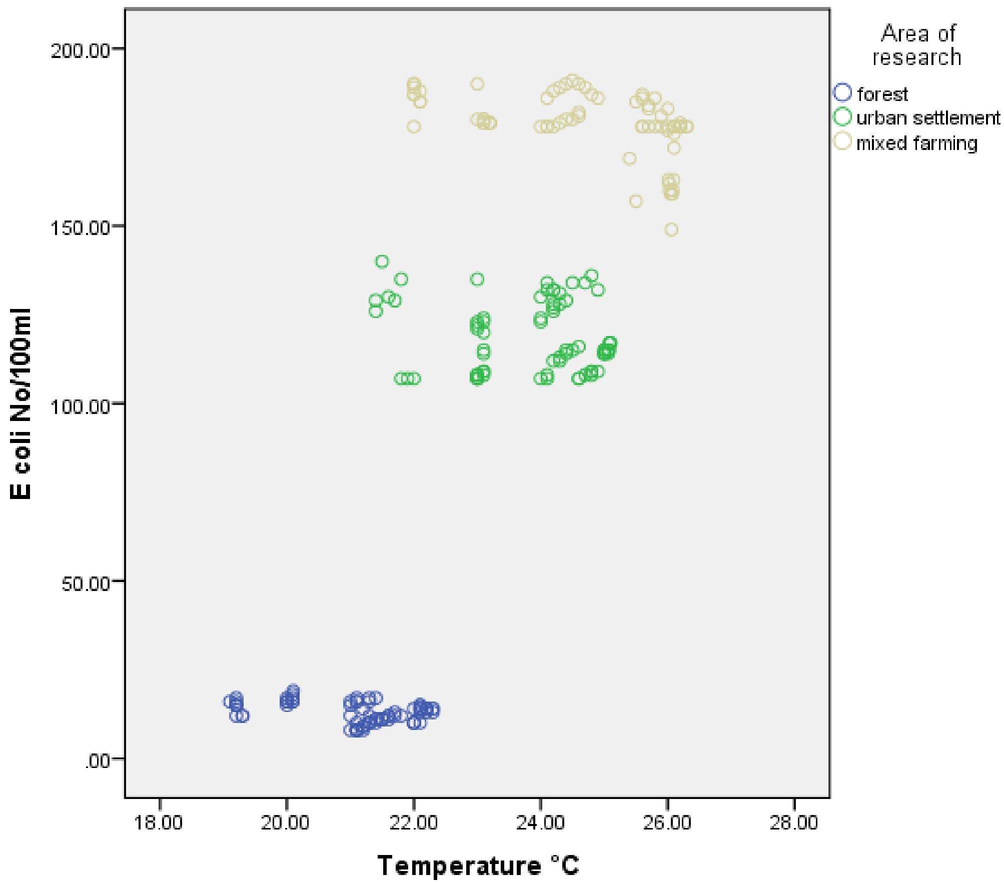

Figure 4.8: Mean values of Temperature versus E. coli concentration along land use gradients.

