EFFECTS OF HUMAN ACTIVITIES ON WATER QUALITY AND MACROINVERTEBRATES ALONG NYANGORES STREAM, MARA RIVER BASIN, KENYA

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

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DEDICATION

To my late mum Alice Gesare, from you I acquire the strength, hope and fighting spirit in life. To my dear son Alvan Ondieki “*your innocence, cry and happiness gave me hope, you are my cheerleader”*. To my dear husband Hezbon Opiti for your prayers, moral and financial support, patience, understanding, encouragement and love. Thank you for believing in me.

ABSTRACT

The study investigated the effects of human activities on water quality and macroinvertebrates along the Nyangores stream in the upper catchment of Mara River Basin. Seven sampling sites were chosen to correspond to different human activities along the stream. Physico-chemical water quality parameters were measured *in situ* using measuring probes and nutrients determined calorimetrically using standard methods. Habitat quality was determined using the stream visual assessment protocol. Total coliforms and *Escherichia coli* were determined using the membrane filtration technique (MFT). Macroinvertebrate samples were collected from February 2012 to July 2012 using a kick net of 500µm mesh size. The relationship between community attributes and physicochemical parameters was determined using Pearson correlation. Canonical correspondence analysis (CCA) was used to describe the relationship between macroinvertebrate community assemblage and the physico-chemical parameters. ANOVA was used to test for variations in physico-chemical parameters and post hoc Duncan's Multiple Test was used to compare means among stations and sampling period. Results indicated an increase of nutrients and coliform bacteria as human activities intensified. Significant ($p<0.05$) spatial variations in conductivity, pH, TSS, discharge, NH_4, NO_3 and NO_2 and temporal variations in discharge and TSS were also recorded. There were significant relationships between nutrients, discharge and coliform bacteria. A total of 42 macroinvertebrate genera were encountered with EPT dominating the upstream stations Ephemeroptera taxa dominated followed by Diptera which increased downstream. Most physicochemical parameters determined the structure of macroinvertebrates in the stream. The variation of macroinvertebrates among sites was influenced by temperature, conductivity, nitrites and biological oxygen demand. This results show that water quality and structure of macroinvertebrates is influenced by human activities in the Mara River basin. The author recommends continuous monitoring using macroinvertebrates to assess water quality of the stream. The riparian land use should be controlled and buffer zones established so as to improve habitat quality of the stream.

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LIST OF ACRONYMS AND ABBREVIATIONS

a.s.l	Above sea level
APHA	American Public Health Association
BOD	Biological Oxygen Demand
CFU	Colony Forming Units
DO	Dissolved Oxygen
EC	*Escherichia coli*
EPT	Ephemeroptera, Plecoptera and Trichoptera groups together
IUCN	International Union for Conservation of Nature
Log	Logarithm
MFT	Membrane Filtration Technique
NBS	National Bureau of Statistics
SE	Standard Error
Sp.	Species
SRP	Soluble Reactive Phosphorus
SVAP	Stream Visual Assessment Protocol
TC	Total coliforms
TP	Total Phosphorus
TSS	Total Suspended Solids
UN	United Nations
UNICEF	United Nations International Children’s Emergency Fund
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

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CHAPTER ONE

INTRODUCTION

1.0 Background of Study

Freshwater ecosystems play a significant role to both man and the environment. These roles range from domestic and industrial use, irrigation, recreational activities, transport, energy production and a habitat to about 6% of the world's total known species, 40% of global fish species and 25% of all vertebrate species (Dudgeon *et al*., 2006). Rivers and streams are considered biodiversity hotspots since they maintain and support both macro and micro ecosystems hence considered to be biodiversity hotspots. Their distribution and availability influences the social, political and economic development of mankind (Turner *et al*., 2003), since most productive agricultural lands in the world and most urban centers are found near rivers. Despite these roles, the exponential growth of socio-economic and industrial activities in has resulted to degradation of rivers affecting their ecosystem structure and function at an alarming rate (Roy *et al*., 2003).

Many freshwater systems in the world have been affected by human activities resulting in pollution and scarcity of water resources (Arnell, 2004). The systems have been impacted by various physical, chemical and biological pressures. The nature of human disturbance varies in catchments influenced by different land use patterns (Carpenter *et al.*, 2011). For example, agricultural land use may be associated with increased non-point pollutants combined with more erratic runoff as a result of limited interactions between stream channels and their land edges caused by removal of riparian vegetation (Allan, 2004). Land use changes influence the natural functions of streams by impacting on water quality and altering water flow. Watershed land use impacts water quality through non-point sources of pollution. These sources are major contributors of contaminants to both surface and ground water that are difficult to regulate (Salajegheh *et al*., 2011). The increasing and dynamic effects of land use activities can adversely affect aquatic ecosystems (Allan, 2004). The morphology of the stream channel and the dynamics of a watershed are influenced by changes in land use. The chemical properties of water such as acidity, turbidity and dissolved constituents such as heavy metals and nutrients are also affected by land use changes in a watershed. Changes in water quantity and quality as a result of land use changes can adversely affect aquatic organisms by exerting pressure on individual species and communities and may to a decrease in biodiversity (Masese *et al*., 2009; Salajegheh *et al*., 2011).

Human activities such as urbanization, industrialization, expansion and intensification of agriculture and abstraction of freshwater in Lake Victoria basin have altered the ecological integrity of aquatic ecosystems in the basin (Masese and McClain, 2012). For example, farming activities ranging from small scale labour intensive to mechanized farming, which requires inputs such as pesticides and herbicides have increased chemical pollution in the Lake (Odada *et al*., 2006). Increased levels of nutrients from the catchment have also resulted to increased production of phytoplankton biomass in river mouths and offshore areas of the Lake (Sitoki *et al*., 2010; Masese and McClain, 2012). The Lake is now affected by high phosphorus and sediment loads from the catchment, fluctuating water levels and persistent invasion of water hyacinth *Eichhonia crassipes* (Offula *et al*., 2010; Masese and McClain, 2012). The increased pollution in the Lake Victoria basin has led to depletion of oxygen levels in water and reduction in fish species (Njiru *et al*., 2008) and increased outbreak of diseases which has a negative impact on human health (Odada *et al*., 2006).

The Mara River is one of the ten drainage basins that feed Lake Victoria. It is a lifeline to the Maasai Mara and Serengeti Game reserves which host the most diverse combination of grazing mammals in the world (Mango, 2010). The river plays an important ecological role during the annual wild beast (*Connochaetas taurinus*) migration between the two parks. The river is also a lifeline to the local community who depend on it directly or indirectly, since it is a major tourist site to both Kenya and Tanzania (Mati *et al*., 2005; Mango, 2010). Despite this, its usefulness may not last long with the current accelerated loss of forest cover in the upper catchments, land degradation, waste disposal into the river and over-abstraction of water which poses a threat to the quantity and quality of water (Mati *et al.*, 2005).

Mara River traverses vast areas of varied human activities ranging from destruction of forests in the upper reaches, agriculture and pastoralism in the middle and lower reaches (IUCN, 2000; Machiwa, 2002; Mango, 2010). The river supports livelihoods of people in the lower reaches by providing aquatic resources such as fish. However, rapid land use change in the upper reaches has modified the biophysical and hydrological processes resulting in degradation of water quality and flooding in the lower reaches (Machiwa, 2002. These effects are likely to be exacerbated by climate change influences which will greatly affect the filtering effect of the rich wetland ecosystems in the lower reaches of Mara River (Makota, 2002).

This study therefore will focus on water quality of Nyangores stream, Mara River Basin and will provide data that can be used to design measures for mitigating and monitoring environmental changes that can arise from human activities within the basin.

1.1 Problem Statement

The water quality of Nyangores stream, a tributary of the Mara River has continued to deteriorate due to increased anthropogenic activities along it. Land use changes in the upper reaches have resulted in the conversion of natural land to agriculture (Mati *et al*., 2005; Mango, 2010). These changes together with discharge of partially or untreated wastewater and water abstractions affect the quality and quantity of water which in turn affects aquatic biodiversity. The community in the Mara River basin have also been affected by waterborne diseases as a result of toxic pollutants and high nutrient levels in the water (GLOWS, 2007). This environmental problem is left unabated hence affects the downstream communities that depend on the same water for goods and services. There is also no existing monitoring protocol and inadequate data on which to base management measures.

1.2 Justification

The Mara River plays an important ecological role during the annual wild beast migration between the Mara and Serengeti game reserves. The two parks are world-famous for their rich wildlife and natural beauty making them among the most vibrant attractions in the region. Besides this the river provides a suite of benefits to the riparian communities (Mati *et al.*, 2005) by supporting the livelihoods of pastoral people, farmers, fishers, some hunter-gatherers in the forested catchment areas, and other people who directly or indirectly rely on these resources. The use of forest resources remains an important source of livelihood to the people in the highlands, while fishing is more important in areas around Lake Victoria. The Serengeti game reserve is a world heritage site and a biosphere reserve and therefore of global conservation significance (Mati *et al.*, 2005). The Mara-Serengeti area is surrounded by nomadic pastoralists, who sell traditional artefacts, while tourist related services provide important additional income for local communities (Thompson, 2002; Mati *et al.*, 2005).

The Mara basin has undergone large changes in land use resulting from destruction of the Mau forest in the upper reaches from 752 km^2 (1973) to 650 km^2 (1985) and 493 km^2 (2000) (Gereta *et al.,* 2002). Anthropogenic activities like increased water abstraction for irrigation purposes coupled with unsustainable agricultural practices has resulted to reduced water quantity and increased water pollution (Hashimoto, 2008). There is increased pressure in the basin during the dry season since it is the only perennial water source that supports water supply needs of humans and over 1.6 million wildlife immigrants in the Maasai Mara (UNEP, 2009). These changes together with pollution from urban effluents, soil erosion resulting from unsustainable agricultural practices, increasing large scale irrigation practices and increased abstraction of water due to increased population growth, presents serious uncertainties for the water resources in terms of quantity and quality (Mango, 2010).

The Mara River basin is shared between Kenya and Tanzania and is home to 1.1 million people (775,000 live in Kenya and 325,000 in Tanzania); the community is mostly engaged in agricultural activities. It faces serious environmental and water resources problems, primarily from settlement and intensive cultivation (Mati *et al.*, 2005). This leads to loss of vegetation cover, widespread soil erosion, decreased soil fertility in the upper catchment and increased sedimentation and water pollution downstream. Conflicts between residents living downstream and upstream can arise on the management of the transboundary resource.

There is therefore need to manage the water quality and quantity of the Nyangores stream to minimize changes in habitat integrity of this ecosystem on which many organisms and human beings depend on. Loss of both aquatic and terrestrial biodiversity in the Mara system will be disastrous to the economy of Kenya, Tanzania and the world at large. Findings of this study can be used to develop a harmonized framework for the management of the Mara River Basin water resources.

1.3 Research Objectives

The overall objective of the study was to assess the effects of human activities on water quality and macroinvertebrates along Nyangores stream, Mara River Basin, Kenya

1.3.1 Specific Objectives

The specific objectives for the study include;

1. To determine the spatial-temporal changes in physico-chemical parameters along Nyangores stream.
2. To establish the changes in the abundance of coliform bacteria in relation to wastewater discharges along Nyangores stream.

3. To determine the effects of human activities on the distribution, composition, diversity and abundance of benthic macroinvertebrates along Nyangores stream.
4. To investigate the relationship between macroinvertebrates structure and water quality parameters along Nyangores stream.

1.4 Research Hypotheses

H_0; Human activities along Nyangores stream have no influence on the levels of nutrients in the water downstream.

H_0; Non-point and point sources of pollution in Nyangores stream have no influence on the abundance of coliforms downstream.

H_0; Human activities along Nyangores stream do not affect the distribution, composition and abundance of benthic macroinvertebrates.

H_0; There is no relationship between macroinvertebrates structure and the water quality parameters along Nyangores stream.

CHAPTER TWO

LITERATURE REVIEW

2.0 Spatial-temporal variations in water quality

Rivers and streams are very important ecosystems for socioeconomic development and sustainability of environment since they provide a variety of valuable functions to the environment, national economies and the communities that depend on them (Mbuligwe and Kaseva, 2005; Yillia, 2008). However, the systems are unable to provide basic functions to the rapidly growing population because they are threatened by pollution from various human activities (Raburu, 2003; Yillia, 2008; Flores *et al*., 2012). For example, agricultural land use, commercial establishments and mining introduce soil, fertilizers, faecal matter, organic matter, toxic metals, pesticides and solid wastes, (Dabrowski *et al*., 2002; Mbuligwe and Kaseva, 2005; Yillia *et al*., 2007) whereas industries discharge heavy metals, organochlorides, sulphates and carbonates (Mwannuzi, 2000; Fatoki *et al*., 2001) to the aquatic environment.

Assessment of spatio-temporal variations in water quality of rivers at a watershed level has been recognized as a significant aspect of physically or chemically characterizing aquatic environment due to seasonality and regionality of riverine ecosystems (Caccia & Boyer, 2005). Research on spatio-temporal variations of water quality in riverine ecosystems has shown that pollution is highly dependent on land use patterns and the influence from watershed runoff (Caccia & Boyer, 2005). Many studies on the effects of land use on aquatic ecosystems in Africa have shown that different land use types and human activities such as industrialization and urban development have an influence on levels of pollution in streams (Dabrowski *et al*., 2002; Mokaya *et al*., 2004; Yillia, 2008; Masese & McClain, 2012). Some studies have related high organic matter loading and faecal matter in streams that drain urban catchments to urban storm runoff and inadequate sanitation facilities (Byamukama *et al*., 2005; Mbuligwe and Kaseva, 2005). In addition, most studies have identified the sources of pollution and reported that spatial-temporal variations in water quality can be influenced by natural processes and anthropogenic activities (Kannel *et al*., 2008).

2.1 Effects of human activities on stream water quality

Anthropogenic activities such as conversion of land from natural and low intensity uses to urban, industrial and high intensity agricultural uses (Larson, 2002; UN, 2002) due to increasing population (UN, 2003) and high consumption rates influence the quality of water, flow regime (Doylep, 2005) and affect biodiversity (Roy *et al*., 2003; Doylep, 2005) in catchment areas (Buck *et al.*, 2004). For instance, urban and rural land use changes the stream flow regime (Uriate *et al*., 2011) and reduces the quality of water (Paul and Meger, 2001; Uriate *et al*., 2011). Forest clearing to create land for agriculture increases the mean stream flows mainly due to reductions in transpiration (Flores and Zafaralla, 2012) while urbanization has been found to cause greater changes in flow regimes. While in urban areas, roofs, paving and impermeable barriers prevent filtering of rainwater into the soil thus increases runoff volumes (Allan, 2004). These high flows cause erosion of stream bed resulting in destruction of habitat areas for biota, enlarges the stream’s channel and increases turbidity as the eroded sediment travels through the stream (Pizzuto *et al*., 2000; Allan, 2004).

Agriculture and urban land uses alter the quality of water by polluting rivers with sediments, faecal bacteria, nutrients and other contaminants. Land use is a critical characteristic because it leads to erosion and hence geomorphologic change in streams which leads to a possible greater chemical contamination and increase in turbidity (Ndaruga *et al*., 2004). The transformation from forest to cultivated areas give rise to increased levels of temperature, conductivity, total suspended and dissolved solids (Kibichii *et al.,* 2007, Kasangaki *et al*., 2008). Presence of livestock in these areas results to increased nutrients such as ammonia and nitrite in rivers (Kibichii *et al.,* 2007; Kasangaki *et al*., 2008; Masese *et al*.,2009). Studies have shown that phosphorus and nitrogen in streams can be influenced by fertilizers and animal wastes and their concentration in streams have been correlated to the amount of fertilizers applied (Kibichii *et al*., 2007). Stream habitat and biota can also be affected by activities such as animal watering, bathing and laundry washing (Mathooko, 2001; Malmsqvist & Rundle, 2002).

2.1.2 Mara River Basin

The Mara River Basin consists of mainly closed and open forests, tea plantations in the upper catchment. The lower catchment is characterised by agricultural land, shrub lands and grasslands used for livestock and game grazing, savannah grasslands which comprise shrub grasslands and wetland (Mango, 2010). Since 1970 there has been conversion of forest land in the basin into agricultural use. For instance, the land surrounding the Maasai Mara National Reserve has been converted to large scale wheat farming (Serneels *et al*., 2001) and in Loita plains wheat farming has increased by an area of 44,000 ha from 1975 to 1995. Rangeland modification and increase in mechanized agriculture in the basin is driven by land suitability and economic factors while smallholder agriculture is driven by changes in demography which is caused by migration and population growth within the basin (GLOWS, 2007; Mango, 2010). The land use change in the upper part of the basin is as a result of smallholder agriculture while that of the lower basin is mainly due to mechanized agriculture in form of wheat and maize farming (Mango, 2010).

