INFLUENCE OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY OF NYANGORES AND AMALA TRIBUTARIES OF MARA RIVER, KENYA

By

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ABSTRACT

The Mara River and its tributaries are important, not only ecologically but socially, since they serve as the main source of water for inhabitants living within the basin. However, overdependence on their water resource has initiated concerns pertaining to human health because the two tributaries also serve as receptacles of waste resulting from anthropogenic activities particularly within Mulot and Bomet Towns, which lack waste treatment facilities, resulting in water quality degradation. However, the extent to which the water is polluted with respect to different uses and the spatial variation in pollutant levels, is not clear, which necessitated this study, whose main objective was to determine the influence of anthropogenic activities on water quality of Nyangores and Amala tributaries of the Mara River. The specific objectives were to: observe and describe site characteristics and on-going anthropogenic activities, identify and characterize solid waste resulting from anthropogenic activities and deposited within and along the river channels, determine variations in physico-chemical parameters, nutrients, benthic macroinvertebrates, and coliform bacterial levels resulting from antrhopogenic activities along Amala and Nyangores tributaries. This was a crossectional study in which eight sampling sites were purposively selected; four along each tributary. On each tributary, three sites (1.5km apart) were located within the urban areas (Bomet or Mulot) at the upper, middle and lower parts of each town, to effectively capture the influence of anthropogenic activities within the urbanized area on water quality. Also for each tributary, a fourth site was located approximately 20km upstream at a spring draining into the tributary, to act as a control. Site characteristics including on-going anthropogenic activities were observed and recorded, while solid waste was visually identified and categorized. Physico-chemical parameters were determined *in situ* while water samples for nutrients determination were collected in replicates and analysed in the laboratory following the standard methods outlined by the American Public Health Association. Benthic macroinvertebrates were sorted out from sediment samples and classified into taxa. Microbial analysis was performed on water samples using the multiple tube fermentation technique. Analysis of Variance followed by Duncan Multiple Range Test were used to determine variations in water quality parameters between sites along each tributary, while Student's t-test was used to establish differences in solid waste and water quality parameters between Amala and Nyangores tributaries. Regression analysis was used to describe relationships between the predictor and response variables. Results showed that all sites were disturbed by anthropogenic activities, except the upper catchment spring draining into Nyangores tributary, which was protected. Most (96.1%) of the solid waste encountered was recyclable, with polythene bags being dominant (48.9%). Significantly more (62.4%) waste was recorded along Amala than Nyangores tributary ($p=0.031$). Dissolved oxygen, conductivity, total suspended solids and total phosphorus varied significantly ($p<0.05$) between sites, along the two tributaries, while total phosphorus levels were significantly higher along Amala than Nyangores tributary ($p<0.02$). Total nitrogen levels varied significantly ($p<0.0001$) between sites along Nyangores tributary but, not Amala tributary. Benthic macroinvertebrate diversity was significantly higher along Nyangores than Amala tributary ($p=0.02$), with significant variations observed between different taxa along both tributaries ($p<0.0001$). Only total dissolved solid was predictive of benthic macroinvertebrates. *Escherichia coli* and total coliform levels varied significantly between sites along Nyangores tributary. However, only total coliform showed significant variation between sites along Amala tributary ($P=0.012$). Total nitrogen, pH and total suspended solids were predictive of *E. coli* abundance along the Mara River tributaries. Regular monitoring of water quality, maintenance of ecological integrity by controlling anthropogenic activities, proper sanitation and waste disposal practices, protection of water sources and public education with regard to water treatment before consumption are recommended based on the findings from this study.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Worldwide, rivers are aquatic systems most affected by anthropogenic activities because they provide ecosystem goods and services that sustain human societies; meaning that the genesis of anthropogenic impacts on rivers is as old as human history, dating back to early civilizations (Shaw, 2003). Earth's freshwater resources are severely limited, comprising less than three percent of global reserves. Furthermore, the bulk of this water is frozen or otherwise inaccessible for use (Miller, 2008). The uneven distribution of fresh water, coupled with variations in precipitation therefore complicates access to, and exploitation of freshwater resources. This is further worsened by the fact that the available viable freshwater resources are often unusable due to contamination with pathogens and other types of pollutants, thus making surface waters the singlemost cause of illness in most developing countries (NRDC, 2007).

Although progress has been made in providing more people with access to safe drinking water and sanitation facilties, many regions in developing countries still lag behind in terms of clean water availability and accessibility (NRDC, 2007). While Morisawa (1985) considered urbanization and industrialization as the most effective cause of water pollution, Tripathi and Pandey (1990) regarded human activity as the most important and of greatest concern. Likewise, Mokaya *et al.* (2004) observed that increased intensity of human activities on terrestrial ecosystems adjacent to water bodies, as was the case along some sections of the Mara River, often impacted negatively on quantity and quality of water in the aquatic system. With the advancement in science and technology, industries, tourist facilities, agricultural activities, urban developments and human settlements have sprung up along the banks of most rivers in the world, causing great impact on the discharge and morphology of these rivers, with subsequent degradation of their water quality (Sharma, 1987). According to UN WWAP (2003) an estimated 2 million tons of sewage, industrial and agricultural wastes are discharged into the world's waters every day. However, while many studies link anthropogenic activities to water quality degradation, most do not show the extent to which these water bodies are polluted with regard to various specific water uses. For instance, Xiao *et al.* (2006) reported that conversion of landscapes from natural and pervious to urban areas and impervious surfaces (buildings, roads, and parking lots) reduces the infiltration rates and increases the runoff rates, discharging with them a variety of waste into the river channels. These researchers did not however investigate the degree to which the water quality was impaired nor did their study show the suitability of the river water for domestic or other uses.

Waste discharge into rivers originates from various anthropogenic activities such as agriculture, laundry, livestock keeping, industries, urban development, among other sources (Xiao *et al.*, 2006). Increase in human population within a river basin can therefore contribute not only to water quality degradation but also to a reduction in stream levels resulting from over-abstraction, with potentially negative effects on the river's natural self purification processes (Sharma, 1987). Studies estimate that up to 18% of the world's population, or about 1.2 billion people (1 out of 3 in rural areas), defecate in the open due to insufficient communal sanitation facilities (WHO and UNICEF, 2008). This creates a tendency for faecal matter to become intermixed with surface waters thus compromising on the quality of rivers and as a result exposes the water users to waterborne diseases, especially when the water is used for domestic purposes like drinking and cooking (UNICEF and WHO, 2004).

Increased sewage discharge into aquatic systems may lead to high coliform levels, nutrient enrichment, altered physico-chemical water quality parameters as well as change in the structure and composition of benthic macroinvertebrates, thus alter the general ecology of the system (Kanu and Achi, 2011). Lack of proper management practices and laxity in enforcement of the existing regulations have exacerbated pollution problems in many parts of the world, with polluted water estimated to cause up to 4 billion diarrheal cases across the world yearly, resulting in 2.2 million deaths, mostly among children under the age of five (WHO and UNICEF, 2000). Hornberger (1998) attributed 80% of diseases and 33% of deaths in developing countries to consumption of contaminated water, while UNICEF (2006) approximated that about 1 billion people lack access to improved safe drinking water. A critical assessment of water quality is therefore essential in safeguarding human and ecosystem health.

Africa's fresh water resources play a critical role in supporting growing domestic and industrial needs, livelihoods and wildlife, and promoting food security (Curtin, 2003). Unfortunately the same resources are highly impacted by anthropogenic activites like deforestation, urbanization, river flow modification, destruction of riparian and wetland habitat, poor cultivation methods, overgrazing, extension of settlements into catchment areas, sewage discharge into aquatic systems, washing and bathing directly in the river among other destructive practices all of which threaten to further degrade freshwater resources permanently and irreversibly (UNEP, 2002; Kundzewicz *et al.*, 2007).

In Kenya, municipal waste form a large proportion of solid waste produced in many mushrooming urban centers especially those that lack large industries which could otherwise contribute to even larger quantitites of waste (Benneh *et al.,* 1993). Waste from such urban centres is commonly comprised of grocery polythene bags, broken glasses, plastic bottles, tin cans, office paper/newspaper, card boards, textiles, food remains among others (Leton and

Omotosho, 2004). In addition, increased anthropogenic activities also produce large quantities of sewage and waste-water which when discharged into aquatic systems mixes with river water resulting in water quality degradation (NISP, 2003). It has been established that since the capacity to handle solid and liquid waste generated in most urban centers in Kenya is normally weak, about 83% of the waste is often dumped in unauthorised sites, creating unsanitary conditions with significant consequences on water quality (JICA, 1998).

Water quality as defined by DWAF (1996) is the physical, chemical, biological and aesthetic condition of water that determines its fitness for human consumption and also the maintenance of a healthy ecosystem. A number of parameters can be used to determine the quality of water in a river, including physico-chemical parameters, nutrient levels, bacterial levels as well as benthic macroinvertebrate community structure. Kashian and Burton (2000) showed that the use of benthic macroinvertebrates as a measure of continous and chronic effects of pollutants on surface water quality is an effective monitoring tool in evaluating stream degradation from urban water runoff and point source discharges.

In addition, Karr and Yoder (2004) established that benthic macroinvertebrate indices such as the Shannon-Weinner diversity and evenness indices are equally important in determining the health of aquatic systems. Likewise, Adams and Papa (2000) linked high levels of turbidity, suspended solids, nutrients and coliform bacteria to compromised systems which they attributed mainly to solid and liquid waste resulting from anthropogenic activities, while USEPA (2002) reported that water quality can be determined by a combination of biological (benthic macroinvertebrates and coliforms), physico-chemical (dissolved oxygen, pH, conductivity, dissolved and suspended solids), and nutrient (phosphorus and nitrogen) levels in a water body. However, not many researchers have used a combination of these water quality parameters in establishing the impact of anthropogenic activities of the perennial Mara River tributaries as was done in this study.

The Mara River and its associated resources are of critical importance, not only ecologically but culturally, as they provide essential services to the people living within the basin. Dependence on this water resource has initiated concerns pertaining to scarcity and quality. Despite its' usefulness to the basin's inhabitants, the river is facing numerous challenges posed by the ever increasing anthropogenic activities. Most sections of the upper Mara River catchment, encompassing Amala and Nyangores tributaries, have been encroached upon, up to the river banks, in attemps to create room for human settlement and urbanization (Mati *et al.*, 2008).

In addition, sanitation facilities among households along the river are inadequate or ineffective, while some individuals still defecate in the bushes along the river banks. This coupled with lack of sewage treatment facilities in Mulot and Bomet Towns facilitates the introduction of pathogens, nutrients and other pollutants into the Mara River tributaries, resulting in water quality degradation (Mutie *et al.*, 2006). The extent to which the water in the two tributaries is contaminated and the potential risk to human health cannot, however, be established without analysis of the pollution levels using faecal indicator species such as *Escherichia coli* alongside other water quality parameters or indicators as was done in the current study.

Other studies have shown that over-abstraction to serve the rising population especially during the dry season can reduce the levels of water in the channel, raise the concentration of pollutants and interfere with ecosystem processes (Aboud *et al.*, 2002). This has far reaching consequences on the long-term sustainability of Mara River in terms of ecology, water quality and quantity (Gereta *et al.*, 2003). While acknowledging that seasonality plays a crucial role in water quality fluctuation in the Mara River, this study was conducted during the dry season to give a clear picture of localized and point source pollutants resulting from anthropogenic activities along the river during the period of low water levels.

Since the pollution levels along the Mara River like any other river is highly dynamic and a function of pollutant load (point and non-point sources), varying flow rates, seasonality, water levels, and natural self purification processes, there is need to monitor the changes in water quality consistently and at regular intervals. However, Spellman and Drinan (2001); McClain (2002) and Naiman *et al.* (2005) all concur that, although natural rivers have the capacity for self purification, a constant and un-interrupted flow is needed to dilute pollutants to harmless levels as the water flows downstream. This implies that the pollution levels keep changing in space and time owing to the fact that the river is lotic and not lentic in nature, thus necessitating regular monitoring of such water bodies to establish the water quality during specific times and points as was done in the current study.

While several studies have been carried out within the Mara River with regard to water quality (Mati *et al.*, 2005; Mutie *et al.*, 2006; Aboud *et al.*, 2002), it is still evident that many aspects and areas of the Mara River basin remain unexplored due to limited capacity and lack of urgency, resulting in uncertainty and ambiguity when formulating management strategies. For instance, though it is obvious that increased anthropogenic activities along the Mara River channel contributes to water quality degradation, the degree to which the waters of the two tributaries is polluted and the spatial variation in pollutant levels remains unclear, making it difficult to advice the local communities on best ways to handle Mara River waters before use. Likewise, eutrophication, flow alteration, landuse conversion, microbial contamination, and suspended sediment, all resulting from anthropogenic activities within the basin, are still a concern throughout the region that are yet to be critically studied and their levels documented.

In addition, while a few researchers have attempted to link anthropogenic activities to water quality degradation in the Mara River, not many have compared the two tributaries with respect to various water quality parameters like physico-chemical parameters, nutrients, microbial levels, and benthic macroinvertebrate community structure. Since Amala and Nyangores tributaries serve as the main sources of water for domestic use by the basin's inhabitants (Mati *et al.*, 2005), consumption of the water without prior knowledge of its sanitary quality including microbial contaminants, exposes the water users to risk of waterborne diseases (Mutie *et al.*, 2006), thus increasing the urgency of formulating effective policies aimed at safeguarding the water users from waterborne diseases and also protecting the river from further deterioration.

Gaps of this nature create uncertainty and ambiguity when formulating comprehensive management strategies, which ideally need an inventory of scientific facts obtained from rigorous research within the basin for sound decision making. This study therefore sought to evaluate the influence of anthropogenic activities on water quality of Nyangores and Amala tributaries during the dry season month of August 2011. Focus was mainly on specific sites located within the urbanized areas (Mulot and Bomet Towns) while two springs located at the upper catchment areas and draining into the two tributaries, respectively, were used as control sites for comparison with those located within the urbanized areas.

1.2 Problem Statement

Water quality of the Mara River and its tributaries continues to deteriorate due to increased anthropogenic activities within the catchment and along the river continuum. While solid and liquid waste generation is an inevitable consequence of production and consumption, a high population coupled with poorly planned urban centres like Mulot and Bomet Towns which lack critical infrastructure, compound the pollution problem. In addition, increased anthropogenic activities like washing clothes, water collection, small scale irrigation, livestock watering, bathing, among others can also influence the water quality along the two tributaries. Since the two towns differ in terms of size, development status, and population size, they are likely to generate varying amounts and types of waste, thus resulting in pollution of the Mara River tributaries (Nyangores and Amala) differently.

Changes in water quality as exhibited by high levels of suspended and dissolved solids, conductivity, nutrients, turbidity, coliform bacteria, among others, have been reported in many surface waters including the Mara River. Sewage effluents from urban runoff containing high organic matter content, nitrogen compounds, phosphorus and other nutrients, can enrich the water and thus create eutrophic conditions, while at the same time contributing to high microbial levels, particularly *E. coli* in surface waters. Likewise, increased pollutant load can result in alteration of the ecological processes, and interfere with the normal metabolism of aquatic biota including benthic macroinvertebrates and fish.

However, while increased waste load into the river contributes to water quality degradation, other factors such as the natural self purification ability, flow rate, seasonality and inflows from other relatively clean streams along the main river continuum can dilute the pollutants, hence the need for regular monitoring of river water quality by use of various water quality parameters to determine the status of the water quality at a specific point in time, as was done in this study.

Though many researchers acknowledge that pollution levels along the Mara River tributaries are increasing due to various anthropogenic activities, they fail to clearly show which sections or points along the tributaries are impacted most and the extent to which the water is polluted with respect to different water uses. This exposes the large number of people dependent on the water to risk of waterborne diseases, since they continue to use the water without prior knowledge of its sanitary quality. The fact that Mara River waters serve as the main source of water for the basin's inhabitants adds urgency to this problem.

Since available data on water quality of Mara River tributaries only provides a snapshot of the tributaries at a specific time, there is need to identify sections of the river that are most susceptible or prone to pollution by use of various water quality parameters so as to generate reliable data that can be used when formulating effective policies aimed at curbing further pollution. However, not many researchers have attempted to use a combination of physico-chemical parameters, coliform bacteria and benthic macroinvertebrates to determine the influence of anthropogenic activities on water quality of the two perennial tributaries of the Mara River. Therefore, in a bid to fill the gaps identified, this study sought to determine the influence of anthropogenic activities on water quality along Nyangores and Amala tributaries of Mara River, Kenya, using a combination of various water quality parameters namely physico-chemical parameters, nutrients, benthic macroinvertebrates, and coliform bacteria.

1.3 Main Objective of the Study

To determine the influence of anthropogenic activities on the water quality of Nyangores and Amala tributaries of Mara River, Kenya.

1.4 Specific Objectives of the Study

1. To observe and describe site characteristics and on-going anthropogenic activities along Amala and Nyangores tributaries of Mara River, Kenya.
2. To identify and characterize solid waste resulting from anthropogenic activities and deposited within and along the banks up to 30 metres from the channel of Amala and Nyangores tributaries of Mara River, Kenya.
3. To determine the spatial variation in physico-chemical parameters namely dissolved oxygen, turbidity, pH, conductivity, total suspended solids (TSS) and total dissolved solids (TDS) resulting from anthropogenic activities along the Mara River tributaries, Kenya.
4. To determine the spatial variation in total phosphorus (TP) and total nitrogen (TN) nutrients concentrations resulting from anthropogenic activities along the Mara River tributaries, Kenya.
5. To determine the spatial variation in benthic macroinvertebrate species diversity and coliform bacterial levels resulting from anthropogenic activities along the Mara River tributaries, Kenya.