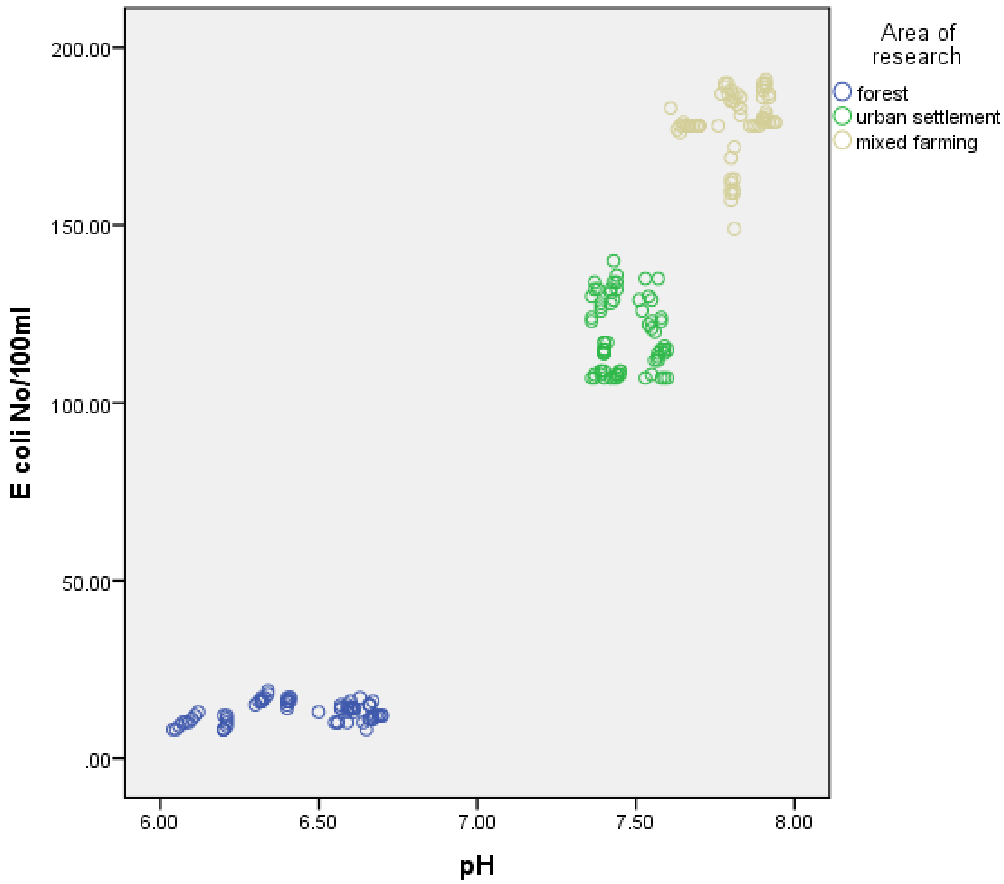

Figure 4.9: Mean pH versus E. coli concentration along land use gradients.

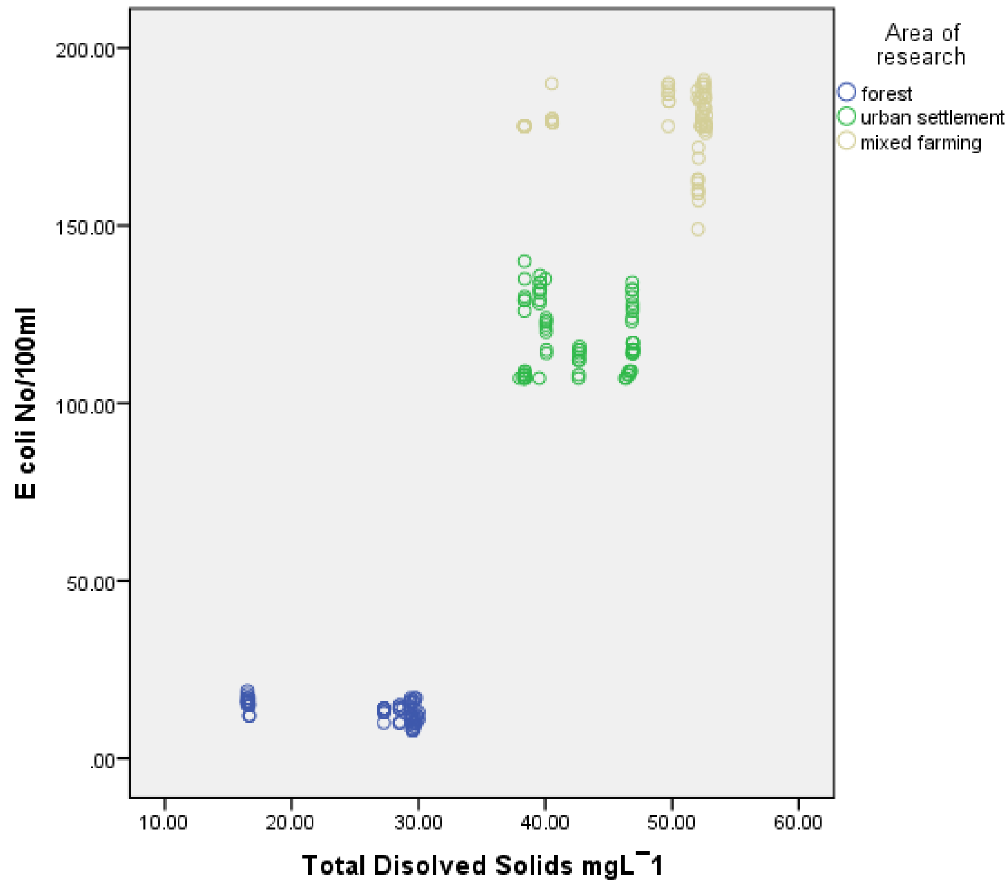

Figure 4.10: Mean TDS versus E. coli concentration in River Shimiche along land use gradients.