Land use changes in the Mara between 1973- 2000 indicated a decrease in closed forests by 31% (Mati *et al.*, 2005) due to clearing of forests for timber, charcoal burning, settlement and tea plantation (which increased by 82%). Rangeland which includes shrub land, grassland and savannah which was mostly used for livestock and wildlife grazing decreased by 35% due to an expansion of agriculture (which increased by 55%). Wetlands in the lower basin showed a significant increase attributed to build up of sediments in the mouth of the river resulting from erosion in the upstream and erratic river flows (Mango, 2010). This has been caused by change in the vegetation cover in terms of deforestation, conversion of rangelands to agriculture and poor soil and water conservation practices within the basin (Mati *et al*., 2005).

Pastoralists in the Mara Basin are also finding it difficult to support their families since the area is highly vulnerable to drought because more land is being opened for agriculture. For instance, the pastoralists lost 35% of their cattle due to drought in the year 2000 (Ottichilo *et al.*, 2001; Reid *et al.*, 2003). The locally driven forest degradation has increased vulnerability of thousands of families who have no alternative income (Thompson, 2002). Land use change has made pastoral people in the Mara ecosystem to have less livestock per person than they did for the past 20 years and about half of them survive today on an income of less than 1 USD per day per person. Overgrazing on the river banks has also led to increased erosion and sedimentation (Obando *et al.*, 2006). It is clear that the Mara will support less wildlife and poorer pastoral people 20 years from now if the trend in land use changes continues this way (Reid *et al.*, 2003).

2.2. Changes in Coliform bacteria in relation to pollution along streams

Millions of lives are claimed every year in developing countries as a result of waterborne diseases such as cholera, typhoid and dysentery due to lack of safe drinking water and adequate sanitation (WHO, 2005). According to (UNICEF, 2006) approximately 1 billion people lack access to safe drinking water while 2.6 billion lack appropriate sanitation. It has been estimated that 80 percent of diseases and 30 percent of deaths occur due to consumption of contaminated water in developing countries (WHO, 2005).

Pollution from faecal matter may present significant public health risks with the risk level largely depending on the level of contamination and origin (Byamukama *et al.*, 2005). For instance, contamination from human excreta has a greater risk to human health since it is likely to contain human-specific enteric pathogens (Moe and Rheingans, 2006). Researchers have been concerned about increase of waterborne diseases in Africa; this has resulted into a focused attention on microbiological water quality in order to minimize health risk (Moe and Rheingans, 2006). This has been done through regular monitoring of indicator parameters in aquatic ecosystems (Kong *et al*., 2002; McLellan and Salmore, 2003; Shah *et al*., 2007; Yillia *et al*., 2007). These studies are also useful in determining the course of action that may be needed to solve the problem (Graves *et al.*, 2007). Microbiological water quality monitoring uses indicator bacteria such as total coliforms and *Escherichia coli (E. coli)* to determine the level of bacterial contamination.

Faecal pollution of water is contamination of water with disease causing organisms that may inhabit the gastrointestinal tract of mammals, but the human faecal sources are relevant sources of human ill health (Ashbolt, 2004). Monitoring of microbial water quality is done using cultures to selectively promote the growth of faecal bacteria indicators. World health organization (WHO) has strongly promoted the use of *E. coli* as the principal faecal indicator for waters since it is easy to analyze and is often present in high numbers than other pathogens. The advent of selective and more reliable methods makes it easier to measure the faecal indicator; it is also used by regulations world over to set bacterial water quality standards (Simpson *et al*., 2002). The indicator seems to be more sensitive because it is found in large numbers in human gut (Edberg *et al*., 2000) than other thermo-tolerant bacteria.

The growth and abundance of bacteria in water can be influenced by temperature, light, salinity, rainfall, predation, available nutrients and environmental pollution (Lobitz *et a*l., 2000; Solo-Gabriele *et al*., 2000). Solo-Gabriele *et al*., (2000) demonstrated that the cyclic variations in *E. coli* counts in water could also be ascribed to runoff due to storms. Soil and runoff after rains may have an influence on bacterial numbers detected. For instance, when sediments are disturbed during in-stream activities such as livestock watering, there is an increase in bacteria levels (Yillia, 2008) due to re-suspension of bacteria from the sediments. The bacteria can also be influenced by velocity and turbidity of surface water. Bacteria are more evenly distributed over a great distance when the velocity is high. For instance, when the velocity of water is low and temperature high there are higher densities of total bacteria (Jamieson *et al.,* 2003). Higher turbidity of surface water has been found to correlate with higher numbers of faecal coliform bacteria (Madge & Jensen 2006); this is as a result of faecal bacteria release from sediments into streams during high or low flows (Jamieson *et al.*, 2003).

Most people in Kenya lack access to potable clean water hence rely on polluted surface water (Yillia, 2008). During the dry period, people make frequent visits to rivers to either abstract water for domestic needs, water livestock, bath, swim and wash vehicles and clothes because other sources of water such as rainwater or pipe water are lacking (Mathooko, 2001; Yillia *et al.*, 2007). These activities may influence microbial water quality in shallow streams due to faecal matter littering in the surrounding area (Yillia, 2008). Improper disposal of human and livestock wastes are routes through which faecal matter enter the aquatic ecosystems. Faecal matter introduces pathogens, organic matter and nutrients which degrades the quality of water (Langergraber and Muellergger, 2005).

Waterborne diseases were not a problem in the Mara river basin in the past (GLOWS, 2007). However, an emergence of these diseases in the basin has been reported in the recent past (GLOWS, 2007). This was linked to effluent discharge from untreated or partially treated wastewaters from settlements and tourist hotels. Increased nutrient loads in form of surface runoff from the catchments which are rich in fertilizers, pesticides and herbicides were also reported to cause waterborne diseases in the region. The situation has been exacerbated by an ever increasing population growth rate in both the rural and urban areas. For instance, the volume of wastes in the Mara River is reported to have increased as a result of high population growth rate of 7% (Hoffman, 2007).

2.3. Impact of human activities on macroinvertebrate diversity, composition and abundance

Abundance and diversity of macroinvertebrate community can be used to assess ecological changes and impacts that might occur due to changes in land use (Roy *et al*., 2001). Studies have recognized a significant correlation between different human activities and macroinvertebrate communities (Raburu, 2003; Masese *et al*., 2009; Mango, 2010 Aura, 2011). The studies show the total number of taxa and percentage of groups like Ephemeroptera, Plecoptera and Trichoptera (EPT) decreasing and Oligochaeta and Diptera increasing as the quality of water decreases with increase in pollution (Masese *et al*., 2009). Human activities that affect habitat and water quality at the catchment level often have a direct influence on the distribution and composition of macroinvertebrates (Weigel *et al*., 2002). For instance, tolerant macroinvertebrates dominate degraded areas while those that show limited distribution occur commonly in least degraded areas and are considered as intolerant taxa (Roy *et al*., 2001). Various studies conducted in Kenya have utilized macroinvertebrates as bio-indicators of water quality in riverine ecosystems (Raburu, 2003; Masese *et al*., 2009; Aura *et al*., 2010).Such studies have linked land use activities along a gradient of anthropogenic influences with the occurrence of macroinvertebrates in such habitats, as a better means of ascertaining the degree of ecosystem degradation

Longitudinal changes in human activities have been found to influence macroinvertebrate distributions in riverine ecosystems (Masese *et al*., 2009; Aura *et al*., 2010). Community in the upper zone depends on allochthonous matter from forests as source of food, and its decline downstream has been attributed to destruction of riparian vegetation along the river. This results to a reduction in diversity, species richness and evenness of macroinvertebrates. A study carried out in Uganda by Kasangaki *et al*., (2008) revealed that agricultural areas downstream of deforested areas were dominated by tolerant macroinvertebrate taxa. In a stream flowing through human settlements, agricultural and urbanized areas, chironomids and oligochaetes were positively correlated with poor water quality while Ephemeroptera, Plecoptera and Trichoptera displayed a negative response that is, they were negatively impacted by such conditions (Ndaruga *et al*., 2004). Similar studies (Masese *et al.,* 2009; Kasangaki *et al*, 2008; Aura *et al*., 2010; Maldonaldo, 2010) reported high abundance of tolerant taxa in agricultural areas were dominated by tolerant macroinvertebrate taxa. Headwater stations were dominated by taxa associated with pristine waters and pollution-sensitive macroinvertebrates such as Ephemeroptera, Plecoptera and Trichoptera, which declined downstream.

2.4 Macroinvertebrates and water quality

Physical characteristics of riverine ecosystems and human alteration of these characteristics are among the factors that influence freshwater organisms such as fish and macroinvertebrates in terms of their diversity, abundance and stream productivity (Bögi *et al.*, 2003). These characteristics include water velocity, turbidity, river depth and width. Aquatic organisms are known to generally select physical conditions that promote growth, survival and reproduction. The organisms are commonly employed as biological indicators since they are sensitive to habitat destruction, altered physical and chemical properties of their environment (Carpenter *et al*., 2011).

Macroinvertebrates have been used since the beginning of the last century as an important bio-monitoring tool to evaluate the quality of water and levels of pollution in rivers. Benthic macroinvertebrates are among the most used bio-indicators due to their sensitivity to environmental changes and provide scientifically defensible evidence of environmental status (Klemm *et al*., 2003). Bio-indicators are living organisms which are sensitive to environmental disturbances and stressors hence provide a response that can explain ecological processes (Alam, 2008). Macroinvertebrate characteristics such as diversity and richness are often used as indicators of the degree of pollution of water bodies to supplement and deepen the meanings of physico-chemical information (Flores and Zafaralla, 2012).

Benthic macroinvertebrates depend on the quality of water for their survival. For instance temperature plays a significant role in their growth, ecology, life cycles and some behavioural and morphological characteristics (Maldonado, 2010). Dissolved oxygen is also important for the survival of aquatic organisms since low oxygen levels can heavily affect some species like Plecoptera and some Ephemeroptera. However, some taxa such as Diptera and Oligochaeta are tolerant to oxygen deficiency (Maldonado, 2010).

Some research studies have been done in the Mara Basin as a whole but there has been no focused attention on water quality and macroinvertebrates in head water streams like the Nyangores stream. Water quality and biodiversity of riverine ecosystems depend on the functions provided by headwater streams. The headwater streams maintain discharge patterns, regulate nutrient and sediments, decomposition of organic material and supports biodiversity with habitat niches (Lowe and Likens, 2005). Relatively few research studies in the Mara River Basin have focused on coliform bacteria, while other studies were inconclusive due to excessive culture growth (McCartney, 2010). For instance, no proper growth and colony formation were found, hence need for this study to give the status of coliform bacteria in the Nyangores stream. Therefore, this study seeks to determine the effects of human activities on water quality, macroinvertebrates and coliform bacteria along Nyangores stream. Limitations of the study include very few literature that focus on the Nyangores stream. There is also inadequate data in the Mara River Basin resulting in uncertainty thus no appropriate strategies for management of this river basin can be formulated. This study was therefore set out to provide data to manage the Basin.

CHAPTER THREE

MATERIALS AND METHODS

3.0. Study Area

The research was conducted in Nyangores River, a tributary in the upper catchment of the transboundary Mara River basin between Tanzania and Kenya (Fig. 1). The Nyangores River is one of the two permanent tributaries of the Mara River, the other being the Amala River. These two rivers are very important for maintaining base flows in the Mara River mainstream and are the only source of water for the Maasai Mara Game Reserve (Kenya) and the Serengeti National Park (Tanzania). The Nyangores River is located between longitudes 33º 47’ E and 35º 47’ E and latitudes 0º 28’ S and 1º 52’ S. It covers an area of 696km^2 and runs approximately 94km before joining Amala River at Kaboson to form the main Mara River (Mutie *et al.*, 2006). The area experiences two rainy seasons with the long rains starting in mid-March to June with a peak in April, while short rains occur between September and December (Kairu, 2008). The altitudes range between 2951m around the Mau Escarpment to 1706m downstream. The major land use in the Nyangores River Basin includes closed forest, and tea in the upper slopes, and agricultural land. Nyangores sub catchment covers Bomet and Nakuru counties with a total population of 225,458 residents. Agriculture is the dominant economic activity to the majority of the population and about 62% of the agricultural area is occupied by small scale farmers (Mutie *et al.*, 2006).

3.1 Sampling stations

Sampling stations in this study were selected longitudinally downstream based on different forms of degradation and prevailing human activities within the Nyangores stream taking into account accessibility of the stations.

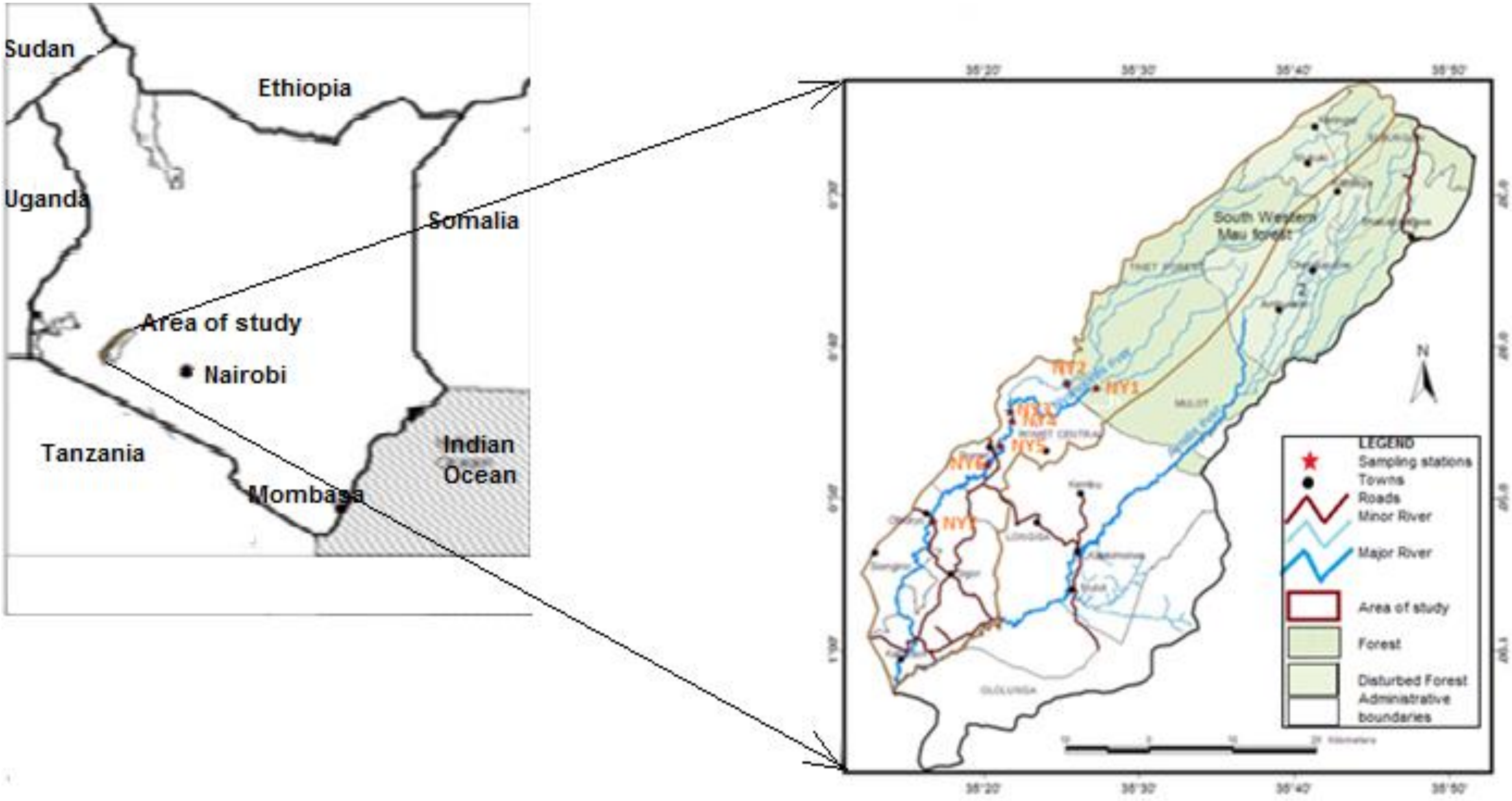

Figure 1: Map of Nyangores stream a tributary of the Mara River, Kenya showing sampling sites

A total of seven stations were selected, two in the forest ecosystem to act as reference points, three in small scale farming areas and the other two in the urban area after Bomet and Tenwek towns. The effects of point source pollution were captured by selecting stations in the upstream and downstream of discharge points. In each station a sampling reach of 100 m was selected for macroinvertebrate sampling. The characteristics of the stations that were studied are as described below.

i) Station NY1 (Ainapng’etunyek)

The stations described are as shown in Figure 1. The station was located in a forest ecosystem with little human activities at an altitude of 2070 m above sea level at S 00˚72.467' and E 035˚ 43.779'. The canopy cover was about 70% with diverse microhabitats (riffles, pools and runs). The water was clear with bed sediment of boulders of different diameters, sand and silt. The banks were moderately stable due to little disturbance from wildlife. The station was used as a reference site due to minimal human activities.

ii) Station NY2 (Chepkosiom)

The station was at an altitude of 2070 m a.s.l at S 00º70.713´ and E 035º42.348´. It is about 8km from Ainapng’etunyek. It is located in a forested area but there is cultivation of crops such as large scale tea plantation upstream. The canopy cover was over 50% and the bed sediment had soft substrate of sand.