1.5 Research Hypotheses

1. Ho: There are no significant differences in site characteristics and on-going anthropogenic activities along Amala and Nyangores tributaries of Mara River Kenya.
2. Ho: There are no significant variations in solid wastes resulting from anthropogenic activities and deposited within or along the banks of Amala and Nyangores tributaries of Mara River, Kenya.

3. Ho: There are no significant spatial variations in physico-chemical parameters resulting from anthropogenic activities along Amala and Nyangores tributaries of Mara River, Kenya.
4. Ho: There are no significant spatial variations in nutrient (total nitrogen and total phosphorus) levels resulting from anthropogenic activities along Amala and Nyangores tributaries of Mara River, Kenya.
5. Ho: Benthic macroinvertebrate species diversity and coliform bacterial levels are not significantly influenced by anthropogenic activities along Amala and Nyangores tributaries of Mara River, Kenya.

1.6 Justification of the Study

Mara River serves as the main source of water for domestic use and also plays an important socio-economic role among communities living within its' basin. The river is considered a last resort for wildlife in the dry season, most evident in the massive wildebeest migrations from Tanzania each year. During the dry season the Mara River is often the only flowing surface water available in lower Mara River basin northwest of Tanzania with studies suggesting that its saline nature makes it even more enticing to wildlife (Gereta, 1998). The river is therefore considered a lifeline to Masai Mara National Reserve in Kenya and Serengeti National Park in Tanzania, both of which are vibrant tourist attraction sites.

However, the future of the Mara River is threatened by increased anthropogenic activities that contribute to the discharge of large quantities of waste especially along urbanized sections, as most of the urban centers through which it flows lack sewage treatment facilities. Since the principal cause of water scarcity is water quality degradation resulting from increased anthropogenic activities, high pollutant load into Amala and Nyangores tributaries of Mara River is therefore a threat to the Mara River ecosystem integrity.

Due to overreliance on the waters of the Mara River, deteriorating water quality of Amala and Nyangores tributaries continues to expose the basin's inhabitants to risk of water borne diseases as well as affect wildlife, livestock and aquatic biota within the river. This is worsened by the lack of clear information on the extent of contamination with respect to specific water uses. This study, therefore, sought to determine the extent to which anthropogenic activities especially within Bomet and Mulot Towns, influence the water quality of Nyangores and Amala tributaries, respectively. The study findings can provide an important source of information for policy makers and other stakeholders on waste management and also on conservation and protection of the Mara River water as well as contribute to academia.

1.7 Scope and Limitations of the Study

This study covered the perennial tributaries of the Mara River; Amala and Nyangores, located on the upper Mara River basin and focused on the influence of anthropogenic activities especially within Mulot and Bomet Towns to water quality degradation, while two springs draining into each of the tributaries and located at the upper catchment were used as controls. Physical, chemical and biological parameters were investigated to establish the water quality.

However, the study was limited in terms of seasonality since data was collected on a one-of basis; during the dry season and, therefore, variations with respect to seasonality were not taken into consideration. In addition, due to the nature and distance between sites, sampling could not be carried out on the same day and time when climate-related controls would have been more uniform. Instead sampling was carried out on different days and times, and this could have influenced the outcome of some parameters especially water temperature that is strongly influenced by solar radiation, hence the reason for its exclusion from the study.

Considering the nature of the tributaries, contributions from natural and instream processes such as flow rate, water levels, short residence time of water, channel depth, seepage from ground water and inflows from unpolluted streams along the river continuum among others; all of which can influence water quality changes could not be detached from anthropogenic factors due to the complexities of isolating them from anthropogenically induced changes.

CHAPTER TWO
2.0 LITERATURE REVIEW

2.1 Introduction

This section gives an overview of existing information relevant to the topic under study and also seeks to identify gaps in knowledge that need attention or further research. Water quality aspects, effect of waste on water quality, growth of urban centers and their contribution to aquatic system degradation are given. In addition, solid and liquid waste disposal along the Mara River, water quality determination by use of various indicators and the conceptual framework are also given.

2.2 Water Quality Aspects

An adequate supply of safe drinking water is universally recognized as a basic human need, yet millions of people in the developing world do not have ready access to adequate and safe water supply (UNICEF and WHO, 2004). The WHO (2002) reported that the number of people without access to safe water in urban areas of developing countries rose sharply in the 1990s as a result of rapid urbanization, much of which was occurring in peri-urban and slum areas. Among African nations, concerns over insufficient freshwater resources and poor water quality are significant (UNEP, 2002), with a study by WWF (2002) estimating that over 778 million people suffered from water related diseases in the year 1997 alone.

Clean water is an extremely important life support resource, which lacks a substitute, and is therefore the lifeline to all living organisms on earth (UNEP, 2002). As such, provision of clean water is critical for human survival and sustainable development since water is essential for agriculture, industries, power generation, livestock production, domestic use and many other important activities. Studies by UN-Water (2006) showed that only 1.9 percent of Kenya is covered with water, most of which is supplied by the country's rivers, that are concentrated in few water towers including Mau forest, which is also the source of Mara

River. In terms of water supply, Kenya receives an annual average rainfall of 630mm, an amount that is relatively low for an equatorial country according to FAO (2005). It is also categorized as a water scarce country based on average per capita water availability (WRI, 2007). This makes it a challenge for the country in many ways and hence necessitates protection of the few available fresh water resources against all forms of pollution or over abstraction. Unfortunately, degradation of catchment areas is currently on the rise, further aggravating the problem, with access to adequate water for livestock, agriculture, wildlife, and for domestic and industrial use being limited in space and time (WRI, 2007).

2.3 Sources of River Water Pollution and Their Resulting Effect on Human Health

The major sources of water pollution include municipal, industrial and agricultural activities, all of which are driven by anthropogenic forces. Agricultural activities for instance contribute organic and inorganic pollutants like sediments from erosion of crop lands, phosphorus and nitrogen from animal waste and commercial fertilizers used in farmlands to water bodies (EPA, 2003). Poor sanitation and discharge of solid and liquid waste into the Mara River tributaries from various sources and extension of human settlements and mushrooming urban centers along the banks of the river can significantly influence the water quality as was observed by Trivedi (2000). Herath (2003) also showed a strong relationship between faecal pollution and human settlements in which frequent microbial contaminants resulting from human excreta and solid waste discharged from houses and shops from Kandy city surburbs, in Sri Lanka, were reported in a nearby river. Other studies on small sized streams within the Mara River basin of East Africa by Valimba *et al.* (2004) established the effects of human activities on terrestrial ecosystems and their influence on flow regimes in the Mara River basin, though the study did not establish if there were changes in water quality parameters with the changing flow regime.

Apart from poor water quality, the diminishing water resources resulting from poor land use practices, encroachment of forests, over abstraction of water for domestic and industrial use, and droughts also pose a challenge to the Mara River ecosystem. Gereta *et al.* (2002) working within the Mara River basin, projected that with continued deforestation, irrigation and diversion of water for hydropower generation like was the case at Tenwek area along the Nyangores tributary, the Mara River flow may cease completely in some sections especially during severe droughts. Low water levels will likely increase the pollutant concentrations in water as well as inhibit the river's natural self purification capabilities, thus resulting in an altered ecosystem in the process.

Many infectious diseases, including cholera, typhoid, hepatitis, polio, cryptosporidiosis, ascariasis, and schistosomiasis have been associated with increased pollution load especially pathogenic microbes from human excreta and animal waste deposited either directly or along the river banks (WHO, 2000). It is estimated that one-third of deaths in developing countries results from consumption of contaminated water, and on average, as much as one-tenth of each person's productive time is sacrificed to water-related illnesses (WHO, 1997). In addition, the World Health Organization estimates that upto 2.2 million people die annually from diarrheal diseases and that 10% of the population in the developing world are severely infected with intestinal worms, all associated with improper waste and excreta management (Murray *et al.*, 1996; WHO and UNICEF, 2000).

2.3.1 Effect of solid and liquid waste from anthropogenic activities on water quality

Anthropogenic activities such as industrialization and urbanization amid continous economic growth, results in a rapid increase in volume and variety of solid and liquid waste in many mushrooming urban centers of developing countries. Studies show that in developing countries, it is still common to find communities discharging raw sewage into streams with the hope that the water will wash it away; something that is completely unacceptable in developed countries (WHO and UNICEF, 2000). This poses a serious challenge to national and local governments. Syed (2006) observed that there is already more waste (both liquid and solid), generated and disposed currently, than at any other time in the history of mankind, while a study by UNCHS (1996) on solid waste in middle income countries reported that one third to one-half of solid waste generated within most towns are never collected, and usually end up as illegal dumps on streets, open spaces, and water bodies. These two studies did not, however, establish the extent to which such waste influences the water quality in adjacent aquatic systems nor did they show how the aquatic biota within the river is affected.

A high population growth rate and rapid urbanization without corresponding expansion of infrastructure and sanitation facilities is partly responsible for the increasing waste management problem, which is made worse by lack of adequate capacity in terms of funding and infrastructure that hinders effective collection and disposal of waste generated within most African countries (Porter *et al.*, 1997; Onibokun and Kumuyi, 1999). Improper attitudes among the inhabitants also worsen the situation for the local authorities since they also contribute greatly to poor waste disposal through their seemingly care-free attitudes, as was also observed by Kendie (1999). Urgent and elaborate public awareness campaigns are therefore necessary to re-orient the mindset of the general public, particularly the riparian populations, regarding their perception of waste handling and disposal.

Due to weak institutional policies and lack of sufficient resources - both human and capital, management of waste, hygiene and sanitation in many cities on the African continent are in pathetic conditions (UNEP, 1999). A study by JICA (1998) on solid waste generated within Nairobi city for instance, established that most of the waste was left uncollected and that food waste formed the largest proportion (51.5%) of the total waste generated followed by plastics (containers and others) 11.8%; paper (recyclable and other) 7.3%; wood 6.7%; textiles 2.7%; ceramic/soil 2.7%; metal (containers and others) 2.6%; glass (containers and others) 2.3%; rubber 1.5%; and leather 0.9%, in that order. This study did not however establish the effect of the waste on the quality of water in nearby aquatic systems.

WHO and UNICEF (2004) estimated that over 2.6 billion people worldwide lack adequate sanitation while more than 3,900 children die every day from water borne diseases across the world, while a report by UNEP (1999) estimated that between 20% and 80% of solid waste is disposed of by dumping in open spaces, water bodies, and surface drains in most African cities due to inadequate infrastructure, thus resulting in surface water pollution. An earlier report by the Economic Commission for Africa (1996) also showed that most African cities either lack sewerage systems or operate inefficient systems serving only a small proportion of the urban population. The same study established that even where sewers existed, some were often blocked with solid waste resulting in overflow into streets and open spaces, thus providing suitable grounds for disease causing pathogens.

A different study by Gelinas (1996) carried out in two districts of Conakry in the Republic of Guinea, also reported that a majority of urban residents, especially those living in informal settlement areas used pit latrines, bucket toilets or other sub-standard facilities, which increased the chances of encountering raw human waste in surface drains and surface water bodies. Elder *et al.* (1999) also observed that most pollution problems affecting rivers do not always begin in the rivers but in adjacent terrestrial ecosystems through anthropogenic activities such as poor waste disposal, agricultural activities, livestock rearing, industries, urbanization, among others, all of which contribute to water quality degradation. This according to them is the reason why restoration or protection of rivers can only be achieved through integrated watershed management incorporating all social, economic and environmental aspects.

Urbanization is therefore a pervasive form of land use that is rapidly growing owing to increased human population and economic development and involves destructive processes like conversion of natural undisturbed land to croplands, residential areas, commercial and industrial centres among other uses. Fu *et al.* (2009), considers urbanization as the principal contributory factor to many environmental problems facing surface water bodies today.

Rapid urbanization and rural to urban migration, amid economic stagnation in Kenya, has resulted in an increased proportion of people living in absolute poverty in most urban and peri-urban areas (CSB, 2003). This has overwhelmed the existing infrastructure as well as the natural resources within these areas leading to increased consumption, depletion and subsequent increase in pollution of the environment (World Bank, 1999). In most cases, residents of informal settlements rarely receive government services like piped water, drainage systems, sewer lines, and rubbish collection services. As a result, poor environmental conditions that predispose inhabitants to poor health outcomes characterize such informal settlements (APHRC, 2002). Evidence show that children from poor backgrounds in urban and peri-urban areas of Kenya exhibit poorer health conditions than their counterparts in rural areas attributed to insufficient or lack of sanitation and poor human waste disposal (APHRC, 2002).

The major water quality threats to human health and environmental safety are sewage, dissolved nutrients, toxic metals and chemicals all resulting from anthropogenic activities

(Economic Commission for Africa, 1996). However, faecal matter present in raw sewage is undoubtedly the most widely spread pollutant in surface waters with the ability to cause high levels of pathogens in untreated water supplies. Studies by WHO and UNICEF (2004) concur that high coliform counts are found in most surface waters used in the rural areas, and that sewage remains the largest source of contamination of water masses. Cardell *et al.* (1999), pointed out that very little or complete absence of DO, high BOD, high bacterial counts, low species diversity, turbid and dark coloured water, and increase in organic carbon content characterize polluted rivers, while Spellman and Drinan (2001) observed few species of blue-green algae, sludgeworms, mosquito larvae, rattailed larvae, and a general absence of fish and other biota in polluted water bodies. Peierls (1991) also reported significant positive correlations between human population and nutrient levels within the rivers' watersheds, leading to the conclusion that human population in the watershed was the best predictor of river nutrient concentrations and export. All these studies imply that pollution from anthropogenic activities alters various parameters in the aquatic system and impacts differently on various aquatic biota.

Studies show that effects of human activities on a small scale can have implications on the entire drainage basin, with possible cyclical and cascading effects on water quality through the hydrologic pathways (Peters and Meybeck, 2000). However, it is almost certain that most communities in developing countries, including Kenya, have not yet fully realized the link between their actions on land and the resulting effect in adjacent aquatic systems, which calls for more studies to fill the knowledge gaps among the Mara River basin inhabitants. Laxity on the part of responsible authorities, poor governance, and weak enforcement of existing laws have also been identified as some of the contributors to the pollution problems (Ikiara *et al.,* 2004). The World Water Assessment Report (2004) also noted that the laws and regulations governing the protection of water masses and catchment areas are not fully enforced by local authorities in most urban centres, thus allowing discharge of untreated waste directly and deliberately into water masses. In addition, provisions in the Environmental Management and Coordination Act and other relevant statutes that are designed to protect the aquatic ecosystems are often ignored (World Water Assessment Report, 2004).

2.4 Status of Mara River with Respect to Anthropogenic Activities within the Basin

According to Mati *et al.* (2008), issues associated with anthropogenic activities such as land alteration and modifications of the natural flow regime are currently evident within the Mara River basin although their extent warrants further investigation. Mati *et al.* (2008) also warned that while some water quality parameters may fall within permissible ranges, the potential for exceeding these thresholds in the future may be high. Hoffman (2007) observed that over half of the households in the Mara River basin rely on its water for domestic and livestock needs, with the most common uses being washing of clothes, personal bathing, drinking, and watering livestock. Additional abstractions are also made to supply water to towns such as Bomet, Mulot among other activities along the river continuum.

The Mara River's connection to Lake Victoria is crucial considering that the lake is a major supplier of fresh water to, among others, Kenya, Tanzania and Uganda and eventually feeds the Nile River (UNEP, 2002). Likewise, the wildebeests' migration in the Mara River basin is a critical component in supporting the tourism industry. Any significant alteration to the quantity and quality of water in the upper Mara River basin can therefore have serious ramifications downstream. Though economically beneficial, tourism activities can however impair the Mara River waters through degradation resulting from destructive activities such as land clearing for infrastructure development, increased water abstraction and sanitation demands among others. Issues pertaining to water quality and quantity threaten a collapse of the tourism industry should the wildebeest migration cease (Gereta *et al.*, 2003). This has created a dilemma between economic gains and conservation activities for the two countries of Kenya and Tanzania.

Though the Mara River has been regarded as prestine for a long time (Mati *et al.*, 2008), increased anthropogenic activities especially at the upper Mara River basin continues to degrade its waters. Studies by Mati *et al.* (2008) estimated that 62% of households within Amala and Nyangores sub-catchments of the upper Mara River basin were involved in small-scale farming, while the second largest land use type after farming was forestry. It has also been reported that cultivated areas in the upper Mara River basin alone increased by more than 31% between 1960 and 1991 and these numbers did not even reflect the influx of immigrants to the area between 1999 and 2002 when the number of households increased by 13% (Mati *et al.*, 2008).

Agricultural activities on the steep slopes along the Amala and Nyangores tributaries therefore threaten to increase sediments, nutrients, coliforms and other pollutants into the river. Furthermore, while there are reports that many small-scale farmers at the upper Mara River are not using fertilizer currently, the potential for its use exists thus setting the stage for possible nutrient load into the Mara River through surface runoffs and percolation in the near future. Mati *et al.* (2008) reported that some of the regions downstream of agricultural areas were already showing signs of high nutrient load, and therefore, expansion of these activities within the basin will most likely result in more widespread and severe impact on water quality.

Apart from agricultural activities, urban development also posses a significant challenge to surface water quality of adjacent aquatic systems. According to UNEP (1999), rapid development of urban centres and expansion of those already present coupled with poor design and planning, population growth, agricultural and industrial activities, has generated vast amounts of solid and liquid waste that can easily pollute the environment and interfere with water quality. Mulot and Bomet urban centers like most other centers in Kenya experience rapid population growth characterized by poor urban planning, informal settlements, limited amenities and poor sanitation (KNBS, 2007). Du *et al.* (2009) reported that damage to and loss of many surface water bodies in urban areas is directly or indirectly as a result of anthropogenic activities like disorderly land development during urban expansion and increased pressure on the limited fresh water resources. Population growth rates of up to 7.5% per year have been reported within the Mara River basin, eliciting an inevitable increase in consumptive demands at personal, domestic and commercial levels (Mutie, 2006). Fu *et al.* (2009) reported that the population size of an area has significant impact on surrounding water quality, while many other studies including those of Anbumozhi *et al.* (2005) and Haase (2009) demonstrated the direct impact of human activities on the environment especially with respect to pollution.