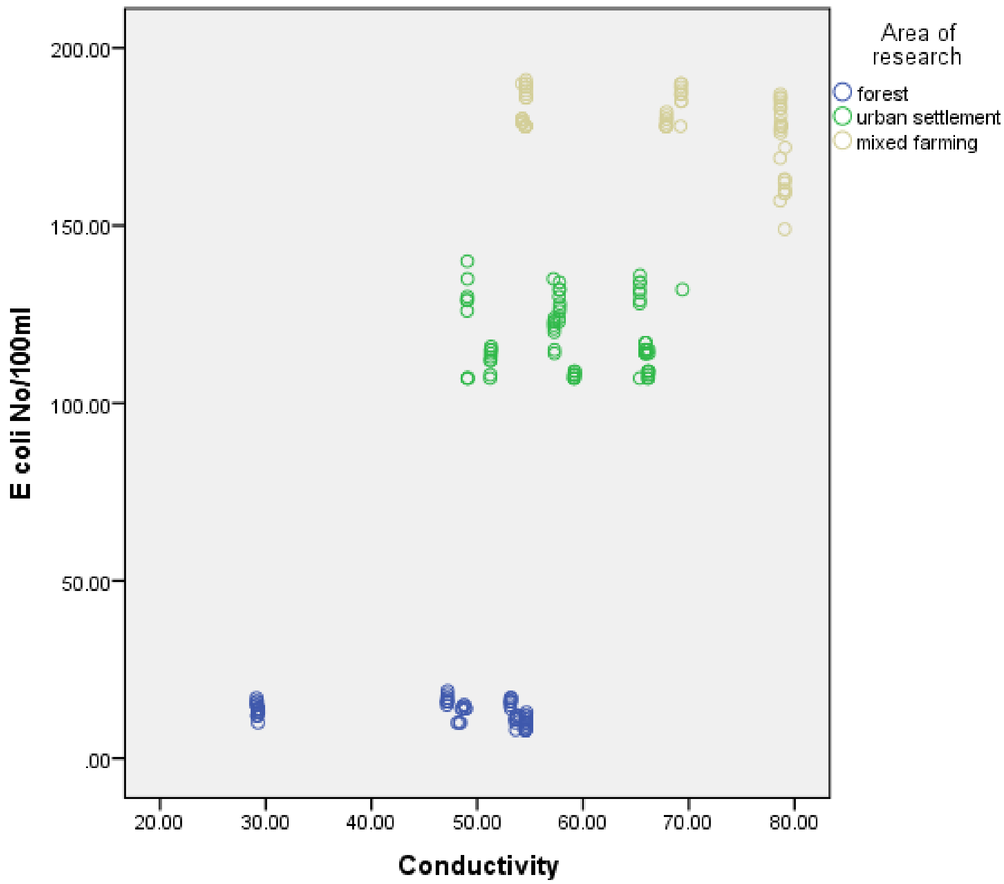

Figure 4.11: Mean Electrical Conductivity (NTU) versus E. coli concentration in River Shimiche with respect to land use gradients land use gradients.