iii) Station NY3 (Silibwet)

The station was at an altitude of 1953 m a.s.l at S 00º 72.775´ and E 035º 36.255´ approximately 10 km longitudinally from Chepkosiom. It is located upstream of

Tenwek mission hospital where there is small scale maize farming and livestock keeping. Maize cultivation is up to 2m from the bank leaving no buffer zone. The canopy cover was over 30% and eucalyptus trees dominate as compared to indigenous trees. The substrate had boulders of different sizes and sand. Human activities in this area include livestock watering, laundry and abstraction of water for domestic use with the major land use being agriculture.

iv) Station NY4 (Tenwek)

The station was roughly 100 m downstream Tenwek mission hospital at an altitude of 1929 m a.s.l at S 00º 74.640´ and E 035º 36.490´ approximately 2.5 Km from Silibwet. It is located 150 m from Tenwek hospital sewage discharge and 500 m from Tenwek hydropower plant. The left bank was very steep with minimal vegetation and the riparian zone was degraded unlike the right bank which was occupied by trees. The canopy cover was about 25% and the substrate consisted of sand and boulders. Activities in this area include bathing, swimming and laundry. The major land use is urban settlement in the upcoming Tenwek town. Water abstraction is at a large scale indicated by presence of a dam upstream of this station used for hydroelectric power generation supplying the adjacent Tenwek Hospital.

v) Station NY5 (Raiya)

The station was at an altitude of 1940 m a.s.l approximately 6 km from Tenwek at S 00º 77.517´ and E 035º 35.139´. It was located 200 m downstream of Bomet town. The canopy cover was less than 25% with cultivation being done in the riparian zone. The substrate has boulders sand and silt with fine matter. The major land use is agriculture and other human activities include; washing, bathing and livestock watering.

vi) Station NY6 (Bomet)

The station was located approximately 500 m downstream of Bomet Prison at an altitude of 1916 m a.s.l at S 00º 79.576´ and E 035º 33.847´. There is an open dumpsite about 200 m from the river. The canopy cover was about 20% and the substrate consisted of sand and silt. The station is near livestock watering points where the residents also collect water for domestic use. The river banks are not stable due to disturbance from livestock. The station is approximately 6 km from Raiya (NY5).

vii) Station NY7 (Olbutyo)

The station was located in a semi arid area with little farming activities at an altitude of 1855 m a.s.l at S 00º 85.663´ and E 035º 27.992´. The canopy cover was about 15% and the substrate consisted of boulders in riffles and sand, silt and fine materials in pools. The major land use in this area is quarrying and livestock keeping. The area is used for livestock watering, abstraction of water for domestic use and laundry. The banks are unstable due to the impact of livestock. The station is approximately 20 km from Bomet town.

3.2 Sampling Design

Samples were taken from the seven sampling stations twice a month from February 2012 to July 2012 to cover the wet (Mid March - June) and dry (February, Early March and July) seasons in order to establish flow and dilution effects on water quality in the Nyangores stream. The physico-chemical water quality parameters were measured *insitu.* Triplicate water samples for nutrient analysis were taken in labelled 500ml plastic bottles while water samples for culturing bacteria were taken in labelled sterilized glass bottles. The stream habitat was assessed using the Stream Visual Assessment Protocol (SVAP) (USDA, 2009). Triplicate macroinvertebrates samples were also taken from each microhabitat (pool, riffle and run) using a kick net. The description below details how each parameter was determined.

3.3 Physical and chemical parameters

Temperature, dissolved oxygen, conductivity and pH measurements were made *in-situ* using electronic probes. The parameters were sampled mid morning hours. HACH HQ 4d was used for DO and temperature while HACH Eco 40 was used for pH and conductivity measurements. The probes were immersed in water at a depth of 2cm and readings on the meters recorded. The other physical-chemical parameters include:

i) Discharge

Discharge is the amount of water passing through a cross-sectional area of the channel during a certain time. The discharge of surface or underground streams is an important environmental variable to measure (Jaya and Rami, 2005). The low flows and flood frequency can be estimated from a time-series of stream discharge. Discharge is expressed as volume per unit time. It was calculated by first determining velocity and cross sectional area of the stream.

Flow velocity was determined using a measuring tape and a Marsh-McBirney portable flow meter model 2000. The tape was stretched across the stream at the selected site. The meter was set to average velocity readings every 15 seconds. The measurements were taken along the tape at constant intervals of 0.4m and the number of measurements ranged from 10-15. The gauge level and time before and after taking the velocity readings were recorded. The first measurement was taken at the edge of water with the current meter rod held vertical while the sensor pointed directly upstream parallel and into the flow. The measurements of water flow were taken at a depth of 0.6m. A tape measure was used to measure the channel width and a calibrated rod was inserted in water to determine the depth of water in meters. The depth and width were used to determine the cross sectional area of the stream. The stream discharge was calculated as:

$$Q = VA$$

Where Q = Discharge (m^3/s)
V= Velocity (m/s)
A= Area (m^2)

ii) Total suspended solids

Total suspended solids (TSS) were gravimetrically determined according to APHA (2002). The water sample was shaken to mix the sample contents to get a homogenous sample for analysis. The filters were first oven dried at 95℃ overnight to obtain their constant weight (W_f). After homogenizing the sample, 300ml of water was filtered using pre-weighed glass fibre filters (GF/F) with a pore size of 0.45μm. The filter was removed from the vacuum pump using forceps onto a glass weighing dish. The filters were then oven dried at 105℃ for one hour and reweighed. The weight of the filter paper and filtrate were recorded as Wc.

TSS was then calculated using the following formula (APHA, 2002):

$$TSS[mg/l] = \{(\mathrm{W_c} - \mathrm{W_f}) \times 10^6\} / \mathrm{V}$$

$\text{Where TSS} = \text{Total suspended solids}$

$\text{Wc} = \text{Constant weight of filter} + \text{residue (g)}$

W_f = Weight of Pre-dried filter (g)

V = Volume of water sample used (m*l*).

iii) Biological oxygen demand

Biological oxygen demand (BOD) is the amount of oxygen required for the biological decomposition of dissolved organic matter under standardized time and temperature (APHA, 2002). The amount of pollution can easily be measured using BOD since it gives an idea of the biodegradability of a sample (APHA, 2002). Triplicate water samples were filled in 300 ml airtight bottles. The stopper was removed and 0.5ml of manganese sulphate and 0.5ml alkaline reagent introduced below the surface using a pipette followed by 0.5ml of concentrated sulphuric acid. The stopper was then replaced firmly and carefully to avoid trapping air in the bottles. The mixture was then shaken well. The initial dissolved oxygen (O_E) was determined using Winkler's method using the formula below (APHA, 2002):

$$DO(mg/l) = \frac{SV\ X\ CV\ X\ CB\ X\ 8000}{SV\ X\ SB - (a + b)}$$

Where; CV= Volume of thiosulphate used

CB = Concentration of thiosulphate used

SV= Volume of the water sample bottle used

SB= Volume of sample bottle used

a+b = Volume of manganese sulphate + alkaline used.

The bottles were then wrapped in aluminium foil and stored in a dark cabinet at room temperature. After 5 days, the final dissolved oxygen was determined using Winkler's method *(O_s)*. The BOD was then determined using the formula;

$$BOD\ (mg/L) = O_E \quad - O_S$$

Where; $BOD \ = Biological\, oxygen\ \ demand$

O_E = Oxygen concentration (mg/L) before incubation

O_S = Oxygen concentration (mg/L) after incubation

3.4 Nutrient Analysis

Water samples for nutrient analysis were collected in 500 ml polyethylene containers; the analysis was done following the standard analytical procedures (APHA, 2002).

i. Nitrate-Nitrogen (NO_3-N)

Nitrate-nitrogen was determined using the sodium-salicylate method (APHA, 2002). A stock solution was prepared by dissolving 1.517 g of sodium nitrate in 250 ml of distilled water which made a stock solution of 250 mg/L. A working solution with a concentration of 5 mg NO_3-N per litre was made by taking 5 ml of the stock solution and diluting it to 1 litre. Different concentrations of working solution were diluted with distilled water and used to make standard series with different concentrations (Table 1)

Table 1: Concentration used to draw calibration curve for nitrates

Concentration (mg/L)	0	0.25	0.5	1	2.5	5
Working solution (ml)	0	1.0	2.0	4.0	10.0	20.0
Volume of distilled Water (ml)	20	19.0	18.0	16.0	10.0	0.0

20ml filtered water samples were put into beakers and 1 ml of freshly prepared sodium salicylate solution added into every beaker. The beakers were then put into an oven and samples dried at 95°C. After evaporation, 1 ml of concentrated sulphuric acid was added to the residue and the beakers swirled before cooling. After cooling, 40 ml of distilled water was added into the contents, followed by 7 ml of potassium-sodium hydroxide-tartarate solution and mixed well. Then absorbance of each sample was then determined at a wavelength of 420 nm using a spectrophotometer (Pharmacia Biotech model, 65455). A standard curve of concentration of known standards versus absorbance was plotted. The unknown concentration of samples was found through a standard series of known concentrations of the solution (Table 1). The following formula was used to calculate the concentration of nitrate:

$$NO_3\ Concentration\ (mg/L) = Sample\ absorbance\ \times slope\ of\ standard\ curve$$

ii. Nitrite-Nitrogen (NO_2-N)

The determination of nitrite-nitrogen was carried out using the reaction between sulphanilamide and N-Naphthyl-(1)-ethylendiamin-dihydrochloride. Sodium nitrite salt with a molar mass of 69 g was used to make standard calibration curve. A stock solution with a concentration of 1g NO_2-N per litre was made by dissolving 1.23 g of the salt in 250 ml distilled water. An intermediate solution with a concentration of 10 mg/L was made by diluting 5 ml of the stock solution with 500 ml distilled water. A working solution was then made by diluting the intermediate solution into 1 litre with distilled water. A series of standard solution with known concentrations were made and used to determine the calibration curve by diluting the working solution (Table 2).

Table 2: Concentration used to draw calibration curve for Nitrite-Nitrogen

Concentration (µg/ L)	0	2	5	10	20	50
Working solution (ml)	0	1	2.5	5	10	25
Volume of distilled water (ml)	25	24	22.5	20	15	0

One millilitre of sulfanilamid solution was added to 25 ml of the filtered water sample and left for 5 minutes before adding 1 ml of N-Naphthyl-(1)-ethylendiamin-dihydrochloride. The mixture was gently mixed and left standing for 10 minutes after which absorbance was determined from the spectrophotometer (Pharmacia Biotech model, 65455) at a wavelength of 543 nm. A standard curve of absorbance concentration of known standards versus absorbance was plotted. The unknown concentration of samples was found using a standard series of known concentrations of the solution. The following formula was used to calculate the concentration of nitrite:

$$NO_2\ Concentration\ (\mu g/L) = \ Sample\ absorbance\ \times slope\ of\ standard\ curve$$

iii. Ammonium-Nitrogen (NH_4-N)

Standard calibration curve for ammonia was made using NH_4Cl solids with a molecular mass of 53.49 g in which the nitrogen proportion of NH_4-N is 1:14 of the weight. Then 0.96 g NH_4Cl was dissolved in 250 ml distilled water which gave a stock solution with a concentration of 0.12 g/L. An intermediate solution with a concentration of 10 mg/L was made by diluting 10 ml of the stock solution to 1 litre using distilled water. A working solution with concentration of 250µg/L was made by taking 25 ml of the intermediate solution and diluting to 1 litre. The working solution was then used to prepare solution of different concentrations that were used to determine calibration curve by taking different volumes of the working solution and made up to 25 ml by adding distilled water Table 3.

Table 3: Concentration used to draw calibration curve for Ammonium-Nitrogen

Concentration (µg l^{-1})	0	10	20	50	100	250
Working solution (ml)	0	1.0	2.0	5.0	10.0	25.0
Volume of distilled water (ml)	25	24.0	23.0	20.0	15.0	0.0

Before determining absorbance, 2.5 ml of sodium salicylate solution was added to 25 ml of filtered samples and followed immediately by addition of 2.5 ml of hypochloride solution. The samples were then placed in water bath at $25°C$ in the dark for 90 minutes. The absorbance was then determined using a spectrophotometer (Pharmacia Biotech model, 65455) at a wavelength of 655 nm. A standard curve of absorbance concentration of known standards versus absorbance was plotted. The unknown concentration of samples was found using a standard series of known concentrations of the solution.

The following formula was used to calculate the concentration of ammonia:

$$NH_4\ Concentration\ (\mathrm{mg/L}) = Sample\ absorbance \times slope\ of\ standard\ curve$$

iv. Soluble Reactive Phosphorus (SRP)

Soluble reactive phosphorus was determined using the ascorbic acid method (APHA, 2002) on filtered water samples. The glassware used was acid washed with 10% sulphuric acid and rinsed with distilled water a day before commencement of analysis. Standard solution for the calibration of the standard curve was made by dissolving 5.623 g of potassium hydrogen phosphate pre-dried in the oven for 24 hrs at approximately 70° C in 1 litre of distilled water making a concentration of 1g of PO_4-P per litre. A solution with a concentration of 10 mg/L was prepared by diluting 10 ml of PO_4-P to 1 litre using distilled water. The intermediate solution was further diluted in a ratio of 1:20 (25 ml in 500 ml distilled water) to give a working solution with a concentration of 500 µg/L. The standard series was prepared by taking different volumes of the working solution and dilution was done to 25 ml with distilled water (Table 4).

Table 4: Concentration used to draw calibration curve for soluble reactive phosphorus (SRP)

Concentration (µg/L)	0	10	20	50	100	200	400	500
Working solution (ml)	0	0.5	1.0	2.5	5.0	10.0	20.0	25.0
Volume of distilled water (ml)	25.0	24.5	24.0	22.5	20.0	15.0	5.0	0.0

Ammonium molybdate solution, sulphuric acid, ascorbic acid and potassium-Antimonyltartarate solution were mixed in the ratio of 2:5:2:1 and the resulting solution added to the water sample in a ratio of 1:10. The sample's absorbance was measured 15 minutes after adding the reagent to the sample using a spectrophotometer (Pharmacia Biotech model, 65455) at a wavelength of 885 nm with distilled water as a reference. A standard curve of absorbance concentration of known standards versus absorbance was plotted. The unknown concentration of samples was found with the help of (the linear part of) a standard series of known concentrations of the solution. The following formula was used to calculate the concentration of SRP (Table 4).

$$SRP\ Concentration\ (\mathrm{mg/L}) = Sample\ absorbance\ \times slope\ of\ standard\ curve$$

v. Total phosphorus

Total phosphorus was determined by persulphate digestion and reducing the forms of phosphorus in water into free ortho-phosphate form (SRP). After digestion, the total reduced forms of TP into SRP formed were analysed using the same procedure as for the soluble reactive phosphorus. Six grams of potassium persulphate were dissolved in 50 ml of distilled water by sonification for 30 minutes. Water samples 25 ml each were put into evaporating bottles and 1 ml of the still warm potassium persulphate added into the water samples. The bottles with samples were weighed without lids and weight noted. The lids were put back but not closed tightly and autoclaved for 90 minutes at 120° C and 1.2 atm. The samples were then removed from the autoclave cooled, reweighed and the water that had evaporated replaced by adding distilled water. The steps used to determine the soluble reactive phosphorus were used to determine total phosphorus (APHA, 2002). A standard curve of absorbance concentration of known standards versus absorbance was plotted. The unknown concentration of samples was found with the help of the linear part of a standard series of known concentrations of the solution (Table 4). The following formula was used to calculate the concentration of TP:

$$TP\ Concentration\ (mg/L) = \ Sample\ absorbance\ \times slope\ of\ standard\ curve$$

3.5 Habitat assessment

A qualitative assessment of the condition of the river habitat was determined using stream visual assessment protocol (SVAP). The protocol evaluates the overall condition of streams, their instream habitats and riparian zones (USDA, 2009). It was carried out during the base flow when the habitat features were visible; the habitat score was done by scoring attributes that were available in Nyangores stream (Appendix 1). The scoring was done along 100 m sampling reach and each attribute was scored with a value of 1 to 10 (1-poor; 10- excellent), and one assessment was done per site. The overall score was calculated by getting the total scores divided by the number of elements that were assessed (USDA, 2009). The scores that best fitted the observations were recorded; therefore the protocol was changed to suit the tropical region. The characteristics that were assessed include; the condition of the channel, appearance of water, absence or presence of pools, nutrient enrichment, condition of the riparian zone, stability of the bank, macroinvertebrates, canopy cover and riffle embeddeness (Appendix 1).

i. Channel condition

Signs for channelization like high banks, culverts and irrigation diversions were used to determine the channel condition. Active down cutting and excessive lateral cutting indicated unstable stream channel and a channel with no dikes or excessive down cutting was considered natural while altered channel was considered unnatural.