Studies of the Amala and Nyangores tributaries by Gereta (2003) yielded consistently high suspended solid and turbidity values, exceeding the WHO standards, during a two year period of the study, with highly disturbed sites reported to have been synonymous with higher turbidity and TSS levels. The same study also established that high total nitrogen levels were clustered in some sections along Amala and Nyangores sub-cathcment, though the observed levels were not widespread along the Mara River, thereby decreasing the risk of eutrophication. Further studies by Gereta (2003) on the lower Mara River in Tanzania attributed polluted waters to the top three most common illnesses throughout the Tanzanian portion of the Mara River basin.

2.4.1 Microbial levels along Amala and Nyangores tributaries attributed to anthropogenic activities

Waste handling capacity of the mushrooming urban centers, Bomet and Mulot, are relatively poor or inexistent leading to accelerated dumping of waste along streets, residential areas, side ditches, river banks, and into the river channel (Personal observations, 2011). This affects the quality of water and subsequently animal and human health. According to Yillia *et al.* (2009), a visit to a river entails activities such as watering livestock, bathing and swimming, laundering of clothes, washing of vehicles, collection of water for domestic use, among others, all of which constitute diffuse pollution.

Zamxaka *et al.* (2004) reported that most in-stream activities may influence microbial water quality since faecal matter is often deposited in the water during visits to the river, while the surrounding area may be littered with faeces and other solid waste. Langergraber and Muellergger (2005) and Vikaskumar *et al.* (2007) concur that unsanitary ways of disposing human waste and faecal droppings from livestock are some of the direct routes through which faecal matter degrades surface waters by the introduction of pathogens, nutrients and organic matter. Improperly protected water sources as observed in the current study facilitate water contamination through back flows, exposing the users, who in most cases are often unaware, to waterborne diseases. Hunter *et al.* (2000) advices that where no treatment is given to drinking water, then appropriate protection and management of the water source should be taken into consideration to minimize pollution or source contamination.

A study carried out in Virginia by Shefield *et al.* (1997) reported an improvement in water quality after installing alternative sources of water for cattle from those used by human beings. However, Line *et al.* (2000) in his studies carried out in North Carolina disagrees and instead argues that providing alternative sources of water is not always enough to reserve water quality in the rivers, insisting that cattle can also go to the streams to cool off, thus pollute the river in the process. Larsen *et al.* (1994) however, concluded that a 95% reduction in bacterial loads can be achieved provided a 2.5 meters minimum distance is left between the cattle grazing point and the stream.

Despite the challenges and resource constraints, attempts have been made to establish a number of water quality programs within the Mara River basin. The Ministry of Water and Irrigation, Kenya, for instance designated two water quality offices, one in Narok and another in Bomet, to measure discharge, water quality, and sediment load. However no systematic sampling programs exist with respect to water quality monitoring, with only a few parameters being measured occasionally and irregularly (Mati *et al.*, 2008). In addition, while some areas in the Mara River basin have received considerable attention throughout the years (Gereta, 1998; Mati *et al.*, 2005, 2008; Mutie, 2006), other areas have remained completely unexplored.

Since exposure to waterborne and water related diseases can occur through ingestion as well as contact with contaminated water, leading to waterborne diseases such as typhoid, dysentery, cholera, yaw, malaria, yellow fever, and relapsing fever, among others (Brown *et al.*, 2008; USEPA, 2006), there is need to carry out studies aimed at establishing the quality of Mara River tributaries and their suitability for domestic use. Given that water quality and general assessment data is lacking throughout the Mara River basin region, this study aimed at providing a clear picture of the water quality along Amala and Nyangores tributaries, particularly within urbanized areas (Bomet and Mulot Towns), based on a combination of physical, chemical and biological parameters, to develop a characterization of the specific polluted points along the tributaries.

2.5 Determination of Water Quality by Use of Various Indicators

Water quality parameters are a means to describe the chemical, physical and biological characteristics of water with respect to its suitability for particular purposes (Grillas, 1996). The quality of water can be determined using a combination of biological indicators, nutrient concentrations, and physico-chemical parameters (Sidneit *et al.*, 1992), while presence of coliform bacteria and their relative abundance can also be used as reliable indicators of water quality (USEPA, 2002). Townsend *et al.* (1997) noted that each of these parameters is influenced by anthropogenic activities on the terrestrial ecosystem and may alter ecosystem structure and function of aquatic systems, while Scott *et al.* (2002), reported that the level of health risk will considerably depend on the origin and level of contamination. To minimize health risk, many researchers including Shah *et al.* (2007) advice that regular monitoring of indicator parameters in aquatic systems is necessary.

2.5.1 Dissolved oxygen

Dissolved oxygen (DO) is an important water quality parameter with a strong influence on aquatic organisms. The amount of dissolved oxygen in rivers is dependent on many factors key among them amount of organic matter in water (APHA, 1998). Sewage and waste water form the major contributors of organic matter and pathogens into aquatic bodies, which may result in oxygen depletion during microbial breakdown. Water bodies with consistently high dissolved oxygen levels are most likely to be healthy, stable and capable of supporting a diversity of aquatic organisms (USEPA, 1996), while oxygen levels below 50% saturation are generally indicative of a polluted system. For this reason, there is cause for concern for streams with low DO levels as most aquatic fauna including fish require DO in excess of 2 mg/l (APHA, 1992).

2.5.2 pH

Changes in water pH are influenced by the acidity and alkalinity of river water, which arise from among others surface runoff and direct domestic waste water (sewage) discharge into a river channel (EPA, 2003). The pH of river water is important as it affects the solubility of many toxic and nutritive chemicals; and hence the availability of these substances to aquatic organisms. Acidity for instance increases metal solubility in water, making them more toxic, while ammonia commonly found in waste water becomes highly toxic with a slight increase in pH (EPA, 2003). According to USEPA (1996), the safe aquatic habitat pH range is normally 6.5 to 8.5 with extremely high or low pH values likely to result in the death of aquatic biota. Most natural waters fall within a pH range of 6.0 to 8.5 (EPA, 2003).

2.5.3 Conductivity

Electrical conductivity which measures the mineral content of natural waters gives an indication of the amount of inorganic material in water with low conductivity characteristic of forested rivers (APHA, 1998). Tenagne (2009) noted that conductivity of stream water is partly influenced by urban surface runoff and sewage effluents and is a more-or-less linear function of the concentration of dissolved ions. However, conductivity serves as an indicator of the amount of inorganic material in water and can be a quick way to locate potential water quality problems (APHA, 1998). River water is only good for drinking by human beings and livestock at conductivity levels of between 0-800ms/cm (Tenagne, 2009).

2.5.4 Turbidity and total suspended sediments

Turbidity which refers to the cloudiness of water as a result of suspended, colloidal and dissolved material is a measure of the relative clarity of water and can serve as a preliminary indicator of the quality of water in a river (Water Watch Tasmania, 1996). Eroded soils, solid waste, urban surface runoff, algal blooms, and disturbance of the bottom sediments are some of the sources of high turbidity in surface waters (APHA, 1998).

Total suspended solids (TSS) which is closely linked to turbidity is a measure of the level of suspended matter in water, which can enter the river through urban surface runoff, agricultural inputs, pavement wear, atmospheric deposition, among other routes. Like turbidity, high TSS levels reduce light penetration in the water column, hindering the photosynthetic process in the aquatic system (APHA, 1998). Wagener and LaPerriere (1985) reported that high total suspended solid levels can result in abrasive action, loss of visual efficiency in aquatic fauna, and interference with the food gathering ability by filter feeder macro invertebrates.

2.5.5 Total dissolved solids

Total dissolved solids (TDS) refer to any minerals, salts, cations or anions dissolved in water. They include anything present in water, other than the pure water molecule. In general, the total dissolved solids concentration is the sum of the cations and anions in the water (Sansalone *et al.*, 1998). Some of the common sources of dissolved solids include runoff from urban areas, organic matter from human activities, fertilizers, and pesticides.

2.5.6 Dissolved nutrients (phosphorus and nitrogen) in water

Agriculture, livestock and urbanization contribute relatively higher nutrient concentrations in storm runoff as compared to other land uses (Omernik, 1976). Phosphorous and nitrogen are essential nutrients for the growth of algae and other plants in aquatic systems. Excessive concentrations of these nutrients can, however, over-stimulate aquatic plants and algal growth (La Valle, 1975). Discharge of untreated sewage, waste water containing detergents, urban runoff, soil erosion, animal and plant matter are all sources of high phosphorus input into rivers (La Valle, 1975). Carr and Neary (2008) observed that high nutrient concentrations can trigger excessive growth of weeds and algal blooms which have the potential to deplete dissolved oxygen during the decomposition process thus affect aquatic fauna. For this reason, USEPA (1998) advices that phosphorus testing and removal should be an essential part of any wastewater treatment plant.

Nitrogen is also an essential nutrient for algal growth, but its control is more difficult compared to phosphorus because it can be assimilated directly from the atmosphere by certain organisms, including some species of the blue-green algae (Miller, 2008). Meybeck (1998) reported that urban centers have the capacity to increase nitrogen concentration in rivers for hundreds of kilometers with the extent of the increase likely to be influenced by the waste water treatment technology and degree of raw sewage discharge into aquatic bodies. High nitrogen levels can trigger algal blooms whose decomposition results in oxygen depletion in the aquatic system (USEPA, 2002). Additionally, excessive nitrates in drinking water not only causes methaemoglobinaemia (blue baby) in bottle-fed infants (Davis, 1990), but can be very toxic to aquatic animals when present in higher concentrations (Philips *et al.*, 2002). The limit for human consumption is 11.3mg/l (nitrate-nitrogen) (Davis, 1990).

2.5.7 Benthic macroinvertebrates

Many researchers including O'Keffe and Dickens (2000) have reported that benthic macroinvertebrate species diversity and abundance can provide a clear reflection of the existing water quality conditions in a river, since they form an integral part of a river ecosystem, and are usually the first to be affected by changes in water quality. In addition, they play a vital role in river water purification (Skorozjewski and de Moor, 1999), and also serve as valuable food sources for larger organisms within aquatic ecosystem (Weber *et al.*, 2004).

Benthic macroinvertebrates are reffered to as "indicator organisms" due to their biology, ecology and sensitivity to pollution (O'Keffe and Dickens, 2000). The fact that every specie has a certain range of physical and chemical conditions in which it can survive places them at a better position as biological indicators compared to other organisms. In addition, their sedentary nature and small sized bodies makes them vulnerable to water quality changes and therefore effective in monitoring disturbances in aquatic systems (Bonada *et al.*, 2006).

Water quality can therefore be determined by comparing the number of pollution-tolerant to pollution intolerant species (Shivoga, 2000). To achieve this, researchers have grouped macroinvertebrates taxa according to their sensitivity to pollution to include: (a) sensitive organisms such as stoneflies and mayflies; (b) somewhat sensitive organisms such as damselfly nymphs; and (c) tolerant organisms like oligochaetes and leeches (Mandaville, 2002). However, Peckarsky *et al.* (1990) pointed out that pollution tolerant organisms can also be found in unpolluted waters. Many studies including those of Ebrahimnezhad and Harper (1997) have all shown that any fluctuations in stream conditions can trigger changes in benthic macroinvertebrates community structures, reflected by a loss of certain species and an increase in others. A measure of macroinvertebrate species diversiy and abundance in a river thus provides information on the water quality status or "environmental health" of the system, which can easily be obtained by use of diversity indices (Rosenberg and Resh, 1993).

Diversity indices, such as the Shannon-Weiner diversity index, use statistical methods designed to evaluate the variety of data group among the benthic macroinvertebrates (Rosenberg and Resh, 1993). Features of a population such as the number of existing species (richness), distribution of individuals equally (evenness) and the total number of existing individuals underlie the basis of diversity indices (Allan, 1995). Changes in any of these three features will affect the whole population (Mandaville, 2002). Species diversity is thus a reliable indicator of water quality status (USEPA, 2002).

2.5.8 Coliform bacteria in river water

Total coliforms are found in water polluted with faecal matter and are often associated with disease outbreaks (USEPA, 2002). Urban runoff and untreated sewage are the major contributors of faecal coliforms in water. Although coliforms are not usually pathogenic themselves, their presence in drinking and recreation water indicates the possible presence of pathogens (USEPA, 2002). *Escherichia coli*, one of the coliform groups, is always found in faeces and is, therefore, a more direct indicator of fecal contamination and the possible presence of other enteric pathogens (USEPA, 2002).

Indicators of pathogens, such as *E. coli,* may be introduced in the river through human feaces deposited directly or along the river banks, untreated sewage discharge as well as livestock and wildlife droppings (WRC, 2000). Other ways coliform bacteria enter a river system is through storm drains, faulty sewer lines or receptacles and leakages in septic tanks. Some of the recommended coliform limits based on the median value are: 0 *E. coli*/100ml for drinking water and 126 *E. coli*/100ml for contact recreation (USEPA, 2002). While many researchers advocate for coliform bacteria use in determining the sanitary quality of surface water bodies, other researchers like Barrell *et al.* (2000) have criticized *E. coli* and total coliform use in routine microbiological assessment, insisting that they are not representative enough, especially for viral, fungal, helminthic and protozoan pathogens that may be present where bacteria indicators are shown to be absent. However, Byamkhama *et al.* (2005) maintains that *E. coli* is still a dependable indicator of faecal pollution especially in tropical environments.

2.6 Conceptual Framework

The status of river water quality is determined by both natural as well as anthropogenic factors. However of greater influence are anthropogenic activities such as agriculture, human settlement, industrialization, livestock rearing, and urbanization which are the main driving forces in terms of ecological integrity, nutrient and organic pollution, and water quantity and quality. However, lack of waste treatment facilities, topography of the area, storm water runoff, and a rising population can act as intervening variables which may also contribute to, and facilitate the deposition of pollutants in river channels, resulting in water contamination. The aim of managing water resources is to safeguard human health while sustainably managing terrestrial ecosystems and associated aquatic bodies. However, this can only be achieved with the existence of reliable data to support the argument on protection. It was, therefore, important to determine the influence of anthropogenic activities on water quality of Amala and Nyangores tributaries of the Mara River using a combination of physical, chemical and biological parameters to detect changes in water quality. Figure 2.1 gives a flow chart of the conceptual framework.

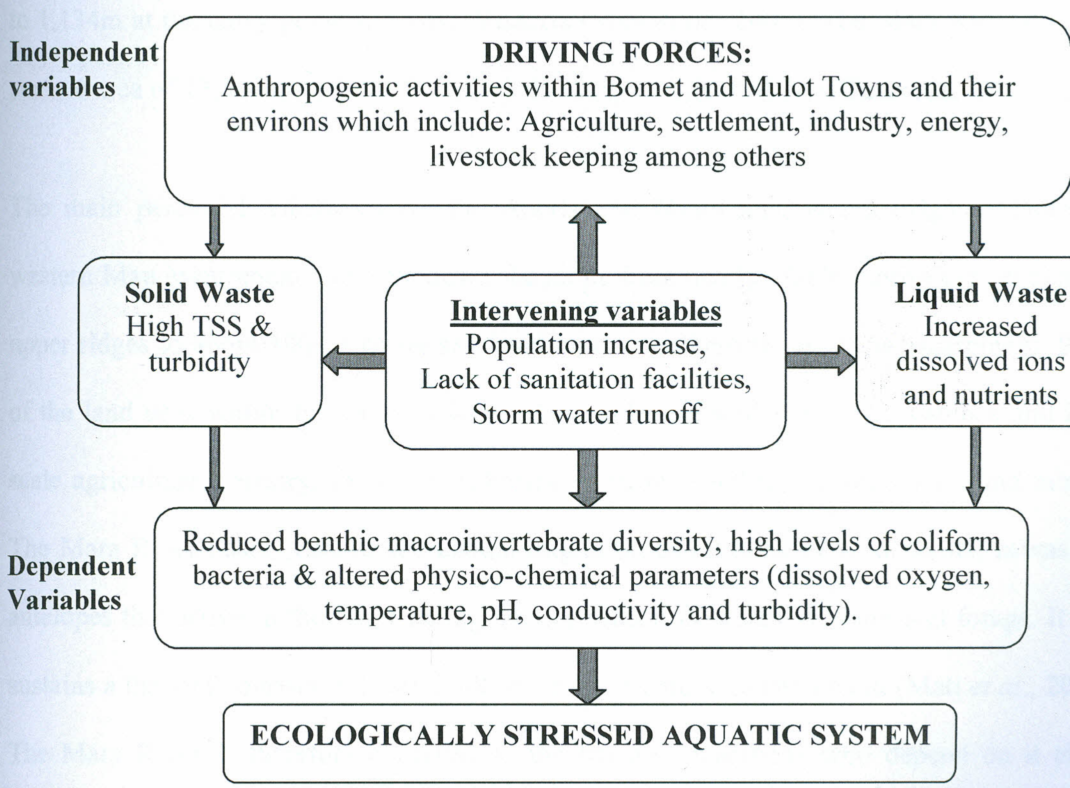

Figure 2.1. Conceptual framework

Source: Researcher (2011).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

In this chapter, the study area, research design, study population and sampling procedures are given. The chapter also outlines the sample collection tools, sample handling and analysis. In addition, data analysis procedures are also given.