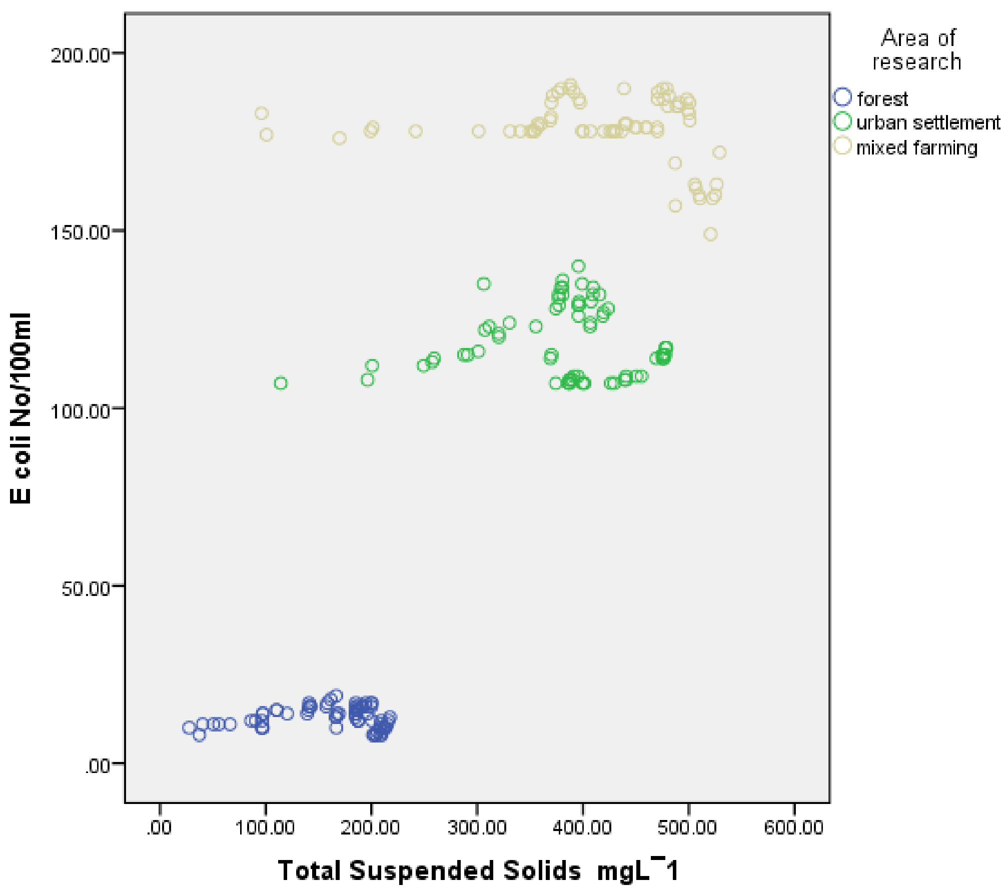

Figure 4.12: Mean TSS versus E. coli concentration in River Shimiche along land use gradients.