The scoring criteria was 1 – 10; if the channel was natural the score was 10 but if there was evidence of past channel alteration, but with significant recovery of channel and banks, the score was 7. Altered channel where <50% of the reach had channelization with excess aggradations and braided channel score was 3 and if channel is actively down cutting or widening, >50% of the reach with channelization was score 1.

ii. Riparian zone

The quality of the riparian zone was assessed by comparing the width of the riparian zone to the width of the active channel. However, in case of V-shaped valleys where there was no room for a floodplain riparian zone extending as far as one or two active channel widths, the extent of the flood plain that covered the riparian zone was assessed. Assessment of any kind of regeneration was done, for instance, the presence of only mature vegetation and few seedlings indicated lack of regeneration.

The scoring criteria used; an extension of natural vegetation to at least two active channel widths on each side the score was 10 while an extension of one active channel width on each side score 8. If the natural vegetation extended a third of the active channel width on each side the score was 3 and if there was lack of regeneration or the natural vegetation was less than a third of the active channel width on each side score 1 (USDA, 2009).

iii. Bank stability

Bank stability is the potential for detachment of soil from the upper and lower stream banks and its movement into the stream. Some bank erosion is normal in a stream that is not degraded while excessive erosion occurs where the stream is unstable because of changes in sediment load and hydrology (USDA, 2009). The stability of the bank was assessed by looking for signs of erosion like exposed tree roots, unvegetated stretches and conditions that may lead to collapse of banks like animal paths or grazing areas.

Low and stable banks at elevation of active floodplain score was 10 and low moderately stable banks at an elevation of active flood plain score was 7. In case of moderately unstable banks with signs of active erosion score were 3, with unstable banks with straight reaches and inside edges eroded score was 1.

iv. Water appearance

Water appearance compares colour, turbidity and other characteristics with a reference stream. The depth to which an object can be clearly seen is a measure of turbidity. The clarity and colour of water was assessed.

The following scoring criteria was used to assess water appearance: scored 10 if the water was very clear or clear but tea-coloured and objects visible at depth 3 to 6 feet, no oil sheen on surface, no noticeable film on submerged objects or rocks while 7 was scored if the water was occasionally cloudy especially after storm event but clears rapidly and objects were visible at depth 1.5 to 3 ft, slightly green color; no oil sheen on water surface. Scored 3 if there was significant cloudiness most of the time and objects were visible to depth 0.5 to 1.5 ft, slow sections appeared pea-green, submerged objects covered with heavy green film. Scored 1 if the water was very turbid in appearance most of the time and objects visible to depth < 0.5 ft, slow moving water but bright green, floating algal mats, surface scum, sheen or heavy coat of foam on surface (USDA, 2009).

v. Canopy cover

The surface area of water for the whole reach that was shaded was assessed by estimating areas with no shade, poor shade and shade. The following guidelines for percent shade were used: if the stream surface was not visible > 90% was scored but if the surface was slightly visible or visible only in patches 70% – 90% was scored. The percentage used for visible surface with invisible banks was 40% – 70% while for the visible surface with visible banks at times 20% – 40% was used (USDA, 2009). Lastly if the surface and banks were visible < 20% was used.

vi. Riffle embeddness

Riffles are areas where water breaks over rocks and cause surface agitation (USDA, 2009). In most streams the riffles maintain high species diversity and insect abundance. The measure describes the degree that the cobble, gravel, and boulder substrates are surrounded by fine material (sand and silt), so that they cannot easily be dislodged. The measure was determined by estimating the percentage of materials that were embedded. The guideline for embeddness used is as follows; Scored 10 if the cobble particles were < 20% embedded and scored 8 if the cobble particles were 20 to 30% embedded. If the cobble particles were 30 to 40% embedded the score was 5 but if the cobble particles were >40% embedded score was 3 and lastly if riffle was completely embedded score was 1.

vii. Macroinvertebrates

Macroinvertebrates reflects the ability of the stream to support aquatic insects. The measure was assessed by collecting macroinvertebrates by picking cobbles in water and careful observation made and kinds of insects noted. The scoring values for this element ranged from – 3 to 15 (USDA, 2009). Scored 15 if there was a high species diversity and dominance of intolerant species such as caddisflies, mayflies and stoneflies but scored 6 if the community was dominate d by facultative species, such as damselflies, dragonflies, aquatic sow bugs, black flies and crayfish. Scored 2 if the community was dominated by tolerant species, such as midges, leeches, aquatic earthworms and tubificid worms but if there was near absence of all macroinvertebrates the score was -3.

3.6 Coliform bacteria

Water samples for assessment of coliform bacteria were collected using sterilized glass bottles 30 cm below the surface of water. They were then wrapped in aluminium foil and placed in a cool box and taken to Longisa District Hospital for analysis. The samples were processed within 6-24 hours of collection to avoid changes of bacterial count due to growth or die off. The Membrane Filtration Technique (MFT) as described in APHA (2002) was used in the analysis of samples for the presence of indicator organisms.

For Membrane filtration technique, aseptic filtration was done separately for each dilution. A sterile funnel was detached and a sterile filter membrane placed on sterile filtration device using a pair of forceps, flamed for 10 minutes and the funnel reattached. Serial dilutions of 10, 1 and 0.1 ml were made in five tubes for the surface water samples. The diluted water samples were filtered starting with the highest (10 ml) to the lowest dilution (0.1 ml). After sucking off the whole samples, the tap was turned off and the funnel detached. The membrane filter was taken off using a pair of forceps and placed on the surface of chromocult coliform agar (ISO 6222, OXOID) and incubated at $37°C$ for 18-24 hours. Typical colonies appearing pink and dark blue were counted as total coliforms and *E. coli* respectively. For all colonies forming units (CFU) counted, total numbers per 100 ml was expressed as (APHA, 2002);

$$Total\ numbers\ (per\ 100\ ml) = (CFU's \times Dilution/Volume\ filtered\ \times 100)$$

3.7 Macroinvertebrates

Triplicate random samples of macroinvertebrates were taken from each station over an approximately 100 m reach using a kick net of 500µm mesh size with effective area of 0.0625m^2. Three sweeps were made by dragging the kick net with its open end against the water current, and around aquatic vegetation, the vegetation was disturbed by kicking it to dislodge the invertebrates. The samples were washed through a series of sieves that ranged from 500µm to 100µm. They were then sorted using a white plastic tray, placed into labelled vials and preserved with 70% ethanol. In the laboratory, samples were sorted and placed in individual vials, counted and identified up to genus level according to Quigley (1977); Merritt and Cummins, (1996) and Mathooko, (1998). Dissecting microscope at magnification x15 was used for identification. Relative abundance and diversity indices were used to evaluate macroinvertebrate composition in different sampling stations.

i) Relative abundance

The relative abundance is used to show the distribution of macroinvertebrate community in an area. This can be used to determine the level of disturbance in a station since the density of macroinvertebrates decreases in response to toxic pollution such as insecticides. The index can be variable since some species can increase with nutrient enrichment. The relative abundance was calculated as:

$$R.A = \frac{No. of\ individuals\ of\ one\ taxon}{Total\ no. of\ individuals\ from\ all\ taxon\ in\ a\ station} * 100$$

ii) Diversity index

Diversity index represent a measure of the distribution of individuals among different taxa present in a sample. The index provides important information about rarity and commonness of species in a community. It is an important tool since it makes understanding of community structure easier. The Shannon-Wiener diversity index (H') was calculated as (Shannon and Weaver, 1949);

$$H^{'} = -\sum((n/N) \times \ln(n/N))$$

Where *n* = number of individuals of a taxon,

N = total number of individuals in the sample

ln = natural logarithm

ii) Evenness index

The evenness index is also a measure of biological diversity and is also used to assess level of disturbance in streams. The index was calculated as(Shannon and Weaver,1949);

$$E = H/\ln N,$$

Where H and N are as used in the Shannon-Weiner Index equation above and

ln = natural logarithm

iii) EPT index

The EPT index for each site was calculated as (Jorgesen *et al.*, 2005). EPT is the number of genera belonging to the orders Ephemeroptera, Plecoptera and Trichoptera. The orders are considered to be sensitive to organic pollution.

$$EPT\ index = \frac{Number\ of\ all\ EPT\ genera\ in\ a\ station}{Total\ number\ of\ organisms} \times 100$$

3.8 Statistical Analysis

Statistical analyses were performed with the aid of Microsoft excel spreadsheet for windows 2007, Minitab^{TM} version 14.0 for windows. Macroinvertebrate count data was log10(x+1) transformed prior to analysis. Two-way ANOVA test was used to test for variations in physico-chemical parameters and post hoc Duncan's Multiple Test was used to compare means among station. Pearson correlation analysis was performed to investigate the relationship between macroinvertebrate community attributes, coliform bacteria and physico-chemical parameters. Finally, canonical correspondence analysis (CCA) was used to investigate the relationship between macroinvertebrate community assemblage and measured physico-chemical parameters in order to determine important parameters responsible for the observed spatial distribution of macroinvertebrate species. A Monte Carlo permutation test with 100 random permutations was applied for the determination of statistical significance of the CCA model. Significant differences for all inference tests were accepted at 95% confidence level.

CHAPTER FOUR

RESULTS

4.0 Spatial - temporal variations in physical chemical parameters

Mean (±SE) values of physical chemical parameters obtained from the study are presented in Table 5. The highest temperature (22.9 ± 0.66 ºC) was recorded in station NY3 while the lowest was at NY1 (12.8 ± 0.34 ºC). There was significant difference with sampling station (p<0.001), station NY1 and NY2 differed significantly with the rest of stations downstream while stations NY4; NY5 andNY6 had no significant difference. There was no significant difference with and sampling period (p= 0.950). The highest dissolved oxygen (DO) was recorded in stations NY1 and NY2 with mean value of 7.6 ± 0.14 mg/L while the lowest oxygen levels were recorded in station NY6 (6.2 ± 0.14 mg/L). There was significant difference in DO between stations (p <0.001), station NY3 and NY6 differed significantly from the rest of the stations, but no significant difference between sampling dates (p = 0.313) but NY2 differed significantly among the stations. The highest pH was recorded in station NY3 (7.8 ± 0.14) while the lowest recorded in NY1 (7.3 ± 0.12). There was a significant spatial variation in pH (p < 0.001). Station NY1 was significantly different from NY2, NY3, NY4 and NY7 but no significant difference with NY5 and NY6. There was no significant temporal variation with pH (p = 0.104). The highest conductivity levels were recorded in station NY7 (87.8 ± 2.63 µs/cm) and the lowest recorded in station NY1 (55.3 ± 1.18 µs/cm). There were significant variations in conductivity between stations (p < 0.001) but not with time (p=0.204). Station NY1 and NY2 differed significantly with the rest of the stations downstream. The highest mean TSS was recorded in station NY7 (128.6 ±14.2 mg/L) and lowest recorded in NY1 (39.7 ± 8.6 mg/L). There were significant temporal and spatial (p <0.001) variations in TSS.

Station NY1 differed significantly with the rest of the stations but there was no significant difference from station NY2-NY5. The highest discharge levels were recorded in station NY7 (2.7±0.31 m^3/s) and the lowest in station NY1 (0.9 ± 0.14 m^3/s). Spatial and temporal ($p<0.001$) variations in discharge were recorded. Station NY1 differed significantly among the stations. Station NY6 recorded the highest biological oxygen demand (BOD) levels (2.5 ± 0.04 mg/l) and lowest in station NY1 (1.4 ±0.10 mg/L).There was no temporal variation in BOD but the spatial variation in BOD was significant ($p<0.001$). Station NY1 was significantly different from the rest of the stations downstream.

Table 5: Mean (± SE) physico-chemical parameters of the studied stations in Nyangores stream during the study period

Physical – chemical parameters	**SAMPLING STATIONS**						
	NY1	**NY2**	**NY3**	**NY4**	**NY5**	**NY6**	**NY7**
Temperature (ºC)	12.8 ± 0.34	15.1 ± 0.57	22.9 ± 0.66	21.1 ± 0.22	20.8 ± 0.38	19.5 ± 0.10	18.4 ± 0.40
DO(mg/L)	7.6 ± 0.14	7.6 ± 0.03	7.1 ± 0.16	7.2 ±0.07	7.3 ± 0.01	6.2 ± 0.14	7.2 ± 0.18
DO% saturation	95.8 ± 1.44	96.2 ± 0.58	105.5 ± 2.47	103.5 ± 1.67	95.7 ± 6.38	85.5 ± 1.85	99.4 ± 0.73
pH	7.3 ± 0.12	7.5 ± 0.06	7.8 ± 0.14	7.7 ± 0.08	7.4 ± 0.10	7.5 ± 0.10	7.7 ± 0.09
Conductivity(µs/cm)	55.3 ± 1.18	58.3 ± 1.46	74.5 ± 3.49	77.6 ± 4.29	82.0 ± 3.29	85.2 ± 2.77	87.8 ± 2.63
TSS (mg/L)	39.7 ± 8.60	60.1 ± 15.70	78.0 ± 15.7	91.9 ± 15.8	99.3 ± 16.50	109.3 ± 14.6	128.6 ±14.20
BOD(mg/L)	1.4 ± 0.10	1.5 ± 0.05	2.2 ± 0.05	2.4 ± 0.06	2.2 ± 0.09	2.5 ± 0.04	2.5 ± 0.08
Discharge(m^3/s)	0.9 ± 0.13	1.1 ± 0.18	1.3 ± 0.21	1.6 ± 0.20	1.9 ± 0.23	2.1 ± 0.25	2.7 ± 0.31

Temperature in Nyangores stream was uniform throughout the study period while pH levels where highest in the month of February and lowest in the month of March (Figure 2).

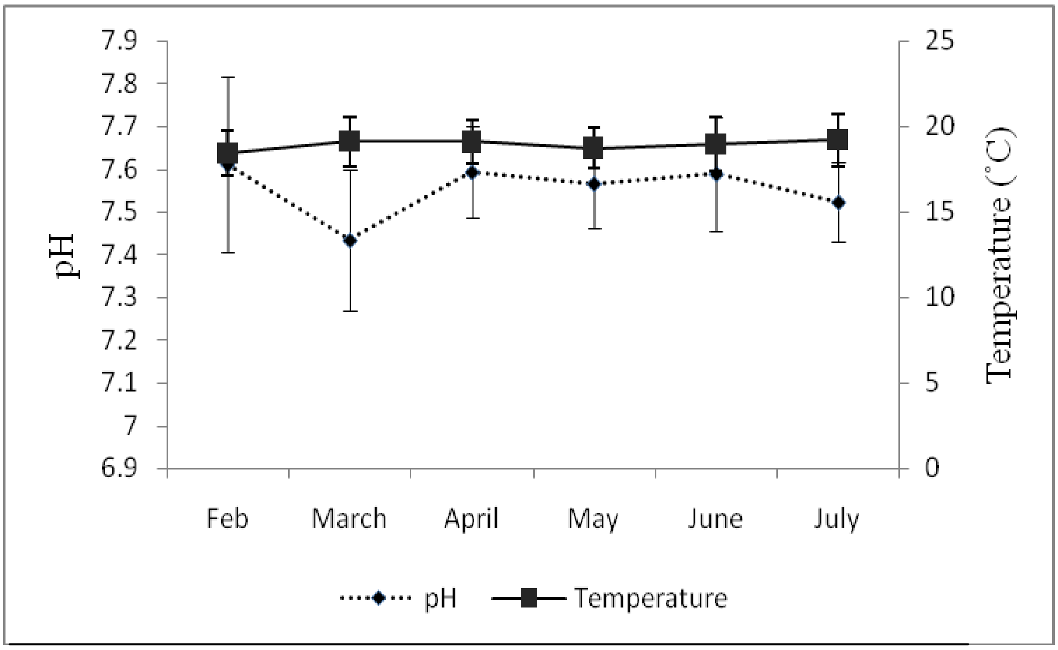

Figure 2: Temperature and pH levels during the study period in Nyangores stream

Conductivity levels were low in the month of February. But, an increasing trend was recorded in March and April and then decreased from May to July (Figure 3). A constant total suspended solids levels was noted during the dry season (February – April), but their levels increased during the wet season (May to July) with the highest levels recorded in May.