3.2 Study Area

The Mara River is approximately 395km long and originates from the Mau escarpment in Kenya and drains into Lake Victoria at Musoma Bay in Tanzania. It is located between longitudes 33.88372^0 and 35.907682^0 West, latitude -0.331573^0 and -1.975056^0 South (Figure 3.1), with altitudes ranging from 2,932m at its source in the Mau Forest escarpment to 1,134m at the entry point into Lake Victoria (Mati *et al.,* 2005). The Mara River covers a surface area of $13{,}504km^2$; 65% of which is in Kenya while 35% is in Tanzania.

The main perennial tributaries are the Amala and Nyangores, which originate from the western Mau escarpment and flow down the slope from nearly 3000m above sea level at the upper ridges to about 1000m above sea level on the southern slope of the escarpment. Some of the land uses within the basin include urban and rural settlements, subsistence and large scale agriculture, forestry, livestock, fisheries, tourism, wildlife, conservancies and mining. The Mara River basin sustains the annual migration of millions of wildebeests, zebras and antelopes that arrive in the basin during the dry season in search of water and forage. It also sustains a thriving tourism industry built around this natural phenomenon (Mati *et al.*, 2005). The Mara River is therefore a lifeline to the basin's inhabitants who depend on it either directly or indirectly.

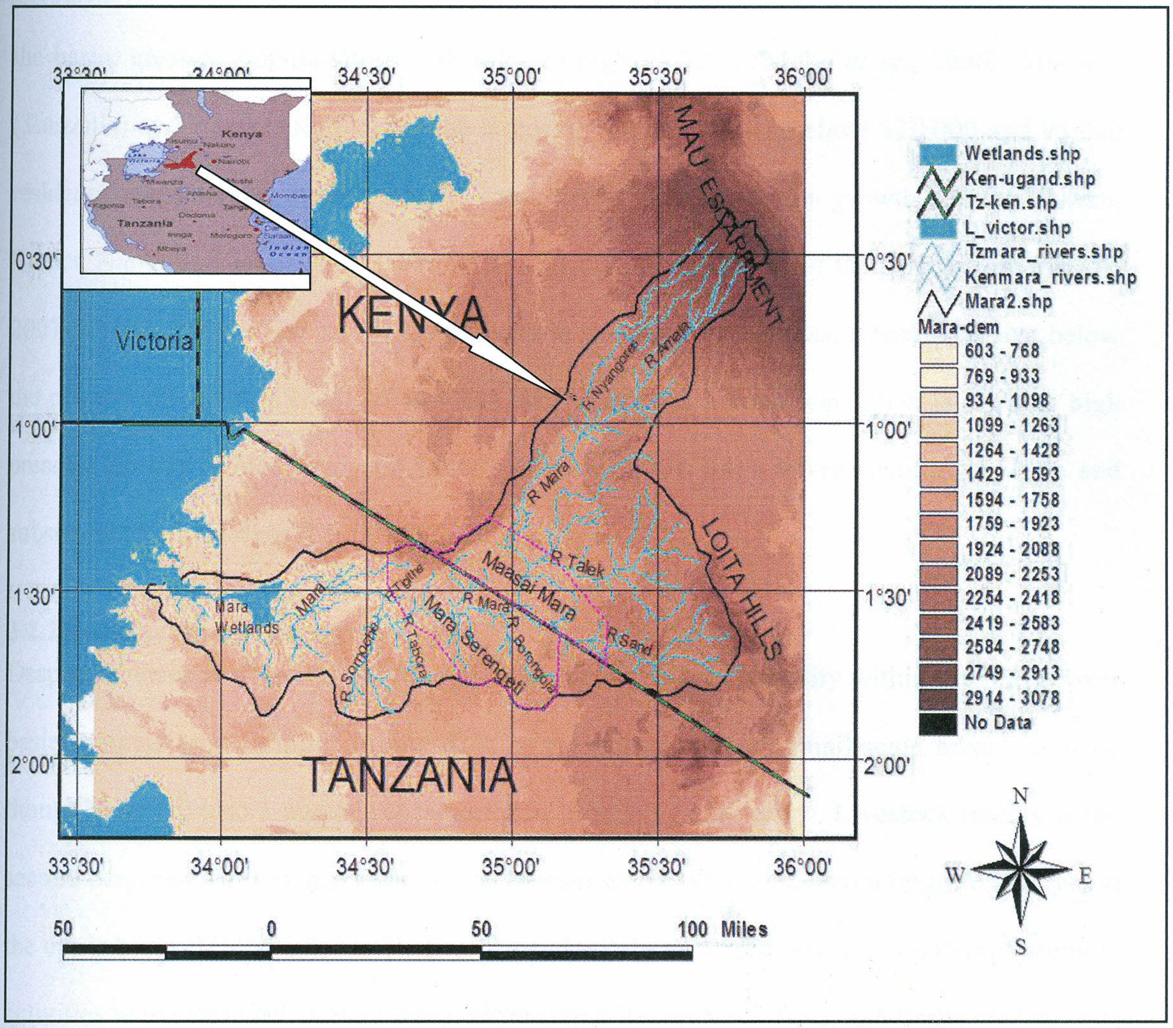

Figure 3.1. Map of Mara River basin showing Nyangores and Amala tributaries (Source: Hoffman, 2007).

However, the Mara River including Amala and Nyangores tributaries faces serious threats resulting from anthropogenic activities, some of which have significantly reduced the forest cover in the Mau escarpment which is also the source of the Mara River thus affecting the recharge of the river while also encouraging rapid surface runoff which leads to increased sediment load into the river.

3.2.1 Population within the Mara River basin

The Mara River basin is home to 1.1 million people, majority (775,000) of who live in Kenya and the rest (325,000), in Tanzania (Hoffman, 2007). The previously reliable high and well-distributed rainfall in the highlands of this basin and its fertile soils attracted immigrants into the basin, creating population growth rates as high as 7.5% (Mutie *et al.*, 2006). Musoma (Tanzania) and Bomet (Kenya) are the largest urban centres with about 120,000 and 95,000 residents, respectively. In addition, the combined annual population growth rate for Nakuru, Bomet, Narok and Trans Mara Districts was approximately 4.8% for the period from 2001 to 2007 (KNBS, 2007). The rest of the population resides in rural areas, where 64% live below the poverty line (Mutie *et al.*, 2006). The ever increasing human population is exerting high pressure on the limited land and water resources in the Mara River basin as a whole and subsequently on wildlife (Mutie *et al.*, 2006).

3.2.2 Socio-economic activities

Despite recurrence of droughts, the dominant socio-economic activity within the Mara River basin remains crop farming. About 62% of the households are small-scale mixed farmers; though there are also a number of large farms producing cash crops. Livestock rearing is the second dominant activity practiced by the Maasai who have maintained a pastoral lifestyle in the upper basin (Mati *et al.*, 2005). Tourism and wildlife conservancy are important economic activities as exemplified by the Maasai Mara Game Reserve in Kenya, and Serengeti National Park in Tanzania. However, the Mara's world-renowned wildlife populations are currently threatened by increased anthropogenic activities key among them deforestation at the upper catchments while land degradation is critically impacting the river's flow and the ecosystem thus threatening the economy of the entire Mara-Serengeti ecosystem (Mutie *et al.*, 2006).

3.2.3 Climate and weather patterns

Weather patterns within the Mara River basin are bi-modal, with the long rains falling between March and April, short rains between October and November, long dry season between July and September and short dry season between December and February (Mati *et al.*, 2005). This study was carried out in August and therefore in the middle of the long dry season. Rainfall in the Mara River basin varies with altitude with the Mau escarpment receiving most rainfall (i.e. mean annual rainfall ranging from 1,000-1,750mm); the middle rangelands between 900-1,000mm; while the lower Loita Hills and Musoma receive between 700–850mm of rainfall (Mati *et al.*, 2008). However, due to climate change variability, prediction of rainfall patterns is no longer very dependable (Mati *et al.*, 2008).

3.3 Study Design and Sampling Sites Selection

This was a cross-sectional study with both field and laboratory components carried out on a one-off basis and which aimed at determining the influence of anthropogenic activities on water quality of Nyangores and Amala tributaries of the Mara River. The authority to carry out the study was obtained from the office of the Director, School of Graduate Studies (SGS), Maseno University (see Appendix I). The field component was carried out in August 2011 during the long dry season. This study focused mainly on sections of Amala and Nyangores tributaries flowing through Mulot and Bomet Towns, respectively, so as to capture the influence of anthropogenic activities on water quality within the urbanized areas, while two springs located at the upper catchments and draining into each of the tributaries, respectively, were included to act as controls.

A purposive sampling technique was used in the selection of the eight study sites (4 along each tributary), based on their location (i.e. three within each of the towns and one at a spring on the upper catchments draining into each tributary). The sites within the urbanized areas were distanced approximately 1.5km from each other while the upper catchment spring sites were distanced approximately 20km from the nearest site within the urbanized areas. The upper catchment springs were specifically included to act as control points and were thought to be unpolluted and less impacted and were therefore to be used for comparison purposes with the perceived disturbed sites located within the urbanized area.

For easy identification, sampling sites along Amala tributary were coded as follows: AS (upper catchment spring draining into Amala tributary), AUM (Amala tributary at the upper part of Mulot Town), AMM (Amala tributary at the middle part of Mulot Town) and ALM (Amala tributary at the lower part of Mulot Town), while, those along Nyangores tributary were coded as follows: NS (upper catchment spring draining into Nyangores tributary), NUB (Nyangores tributary at the upper part of Bomet Town), NMB (Nyangores tributary at the middle part of Bomet Town) and NLB (Nyangores tributary at the lower part of Bomet Town). Figure 3.2 shows a sketch of the study sites along Amala and Nyangores tributaries.

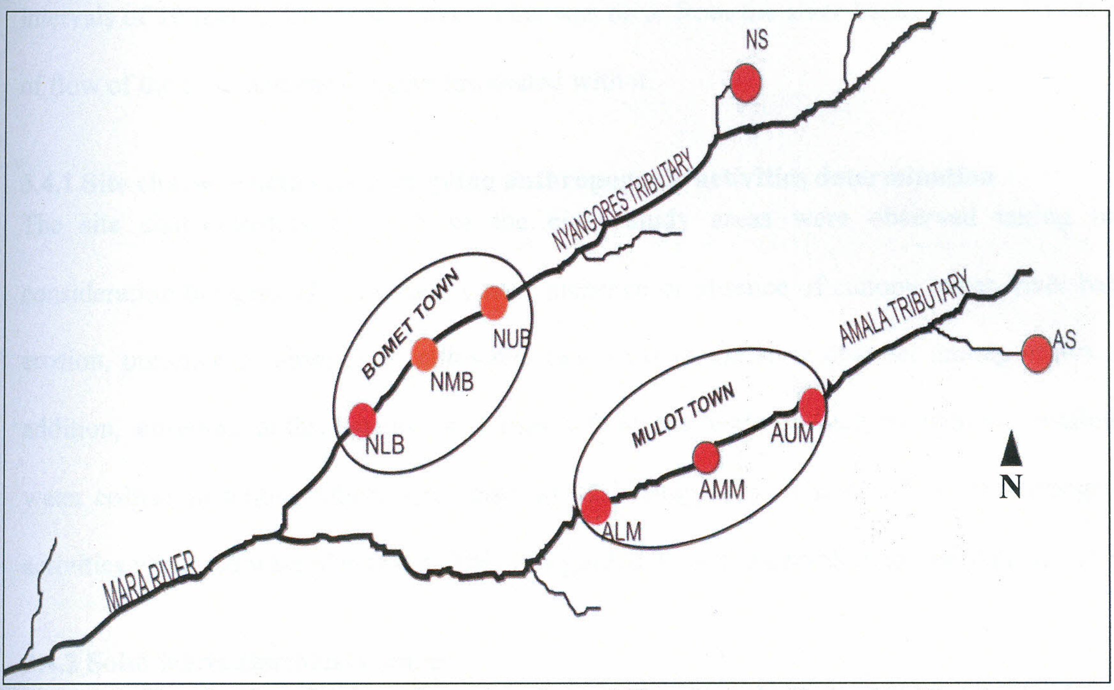

Figure 3.2. Sketch of study sites along Amala and Nyangores tributaries (Not drawn to scale)

Key: AS - Upper catchment spring, AUM - Upper part of Mulot Town, AMM - Middle part of Mulot Town and ALM - Lower part of Mulot Town along Amala tributary, and NS - Upper catchment spring, NUB - Upper part of Bomet Town, NMB - Middle part of Bomet Town and NLB - Lower part of Bomet Town along Nyangores tributary.

Information on the characteristics of each site and on-going anthropogenic activities was collected using an observation guide, see Appendix (II). Variables including solid waste, physico-chemical parameters, nutrients, benthic macroinvertebrates and coliform bacterial levels were determined along the two perennial tributaries of Mara River, in an attempt to answer the research questions. The units of analysis were the two perennial tributaries (Nyangores and Amala) of the Mara River.

3.4 Site Observtaions, Sample Collection and Processing

Observations were made at each study site prior to sample collection. Solid waste, physico-chemical parameters, nutrients, benthic macroinvertebrates and coliform levels were determined across all the 8 sampling sites. All samples were collected on a one-off basis (cross-sectional). The replicate water samples were collected along the edges of the river at intervals of 10 metres from each other. This was done from the river banks due to the nature of flow of the river and the dangers associated with it.

3.4.1 Site characteristics and on-going anthropogenic activities determination

The site characteristics of each of the eight study areas were observed taking into consideration the general vegetation cover, presence or absence of canopy cover, river bank erosion, presence or absence of cultivated land next to the river channel among others. In addition, on-going anthropogenic activities within the vicinity such as bathing, washing, water collection among others were also noted. Photographs of some of the anthropogenic activities observed were also taken. This was guided by site observation guide (Appendix II).

3.4.2 Solid waste characterization

At each of the 8 sites, solid waste samples within the river channels (100 metre stretch) and along the river banks (upto 30 meters from the main river channel on both sides) were collected, identified and characterized. However, due to the focal nature of springs, solid waste around the springs were collected and identified within a 30metres radius. The waste was analyzed at their points of disposal, where characterization was done by visualization and through hand sorting. Visualization was carried out for waste that was nearly homogeneous, such as mill tailings, agricultural chaff, sawdust, liquid waste among others, since hand sorting was not possible to characterize such waste. The identified solid waste was then grouped into different categories based on their physical characteristics and recorded in a solid waste frequency and composition recording sheet (Appendix III).

3.4.3 Measurement of physico-chemical parameters

Physico-chemical parameters namely dissolved oxygen, conductivity, turbidity and pH were measured *in situ* at the point of sampling in replicates of three, spaced at intervals of 10metres downstream using a YSI 556 MPS Handheld Multi Parameter Instrument (YSI Incorporation, Yellow Spring, USA). Total suspended solid (TSS) was determined following the standard methods outlined in APHA (1998), on water samples obtained in replicates of three from each of the eight sites. This was done by filtering 50mls of each water sample through a pre-weighed standard glass-fiber filter paper using a suction pump. The residue retained on the filter paper together with the paper were dried to a constant weight at 103°C to 105°C for at least 1 hour in an oven, cooled in a desiccator and weighed using a weighing balance. The cycle of weighing was repeated until a constant weight was obtained. The initial weight of the filter paper (without sample) was subtracted from the final weight (filter paper + reside retained on paper) obtained to give the total suspended solids calculated as follows:

$$\text{Total Suspended Solids in milligrams per litre} = \frac{(A-B) \times 1000}{\text{Sample volume (millilitres)}}$$

Where:

A = weight of filter + dried residue (in milligrams)

B = weight of filter, (in milligrams)

Total dissolved solids (TDS) was also determined following the standard methods outlined in APHA (1998), on water samples by filtering 50mls of the water sample through a standard glass-fiber filter paper using a filtration pump. The filtrate was then transferred from the filtration unit into a clean, pre-dried and pre-weighed evaporating dish and evaporated at

103°C to 105°C in an oven for atleast one hour. This was cooled in a desiccator and weighed using a weighing balance. The cycle of weighing was repeated until a constant weight was obtained. The solids left after evaporation marked by the increase in weight of the evaporating dish represented the total dissolved solids (TDS), calculated as follows:

$$\text{Total Dissolved Solids in milligrams per litre} = \frac{(A-B) \times 1000}{\text{Sample volume (millilitre)}}$$

Where:

A = weight of dried residue + evaporating dish (milligrams)

B = weight of evaporating dish (milligrams)

3.4.4 Nutrient analysis

Water samples for nutrient determination were collected either directly or using a 2.5L capacity Van Dorn water sampler, depending on site characteristics, and stored in sterile plastic sample bottles. The standard methods outlined in Wetzel and Likens (1991) were used in nutrient analysis. In summary, total Nitrogen was analyzed using the persulfate digestion method on unfiltered water samples by digestion with ammonium persulfate, which oxidized all forms of nitrogen to nitrate. The nitrate was then reduced to nitrite after passing through a copperized cadmium reduction column. The nitrite was then diazotized with sulfanilamide and coupled with N-(1-napthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye, whose absorbance was measured colorimetrically on a spectrophotometer at a 520nm wavelength. Ammonium molybdate method was used in total phosphorus determination. Since phosphorus may occur in combination with organic matter, samples for the determination of total phosphorus were oxidized using hot 5% potassium per sulfate in distilled water, autoclaved for 30 minutes, then further cooled at room temperature to liberate organic phosphorus as orthophosphate. These were read on a spectrophotometer at an absorbance of 880nm wavelength.