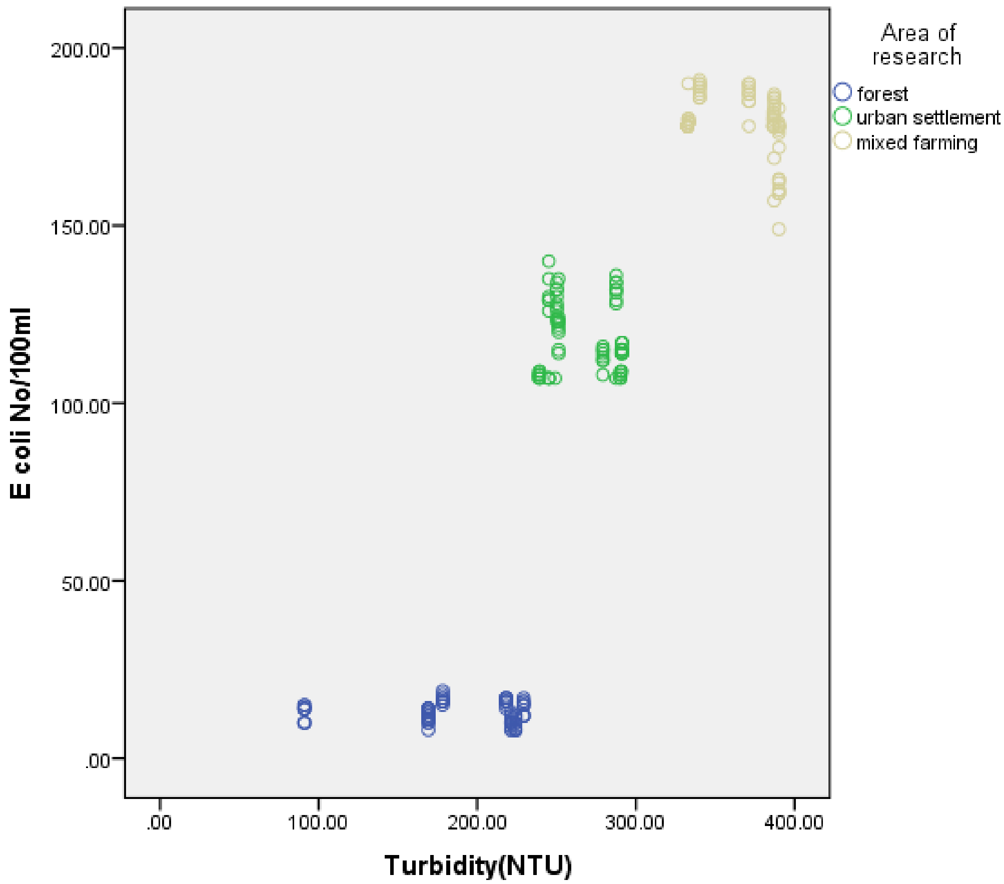

Figure 4.13: Mean Turbidity versus E. coli concentration along land use gradients.

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. DISCUSSION

All the water quality parameters (pH, TDS, EC, TSS, Turbidity, Temperature and E. coli concentration) showed similar patterns; low in the upstream increasing in the middle stream and highest downstream

Variations in physico-chemical parameters in River Shimiche along land use gradients

Temperature

The highest temperature value (24.71 °C) was recorded in the mixed agricultural areas and the lowest within the forest (21.08 °C) as shown in Table 4.1. Landuse practices had significant impact on temperature within the watershed (df=2; F=185.581, p=0.000). Least Significance Difference (LSD) analysis showed further that the means of temperature within the three land uses studied were significantly different ($p=0.000<0.05$).

Figure 4.1 shows that temperature in the three land uses was significantly different across the eight months. In all the sites, the temperature rapidly decreased during the months of March to April due to heavy rainfall and increased during the month of April to May which is a short rains season. In both urban settlement/mixed farming sites temperature sharply increased in the month of July/August because of intense human activities along the watershed while there was relatively lower temperatures in the forest area.

As water flows downstream, its temperature was found to change and this could be attributed to several factors that constitute the heat balance of water. The net rate of gain or loss of heat by a stream as it moves through a forest is the sum of net radiation, evaporation, convection, conduction, and advection (Nderitu, 2003). In the tropics, net solar radiation has major influence to a river water heat balance and is generally dominated by the amount of direct-beam solar radiation that reaches a stream's surface.

The low temperatures in River Shimiche recorded within the forested environment can be explained by the shadowing effects of the riparian vegetation cover on the river channel preventing direct heating of the water surface by the tropical sun. This concurs with Tabacchi et al., (1998), who reported that riparian vegetation have a shading effect on river channels hence reduces direct water heating by solar energy, providing a cooling by evapotranspiration from soil and water and that forests do this better because of the high leaf area index. The findings are also in line with the common observation that temperatures of rivers on spatial scale vary depending on vegetation cover.

It has often been demonstrated that removal of riparian vegetation alters stream temperature regimes. Where streamside vegetation has been removed, light availability and stream temperatures typically increase. Within peri-urban and mixed agricultural land uses, riparian vegetation has been destroyed greatly as a result of agricultural activities hence reducing shading effects, which according to Enanga et al. (2010) increases water temperature. The exposed water surface coupled with widened river channel downstream allows for maximum heating of the water surface by solar energy leading to higher water temperature. Swallow et al. (2002) also observed consistently lower temperature in beech and pine forest streams than in open scrubland and pastoral sites regardless of the season. Moreover, in the tropical streams on the northeast shores of Lake Tanganyika, it is reported that stream water temperature increases with increased vegetation loss as vegetation provides shade that keeps the water cool. Consequently, in places where the riparian vegetation have not been destroyed, plant leaves either absorb or scatter light energy leading to lowered water temperature.

pH

The highest pH (7.81) was recorded in the mixed agricultural areas and the lowest pH 6.44 was observed within the forest area (Table 4.1) Land use had significant impact on pH within the watershed (df=2; F=1850.695); p=0.000). LSD analysis showed further that the means of pH within the three land uses studied were significantly different ($p=0.000<0.05$).

Results in Figure 4.2 show that pH in the three land uses were significantly different across the eight months. In all the sites, the highest mean pH values occurred during the month of March-April and June-July both periods are characterized by high dilution rate due to heavy rainfall. A sharp drop in pH occurred in the forest area during the month of May-June because of reduced human activity in the forest.

The river stretch draining the forest recorded a relatively lower pH, tending towards acidity, probably because of minimal human disturbance and possible contribution of humic acids from exudes and leachates of plants and leaves or decomposing organic matter that leach into the river channel.