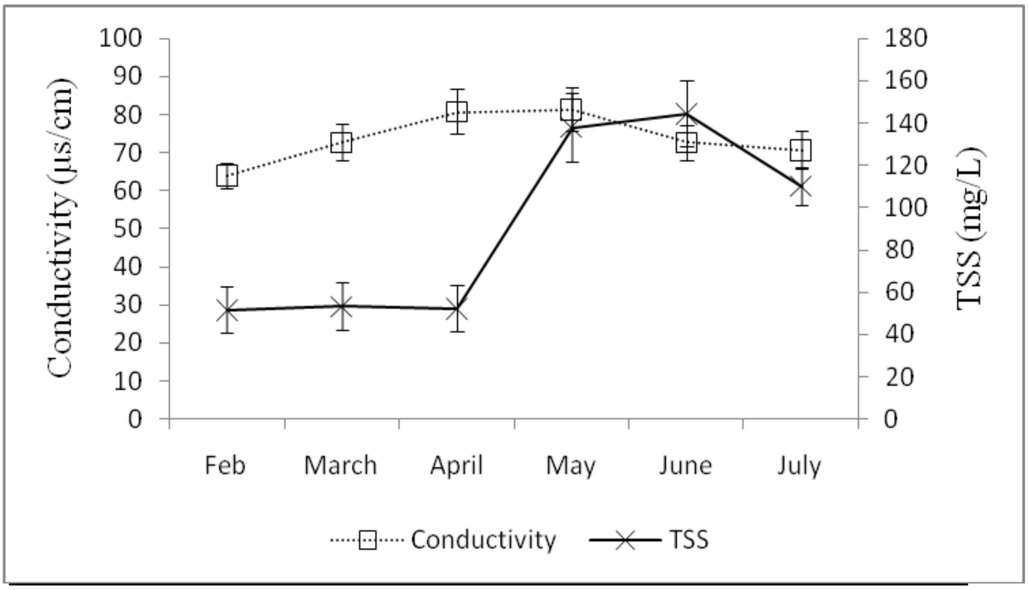

Figure 3: Conductivity and TSS levels during the study period in Nyangores stream

The dissolved oxygen levels were constant throughout the period with the highest DO noted in July (Figure 4). BOD level was generally low in February, it shoot up in March and then declined from April to July.

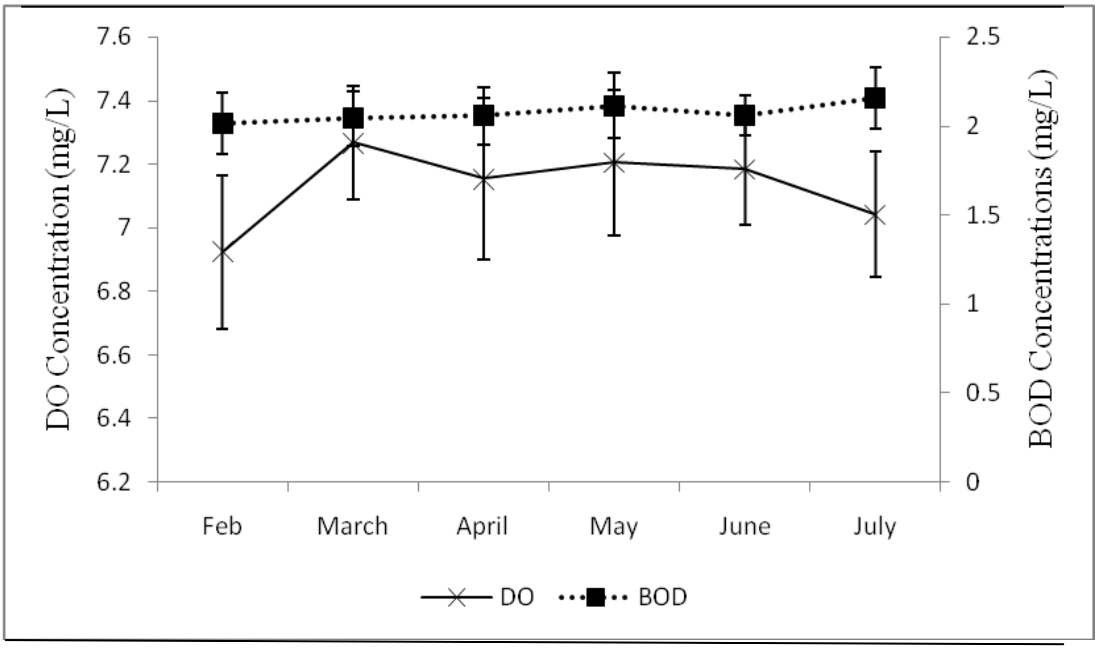

Figure 4: BOD and DO levels during the study period in Nyangores stream

4.1 Nutrients

Station NY7 and NY6 recorded the highest NO_3 (0.43±0.07 mg/L) and NH_4 (0.09±0.04 mg/L) concentrations and the lowest concentrations of nitrates (0.06±0.01 mg/L) and ammonia (0.02±0.03 mg/L) were recorded in station NY1 (Figure 5). Nitrate concentrations differed significantly between stations ($p < 0.001$). Station NY1 and NY2 differed significantly with other stations downstream. Ammonia differed significantly among stations ($p < 0.001$), with sations NY1,NY2 and NY3 differing significantly with other stations. The results also indicate that the concentrations of both ammonia and nitrates increased downstream.

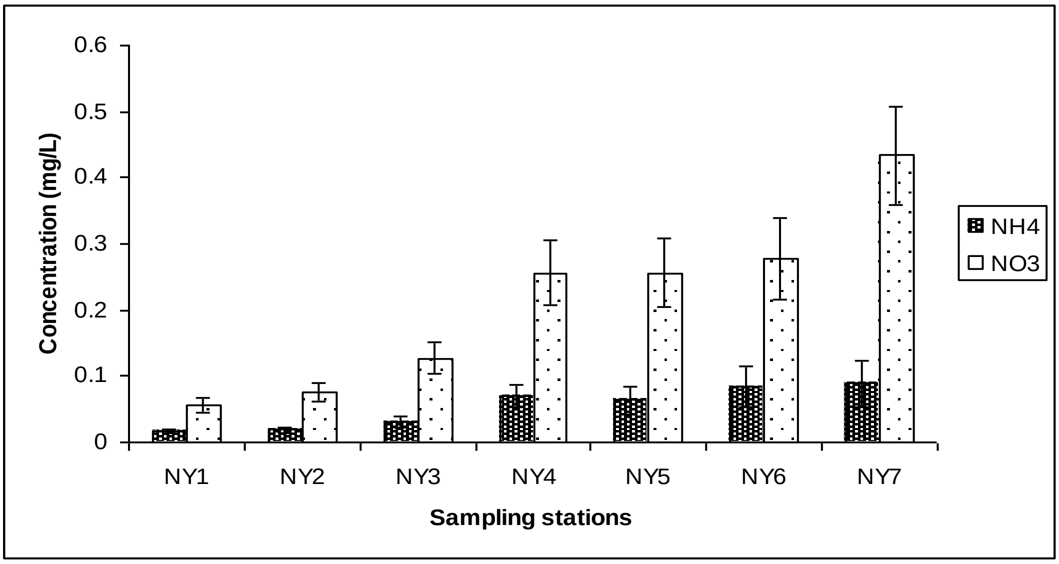

Figure 5: Mean (±SE) of ammonia (NH_4) and nitrates ($NO_{3)}$ concentration in different sampling stations in Nyangores stream during the study period

The highest NO_2 concentration was recorded in station NY7 (4.98±0.98 µg/L) and the lowest recorded in station NY1 (1.74±0.41 µg/L) (Figure 6). The concentrations differed significantly with sampling among stations ($p = 0.001$). However, there was no significant difference among stations NY1 to NY3 but significant differences were recorded in among stations NY1, NY2 and NY3 and stations NY4-NY7. Highest concentrations of nitrites were recorded in downstream stations and lowest in upstream stations.

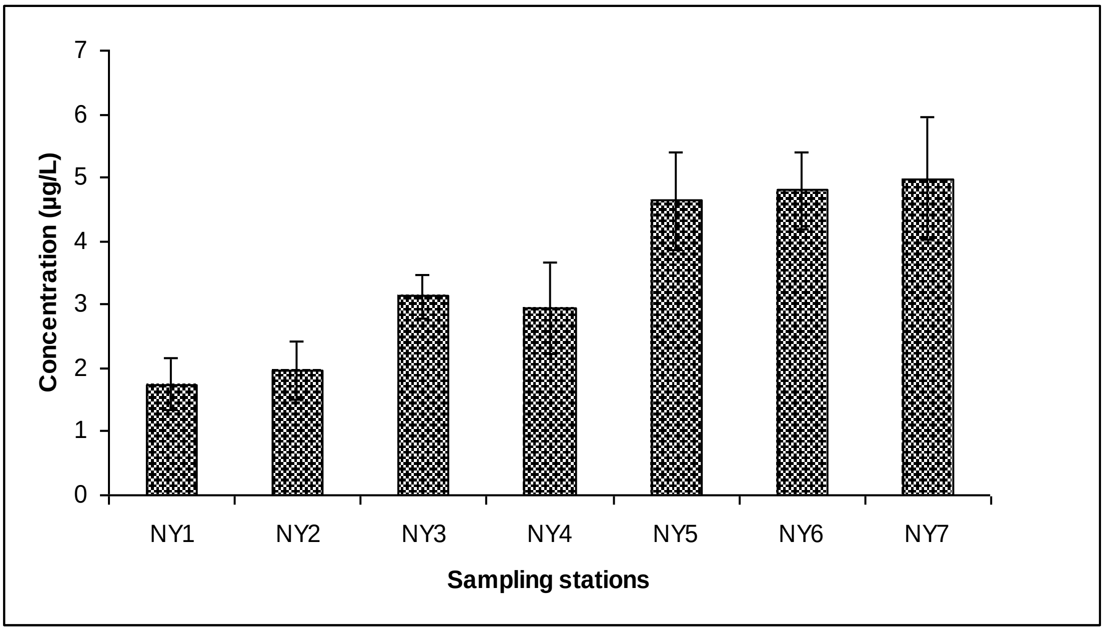

Figure 6: Mean (±SE) of nitrite (NO_2) concentrations in different sampling stations in Nyangores stream during the study period.

Concentration levels of total phophorus (TP) and soluble reactive phosphorus (SRP) are presented in Figure 7. The highest TP and SRP concentrations were recorded in station NY7 (0.27±0.03 mg/L) and (0.18±0.02 mg/L) respectively while station NY1 recorded the lowest TP (0.08±0.03 mg/L) and SRP (0.03±0.07 mg/L) concentrations. There was no significant difference of TP concentrations among stations while SRP concentrations differed significantly among stations ($p<0.001$). Significant differences were recorded among stations NY1 and NY2 with other stations downstream. The concentation of both SRP and TP generally increased downstream.

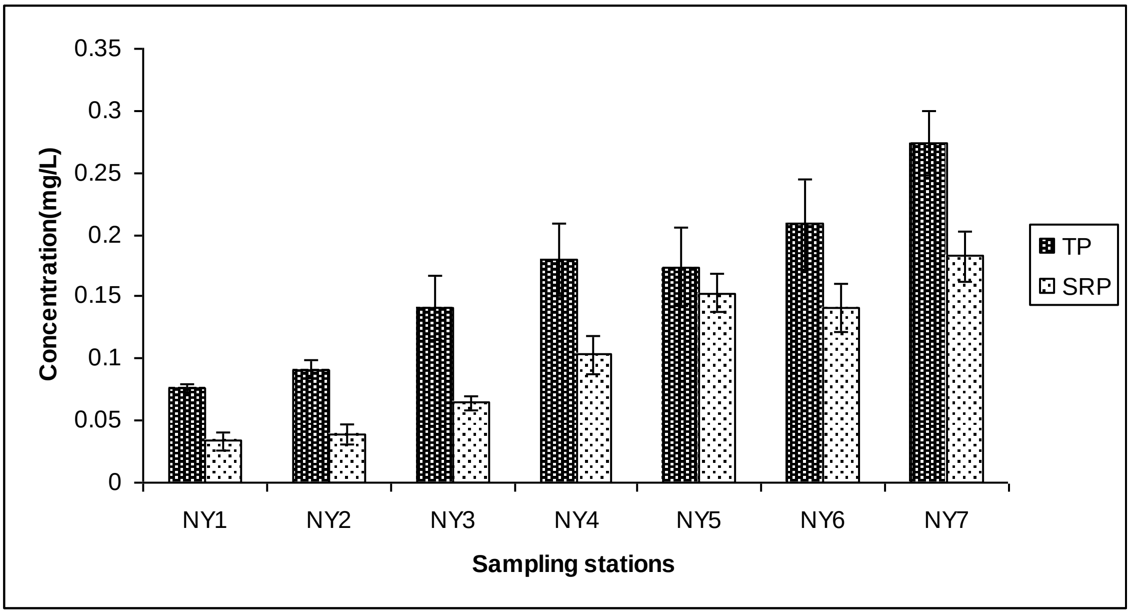

Figure 7: Mean (±SE) of SRP and TP in different sampling stations in Nyangores stream during the study period.

Higher nutrient concentrations were recorded in station NY7. The concentrations increased during the month of April which was the start of wet period and decreased in June. Nitrates and total phosphorus concentrations were generally higher than other nutrients during the wet season (Figure 8). There were significant differences ($p<0.001$) in ammonia, nitrites and total phosphorus.

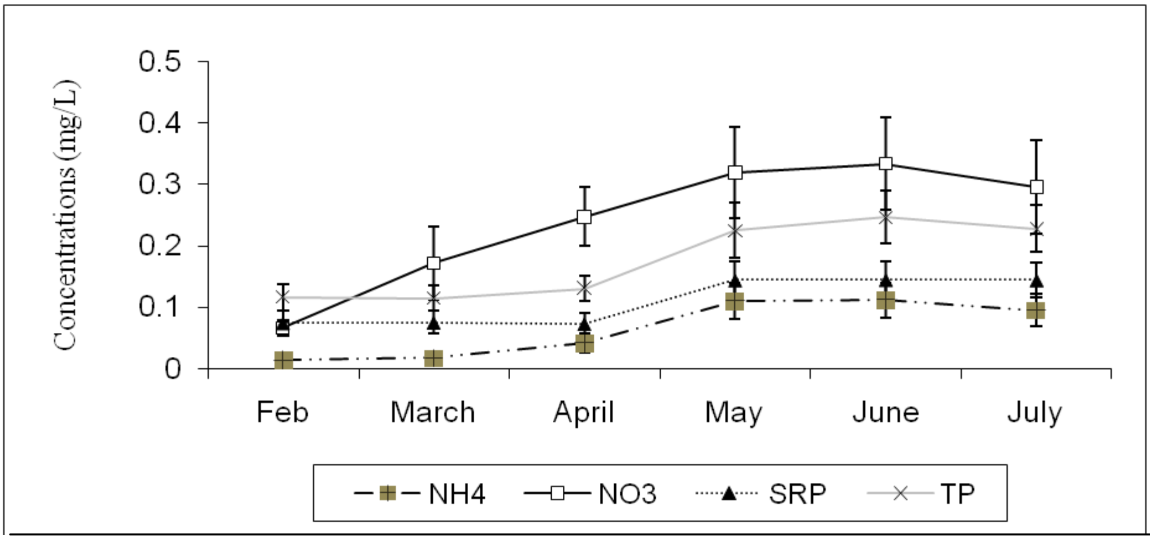

Figure 8: Temporal variation of nutrients in Nyangores River during the study period

4.2 Habitat Quality

The only station that was classified as having good quality habitat was Station NY1 with SVAP score of 8.9, while station NY2 (7.3), NY3 (6.4) and NY4 (6.3) had fair habitat quality and NY5 (5.1), NY6 (4.9) and NY7 (4.4) were classified as having poor habitat quality (Table 6). Station NY1,NY2 and NY3 scored high values in riffle embeddeness and macroinvertebrates observed, in general station NY1 scored high values in all SVAP elements. In station NY7, lower values of all SVAP measures were scored.

Table 6: Habitat quality assessment scores for each sampling site in the Nyangores stream during the study period

SVAP Elements	**NY1**	**NY2**	**NY3**	**NY4**	**NY5**	**NY6**	**NY7**
Channel condition	7	6	6	5	6	4	4
Riparian zone	9	7	5	7	4	5	4
Bank stability	8	7	6	6	5	4	4
Water appearance	9	6	6	6	5	4	4
Canopy cover	8	8	6	5	4	5	3
Riffle embeddeness	8	8	8	7	5	5	6
Macroinvertebrates	13	9	8	8	7	7	6
Overall scores	**8.9**	**7.3**	**6.4**	**6.3**	**5.1**	**4.9**	**4.4**

4.3 Coliform bacteria

The mean total coliform and *Escherichia coli* are presented in Figure 9. The highest mean *E. coli* bacteria was recorded in station NY3 (1350±116 cfu/100ml) and lowest in NY1 (270±47.3 cfu/100ml). There were significant differences in *E. coli* between stations (p=0.002) and sampling dates (p=0.003). The highest mean counts of total coliforms were recorded in station NY3 (2970±282 cfu/100 ml) and lowest in station NY1 (860±159 cfu/100 ml). There was significant difference in total coliforms between stations (p=0.008) and with time (p=0.001).