3.4.5 Benthic macroinvertebrate determination

Sediment samples for benthic macroinverterbrate determination were collected, in replicates of three, using a D-frame dip net of 0.3m width by 0.3m height attached to a long pole and with a cone shaped bag for capture of organisms. Sampling was done from downstream end of the river to upstream. A total of 3 jabs were made at each sampling point, with a single jab consisting of a forceful thrust of the sampler into the sediment for a linear distance of 0.5m. The sediment samples collected were transferred into plastic buckets, sieved using Tyler sieve of mesh size of between 1.00mm and 250mm. The organisms retained in the mesh were segregated in a white tray and preserved in plastic bottles with 90% ethanol (Gretchen, 2007) pending laboratory analysis. Counting and identification was done using a dissecting microscope at a suitable magnification (10 - 500x magnification). Benthic macroinvertebrates were identified to genus or species level using manuals of Needham and Needham (1962) and Egborge (1995). The Shannon-Weiner (H') Diversity index (1949) and Shannon evenness index were worked out to determine the benthic macroinvertebrate community structure as follows:

Shannon - Weinner Diversity Index: $\mathbf{H^l = -\Sigma\ [(ni / N) \times (ln\ ni / N)]}$

Where: **H^l**: Shannon Diversity Index

ni: Number of individuals belonging to i species

N: Total number of individuals

Shannon Evenness Index: **E = H/log(S)**

Where: **E**: Evenness index

H: Shannon Diversity Index

S: Species number

3.4.6 Total coliform count and *Escherichia coli* determination

Water samples for coliform bacteria determination were collected from the river below the water surface using sterile 250ml glass bottles, inverted downwards and against the water current, with the hand kept downstream from the neck of the bottle to avoid contamination. A total of 5 replicate water samples for coliform determination were collected from each site at intervals of 10 meters along the length of the river. The samples were collected in replicates of five per site so as to increase the chances of detecting coliform bacteria in water samples owing to the nature of the river from which the samples were obtained. The water samples were then stored in a cold ice-packed box and transferred to Longisa District Hospital microbiology laboratory within six hours of collection for total coliform and *E. coli* determination.

Microbial analysis on the water samples was carried out using the most probable number (MPN) procedure by the multiple tube fermentation technique (APHA, 1998). The technique involved three successive steps, namely, presumptive test, confirmed test and completed test (APHA, 1998). In the presumptive test, 10ml of McConkey G broth purple (Fluka Sigma-Aldrich) was added into each of the 3 sets of 25ml tubes (with inverted Durham's tubes' inserts). Each set contained three tubes (making a total of 9 tubes). The tubes were sterilized by autoclaving then allowed to cool before being inoculated with a ten-fold difference of water sample inoculums volumes, i.e. 0.1ml, 1ml and 10ml per tube. These were then incubated at 37°C (Gallenkemp, Germany) for 24 to 48 hours. The tubes were examined for acid formation and gas production. Colour change from purple to yellow and formation of gas in Durham tubes indicated a positive test while the absence of colour and lack of gas formation indicated a negative test (APHA, 1998). Each set was scored against the number of positive tubes and the score of all the three sets used to determine the number of total coliforms in water samples from the standard Most Probable Number (MPN) table (APHA, 1998) (Appendix IV).

The confirmed test was performed by streaking a sample from the positive presumptive tube onto Eosine Methylene Blue agar (EMB) (HiMedia Lab. Pvt. Mumbai, India) containing lactose and the dyes eosine Y and methylene blue and incubated at 44.5±0.2°C for 24±2hrs. When *E. coli* grows on EMB, it ferments so much acid that the two dyes precipitate out in the colony producing a metallic green sheen appearance while non-faecal coliforms appear as pale pink mucoid and red colonies (APHA, 1998). A positive confirmed test was therefore exhibited by the presence of typical green sheen colonies, which were subjected to the completed test (Benson, 2002). In the completed test, selected typical colonies from positive confirmed test were inoculated into McConkey G purple broth and incubated at 37°C for 24h. A loop of the colony was streaked onto a slant of nutrient agar. The culture on the nutrient agar was analyzed by Gram staining (APHA, 1998). Analytical grade chemicals and reagents obtained from HiMedia were used in all the tests.

3.5 Data Analysis and Presentation

Data entry and cleaning was done in Microsoft Excel spreadsheet while statistical analysis was carried out using the Statistical Analysis Software version nine (SAS V9.0). Observations made at each site were presented in textual form and also as photographs. Descriptive statistics were used to summarize the data characteristics on non-trandformed data, which were then presented as means and standard deviations. Variations in physico-chemical parameters, nutrients, solid waste, benthic macroinvertebrates and coliform bacteria levels between different sites (upper catchment spring, upper part of town, middle part of town and lower part of town) along Amala and Nyangores tributaries were determined using One-Way ANOVA on transformed data, normalized by log transformation using $\log_{10}(n+2)$.

For effects that were found significant at $p<0.05$, post hoc separation of means was done by Duncan Multiple Range Test (DMRT), to find true differences in means. Regression analysis was used to describe relationships between waste and physico-chemical parameters, benthic macroinvertebrate and coliform bacteria. Students't-test was used to establish possible differences in solid waste, physico-chemical parameters, nutrients, benthic macroinvertebrates and coliforms bacteria levels between Amala and Nyangores tributaries. $P<0.05$ level was considered statistically significant.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

In this chapter, the study findings are presented as per the study objectives, in tables, figures, plates and textual forms. Observations made in all the sampled sites are also presented.

4.2 Observations Made at the Sampling Sites

To gain some qualitative insight as to the impact of anthropogenic activities on water quality, observations were made in all the 8 sites with respect to site characteristics such as topography of the area, degradation status of the river banks, presence/absence of riparian vegetation, proximity of human settlements and latrines to river banks, presence of solid waste dump sites, river bank cultivation, among others. The findings showed that all sites located within the urbanized areas (Bomet and Mulot Towns) were impacted, though to varying degrees. Anthropogenic activities such as bathing, washing clothings, washing of vehicles, water collection using donkeys for domestic use, swimming, among others, were common in all the sites with the exception of spring NS located at the upper catchment and draining into Nyangores tributary, which was relatively protected. This spring site was also undisturbed with greater canopy cover and little human activities at the spring itself and within the vicinity, thus making it the ideal control site.

On the contrary, the upper catchment spring draining into Amala tributary, initially thought to be clean and undisturbed during the study proposal design, was found to be highly impacted by anthropogenic activities as was evident from the observed degraded banks, absence of vegetation/tree cover around the spring, presence of livestock droppings along the banks, among others. Table 4.1 gives a summary of the site characteristics and anthropogenic activities at each site. The GPS locations and altitudes are also given.

Table 4.1. GPS locations, altitudes, and detailed description of study sites characteristics

Site Code	Tributary	GPS Location/Alt	Site Description/Characteristics
AS	Amala	S 054.256 E 35.27'844 1978masl	Site AS was a spring initially designated as a control site, located at the upper catchment that drains into Amala tributary. However, contrary to expectation, the results from this study showed that this site was highly impacted by human activities, and characterized by unprotected banks, bare soils, and a gently sloping topography. The area was also characterized by two hot springs which attracted the locals to the area to bathe, wash and collect water. The area served as a livestock watering point characterized by animal droppings. Since the spring was unprotected, probablility of contamination through back flow was high.
AUM	Amala	S 055.401 E 35.26'337 1876masl	Site AUM was located about 20km from the upper catchment spring (AS) and was highly impacted by anthropogenic activities that contributed to the high solid and liquid waste observed in some of the surface drains discharging into the river from Mulot Town. This site also served as a water collection point, while laundering of clothes as well as an animal watering were also on-going at the site. There was also the presence of human habitation and pit latrines built close to the river banks at this site.
AMM	Amala	S 055.933 E 35.26'240 1855masl	Site AMM was about 1.5km from site AUM. This site was located at the Bomet-Mulot bridge and was characterized by anthropogenic activities among them washing of motor vehicles, laundering of clothes, water collection activities and bathing. Sections of the river banks were degraded and characterized by bare soils while a few other sections were covered with riparian trees that provided a thick canopy cover.
ALM	Amala	S 055.987 E 35.26'118 1896masl	Site ALM was located about 1.5km from site AMM. This area was characterized by anthropogenic activities such as washing, water collection and livestock watering along the river. The banks were relatively covered by vegetation though crops were also cultivated right upto the banks of the river, thus increasing the possibilities of rapid sediment load into the river due to soil erosion during heavy rainfall.

Code	Tributary	GPS /Alt	Site Description/Characteristics
NS	Nyangores	S 044.707, E 035.23'48 2083masl	This was a spring located at the upper catchment draining into Nyangores tributary. This spring was relatively protected, less disturbed and characterized by a thick canopy cover. The livestock watering point was located a few metres from the spring itself and controlled by barriers to restrict livestock from accessing the spring. This site was located approximately 20km from other sites within the urbanized area (Bomet Town) downstream of the same tributary. Thus it was the ideal control site for this study.
NUB	Nyangores	S 046.026 E 035.20'69 2004masl	This site was located next to a densely populated slum area at the point of entry of Nyangores tributary into Bomet Town, and was approximately 20km from spring NS. There was presence of pit latrines along the river banks, though open defecation was also common as evidenced by faeces along the banks. The vegetation along the banks had been cleared in most sections of the tributary for settlement and agricultural purposes. Washing, livestock watering, water collection and bathing were also common at this site
NMB	Nyangores	S 046.405 E 035.20'68 1954masl	This site was approximately 1.5km downstream of site NUB and was located at a bridge on the main road connecting Bomet Town to Longisa. The site was mainly influenced by waste emanating from Bomet urban centre. The surrounding environment area was degraded, with sparse vegetation cover and largely bare soils. Anthropogenic activities mainly washing of motor vehicles, water collection, washing and bathing were also common at this site.
NLB	Nyangores	S 046.895 E 035.20'62 1901masl	Site NLB was the last site at the point of exit from the urbanized area (Bomet Town), located approximately 1.5km downstream of site NMB. The site was also characterized by increased human activities such as water collection, washing, bathing as well as livestock watering. The banks were relatively well vegetated, though at some sections, food crops (maize) and nappier grass were planted upto the river bank. There was also a drainage that discharged waste water from the urban area into the river at this point.

Among all sites sampled along the two tributaries, the upper part of Mulot Town (AMU) characterized by high anthropogenic activities (Plate 4.1), had the highest (44.5%) amount of solid waste and was also characterized by high anthropogenic activities, while the upper catchment spring (NS), draining into Nyangores tributary and relatively undisturbed had the least (0.3%) amount of solid waste.

Plate 4.1. Anthropogenic activities (domestic water collection) along Amala tributary at the upper part of Mulot Town

Site survey using observation guide (Appendix III) revealed careless littering of solid waste, particularly grocery polythene bags, plastic bottles, polythene product wrappers and torn clothing either floating on water or trapped under rocks or by roots and branches of emergent aquatic macrophytes, along the banks of the two Mara River tributaries at various sampling points (Plate 4.2 A & B).

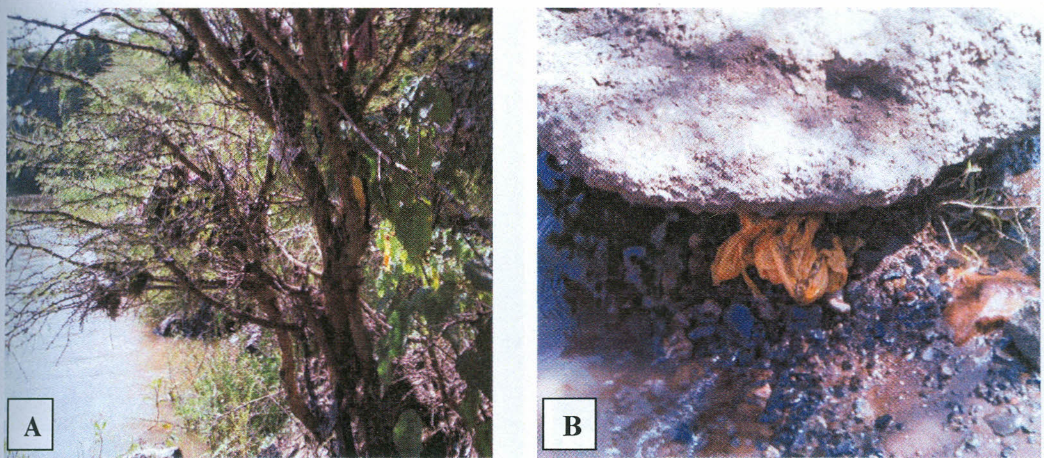

Plate 4.2. Solid waste, (A) polythene bags and clothing, trapped by branches of riverine trees along Amala tributary and, (B) a polythene bag trapped underneath a rock along the edges of the river channel along Nyangores tributary.

Further observations revealed that sections of the Mara River tributaries in close proximity to human settlement and which were characterized by high human activities as was the case at the upper part of Mulot Town (AUM) along Amala tributary, had relatively higher quantities of solid waste, dominated by grocery polythene bags, recyclable paper, and plastic bottles deposited along the gently sloping banks (Plate 4.3A), compared to low quantities recorded at the relatively undisturbed site at the upper catchment spring (NS), draining into Nyangores tributary. In addition, it was further observed that urbanization and poor waste disposal methods among inhabitants was mainly responsible for increased garbage accumulation along the banks of Amala and Nyangores tributaries and even in surface drains (Plate 4.3B). This was likely to facilitate their transportation and subsequent deposition in the river channel during heavy rainfall, thus resulting in pollution.

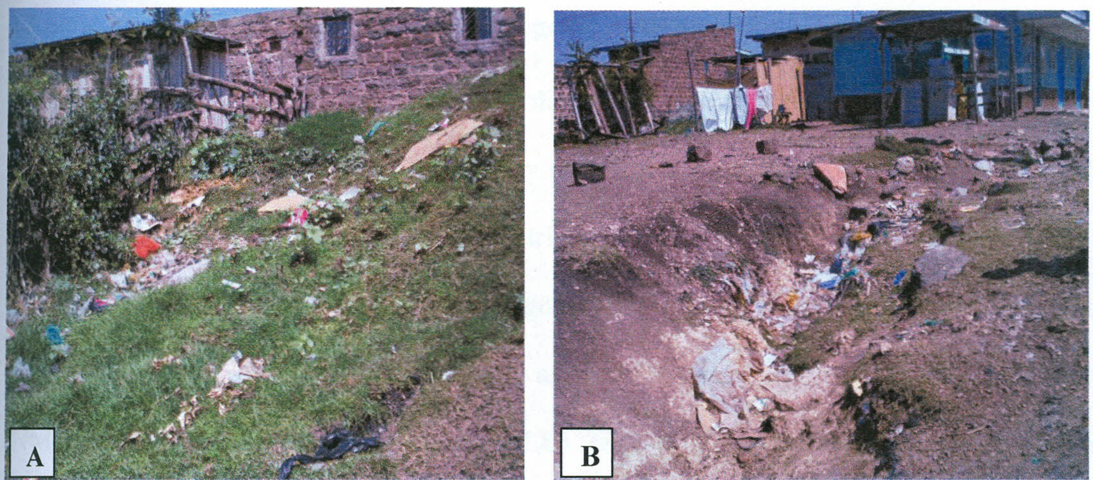

Plate 4.3. Solid waste from various sources, (A) strewn on slopes next to human dwellings, and (B) on surface drainages leading into Amala tributary

Poorly disposed human waste was also observed at various points along the banks of the Mara River tributaries (Plate 4.4). The close proximity between the human waste disposal point and the river bank as shown in Plate 4.4 facilitates the intermixing between faecal waste and surface water within the river channel.

Plate 4.4. Human waste (shown by arrow), along the bank of Nyangores tributary at a site located within Bomet Town

4.3 Solid Waste as Influenced by Anthropogenic Activities along Amala and Nyangores Tributaries

A total of 1020 counts of various types of solid waste were recorded along the banks of the two Mara River tributaries, with significantly more solid waste being recorded along Amala tributary (62.4%), compared to Nyangores tributary (37.6%) (Student's t-test, $P = 0.031$). Considering each tributary separately, Nyangores tributary had relatively higher proportions (50.3% and 44.8%), of solid waste especially at the more disturbed sites located at the middle (NMB) and lower parts of Bomet Town (NLB), respectively, compared to 4.2% and 0.8%, encountered at the upper part of Bomet Town (NUB), and the upper catchment spring (NS), that drains into Nyangores tributary, respectively. Out of a total count of 636 solid waste types recorded along Amala tributary, the site AUM located at the upper part of Mulot Town recorded the highest proportion (71.4%), followed by 16.4% recorded at the upper catchment spring (AS) draining into Amala tributary. However, the middle (ALM) and lower (AMM) parts of Mulot Town along the same tributary recorded relatively lower proportions of solid waste at 3.5% and 8.8%, respectively, Figure 4.1.

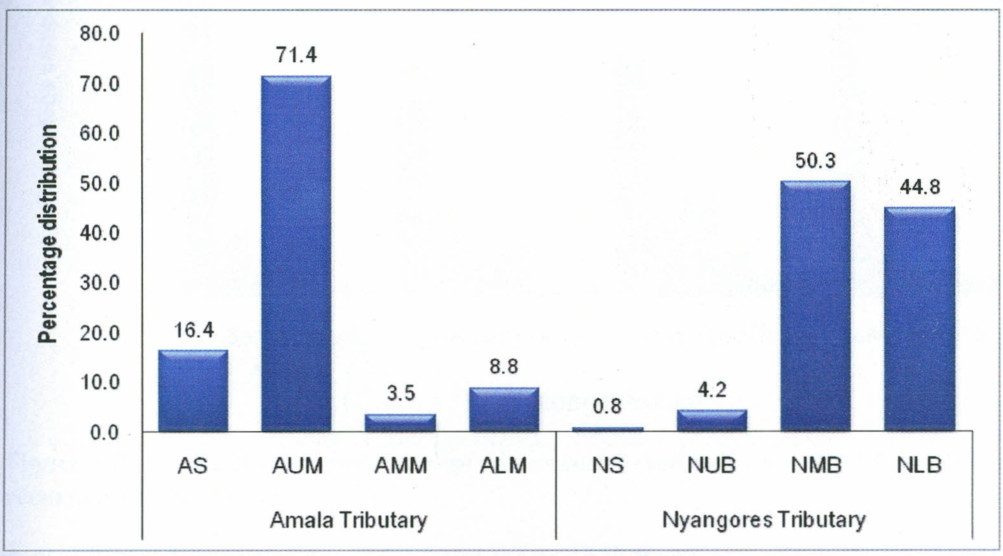

Figure 4.1. Proportion of total solid waste recorded at different sites* along Nyangores and Amala tributaries

*Upper catchment spring (AS), upper part of Mulot Town (AUM), middle part of Mulot Town (AMM) and lower part of Mulot Town (ALM) along Amala tributary, and upper catchment spring (NS), upper part of Bomet Town (NUB); middle part of Bomet Town (NMB) and lower part of Bomet Town (NLB) along Nyangores tributary.