The pH increased within the urban settlement region probably because of the release of large amounts of wastes that are washed by storm waters into the river channel. The river is also joined by a number of canals draining agricultural subsistence farms and Shibale residential estates within the middle course. Some of these wastes are likely to contain soluble compounds that dissolve in water and dissociate producing hydroxyl ions that raise the pH.

Total Dissolved Solids (TDS)

The highest TDS of 50 mg l^{-1} was recorded in the mixed agricultural areas and the lowest 25.92 mg l^{-1} was observed within the area with forest (Figure 4.3). Land use had significant impact on TDS within the watershed (df=2; F=406.447); p=0.000). LSD analysis showed further that the means of TDS within the three land uses studied were significantly different ($p=0.000<0.05$). TDS in the three land use categories were significantly different across the eight months. TDS values were relatively low in the month of March-April due heavy rains hence more dilution.

TDS is a measurement of inorganic salts, organic matter and other dissolved materials in water (EPA, 1986). TDS is naturally present in water as a result of disillusion and weathering of rocks and soils or breakdown of organic matter, mining, some industrial and municipal effluents or various human activities.

It is also possible that some urban wastes from Shibale residential estates washed into the river by surface runoff increased TDS content and consequently salinity. According to Shivoga et al., (2005), TDS concentration in natural waters often result from industrial effluent, changes to the water balance (by limiting inflow, increased water use or increased precipitation), or by salt-water intrusion.

In River Shimiche, the section traversing mixed agricultural landuse has relatively steeper river banks compared to forested area and the lower reaches. These steep banks promote erosion and deposition of materials into the river. This agrees with Shivoga et al. (2005) who reported that the upper reaches of River Njoro are more susceptible to erosion because of the steepness of the banks and agricultural activities that extend to the banks. Farming activities that extend to the river bank result into massive destruction of riparian buffer zones rendering the banks unstable and more vulnerable to erosion and land sliding, increasing TDS. This concurs with Simiyu et al. (2006) who reported that most water quality parameters within the River Nzoia watershed were high because of poor agricultural practices that greatly affect TDS and EC.

Electrical Conductivity

The highest absolute value for EC was about 79 in the mixed agricultural areas in August and lowest was 30 in April and May in forested area as shown in Figure 4.4.

Land use had significant impact on Electrical Conductivity within the watershed (df=2; F=92.7); p=0.000). LSD analysis showed further that the means of Electrical conductivity within the three land uses studied were significantly different (p=0.000<0.05).

Figure 4.4 shows that Electrical conductivity in the three land uses was significantly different across the eight months. It decreased sharply during the month of March in all sites but varied in other months due to heavy rainfall. It was also noted that conductivity increased in the months of May –August for forest area, April – June for urban settlement and June – August for mixed agricultural areas. High conductance readings also came from industrial pollution or urban runoff, such as water flowing from streets, buildings and parking lots. Extended dry periods and low flow conditions also contribute to higher conductance. Organic compounds, such as oil, do not conduct electrical current very well, so an oil spill tends to lower the conductivity of the water. Temperature also affects conductivity; warm water has a higher conductivity.

The high mean of conductivity within mixed agricultural land use category could be attributed to the increase in autochthonous and allochthonous deposition of materials. Dissolved solids originate from dissolution and weathering of rocks and soils or breakdown of organic matter. Some of these sediments act as electrical conductors leading to higher conductivity downstream. Forest land use recorded the lowest conductivity because of very little disturbance in the watershed which leads to lower rates of deposition. Riparian vegetation including trees on the river banks trap and filter most of the sediments within the storm waters and further reduce soil erosion. Riparian vegetation are interfaces between terrestrial and aquatic ecosystems and present an important filter of sediments, nutrients, and Contaminants in water flowing from hill slopes to streams (Lamb, 1985). This observation agrees with Shivoga et al. (2005) that deforestation may result in multiple impacts in receiving rivers e.g., removal of riparian vegetation and establishment of agro-ecosystems leading to changes in water quality. Enanga et al. (2010) also reported that in the tropical streams on the northeast shores of Lake Tanganyika high conductivity within deforested regions could be attributed to erosion and leaching of micronutrients from the soil.