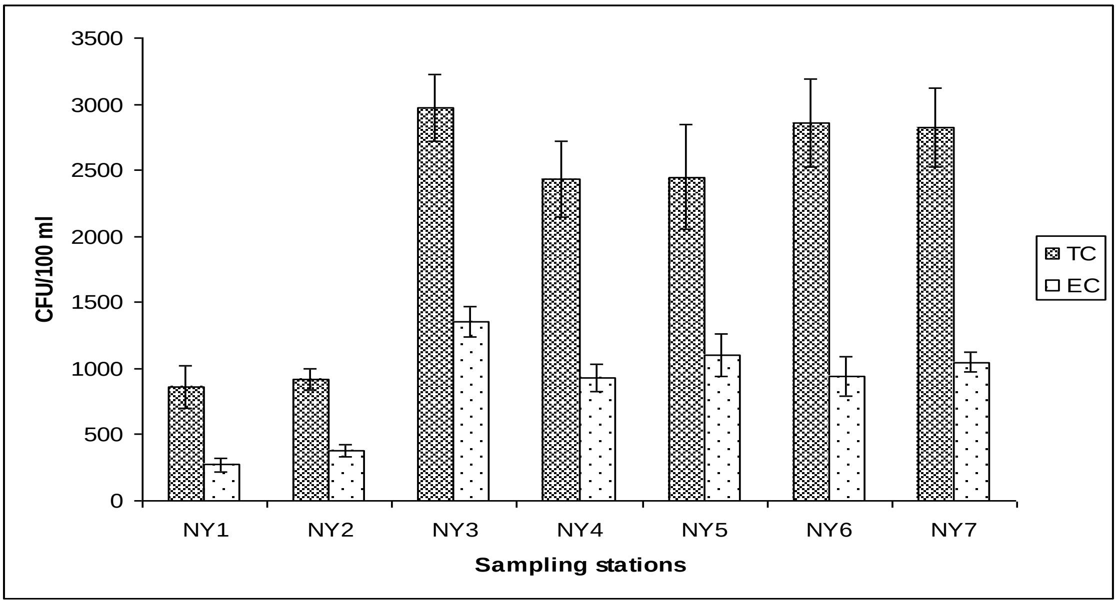

Figure 9: Mean total coliform (TC) and *Escherichia coli (EC)* counts in different sampling stations in Nyangores stream during the study period

Coliform bacteria were highest during the wet season (April) and lowest in February and March during the dry period (Figure 10). Bacteria counts decreased when the rains ceased that is from May to July but the total coliforms increased in July.

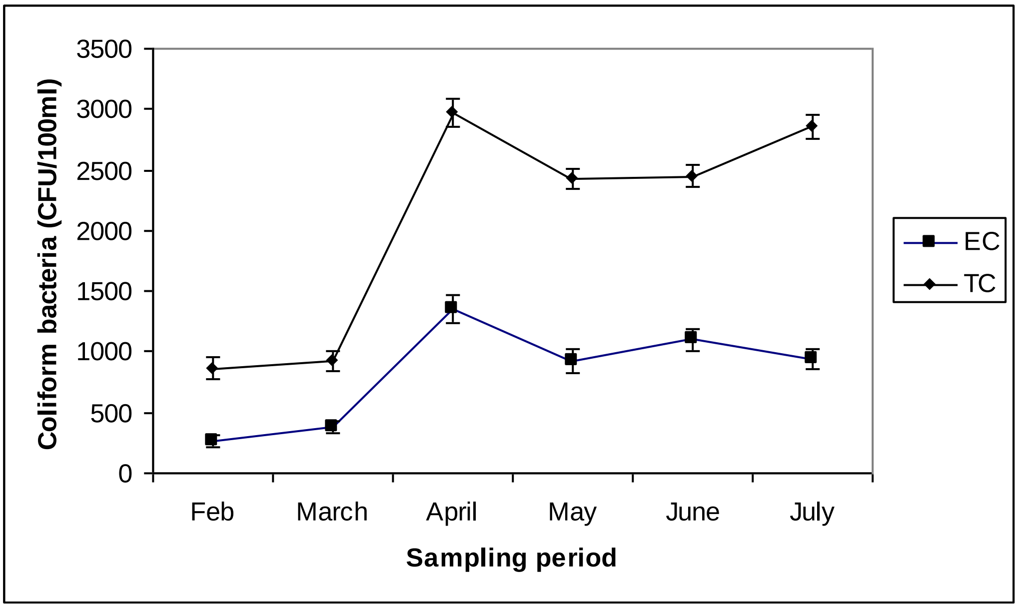

Figure 10: Mean coliform bacteria counts from Feb- July in Nyangores stream

4.3.1 Relationship between coliform bacteria and physic-chemical parameters

The relationship between *E. coli* and total coliform counts in Nyangores stream were statistically significant ($p < 0.05$) Table 7. *E. coli* was positively related to total suspended solids (r = 0.23) and soluble reactive phosphorus (r = 0.23) while total coliforms had a negative relationship with TSS (r = -0.25) and a positive relationship with SRP (r = 0.26).

Table 7: Pearson correlation coefficients among physico-chemical parameters, and between physico-chemical parameters and coliform bacteria (*designate significant correlation at α=0.05)

Parameter	Discharge	BOD	TSS	NO_2	NH_4	NO_3	TP	SRP
E. coli	0.18	0.55	0.23*	0.18	-0.09	0.09	0.09	0.23*
T. coliforms	0.22	0.51	-0.25*	0.18	-0.09	0.16	0.17	0.26*

4.4 Composition and distribution of macroinvertebrates

A total of 2613 macroinvertebrates representing 11 orders, 38 families and 37 genera were sampled (Table 8). The class Insecta was the highest in the study area consisting of orders Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Hemiptera, Diptera and Odonata. Other orders that were recorded are Oligochaeta and Gastropoda. The order Plecoptera was poorly represented in all stations. The order Diptera was the most diverse taxa with nine families followed by Ephemeroptera with seven families while Decapoda and Lepidoptera were the least diverse taxa (Table 8).

Table 8: Distribution of macroinvertebrate taxa in different sampling stations in Nyangores stream during the study period, (x) indicate presence of taxa and (–) absence.

			SAMPLING STATIONS						
ORDER	**FAMILY**	**GENUS**	**NY1**	**NY2**	**NY3**	**NY4**	**NY5**	**NY6**	**NY7**
Ephemeroptera	Baetidae	*Baetis sp*	x	x	x	x	x	x	x
	Caenidae	*Caenis sp*	x	x	x	x	x	x	x
	Heptageniidae	*Heptagenia sp*	x	x	x	x	x	x	x
	Trichorythidae	*Trichorythus sp*	x	x	x	x	x	x	x
		Dicercomyzon sp	x	x	x	x	x	x	x
	Ephemeridae	*Ephemera sp*	x	-	-	-	-	x	x
	Leptophlebiidae	*Habrophlebia sp*	x	x	x	x	x	x	x
	Prosopistomatidae	Prosopistoma sp	x	-	x	x	x	-	x
Diptera	Chironomidae	*Chironomus sp*	x	x	x	x	x	x	x
		Ablabesmyia sp	x	x	x	x	x	x	x
	Ceratopogonidae	*Bezzia sp*	x	x	x	x	x	x	x
	Culicidae		-	-	x	x	x	x	x
	Athericidae	*Atrichops sp*	-	-	-	x	x	x	-
	Muscidae		-	-	-	-	x	-	-
	Simuulidae	*Simulium sp*	x	x	x	x	x	x	x
	Tipulidae	*Tipula sp*	x	-	x	x	x	x	x
	Dixidae	*Dixa sp*	-	-	-	-	-	x	-
	Scritidae		x	-	x	x	-	-	-
Decapoda	Potamonautidae		x	x	x	x	x	x	x
Odonata	Gomphidae	*Gomphus sp*	x	x	x	x	x	-	-
	Cordugasteridae	*Cordugaster sp*	x	x	x	x	x	x	x
	Aeshnidae	*Aeshna sp*	x	x	x	x	-	-	x
	Coenagrionidae	*Coenagrion sp*	x	-	-	x	x	x	x
	Agriidae	*Agrion sp*	x	x	x	x	-	-	x
Lepidoptera	Pyralidae	*Elophila sp*	x	x	x	x	x	x	x
Trichoptera	Hydropsychidae	*Hydropsyche sp*	x	x	x	x	x	x	x
		Cheumatopsyche	x	x	x	x	x	x	x
	Leptoceriidae	*Anthripsodes sp*	x	x	x	x	x	x	x
Plecoptera	Perlidae	*Perla sp*	x	x	x	x	-	-	-
	Nemouridae	*Nemoura sp*	x	x	-	-	-	-	-
		Dimocras sp	x	x	-	x	-	-	-
Coleoptera	Elmidae	*Elmis sp*	x	x	x	x	x	x	x
	Dytiscidae	*Platambus sp*	-	x	x	x	x	-	-
	Gyrinidae	*Gyrinus sp*	-	x	x	x	x	-	-
Gastropoda	Sphaeridae	*Pisidium sp*	x	x	x	x	x	x	x
	Corbiculidae	*Corbicula sp*	-	-	-	-	x	x	-
Hemiptera	Belostomatidae	*Belostoma sp*	-	-	-	x	-	-	x
	Corixidae	*Corisella sp*	x	-	x	x	x	x	x
	Naucoridae	*Naucoris sp*	-	-	x	x	x	x	x
	Notonectidae		x	x	x	-	-	-	x
	Veliidae	*Microvelia sp*	-	-	-	x	-	-	-
Oligochaeta	Lumbricidae	*Lumbricus sp*	x	x	x	x	x	x	x

4.5 Relative abundance of macroinvertebrates

The relative abundance of macroinvertebrates sampled in different stations in Nyangores stream during the study period is shown in (Figure 11). Station NY1 recorded the highest EPT representing 51.5% of the total abundance followed by Diptera with 20.5%, Gastropoda with 10.9%, a total of 11 orders were obtained in this station. A total of 11 orders were also obtained in station NY2 and EPT represented 43.9% followed by Diptera with 26.5% of the total abundance, Hemiptera recorded a relative abundance of 4.8% while Lepidoptera had the lowest abundance (0.4%). Station NY3 recorded 11 orders with EPT dominating (39.2%) followed by Diptera at 27.6% of the total abundance, the remaining orders had lower abundance. EPT also dominated station NY4 (38.4%) followed by Diptera with 31.9% and in station NY5, EPT had a relative abundance of 39.4% followed by Diptera (36.4%) then Oligochaeta (7.3%). Diptera was the most abundant in stations NY6 and NY7 with 44.3% and 41%, respectively followed by EPT with 23.4% and 24.4%, respectively. Station NY7 recorded a higher relative abundance of Lepidoptera (2.1%) compared to other stations which recorded lower abundances. Oligochaeta had a higher relative abundance in station NY4 (11.8%) and lowest in NY1 (4.3%). The remaining orders recorded lower abundances with Coleoptera and EPT decreasing downstream while Diptera and Lepidoptera increased downstream.

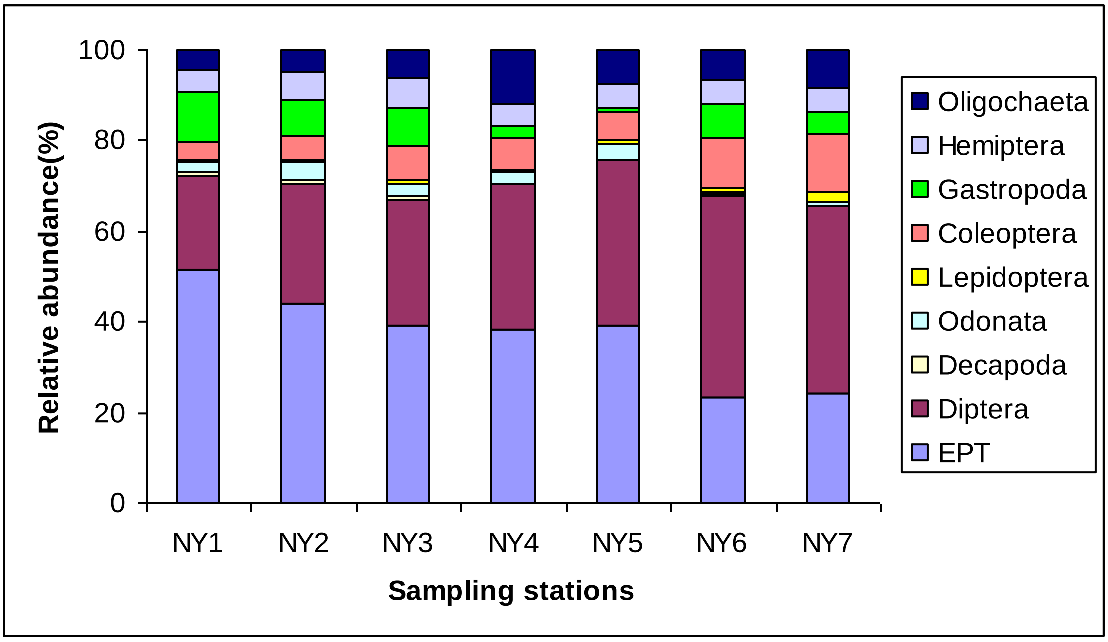

Figure 11: Relative abundance of macroinvertebrate taxa collected from each station in Nyangores stream during the study period

4.5.1 Relative abundance of EPT

Ephemeroptera was highly distributed in all stations with the highest relative abundance in station NY1 (36.5%) and lowest in station NY6 (15.4%) of all the taxa encountered (Figure 12). Plecoptera was abundant in NY1 representing 6.9% of all the taxa but it was not encountered in NY5, NY6 and NY7. Trichoptera was also encountered in all the stations with the lowest relative abundance in station NY7 (3.2%) and the highest in station NY2 (11.8%). There were significant differences in the EPT abundance between stations (H= 32.74, p <0.001) but no temporal difference.

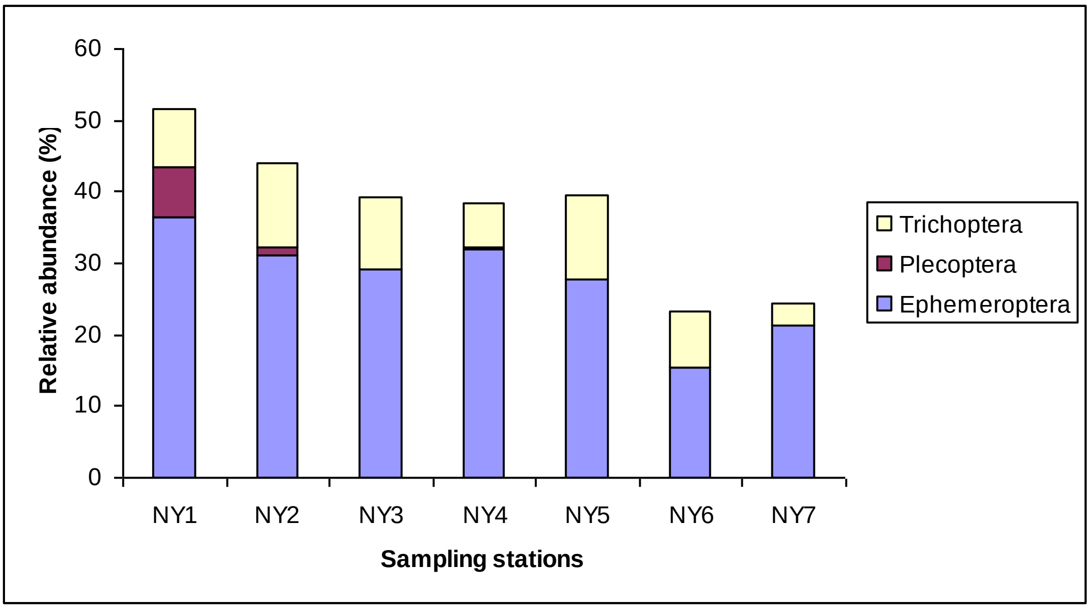

Figure 12: Relative abundance of EPT taxa collected from each station in Nyangores stream during the study period

4.6 Diversity of macroinvertebrates

The species richness and diversity of macroinvertebrates are shown in Table 9. The mean (±SE) taxon richness was highest in station NY1 (10.3±0.55) while the lowest was recorded in station NY6 (4.26 ±0.36). Station NY1 recorded the highest diversity (2.50±0.4) followed by station NY2 (2.32±0.89) while the lowest diversity was recorded in station NY6 with (1.12 ± 0.09). The evenness index was highest in station NY1 (0.79±0.16) while the lowest was recorded in station NY7 (0.40 ± 0.05).

Table 9: The diversity of macroinvertebrate communities at each station in Nyangores stream during the study period

	Sampling Stations						
Composition Measures	**NY1**	**NY2**	**NY3**	**NY4**	**NY5**	**NY6**	**NY7**
Number of Genera	34	29	32	36	31	29	31
Richness index $1/D_S$	10.3±0.55	9.73±1.37	10.02±0.55	6.89±0.5	6.37±0.69	4.26±0.36	5.38±0.74
Diversity index (H')	2.50±0.4	2.32±0.89	1.98±0.08	1.65±0.09	1.59±0.08	1.12±0.09	1.14±0.14
Evenness index (e)	0.79±0.16	0.75±0.02	0.61±0.02	0.52±0.03	0.53±0.04	0.41±0.02	0.40±0.05

4.6.1 Relationships between macroinvertebrates community structure and physical chemical parameters

Canonical correspondence analysis (CCA) ordination plot revealed significant relationships between macroinvertebrate communities and measured physical and chemical water quality variables (Figure 13). Plecoptera were negatively correlated with nutrients while Diptera, Coleoptera and Lepidoptera were positively correlated to TSS. Trichoptera, Hemiptera and Gastropoda were positively correlated to pH and Odonata were positively correlated to both temperature and BOD.