4.3.1 Solid waste composition

Analysis of the waste to establish its composition revealed that grocery polythene bags, including polythene product wrappers were the most dominant (48.9%) and common of all the waste encountered along Amala and Nyangores tributaries. Over 60% of all the waste recorded at the upper catchment spring draining into Amala tributary comprised of polythene bags, compared to 33.3% recorded at the upper catchment spring draining into Nyangores tributary (NS). Other solid waste encountered along the two Mara River tributaries included: recyclable office paper (17.3%), plastic bottles (9.6%), textile/torn clothing (8.5%), manila bags/ropes (2.6%), leather (2.8%) and food waste (4.9%). The relatively rare occurring waste like broken glass, tins/cans, sponge, rotting wooden pieces, gunny bags and ceramic/moulded material were grouped together and these accounted for 3.1% of the total waste encountered (Figure 4.2).

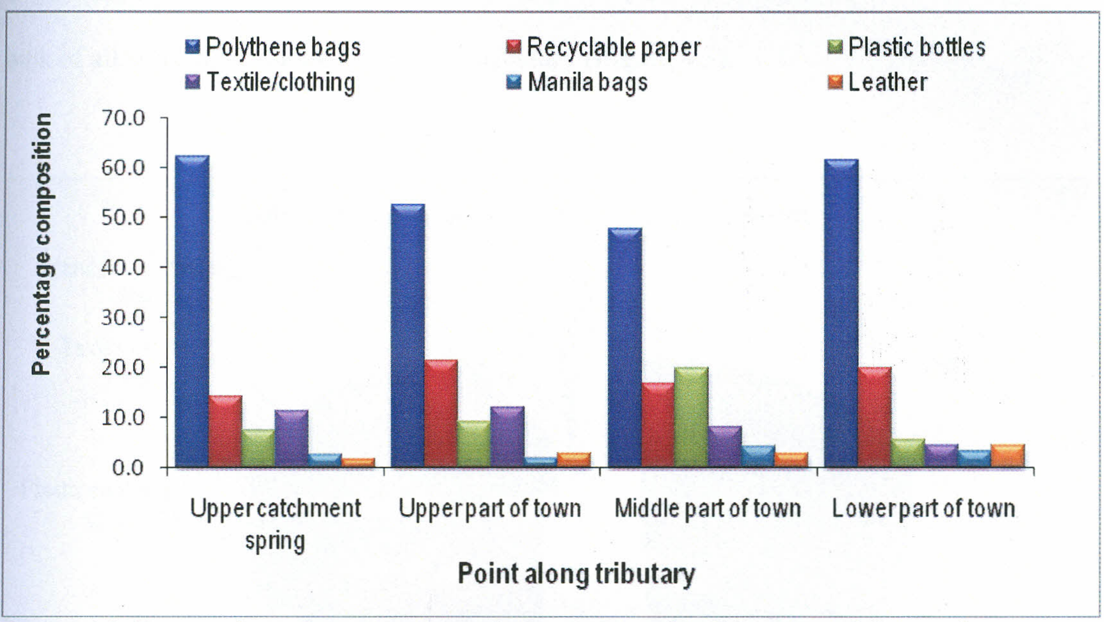

Figure 4.2. Proportion of most commonly encountered solid waste of the total waste recorded in the study

A closer scrutiny of the dominant solid waste (polythene and plastic bottles), revealed that most plastic waste comprised of grocery polythene bags and polythene product wrappers of commonly utilized household goods such as detergents/soaps, bread, milk, sweets, biscuits among others. In addition, most plastic containers comprised of soda bottles and various brands of mineral water bottles. Pieces of clothing/textile, leather, rubber, disposable diapers, cans, paper towels and food waste, were also encountered at some sections along the two Mara River tributaries. Other waste encountered at the upper part of Mulot Town (AUM), along Amala tributary included: broken glass, tins/cans, sponge, rotting wooden pieces, gunny bags and ceramic/moulded waste. Such waste was classified as "other waste" in the context of this study, due to their considerably small proportions.

Generally, waste composition along the two tributaries showed an almost similar trend. There were however significant variations among the solid waste types encountered at different sites along Nyangores tributary (one-way ANOVA, $F_{(3,63)}=5.15$, $P<0.003$), with polythene bags/wrappers (50%), recyclable paper (17%) and plastic containers (12%) making up the bulk of all solid waste along Nyangores tributary (Figure 4.3).

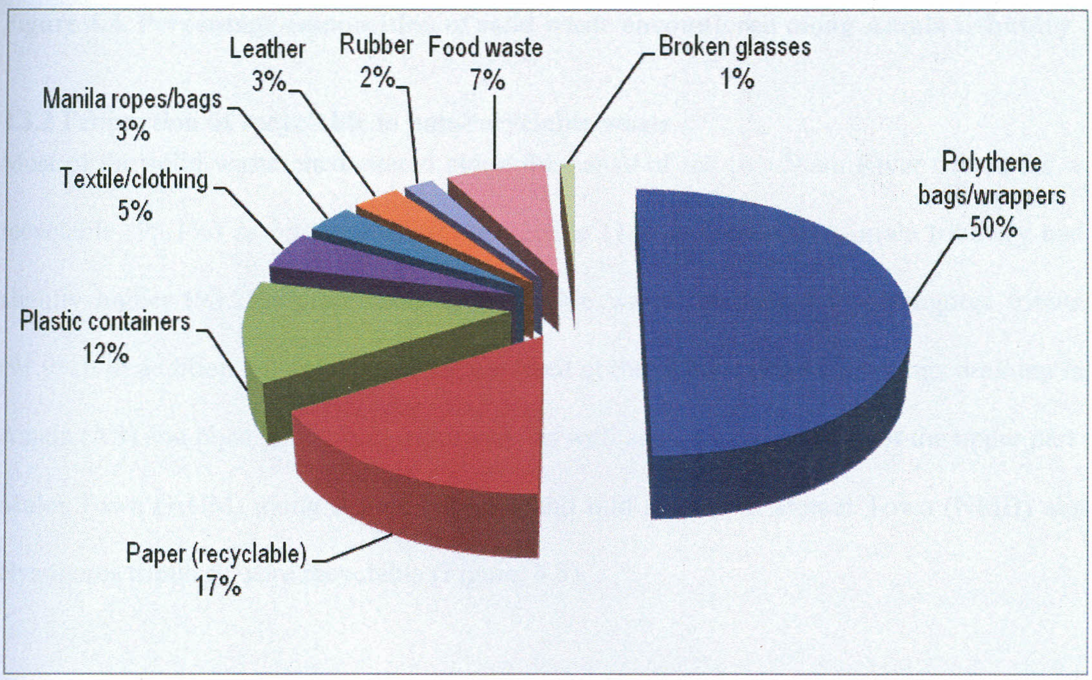

Figure 4.3. Percentage composition of solid waste encountered along Nyangores tributary

Likewise, significant variations were also found between solid waste types encountered at different sites along Amala tributary (one-way ANOVA, $F_{(3,63)}$ =7.23, P<0.0003), with polythene bags/wrappers (48%), paper (recyclable) (18%), plastic containers (8%) and textile (11%), comprising the bulk of the solid waste (Figure 4.4).

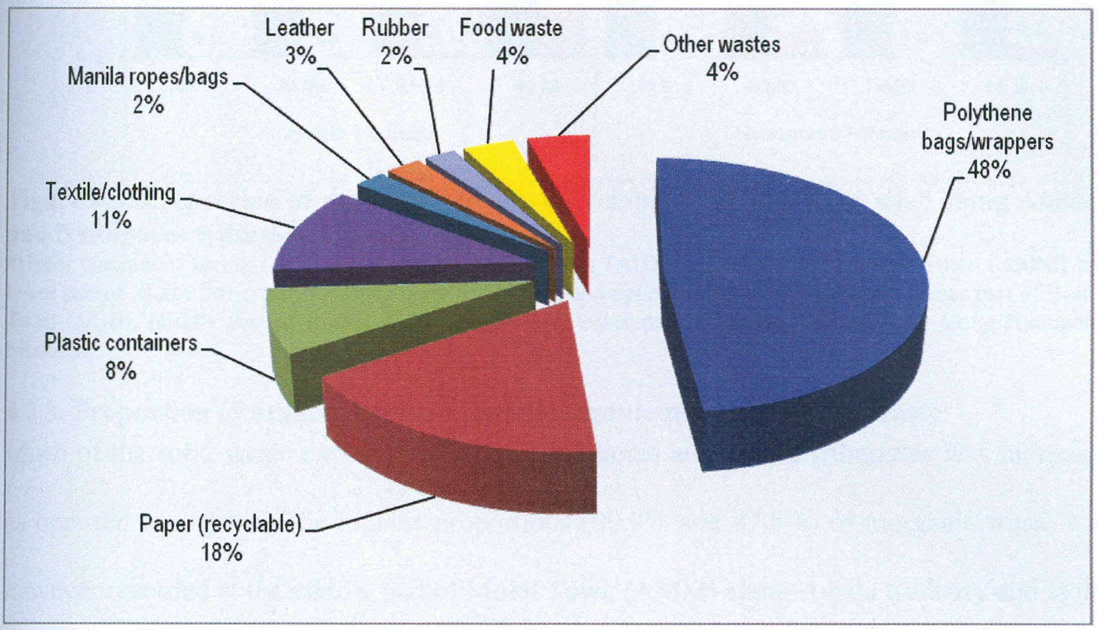

Figure 4.4. Percentage composition of solid waste encountered along Amala tributary

4.3.2 Proportion of recyclable to non-recyclable waste

Most of the solid waste encountered along the banks of the two Mara River tributaries was recyclable (96.1%) as opposed to non-recyclable (3.9%). Generally, Amala tributary had a slightly higher (93.2%) proportion of recyclable waste, compared to Nyangores tributary (91.9%). In addition, all solid waste encountered at the upper catchment springs draining into Amala (AS) and Nyangores (NS) tributaries, as well as those encountered at the upper part of Mulot Town (AUM) along Amala tributary and mid section of Bomet Town (NMB) along Nyangores tributary were recyclable (Figure, 4.5).

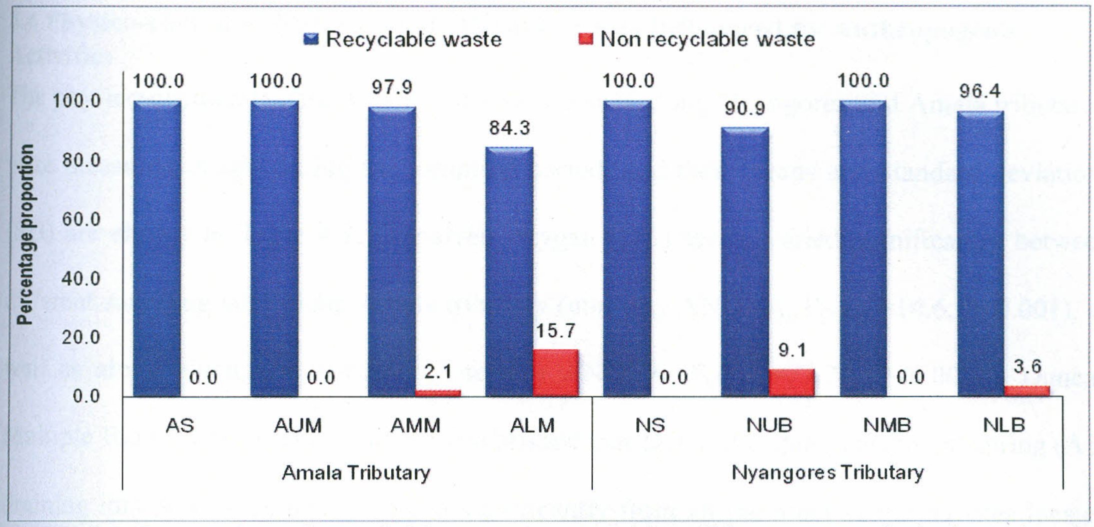

Figure 4.5. Proportion of recyclable to non recyclable solid waste per site* along Amala and Nyangores tributaries

*Upper catchment spring (AS), upper part of Mulot Town (AUM), middle part of Mulot Town (AMM) and lower part of Mulot Town (ALM) along Amala tributary, and upper catchment spring (NS), upper part of Bomet Town (NUB), middle part of Bomet Town (NMB) and lower part of Bomet Town (NLB) along Nyangores tributary.

4.3.3. Proportion of organic/degradable to inorganic/non-degradable waste

Much of the solid waste encountered along Nyangores and Amala tributaries was inorganic as opposed to organic. The highest proportions (90.9% and 87.5%) of inorganic waste was however recorded at the middle part of Mulot Town (AMM) along Amala tributary and at the upper part of Bomet Town (NUB), along Nyangores tributary, respectively (Figure 4.6).

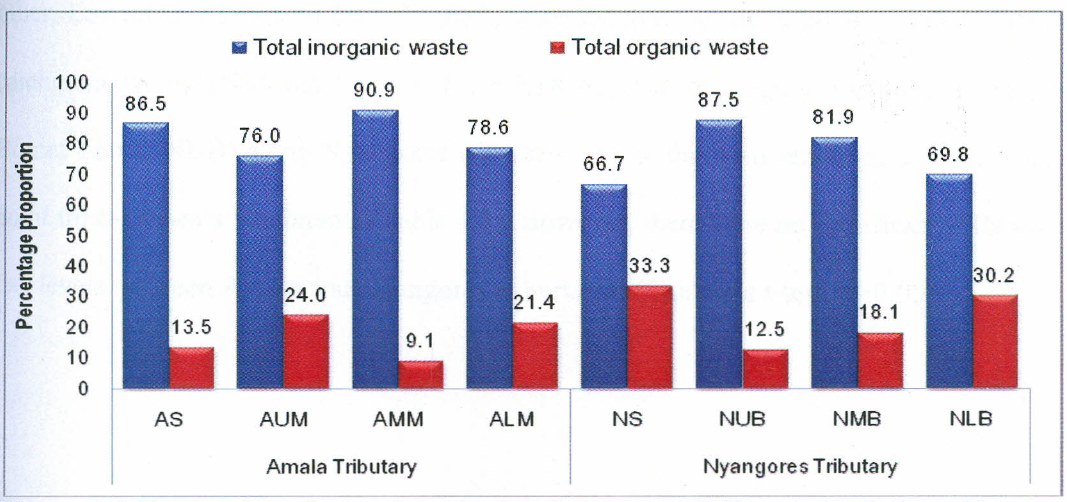

Figure 4.6. Proportion of organic to inorganic waste at differsnt sites* along Nyangores and Amala tributaries

*Upper catchment spring (AS), upper part of Mulot Town (AUM), middle part of Mulot Town (AMM) and lower part of Mulot Town (ALM) along Amala tributary, and upper catchment spring (NS), upper part of Bomet Town (NUB); middle part of Bomet Town (NMB) and lower part of Bomet Town (NLB) along Nyangores tributary.

4.4 Physico-chemical Water Quality Parameters as Influenced by Anthropogenic Activities

The physico-chemical characteristics of selected sites along Nyangores and Amala tributaries were measured *in situ* during the sampling period, and their means and standard deviations (SD) are shown in Table 4.2. Dissolved oxygen (DO) levels varied significantly between different sampling sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ =14.6, P<0.001), as well as along Nyangores tributary (one-way ANOVA, $F_{(3,11)}$ =77.74, P<0.0001). Duncan Multiple Range Test (DMRT) further established that DO at the upper catchment spring (AS) draining into Amala tributary differed significantly from all the other sampling sites located within Mulot Town along the same tributary, with the lowest DO level (6.0 ± 0.8 mg/l) recorded at the upper catchment spring (AS) and the highest (8.23 ± 0.13 mg/l) at the upper part of Mulot Town (AUM) - a site characterized by high anthropogenic activities.

Duncan Multiple Range Test (DMRT) further established significant differences in DO between sites along Nyangores tributary, though the middle part (NMB) and lower part (NLB) of Bomet Town, along Nyangores tributary were not significantly different from each other. Lowest DO levels (6.25±0.22 mg/l) were recorded at the relatively undisturbed upper catchment spring (NS) and highest (8.13±0.18 mg/l) at the highly disturbed upper part of Bomet Town (NUB) along Nyangores tributary – a site that also served as a water collection point for the town's inhabitants (Table 4.2). However, there were no significant differences in DO levels between Amala and Nyangores triburtaries (Student's t-test, P>0.05).