Total Suspended Solids (TSS)

The highest Total Suspended Solids (TSS) (415.14 mg l^{-1}) was recorded in the mixed agricultural areas and the lowest within the forest (161.5 mg l^{-1}) as shown in Figure 4.6. Land use had significant impact on Total suspended solids (TSS) within the watershed (df=2; F=243.55); p=0.000). LSD analysis showed further that the means of Total suspended solids (TSS) within the three land uses studied were significantly different ($p=0.000<0.05$)

Total Suspended Solids (TSS) concentration and turbidity both indicate the amount of solids suspended in the water, whether mineral e.g. soil particles or organic e.g. algae. However, the TSS test measures an actual weight of material per volume of water, while turbidity measures the amount of light scattered from sample (more suspended particles cause greater scattering). This difference becomes important when trying to calculate total quantities of material within or entering a stream. Such calculations are possible with TSS values but not with turbidity readings.

High concentrations of particulate matter can cause increased sedimentation and siltation in a stream, which in turn can ruin important habitat areas of fish and other aquatic life. Suspended particles also provide attachment places for other pollutants, such as metals and bacteria. High suspended solids or turbidity readings thus can be used as indicators of other potential pollutants in a watershed.

The high TSS within the peri-urban and mixed agricultural areas is likely because of storm waters from the highly populated Mumias municipality and agricultural farms flows into the river. This observation concurs with Ahearn et al. (2005) who found out that large storms are needed to increase TSS in a water system. This is coupled with the fact that there has been growth in world population in the 21^{st} century resulting into rapid growth of urban centers and environmental degradation. Farming activities within the mixed agricultural land use category, extending to river banks, and the heavy destruction of riparian vegetation allow for accelerated deposition of materials into the water channel, raising TSS levels. This finding agrees with that of Raburu et al. (2009) who reported that riparian vegetation cover influences turbidity and hence turbidity and TSS tend to be high in areas with farms cultivated up to the banks. Shivoga (2005) in a study in Njoro River watershed reported that increased human population density and inappropriate agricultural practices led to increased deposition of sediments in the river, hence high TSS levels.

Land use is probably the greatest factor influencing changes in TSS or turbidity in streams as shown by the results of this study. As the River Shimiche watershed develops downstream, there is an increase in perturbations (e.g. urbanization, human settlement and construction sites), a decrease in vegetation, and increases in the rate of runoff exacerbated by the heavy rains. These processes increase soil erosion, particulate matter, and nutrients, which in turn elevate the turbidity and TSS in the stream. For example, loss of vegetation due to urbanization exposes more soil to erosion, allowing more surface runoff to form, and consequently reduces the watershed's ability to filter runoff before it reaches the stream. This explains the high turbidity and TSS observed in the sections of the river within at the Mumias-Bungoma bridge area as shown in the Plate 4.1 below. The heavy rains and fast moving water observed downstream of River Shimiche are erosive. They collect and carry wastes and debris that make the stream to look muddy-brown and visibly undesirable for domestic consumption.

Turbidity

The highest Turbidity (366.37 NTU) was recorded in the mixed agricultural areas and the lowest within the forest (187.54 NTU) as shown in Table 4.1. Land use had significant impact on turbidity within the watershed (df=2; F=577.719; p=0.000). LSD analysis showed further that the means of turbidity within the three land uses studied were significantly different ($p=0.000<0.05$) Figure 4.7 above shows that the forest area experiences low turbidity which could be due to minimal human activities characterized by this land use category.

Relationship between E. coli concentration and physico-chemical parameters

Values of E. coli concentration were low upstream and showed increasing but fluctuating trends downstream with the highest values in the middle stream with influence from mixed farming activities and urban settlements.

The highest E. coli concentration (178.97/100 ml) was recorded in the mixed agricultural areas and the lowest within the forest (12.97) as shown in Figure 4.5. Land use had significant impact on E. coli within the watershed (df=2; F=8172.148; p=0.000). LSD

The weak correlations between the concentration of E. coli and all the physico-chemical parameters measured in this study (Table 4.2) could indicate that levels of E. coli are also partly determined by other factors. Higher values of E. coli were observed in the urban settlement and mixed agricultural areas associated with high human populations and livestock keeping respectively, which may be contributors to feacal wastes that support high growth and multiplication of the bacterium.