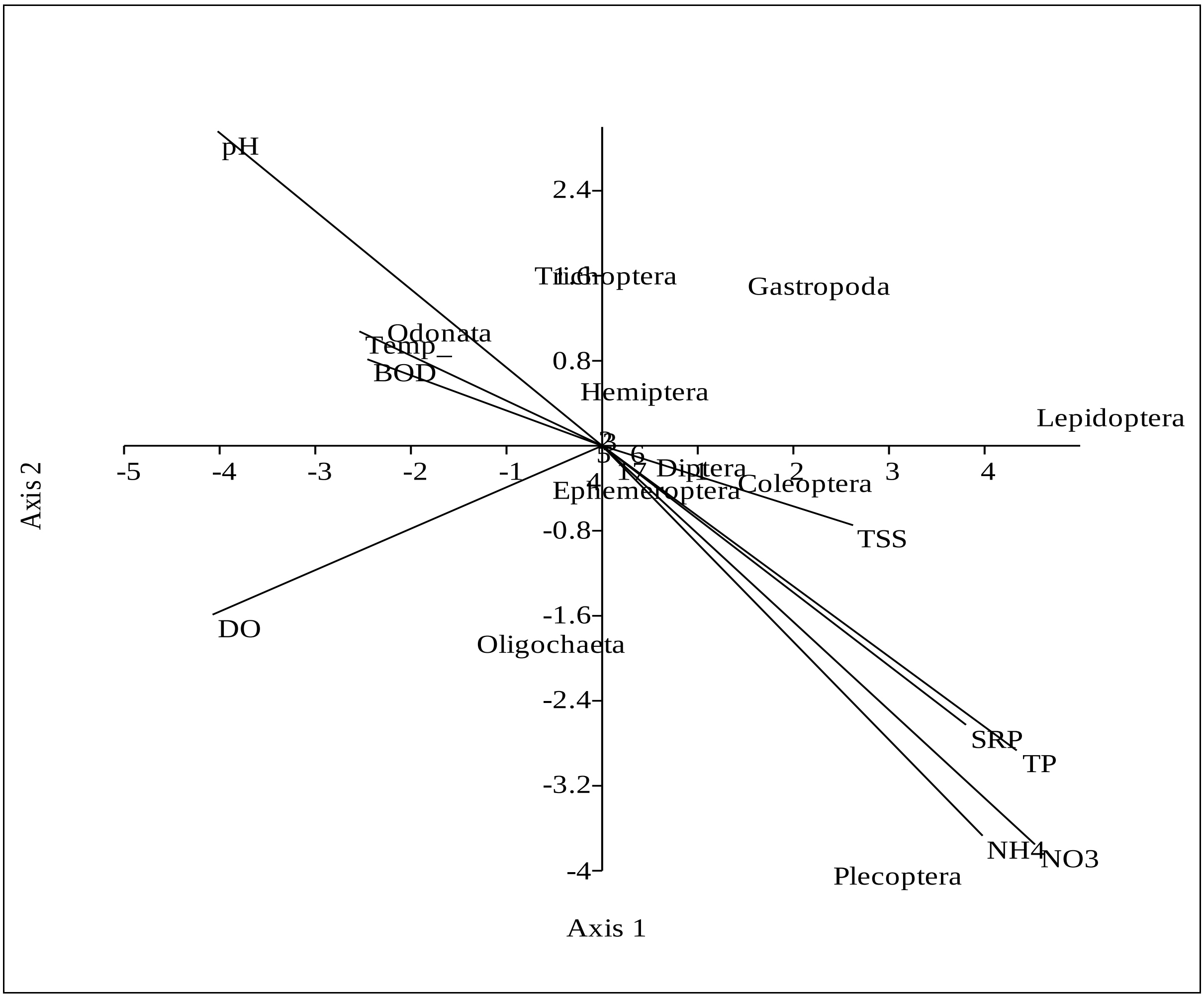

Figure 13: Canonical correspondence analysis (CCA) plots for macroinvertebrate species responses to environmental variables in Nyangores stream. Arrow length is proportional to the relative importance of a physico-chemical parameter

The relative magnitude of Eigen values for each of the CCA axis is an indication of the relative importance of the axis (Table 10). CCA axis 1 accounted for 48.76% of total variance of the data set and in total the first three axes of the ordination accounted for 71.87% of the variance suggesting strong correlation between community data and water quality variables. The statistical significance of the model (Monte Carlo permutation test) and Eigen value for axes 1 and 3 were significant ($p < 0.05$).

Table 10: Properties of the Canonical Correlation Analysis ordination bi-plot for the Nyangores stream macroinvertebrates communities and water quality variables in different sampling stations

Canonical properties	**Axes**		
	Axis 1	**Axis 2**	**Axis 3**
Canonical Eigen value	0.177	0.043	0.041
% Variance explained	48.76	11.81	11.3
% Cumulative variance explained	48.76	60.57	71.87
Monte Carlo test p-value	0.01	0.09	0.01

The Pearson correlation revealed significant relationships between macroinvertebrate community attributes and physicochemical parameters Table 11. Most macroinvertebrate attributes had significant relationship with physicochemical parameters. Abundance had a negative relationship with most physico-chemical parameters except DO and pH. Diversity and evenness had also significant relationship with most parameters except discharge and pH while dominance had no significance with any physico-chemical parameter Table 11.

Table 11: Pearson correlations among physico-chemical parameters and macroinvertebrate community attributes in Nyangores stream during the study period. Values in bold indicate significant differences at *p* < 0.05.

Parameters	Abundance	Dominance	Diversity	Evenness
Discharge	**-0.39**	0.18	-0.24	-0.19
BOD	**-0.51**	-0.02	**-0.51**	**-0.54**
Temp	**-0.31**	-0.01	**-0.41**	**-0.46**
DO	0.3	-0.21	**0.49**	**0.47**
TSS	**-0.54**	0.22	**-0.43**	**-0.39**
Conductivity	**-0.59**	0.04	**-0.82**	**-0.83**
pH	0.11	-0.06	0.09	0.05
NO2	**-0.62**	0.22	**-0.54**	**-0.52**
NH4	**-0.33**	0.29	**-0.33**	-0.29
NO3	**-0.63**	0.14	**-0.67**	**-0.63**
TP	**-0.52**	0.24	**-0.51**	**-0.47**
SRP	**-0.64**	0.18	**-0.61**	**-0.56**

CHAPTER FIVE

DISCUSSION

5.0 Variations in physico-chemical parameters

The spatial variation in temperature in Nyangores stream is attributed to modification of the riparian vegetation in stations at the lower reaches hence no or little canopy cover at most places resulting to increased solar radiation reaching the surface of the water leading to high water temperature. Unlike station NY1 that had good riparian vegetation that regulates the water temperature since the rise in stream temperature is related to the amount of surface water that is exposed to solar radiation. Therefore the sufficient canopy cover in station NY1 regulated the temperature. Variation in altitude can also explain the variation in temperature in the stream since the altitude is higher in the upper reaches (2070 m above sea level) and lower in lower reaches (1855 m above sea level). Similar observations were made by Masese *et al*., (2009) in Moiben River.

Station NY1 and NY2 recorded the highest dissolved oxygen levels which could be related to the lower temperatures in the two stations which is moderated by canopy cover and decreased human activities at these stations. Turbulent water in the stations could have also oxygenated the water. The decline in DO at downstream stations could be attributed to reduced flow velocity and increased temperature. Increased water temperature decreases solubility of oxygen in water and increased velocity increases the amount of oxygen in water (Allan, 2004). High organic load could be another factor that contributed to decreased DO concentration levels in downstream stations. Organic wastes use a lot of dissolved oxygen in water during decomposition

(Busulwa and Bailey, 2004). The organic wastes are discharged into the stream from urban centres and residential areas. This was evident in station NY4 located near Tenwek and NY6 located near Bomet town. This finding concurs with Muwanga and Barifaijo (2006) who reported low oxygen levels in Kinawattaka stream, Uganda.

Conductivity reveals the condition of dissolved inorganic constituents in water (Jonnalagadda and Mhere, 2001). An increase in conductivity was recorded in stations that were located in the lower reaches of the Nyangores stream. This was attributed to discharge of sewage effluents and runoff from agricultural areas into the stream. The low conductivity levels in station NY1 can be linked to minimal disturbance in this area unlike in station NY7 which recorded highest conductivity levels. The conductivity levels in the Nyangores stream increased with increase in nutrient levels. This conforms to the findings of Minaya (2010) who reported significant differences in electrical conductivity in the Mara River.

The pH levels in the stream did not change so much during the study period. However, spatial variations were recorded; this can be due to leaching of fertilizers and manure during the rainy season. The fertilizer is used in farms that grow maize and tea. Low pH in station NY1 was linked to less impact in the stream. The pH values of Nyangores stream were in the permissible range for natural waters (6.0-8.5). This result concurs with GLOWS (2007) who reported that pH levels in the Mara River ranged between 6.0 and 8.5.

The high TSS levels in the middle and lower reaches of Nyangores stream can be attributed to agricultural activities. The predominant agricultural activity in these stations is maize farming which does not take place all year round, at some time the soil is left bare and maize takes time to grow to hold the soil firmly. During the rainy season, a lot of sediments are carried from the bare farmlands into the stream resulting in high levels of suspended solids. The high TSS can also be attributed to animal footpaths and poor agricultural practices such as the removal of protective vegetative riparian buffers, excessive pesticide and fertilizer application and wetland destruction. The low TSS levels in station NY1 is due to little human disturbance and good riparian vegetation which whose roots hold the soil together and leaves reduces the impact of rain on the soil thus reducing soil erosion. Temporal variation in TSS can be linked to sediment loads from agricultural areas during the rainy season. The high flows during the wet season are due to high amounts of water. There were low flows in station NY1 due to unmodified channel and high flows downstream due to modified channel as a result of human activities such as the destruction of riparian zone. Similar results were found in Njoro River, Kenya where Kibichii *et al*., (2007) found that TSS levels increased with increased degradation of the riparian zone. Maldonaldo (2010) also reported significant differences in TSS level along the Mara River, Kenya.

The spatial variation in BOD was attributed to different human activities along the stream. Station NY1 which was located in a forested area recorded the lowest BOD. The station was characterised by little human disturbance. Increased human activities downstream reflected in in-stream and near stream activities such as bathing, livestock watering and agriculture resulted in high BOD levels. Discharge of effluents from urban centres, livestock watering in the stream increases organic wastes in streams. Similar observations were made by Masese *et al*., (2009) in the Moiben

River where BOD levels increased with increased pollution and Kasangaki *et al*., (2008) in high-altitude rainforest streams, Uganda.

Most physical and chemical parameters of water in the Nyangores stream differed spatially and temporally. This variation can be attributed to anthropogenic activities along the stream, for instance, clearing of forests to create land for agriculture. The changes lead to increased concentration of nutrients, temperature, TSS and conductivity.

5.1 Nutrients

Most nutrients in Nyangores stream differed significantly between stations and with sampling period. There was an increase in nutrient concentrations downstream due to increased human activities. The increase in nitrate concentrations downstream could be as a result of excessive use of nitrogenous fertilizers in maize farmlands, these fertilizers get their way into the stream by runoff. This was more evident in station NY7 which recorded the highest nitrate and ammonia levels since the station was severely degraded due to crop cultivation and consistent input of wastes from livestock. Grazing and animal watering point was evident. Station NY1 had the lowest nitrate levels since it was less impacted by human activities. Similar observations were made in Njoro River, Kenya by Mokaya *et al*., (2004) and Aura *et al*., (2010) who recorded high nutrient levels downstream of Sosiani and Kipkarren River in Lake Victoria basin, Kenya.

Nitrite concentrations along the stream had similar pattern like nitrates with low levels recorded in less impacted stations. The concentrations however, increased downstream due to agricultural activities such as crop farming with the intense use of fertilizers that probably leach to the stream during rainy season. The temporal variation of nitrites in the stream could be attributed to high flows that led to transport of wastes from agricultural land into the stream as a result of runoff. Lack of significant variations can however; be attributed to re-suspension of nutrients during the wet season (Yillia *et al*, 2008). Similar findings were reported by McCarteny, (2010) in the Mara River.

An increase in total phosphorus in the middle and lower reaches of the stream can be linked to effluent discharge from water treatment plant in station NY4. Increased TP can be as a result of non-point sources such as runoff from residential and agricultural areas. This is evident in station NY5 and NY6 that were located in both residential and agricultural areas. However, the highest SRP and TP concentrations recorded in station NY7 was attributed to agricultural activities such as application of fertilizers and human activities such as washing and bathing in the stream resulting in increased amount of phosphorus due to use of detergents. This can explain the high TP and SRP levels during the wet season. Temporal variation in SRP levels on the other hand can be as a result of run off from agricultural areas and re-suspension during the wet season but during the dry seasons human activities such as washing and bathing, and watering of livestock in the stream are the major contributors. High TP and SRP levels during the wet seasons were attributed to re-suspension of nutrients and sediments which play a very important role in transport of particulate phosphorus, (Dabrowski *et al*., 2002). This observation concurs with Raburu *et al*., (2009) who recorded high total phosphorus levels in agricultural areas of the Nyando River, and Madonaldo, (2010) in the Mara River.

5.2 Habitat quality

The habitat degradation downstream Nyangores stream downstream stations in the Nyangores was associated with watershed agriculture and the consequent shift and removal of riparian vegetation. Agricultural activities in the stream shifted the riparian vegetation from heterogenous natural condition to agricultural crops and exotic trees. The good quality habitat recorded in station NY1 was due to less human impact. Increased degradation and removal of riparian vegetation downstream resulted to poor habitat integrity. Habitat metrics such as stability of the bank, channel condition and clarity of water were adversely affected at these sites. The poor condition of the channel in station NY6 and NY7 was due to the influence of animals which trample on the banks while watering. The poor riparian zone and bank stability in lower reaches could also be linked to human activities like degradation of the forests leaving the banks bare and livestock which makes the banks unstable leading to sedimentation. Deterioration of habitat integrity in Nyangores stream can be as a result of human actvities such as overabstraction of water,removal of riparian vegetation, bank erosion and modification of stream bed. Braccia and Voshell, (2006) reported low habitat integrity due to household waste discharge, manure domestic animals near the river bank and removal of riparian vegetation.

The clarity of water decreased downstream the Nyangores stream may be as a result of soil erosion due to poor agricultural activities. Canopy cover, riffle embeddness and macroinvertebrates observed scored highly in the upper reaches but decreased downstream due to human influence. This was more evident in station NY7 which had little canopy cover and less micro-habitats for macroinvertebrates. Poor riffle embeddeness was linked to the livestock watering which made the sediments loose hence lowering this element in lower reaches. A similar study in the Mara River by Madonaldo (2010), recorded a high habitat quality in the forested areas and decreased habitat quality downstream.

5.3 Coliform bacteria

Bacterial counts in streams tend to increase during high flows and decrease during base flows as a result of runoff (Medema *et al*.,2003). A significant source of pollutants in rivers and streams is storm water runoff which can include sediments and bacteria (Mallin *et al*., 2000). During the study period, high levels of both total coliform and *Escherichia coli* (fecal coliform) were recorded during the wet season. This was attributed to sedimentation and storm water discharge which introduces faecal materials from contaminated areas to streams.

The microbial water quality of the stream was generally poor with faecal indicator levels higher than the recommended levels. The high levels during the wet season was attributed to storm runoff and leaching of wastes due to land use changes and human activities. Bacterial densities in streams tend to increase during high flows and decrease during the base flows as a result of surface run off which is also evident in the Nyangores stream. George *et al*., (2004) reported high bacteria levels during the wet season in the Seine River, Paris basin. Rain storms increase water velocity and introduce faecal materials from contaminated areas to streams through storm water discharge (George *et al*., 2004). Medema *et a*l., (2003) reported that self purification of water that may remove pathogens such as sunlight inactivation, dilution, sedimentation and predation does not occur during the wet season as compared to the dry season when the velocity of water is low.

The highest coliform bacteria was recorded in station NY3 which was attributed to effluent discharges from the Tenwek sewage treatment plant, the station was located downstream of the sewage treatment plant. Livestock grazing is common in the in the Nyangores area and most residents do not have access to proper sanitation, therefore surface runoff from residential areas and farmlands contain high bacteria density. Animal watering points had high bacterial densities due to animal wastes in this areas. This conforms to Yillia *et al*., (2007), who reported high levels of coliform bacteria as a result of runoff from farmlands and residential areas in the Njoro River, Lake Victoria Basin.

In the Nyangores stream, runoff and discharge influenced the high number of coliform bacteria. This is evident in the lower reaches of the stream which had high counts of bacteria due to increased flows and runoff during the wet season. High concentrations of bacteria in the lower reaches of Nyangores stream can also be attributed to high TSS levels. The suspended particles facilitate their survival and growth since the particles protect them from attack by bacteriophage and UV-radiation and provide organic and inorganic nutrient to the bacteria (Medema *et al*., 2003). The concentrations of coliform bacteria is strongly influenced by spatial distribution, amount of rainfall, runoff, stream flow and light penetration (Medema *et al*., 2003). The survival and growth rate of coliform bacteria is influenced by physico-chemical parameters of water. A study by Murphy (2007) reported high TSS levels which resulted to high numbers of bacteria since suspended particles provide attachment areas for the bacteria.