Table 4.2. Physico-chemical characteristics along Nyangores and Amala tributaries

Parameter	Tributary	Physico-chemical parameters (Mean±SD) at different sites long Amala and Nyangores tributaries				
		Upper catchment spring	Upper part of town	Middle part of town	Lower part of town	**Overall mean**
pH	Amala	7.42 ± 0.77^{A}	7.52 ± 0.06^{A}	7.54 ± 0.03^{A}	7.75 ± 0.04^{A}	**7.56**
	Nyangores	6.64 ± 0.05^{C}	7.63 ± 0.08^{B}	7.77 ± 0.09^{B}	8.13 ± 0.15^{A}	**7.54**
DO (Mg/l)	Amala	6.00 ± 0.80^{B}	8.23 ± 0.13^{A}	8.12 ± 0.23^{A}	7.76 ± 0.05^{A}	**7.53**
	Nyangores	6.25 ± 0.22^{C}	8.13 ± 0.18^{A}	7.59 ± 0.14^{B}	7.72 ± 0.04^{B}	**7.42**
Turbidity (NTU)	Amala	101.4 ± 18.2^{B}	131.9 ± 1.54^{A}	115.9 ± 1.50^{AB}	128.6 ± 0.25^{A}	**119.44**
	Nyangores	111.1 ± 42.6^{A}	121.6 ± 2.76^{A}	136.7 ± 6.5^{A}	127.9 ± 1.21^{A}	**124.12**
Conductivity (µS/cm)	Amala	309.0 ± 19.1^{A}	57.0 ± 2.0^{B}	53.3 ± 1.15^{B}	59.7 ± 0.58^{B}	**119.75**
	Nyangores	74.5 ± 2.5^{A}	51.0 ± 1.73^{B}	58.0 ± 7.55^{B}	52.0 ± 2.0^{B}	**58.87**

Means with different superscripts in the same row are significantly different at $P<0.05$. (Data analyzed by Duncan's Multiple Range Test)

Conductivity levels along Amala tributary varied significantly between sites (one-way ANOVA, $F_{(3,11)}$ =1500.8, $P<0.0001$). Duncan Multiple Range Test further established that conductivity levels were significantly higher (309±19.1 µS/cm) at the upper catchment spring (AS) compared to all other sites, with the lowest conductivity (53.3±1.2 µS/cm) recorded at the middle part of Mulot Town (AMM), along Amala tributary. Likewise, there were significant variations in conductivity between different sampling sites along Nyangores tributary (one-way ANOVA, $F_{(3,11)}$=17.14, $P<0.001$), with DMRT further confirming that conductivity levels at the upper catchment spring (NS) differed significantly from all other sites located within Bomet Town along Nyangores tributary. The highest conductivity (74.47±2.5 µS/cm) was recorded at the upper catchment spring (NS) and lowest (51.0±1.7 µS/cm) at the upper part of Bomet Town (NUB) (Table 4.2). No significant differences were however observed in conductivity levels between Nyangores and Amala tributaries.

pH levels varied significantly (one-way ANOVA, $F_{(3,11)}$ =142.15, $P<0.0001$) between sites along Nyangores tributary. The DMRT further established significant differences in pH between specific sites along Nyangores tributary, though pH levels at the upper part (NUB) and middle part (NMB) of Bomet Town, along Nyangores tributary were not significantly different. The highest pH value (8.13±0.15) was recorded at the lower part of Bomet Town (NLB) along Nyangores tributary characterized by high livestock and human activities and lowest (6.64±0.05) at the upper catchment spring (NS) draining into Nyangores tributary, which was relatively undisturbed. Along Amala tributary, highest pH level (8.13±0.15) was recorded at the lower part of Mulot Town (ALM) and lowest (7.42±0.77) at the upper catchment spring (AS) draining into the tributary (Table 4.2). However, these differences in pH between sites along Amala tributary were not significant (one-way ANOVA, $P=0.766$).

Likewise, no significant differences were observed in pH between Amala and Nyangores tributaries (Student t-test, P=0.465).

Turbidity levels varied significantly between different sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ =5.16, P=0.028), with DMRT further showing significant difference in turbidity between the upper catchment spring (AS), the upper part of Mulot Town (AUM) and the lower part of Mulot Town (ALM) but not with the middle part of Mulot Town (AMM), along Amala tributary. However no significant differences were observed in turbidity between sites along Nyangores tributary (one-way ANOVA, P=0.4315). Likewise, there was no significant differences in turbidity levels along Amala and Nyangores tributaries (Student's t-test, P=0.289). Turbidity levels ranged between 101.4±18.2 NTU and 136.7±6.6 NTU along the two tributaries. The upper catchment springs along Amala (AS) and Nyangores (NS) tributaries had the lowest turbidity levels, (101.4±18.2 NTU and 111.1±42.6 NTU), respectively, while the highest turbidity levels (131.9 ± 1.54 NTU and 136.7 ± 6.6 NTU), were recorded at the upper part of Mulot Town (AUM) and mid part of Bomet Town (NMB), along Amala and Nyangores tributaries, respectively (Table 4.2).

4.5 Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) in Water as Influenced by Anthropogenic Activities

Total suspended solids (TSS) levels varied significantly between sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ =8.04, P<0.01), as well as along Nyangores tributaries (one-way ANOVA, $F_{(3,11)}$ =126, P<0.001). Further, DMRT confirmed that TSS level at the upper catchment spring (AS), draining into Amala tributary was significantly different from all the other sites located within the urbanized section (Mulot Town), along Amala tributary. Similarly, TSS levels at the upper catchment spring (NS) draining into Nyangores tributary differed significantly from all the other sites located within the urbanized section (Bomet Town) along the same tributary, an indication of some influence from anthropogenic activities. However, total dissolved solids (TDS), did not show any significant differences between sites along the two Mara River tributaries (one-way ANOVA, P>0.05). Considering Nyangores tributary separately, TSS levels were lowest (8.3±1.53 mg/l) at the upper catchment spring (NS) and highest (36.2±3.8mg/l), at the middle part (NMB) of Bomet Town, while TDS levels were lowest (148.0±21.0mg/l) at the lower part (NLB) of Bomet Town and highest (181.3± 19.8mg/l) at the upper catchment spring (NS) (Table 4.3).

Along Amala tributary, TSS levels ranged between 21.0±5.3mg/l, at the upper catchment spring (AS) and 37.0±2.0 mg/l at the lower part of Mulot Town (ALM). Similarly TDS levels were lowest (175.3±62.6mg/l) at the upper part of Mulot Town (AUM) and highest (241±17.8mg/l) at the lower part of Mulot Town (ALM), along Amala tributary (Table 4.3) There were significant differences in TDS between the two tributaries (Student's t-test, P=0.05), however no significant differences were observed in TSS between Amala and Nyangores tributaries (Student's t-test, P>0.05).

Table 4.3. Total suspended solids (TDS) and total dissolved solids (TDS) along Nyangores and Amala tributaries

Sampling sites	TSS ±SD (mg/l)		TDS ±SD (mg/l)	
	Amala	Nyangores	Amala	Nyangores
Upper catchment spring	21.0 ± 5.3^{C}	8.3 ± 1.5^{C}	175.3 ± 62.6^{A}	181.3 ± 19.8^{A}
Upper part of town	28.7 ± 2.5^{B}	27.7 ± 1.5^{B}	215.7 ± 3.5^{A}	155.7 ± 9.0^{A}
Middle part of town	33.7 ± 4.2^{AB}	36.2 ± 3.8^{A}	226.0 ± 5.6^{A}	171.0 ± 8.2^{A}
Lower part of town	37.0 ± 2.0^{A}	36.0 ± 2.0^{A}	241.3 ± 17.8^{A}	148.0 ± 21.0^{A}
Mean	**30.08**	**27.04**	**214.58**	**164.0**

Means with different superscripts in the same column are significantly different at P<0.05. (Data analyzed by Duncan's Multiple Range Test).

4.6 Nutrient (Phosphorus and Nitrogen) Concentration as Influenced by Anthropogenic Activities along Amala and Nyangores Tributaries

There were significant differences in total phosphorus (TP) levels between Amala and Nyangores tributaries (Student's t-test, P=0.02). However, total nitrogen (TN) levels did not show any significant difference between the two tributaries. Considering each tributary separately, TN levels varied significantly between sites along Nyangores tributary (one-way ANOVA, $F_{(3,7)}$ =530.71, P<0.0001), with DMRT further confirming that significantly high TN levels (1967.0±5.7μg/l) were recorded at the lower part of Bomet Town (NLB), which was highly disturbed and also served as a water collection and livestock watering point, and the lowest (1229.5±19.1μg/l), at the relatively undisturbed upper catchment spring (NS), draining into Nyangores tributary.

Likewise TP levels varied significantly between sites (one-way ANOVA, $F_{(3,7)}$ =77.47, P=<0.001), with DMRT further showing that TP level at the relatively undisturbed upper catchment spring (NS) was significantly lower (403.5±16.3μg/l), compared to the high levels (684.5±6.4μg/l) recorded at site NLB located at the lower point of Bomet Town (Table 4.4). There were significant variations in TP levels between different sites along Amala tributary (one-way ANOVA, $F_{(3,7)}$ =28.83, P=0.0036), with DMRT establishing exact differences between sites, with the upper catchment spring (AS) draining into Amala tributary recording the lowest TP (429.7±44.3μg/l), while middle part of Mulot Town (AMM), which also served as a water collection and livestock watering point recording the highest TP levels (832.4±3.7μg/l).

As regards total nitrogen, highest (2200.5±157.7μg/l) levels were recorded at the relatively disturbed lower part of Mulot Town (ALM), while the lowest (1701.5±68.6μg/l), were recorded at the upper catchment spring (AS) draining into Amala tributary (Table 4.4). Total nitrogen (TN) levels did not however show any significant differences between Amala and Nyangores tributaries (Student's t-test, P=0.06). In addition, there were no significant variations in TN levels between sites along Amala tributary (one-way ANOVA, P=0.245) (Table 4.4).

Table 4.4. Total nitrogen and total phosphorus levels along Nyangores and Amala tributaries

Sampling Sites	Total Nitrogen ±SD (μg/l)		Total Phosphorus ±SD (μg/l)	
	Amala	Nyangores	Amala	Nyangores
Upper catchment spring	1701.5 ± 68.6^{A}	1229.5 ± 19.1^{A}	429.7 ± 44.3^{B}	403.5 ± 16.3^{B}
Upper part of town	2042.0 ± 190.9^{A}	1943.4 ± 11.2^{B}	711.1 ± 5.8^{A}	663.7 ± 20.2^{A}
Middle part of town	2083.0 ± 366.3^{A}	1967.0 ± 5.7^{B}	832.4 ± 3.7^{A}	684.5 ± 6.4^{A}
Lower part of town	2200.5 ± 157.7^{A}	1925.2 ± 43.5^{B}	788.5 ± 95.5^{A}	665.1 ± 42.3^{A}
Mean	**2006.8**	**1766.3**	**690.4**	**604.2**

Means with different superscripts in the same column are significantly different at P<0.05. (Data analyzed by Duncan's Multiple Range Test).

4.7 Benthic Macroinvertebrate Community Structure as Influenced by Anthropogenic Activities

Several macroinvertebrate speices were recorded along the two Mara River tributaries during the sampling period, with some being dominant over others.

4.7.1 Benthic macroinvertebrate species diversity and abundance

Eight benthic macroinvertebrate taxa from a total of 678 individuals were encountered during the study period, along the two Mara River tributaries combined. The exclusively aquatic orders such as Ephemeroptera accounted for 0.6%, Odonata 2.4%, Plecoptera 0.3% and Trichoptera 6.0%, while partially aquatic orders, mainly Coleoptera accounted for 0.9% and Diptera (the most dominant taxa) accounted for 75.2%, of the total benthic macroinvertebrates collected from all the study sites. Phyla Mollusca and Annelida accounted for the remaining 7.2% and 7.4%, respectively (Figure 4.7).

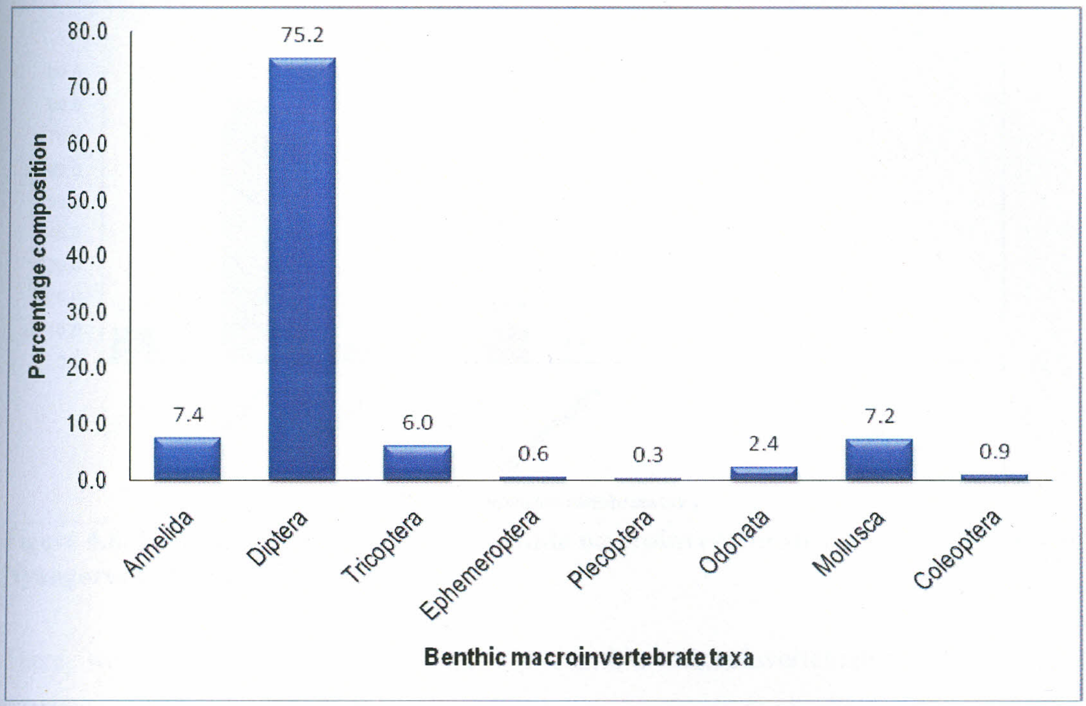

Figure 4.7. Overall macroinvertebrate taxa composition encountered during the study

There were significant differences in benthic macroinvertebrate species diversity and abundance between Nyangores and Amala tributaries (Student's t-test, P=0.02), with Nyangores tributary recording 60.9% and Amala tributary 39.1% of all the 678 benthic macroinvertebrates encountered in the study. The dipterans were the most dominant of all benthic macroinvertebrate taxa along Amala and Nyangores tributaries, with family Chironomidae alone accounting for over 99% of the dipteran density. Indicators of clean water in the orders, Ephemeroptera and Plecoptera combined, accounted for only 0.88% of the total benthic macroinvertebrate taxa recorded in the entire study- a further indication of the anthropogenic influence on water quality of the two tributaries (Figure 4.8).

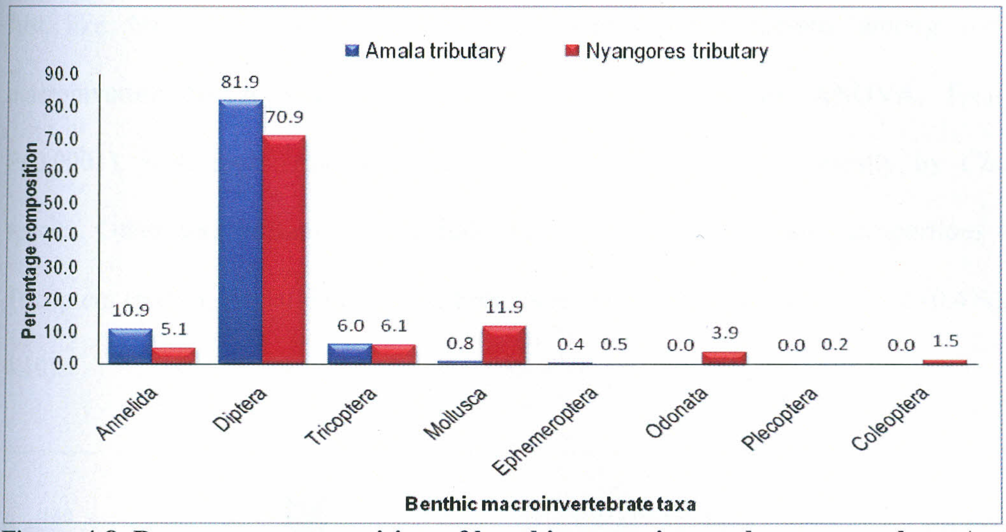

Figure 4.8. Percentage composition of benthic macroinvertebrate taxa along Amala and Nyangores tributaries

There were significant variations among benthic macroinvertebrates recorded along Nyangores tributary (one-way ANOVA, $F_{(7,31)}$ =8.58, P<0.0001), with the dipterans being the most prominent taxa, recording high proportions (47.1%) at the relatively disturbed site at the middle part of Bomet Town (NMB) and lowest (12.0%) at the relatively undisturbed upper catchment spring (NS) draining into Nyangores tributary. Bivalves were also encountered along Nyangores tributary, though most of them were reported at the upper catchment spring (NS) draining into Nyangores tributary (Figure 4.9).