Concentrations of E. coli in the three land uses were significantly different along the land- use gradient (Figure 4.5). The prevailing patterns of concentration of E. coli was similar for the months of April to July in all the three sites. This was attributed to presence of rainfall, as was also suggested by Ahearn et al. (2005) who observed that rainfall and its associated storm water runoff are associated with transport of many pollutants into beach water. Fecal material, from a variety of animals (humans, pets, livestock, and wildlife), can wash into beach water following rainfall and result in microbial contamination of the riparian area and water. Many locales around the world issue pre-emptive beach closures associated with rainfall.

It has been traditionally assumed that E. coli shows natural declines in open environments. However, forming an environmental reservoir of a given size in different conditions, the bacterium can cause risks to human health. The factors that determine the rate of survival of particular E. coli strains, and thus the risks, are not (yet) easily predictable, and our capability to understand the effects of the secondary habitat (especially soil and water resources) on E. coli behaviour will be paramount to our abilities to manage the organism from both environmental and public health perspectives.

It is known that the combination of abiotic (availability of energy and nutrient sources, pH, moisture and temperature) as well as biotic (indigenous microflora, including protozoa) factors sets the conditions under which E. coli needs to survive. Extreme or fluctuating values of each parameter pose varying levels of stress to the cells, leading to different survival times. Hence, these factors per se will determine E. coli survivability in natural systems by their direct effects on the exposed cells. Given the complexity and heterogeneity of most natural environments, it is intrinsically difficult to predict the fate of E. coli populations facing the combined environmental effects. Recent studies on the effect of microbial diversity and community structure on the persistence of introduced E. coli O157:H7 in soil have nevertheless shown the emergence of relationships between the microbial diversity of the system, abiotic factors and the pathogen's invisibility.

5.2 CONCLUSIONS

Based on the findings of this study, the following conclusions can be made:

There are spatial variations in physicochemical variables from upstream to downstream in Shimiche watershed, corresponding with changes in riparian land uses. Within the watershed, forest land use showed lower values of all physicochemical conditions (water temperature, pH, EC, TSS), while peri-urban and mixed agricultural land use zones showed higher values of physical-chemical variables.

There was a general increase in the loading levels based on all the parameters under the study. Findings indicated that mean values for these parameters; were all above both NEMA and WHO recommended standards for effluent discharge into the environment Waste water through the meander fields is discharged at relatively high velocity into the river and no pollution parameter loading is monitored.

Low E. coli concentrations results upstream indicate that the upper part of River Shimiche traversing through the forest and sugarcane is less polluted but the sections of the river downstream are increasingly contaminated and show the risk of being heavily polluted if remedial actions are not taken to check the current trend.

Rainfall and its associated storm water runoff have been associated with transport of many pollutants into the River water. Fecal material, from a variety of animals (humans, pets, livestock, and wildlife), can wash into River water following rainfall and result in microbial contamination of the River. This study suggests that River Shimiche ecosystem needs to be examined on its own with regard to rain impacts on E. coli concentrations in the River water.

5.3. RECOMMENDATIONS

Based on the findings there is need for the stakeholders to embrace cleaner production technologies to ensure an improvement of in-plant pollution prevention measures to minimize the volume and pollution loading in the wastewater before discharge into River Shimiche

Secondly, the water management authorities should consider carrying out periodic "waste audits", for water use, to identify the level of waste discharge and also to improve its treatment process, that which will also cater for River Shimiche as it is with River Nzoia and observe consistency of the process. There is need to contain waste water flows that by-pass the Mumias sugar company treatment plant to lower impacts of pollution on the River Shimiche water.

Third, there is need for the water management authorities to incorporate wastewater by-pass channel in the treatment system. Lastly, the government should ensure concerned companies comply with environmental standards, through enforcement of regulations and legislation governing the environment

In terms of recommendation for further research, there is need for continuous monitoring of River Shimiche water quality and quantity throughout the year to cover both wet and dry seasons. This will help generate data to explain relationships and trends between pollution loads and their environmental impacts in different seasons. A wide ranging and periodic analysis of pollutants such as; heavy metals, biological, agrochemicals, petroleum hydrocarbons is required within the context of effective and wide sample coverage of the Shimiche River. There is need for a health assessment of impact on the riparian community that makes use of water from River Shimiche, through experiments examining agricultural yields and chemical make-up of produce.

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APPENDICES

Appendix I: Photographs showing some of the equipment used in laboratory analyses at the MSC Water Quality Laboratory.

Caption: Electronic balances

Caption: pH meter and Turbidimeter.