The high coliform bacteria in the middle and lower reaches of the stream can easily be related to illness in the community since most people are exposed to the bacteria by drinking contaminated water. Residents around the Nyangores stream lack access to clean water therefore depend on water from the stream that is contaminated. In general the spatial and temporal variations in coliform bacteria can be linked to point and non point sources of pollution in the Nyangores stream. Studies done by Gereta *et al*., (2002) and GLOWS (2007) in the Mara River have also reported waterborne diseases caused by contaminated water in the Mara River Basin.

5.4 Composition and distribution of macroinvertebrates

The most dominant taxa in the Nyangores stream were the Ephemeroptera followed by Diptera while the least dominant taxa were Decapoda and Lepidoptera. The low abundances of Ephemeroptera at the downstream station (NY5 to NY7) could be as a result of increased human activities. Human activities such as destruction of riparian vegetation might have contributed to low abundance through reduction in allochthonous energy inputs hence reduced food for the aquatic insects (Masese and McClain, 2012). These findings conform to those of Masese *et al*., (2009) in the Moiben River and McCartney (2010) in the Mara River.

Higher proportion of Diptera taxa in the downstream stations of the Nyangores stream can be associated with higher ecological impairment. The impairment can be linked to sedimentation due to poor agricultural practices and livestock activities such as weakening the river banks. The Diptera (*Chironomous*) was dominant in agricultural areas as evident in the middle and lower reaches of the Nyangores stream. The genus *Chironomous* was widely distributed in the stream, where it was encountered in all stations. This can be due to the fact the taxa is able to tolerate organic pollution and able to colonize low oxygen habitats by using haemoglobin as a means of respiring more efficiently during low-oxygen concentration in streams (Barbour *et al.*, 1999). Tolerant organisms tend to increase with perturbation (Barbour *et al*., 1999). High abundance of Diptera was also reported by Aura *et al*., (2010) in Sosiani River, Lake Victoria basin.

The highest EPT taxa was recorded in station NY1 and decreased downstream, while the lowest was recorded in station NY7. Plecopterans were poorly distributed along the stream with middle and lower reaches recording a complete absence in abundance. The EPT taxa dominated in station NY1 since it is sensitive to pollution and is associated with pristine environment (Buss *et al*., 2002). Station NY1 is a headwater station with minimal human disturbance and had good habitat quality. The middle and lower reaches were characterised by agricultural activities which release animal and agricultural wastes into the stream thus affecting the quality of water. This was evident in station NY3- NY7 which had little or no canopy cover and is used as animal watering points. This finding concurs with Kibichii *et al*., (2007) who reported high abundance of EPT in forested stations and lower abundances downstream due to different levels of degradation along Njoro River.

The middle and lower reaches of Nyangores stream are characterised by human activities such as maize plantations and livestock rearing, these activities intensified downstream. In stations like station NY3 and NY5 cultivation of maize is done in the riparian zone, grazing and animal watering is common along the stream. Livestock alter the stream substrate leading to destruction of invertebrate habitats and agricultural wastes such as fertilizers have the potential to influence the biotic and abiotic characteristics in streams (Mathooko, 2001). Higher values in macroinvertebrates during the dry season were due to physical stability as a result of low velocity whereas during the rainy season changes like increase in water velocity results in population shifts that lead to uniform distribution. A study in the Mara by McCartney (2010) also reported high abundance of macroinvertebrates in the Mara River during the dry season.

The diversity of macroinvertebrates was high in station NY1 located in forested area. The station is a good source of allochthonous organic matter for the invertebrates and had diverse and quality habitats. The diversity of macroinvertebrates declined downstream, this could be attributed to increased sedimentation and high organic matter in these stations. Excessive sediment load as a result of adverse human activities in the watershed and the riparian zone is a major factor for decline of benthic communities in rivers and streams (Allan, 2004). Sediment affects the instream biotic community by reducing habitat, altering water movement, food quality and interstitial spacing (Wang and Lyons, 2003). Fine sediment decreases the diversity of instream biotic communities since the suspended solids absorb heat from sunlight, causing temperature increase and ultimately reduction in dissolved oxygen. This explains the low diversity recorded downstream the Nyangores stream and is in consistent with findings of Aura *et al*., (2010) who found low diversity of macroinvertebrates downstream of Sosiani and Kipkarren Rivers.

Stations located in the middle and lower reaches of the Nyangores stream were characterized by little or no riparian vegetation, livestock grazing, bank erosion, waste disposal among others. Tolerance of organisms to environmental conditions can explain the low level of diversity in lower reach of the stream since sensitive macroinvertebrates are eliminated while the tolerant ones dominate. Environmental factors reduce the function of the stream system to maintain biological diversity (Brown, 2007). The high abundance of Chironomidae might have masked any differences in the macroinvertebrate community structure. This finding conforms to Uieda and Ribeiro (2005) who suggested that the removal of Chironomidae group can show a different pattern in the diversity of macroinvertebrates because the group plays a big role in structuring aquatic communities.

The high richness in station NY1 is due to the presence of natural vegetation, which provides plenty of food for the insects and diverse macrohabitats such as riffles, runs and pools. The lower richness values in station NY7 was due to the sum of anthropogenic activities such as agriculture and few macrohabitats. Abundance of Chironomidae can be due to its rapid growth rate and its ability to tolerate pollution (Callisto *et al.*, 2001). This study is similar to Aura *et al.*, (2010) who reported that richness of macroinvertebrates can be influenced by hydrological regimes and perturbations.

5.5. Relationships between macroinvertebrates diversity, abundance and physico- chemical parameters

The variation in macroinvertebrate taxa among sites in the Nyangores stream was influenced by BOD, temperature, conductivity and nitrites. Taxa that were negatively correlated with these variables include Perlidae and Nemouridae, while Coenagriidae, Naucoridae, Dytiscidae and Corbiculidae were positively correlated. Most taxa that were clustered in the centre did not show any preference to water quality parameters especially pH. Elmidae, Belistomatidae and Veliidae were positively correlated with discharge, TP and NO3. Negative correlation of both Perlidae and Nemouridae can be attributed to the fact that both families are sensitive to pollution. Therefore any deterioration in water quality parameters affects their growth and survival. The positive correlation with physico-chemical parameters in Dytiscidae, Corbiculidae and Naucoridae means that an improvement in the water quality parameters will favour the growth and survival of these taxa. This study conforms to Aura *et al*., (2010) who reported that low nutrient levels in Sosiani and Kipkarren Rivers resulted in an increase in abundance of sensitive macroinvertebrates while taxa like Oligochaeta increased with increase in nutrient levels.

The negative correlation in abundance, diversity and evenness with all physicochemical parameters can be due to the fact that high nutrient levels affect the survival and growth of macroinvertebrates resulting in low abundance. Increased discharge also led to destruction of microhabitats such as pools and riffles during the rainy season resulting in decreased abundance. The same observation was made by Masese *et al*., (2009) who reported a decreased abundance of macroinvertebrates in nutrient rich areas in the Moiben River, Lake Victoria basin.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.0. Conclusions

- The results from the Nyangores stream indicated significant spatio-temporal changes in physic-chemical parameters
- Stations that were located in agricultural and downstream effluent discharge points recorded the highest number of both *E. coli* and total coliforms. This implies that coliform bacteria counts were influenced by both point and non-point sources of pollution.
- High abundance and diversity of macroinvertebrates was recorded in stations with little impact from human activities but decreased downstream due to destruction of macroinvertebrate habitats and pollution.
- Ephemeroptera dominated in the study area and decreased downstream followed by diptera taxa which increased downstream.
- The EPT index was high in least impacted stations and low in degraded stations.
- The quality of habitat in Nyangores stream was good in the upstream station which served as a reference site; however, the downstream stations recorded a poor habitat quality which was attributed to different levels of degradation along the stream.
- All macroinvertebrate community attributes and taxa were significantly correlated to water quality parameters in the stream with some positively and others negatively. This study therefore has linked the downstream decrease in macroinvertebrate attributes such as diversity and evenness to human activities such as agricultural land-use intensification in downstream stations.

6.1 Recommendations

Based on my findings, I recommend the following:

- Riparian land use should be controlled and buffer zones reclaimed and replanted with indigenous trees to protect the stream from the impact of adjacent land uses.
- Bomet county should invest in sewage treatment plants, this will reduce the levels of nutrients and bacteria in surface water
- The efficiency of wetland plants in Tenwek mission hospital should be studied. The constructed wetland in Tenwek should use more efficient wetland plants such as *Cyperus papyrus* to remove nutrients from wastewater.
- Biomonitoring protocols to be encouraged because of their sensitivity to declining habitats and water quality status.
- Transboundary management plan for the Mara river should be established by taking into account the cost-benefit analysis of deforestation and irrigation

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APPENDICES

Appendix 1: Stream Visual Assessment Protocol

Stream Visual Assessment Protocol

(Modified by the Rutgers Cooperative Extension Water Resources Program, www.water.rutgers.edu)

PROJECT:

Evaluators

Name____________________________________Date_______________________Time__

Property Owners Name (if applicable) _____________________________________

Stream Name____ Grid ID________________

Reach Location ____

Applicable Reference Site____

GPS Coordinates (in degrees, minutes, and seconds):______________________________

Weather conditions today________________________________ past 2-5 days__________

Active channel width_ ft *Dominant* substrate (*circle one*): boulder cobble gravel sand silt mud

Site Diagram: Note direction of flow, pipes, photo locations, stream characteristics, storm water infrastructure, & ditches.

Photo Notes:

1.____

2.____

3.____

4.____

5.____

6.____

7.____

8.____

9.____

10.____

Assessment Scores (1-Poor to 10-Excellent) * (facing upstream) *****

Channel Condition ☐

Hydrologic Alteration ☐

(Score only if Applicable)

Riparian Zone Left: ☐ Right: ☐

Bank Stability Left: ☐ Right: ☐

Water Appearance ☐

Nutrient Enrichment ☐

Barriers to fish movement ☐

Instream fish cover ☐

Pools ☐

Invertebrate habitat ☐

Score only if applicable

Canopy cover ☐
(Use manual for guidance)

Manure presence ☐

Salinity ☐

Riffle embeddness ☐
(Look in riffles)

Macroinvertebrates observed
(Optional) ☐

Overall score	< 6.0	Poor
(Total divided by the number scored)	6.1- 7.4	Fair
Left:______Right:______Average:____	7.5- 8.9	Good
	> 9.0	Excellent

Streamside Land Use

(Within 100 ft. of top of bank)
Check all that apply

Land Use Category	**While observed in the field**	
	Left Bank	**Right Bank**
Forest		
Pasture		
Cultivated field		
Nursery		
Residential		
Commercial		
Industrial		
Other		

Outfall Pipe 1: (Photo #_and mark on site diagram)GPS Coordinates__________________N

Diameter:___________in ____________________W

Headwall? YES NO Double culvert? YES NO Stream bank at outfall eroded?

YES NO

Pipe Material: concrete steel PVC Clay Other

Location of Pipe: in stream, at top of bank, in bank, out of/ under bridge, other__________

Channel downstream eroded? YES NO

Pipe gathers water from (road, yard, farm, etc.):_____________________________________

Flow appearance: clear turbid oily foamy colored other________

Outfall Pipe 2: (Photo # __and mark on site diagram) GPS Coordinates_______________ N

Diameter: __________in ________________W

Headwall? YES NO Double culvert? YES NO Stream bank at outfall eroded? YES NO

Pipe Material: concrete steel PVC Clay Other

Location of Pipe: in stream, at top of bank, in bank, out of/ under bridge, other___________

Channel downstream eroded? YES NO

Pipe gathers water from (road, yard, farm, etc.):___________________________________

Flow appearance: clear turbid oily foamy colored other________

Drainage Ditch: (Photograph #__ and mark on site diagram) GPS Coordinates __________N

Width of ditch_________ft __________W

Begins at: ____________________ Ditch lining: stone, vegetation, concrete, mud, other____

Ditch is: Stable, Eroding Ditch Flow is: none, intermittent, steady

Stream channel downstream is: stable, eroded, silted Flow is: clear, cloudy, oily, foamy, colored

Ditch comes from:

Drainage Ditch: (Photograph #__ and mark on site diagram) GPS Coordinates __________N

Width of ditch_______ft _________W

Begins at: _______________ Ditch lining: stone, vegetation, concrete, mud, other_________

Ditch is: Stable, Eroding Ditch Flow is: none, intermittent, steady

Stream channel downstream is: stable, eroded, silted Flow is: clear, cloudy, oily, foamy, colored

Ditch comes from:

Comments & Suggestions:

Do you have suggestions for remediation along this reach?

Given dry weather, is there any running water in nearby storm water structures?

Access to this site…how far off of road is it? Accessible for large equipment, if necessary?

Debris, trash, litter?

Additional comments:

Appendix 2: ANOVA Tables

Spatial variation in physico-chemical parameters

	NY1	NY2	NY3	NY4	NY5	NY6	NY7	p	F
Temperature	17.324^a	19.055^a	32.437^d	29.092^c	28.806^c	26.505^c	24.508^b	0.000	45.38
DO	7.55^c	7.55^c	6.84^b	7.08^c	7.17^c	5.74^a	7.06^c	0.000	13.00
pH	7.13^a	8.19^c	7.90^b	7.78^b	7.34^a	7.42^a	7.70^b	0.000	7.25
Conductivity	98.23^a	104.69^a	141.50^b	148.95^b	159.14^c	166.55^c	172.76^c	0.000	18.66
BOD	0.35^a	0.67^b	1.27^d	1.11^d	1.36^d	0.84^c	1.27^d	0.000	30.38
TSS	67.93^a	115.13^b	154.14^b	186.42^b	204.22^b	227.79^c	275.68^c	0.003	3.95
Discharge	1.02^a	1.19^b	1.34^b	1.63^b	2.02^b	2.32^c	2.95^c	0.003	3.91

Temporal variation in physico-chemical parameters

	1	2	3	4	5	6	7	8	p	F
Temperature	22.56^b	25.51^c	26.6^c	25.88^c	25.26^c	25.6^c	25.66^c	26.06^c	0.950	0.30
DO	7.33^c	6.67^b	7.12^c	7.13^c	6.97^c	6.93^c	6.98^c	6.87^c	0.845	0.48
pH	8.13^d	7.60^c	7.35^b	7.57^b	7.83^c	7.53^b	7.56^b	7.47^b	0.104	1.82
Conductivity	134.56^b	117.60^a	137.66^b	156.6^c	158.37^c	157.93^c	137.64^b	133.15^b	0.204	1.46
BOD	1.02^c	0.93^b	0.95^b	0.97^b	1.02^c	0.94^b	0.96^b	1.06^c	0.998	0.09
TSS	93.18^a	93.32^a	97.14^a	94.99^a	183.38^b	300.42^d	316.61^d	228.18^c	0.000	11.50

Spatial variation in nutrients

	NY1	NY2	NY3	NY4	NY5	NY6	NY7	p	F
NH_4	0.016^a	0.019^a	0.031^a	0.064^b	0.069^b	0.083^b	0.089^b	0.056	2.231
NO_2	1.74^a	1.97^a	2.94^a	3.13^b	4.63^b	4.79^c	4.98^c	0.001	4.403
NO_3	0.055^a	0.074^a	0.13^b	0.26^b	0.26^b	0.28^c	0.43^d	0.000	8.198
SRP	0.030^a	0.039^a	0.064^b	0.102^c	0.141^c	0.152^d	0.182^d	0.000	17.605
TP	0.12^a	0.13^a	0.15^a	0.18^a	0.18^a	0.20^a	0.23^a	0.869	0.524

Temporal Variation in Nutrients

	M1	M2	M3	M4	M5	M6	M7	M8	p	F
NH_4	0.015^a	0.014^a	0.018^a	0.042^a	0.015^a	0.096^b	0.11^b	0.11^b	0.000	6.288
NO_2	1.44^a	1.74^b	2.05^b	4.34^d	3.49^b	4.95^d	5.52^d	4.09^c	0.000	5.930
NO_3	0.069^a	0.067^a	0.17^b	0.25^b	0.19^b	0.32^b	0.33^b	0.30^b	0.007	3.200
SRP	0.075^a	0.075^a	0.072^a	0.074^a	0.083^a	0.14^b	0.15^b	0.15^b	0.038	2.345
TP	0.079^a	0.074^a	0.082^a	0.11^a	0.12^a	0.32^c	0.33^c	0.26^b	0.000	31.069

Appendix 3: Publications and Conference Presentations

1. Gichana M. Zipporah, “ Proposal; *Effects of Land use changes on water quality & benthic biota in the Mara River Basin, Kenya”* Water Resources Management Authority & key stakeholders in Mara River Basin Workshop, Kericho Tea Hotel, June 2012

2. Gichana M. Zipporah, Njiru M., Raburu P,. *“Influence of land use changes on Water quality and benthic biota in the Nyangores stream Mara river basin”*, The third scientific conference on Lake Victoria basin in Entebbe Uganda, *23rd- 25th October 2012.*