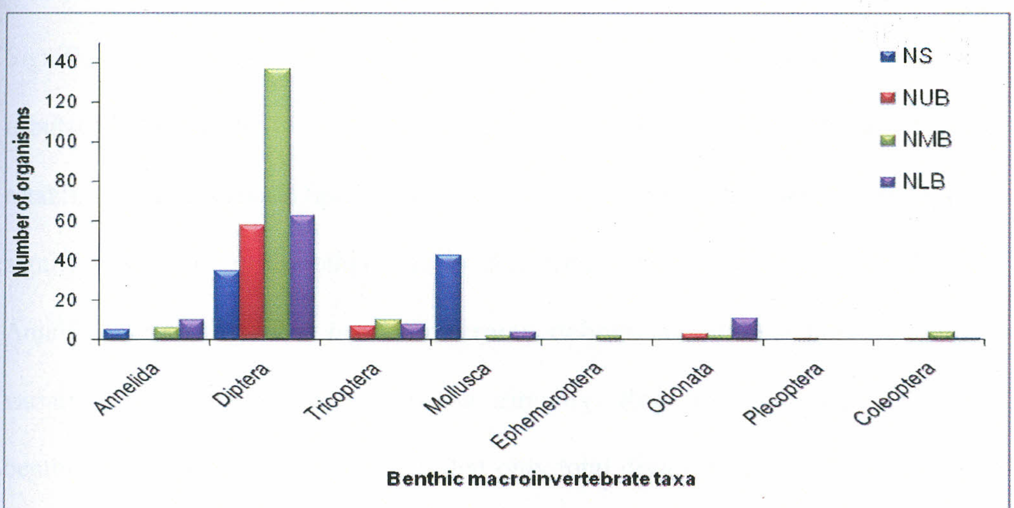

Figure 4.9. Taxa abundance at different sampling sites* along Nyangores tributary
*Upper catchment spring (NS), upper part of Bomet Town (NUB); middle part of Bomet Town (NMB) and lower part of Bomet Town (NLB) along Nyangores tributary.

Just like Nyangores tributary, there were significant variations among the benthic macroinvertebrates recorded along Amala tributary (one-way ANOVA, $F_{(7,31)}$ =9.04, P<0.0001), with high Dipteran abundance (87.9%), contributed mostly by *Chironomus* species. Other taxa present along Amala tributary, though in smaller proportions included, Tricoptera (6.0%), Annelida (10.9%), Ephemeroptera (0.8%) and Plecoptera (0.4%), (Figure 4.10).

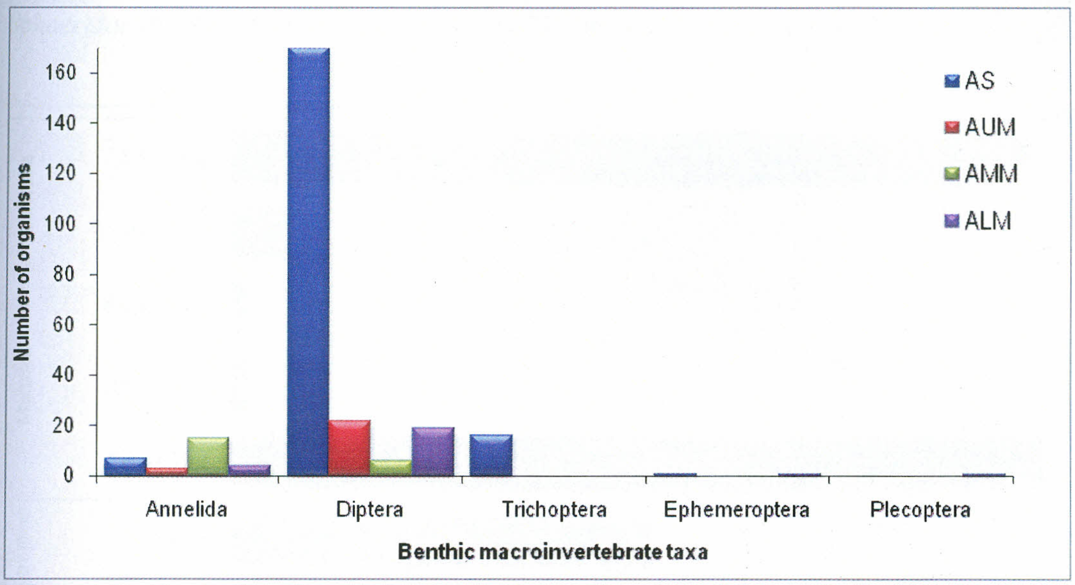

Figure 4.10. Taxa abundance at different sampling sites* along Amala tributary
*Upper catchment spring (AS), upper part of Mulot Town (AUM), middle part of Mulot Town (AMM) and lower part of Mulot Town (ALM) along Amala tributary.

Significant variations were observed in Dipteran abundance between sites along Amala tributary (one-way ANOVA, $F_{(3, 11)} = 4.66$, P = 0.036). Duncan Multiple Range Test further established that mean Dipteran abundace at the upper catchment spring (AS) differed significantly from all the other sites located within the urbanized area (Mulot Town), along Amala tributary. All other benthic macroinvertebrate taxa did not however show significant variations between sites along Amala tributary. Regression analyses on pooled data of benthic macroinvertebrates revealed that only total dissolved solids (TDS) was predictive of benthic macroinvertebrate in the Mara River (R^2= 0.6170, n=8, P=0.02), while all the other parameters were not.

4.7.2 Water quality indicator species abundance along Nyangores and Amala tributaries

Phylum Arthropoda, the most prominent of all the benthic macroinvertebrate taxa encountered was mainly represented by class Insecta, contributed by orders: Diptera, Odonata, Ephemeroptera, Plecoptera, Tricoptera, and Coleoptera. Of all these orders, Diptera was the most dominant and was mainly contributed by *Chironomus* spp. (99.6%), (a pollution indicator species). Odonata was mainly dominated by damselfly (93.8%), Mollusca by *Sphaeridae* (95.9%), and Ephemeroptera by Tipulidae (50%), (Figure 4.11).

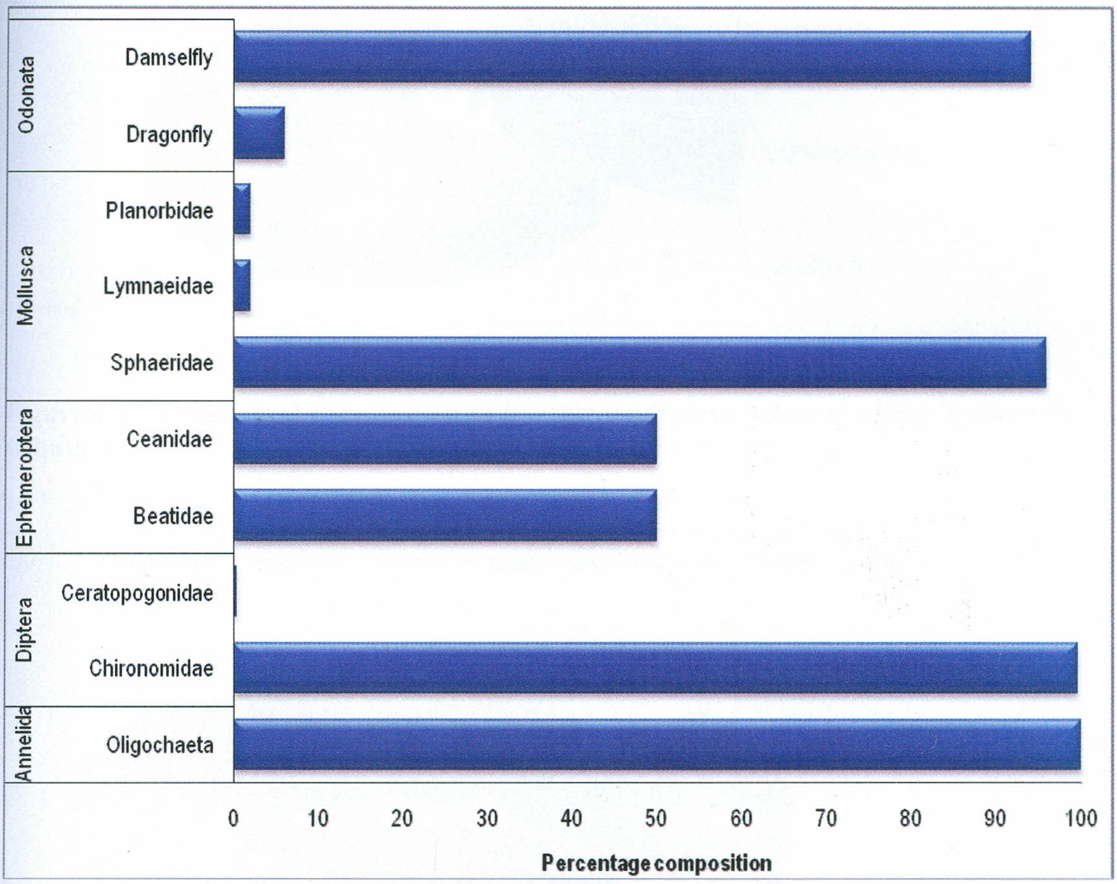

Figure 4.11. Proportion of species abundance per dominant macroinvertebrate taxa

Pollution indicators (*Chironomus* spp. larvae), were numerically abundant along Amala (217, 81.8%) and Nyangores (293, 70.9%) tributaries, while Tricoptera (caddisfly larvae), within the same phyla, were relatively few along Amala (16, 6.04%), and Nyangores (25, 6.1%)

tributaries. There was however no significant differences in *Chironomus* spp. abundance between Amala and Nyangores tributaries (Student's t-test, P=0.210). The composition of all benthic macroinvertebrate taxa found along Nyangores and Amala tributaries are shown in Figures 4.12 and 4.13, respectively.

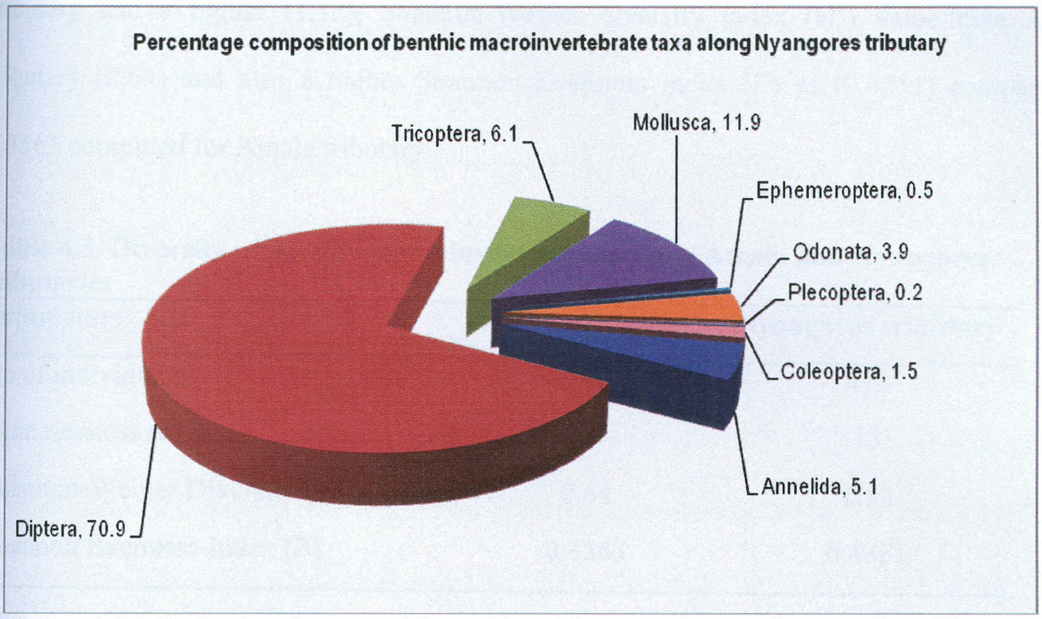

Figure 4.12. Order level composition of benthic macroinvertebrates along Nyangores tributary

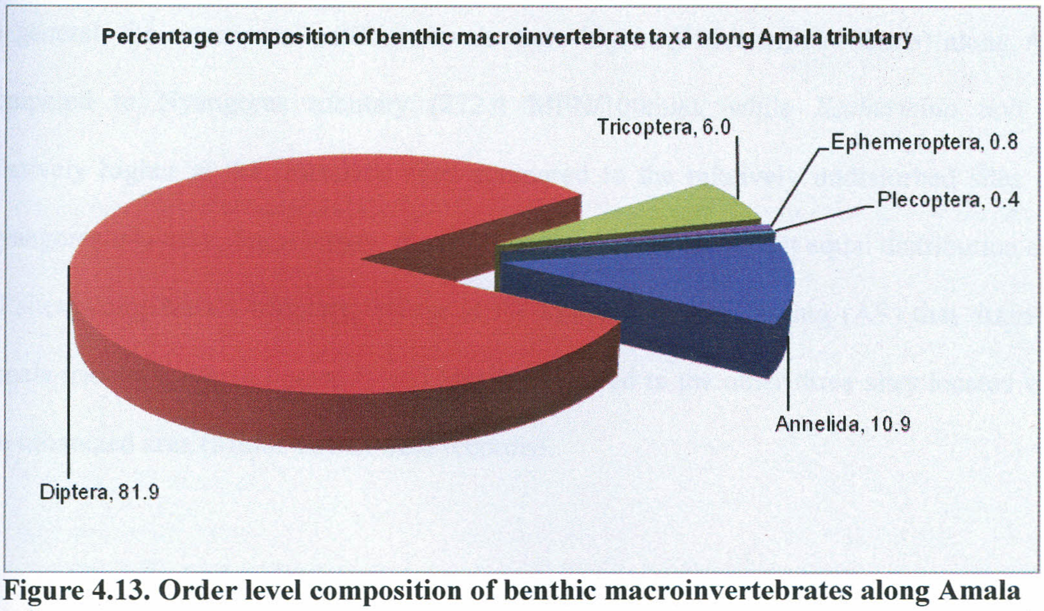

Figure 4.13. Order level composition of benthic macroinvertebrates along Amala tributary

4.7.3 Benthic macroinvertebrate diversity indices

Diversity indices computed for the two tributaries are shown in Table 4.5. The overall taxa richness, diversity and eveness for both tributaries were relatively low - an indication of highly disturbed ecosystems. Nevertheless, benthic macroinvertebrate taxa richness (d) was higher along Nyangores tributary (13) compared to Amala tributary (6). Likewise, Nyangores tributary had a higher (1.12), Shannon-Weiner diversity index (H') value than Amala tributary (0.64) and also a higher Shannon Evenness index (E) of (0.4351) compared to 0.3563 computed for Amala tributary.

Table 4.5. Diversity of benthic macroinvertebrates along Amala and Nyangores tributaries

Parameters	Amala tributary	Nyangores tributary
No of individuals	265	413
Taxa richness (d)	6	13
Shannon-Weiner Diversity Index (H')	0.64	1.12
Shannon Evenness Index (E)	0.3563	0.4351

4.8. Total Coliform Bacteria and *Escherichia coli* Bacteria Levels as Influenced by Anthropogenic Activities along Amala and Nyangores Tributaries

In general, the mean total coliform levels were higher (530.9 MPN/100mls) along Amala compared to Nyangores tributary (272.4 MPN/100mls), while *Escherichia coli* were relatively higher at the urbanized sites compared to the relatively undisturbed sites along Nyangores tributary. Surprisingly, *E. coli* bacteria showed an almost equal distribution across all sites along Amala tributary, except at the upper catchment spring (AS) that drains into Amala tributary, where higher *E. coli* levels compared to the other three sites located within the urbanized area (Mulot Town) were recorded.

4.8.1 Total coliform bacteria (MPN/100mls) along Nyangores and Amala tributaries

There were significant variations in total coliform bacteria (MPN/100mls) between sites along Nyangores tributary (one-way ANOVA, $F_{(3,19)}$ =6.91, P=0.003), with DMRT further showing that total coliform levels at the relatively undisturbed upper catchment spring (NS) were significantly lower (7.2±9.4 MPN/100mls) compared to high levels (569.2±508.8 MPN/100mls) recorded at the relatively disturbed site (NLB) located at the lower point of Bomet Town, along Nyangores tributary. However, total coliform levels recorded within the urbanized area (upper, middle and lower parts of Bomet Town), were not significantly different from each other (Table 4.6).

There were significant variations in total coliform levels between different sampling sites along Amala tributary (one-way ANOVA, $F_{(3,19)}$ =5.09, P=0.012), with DMRT showing that total coliform levels (1100±0.0 MPN/100mls), at the middle part of Mulot Town (AMM) were significantly higher than all the other sites along Amala tributary (Table 4.6). However, no significant differences were observed in total coliform levels between Amala and Nyangores tributaries (Student t-test, P=0.103). Regression analyses revealed that pH (R^2=0.5845, n=8, P=0.03) and total suspended solids (TSS) (R^2=0.7141, n=8, P=0.01) were predictive of total coliform bacteria levels along the two tributaries combined.

Table 4.6. Mean total coliform levels (MPN/100ml) at different sites along Amala and Nyangores tributaries

Sampling Site	Amala tributary (MPN/100mls±SD)	Nyangores tributary (MPN/100mls±SD)
Upper catchment spring	225.4 ± 219.9^{B}	7.2 ± 9.4^{B}
Upper part of town	333.8 ± 466.1^{B}	212.4 ± 228.1^{AB}
Middle part of town	1100 ± 0.0^{A}	300.6 ± 454.4^{AB}
Lower part of town	464.2 ± 580.5^{B}	569.2 ± 508.8^{A}
Mean Coliform (MPN/100mls)	**530.9**	**272.4**

*Means with different superscripts in the same column are significantly different at P<0.05. (Data analyzed by Duncan's Multiple Range Test).

4.8.2 *Escherichia coli* levels along Amala and Nyangores tributaries

Results showed that *E. coli* levels varied significantly between sites along Nyangores tributary (one-way ANOVA, $F_{(3,19)} = 31.82$, $P<0.0001$). The DMRT further showed that *E. coli* levels at the relatively undisturbed upper catchment spring (NS) were significantly lower (1.22%) compared to those obtained from all the other three sites located within the urbanized section (Bomet Town), through which Nyangores tributary flows (Figure 4.14).

Contrary to expectations, the levels of *E. coli* along Amala tributary showed an almost equal proportion across the different sites, with the highest *E. coli* levels (27.5%) being recorded at the upper catchment spring and lowest (23.5%) at the upper part of Mulot Town (AUM) along Amala tributary, (Figure 4.14). However, *E. coli* bacterial levels did not vary significantly between sites along Amala tributary ($P>0.05$).

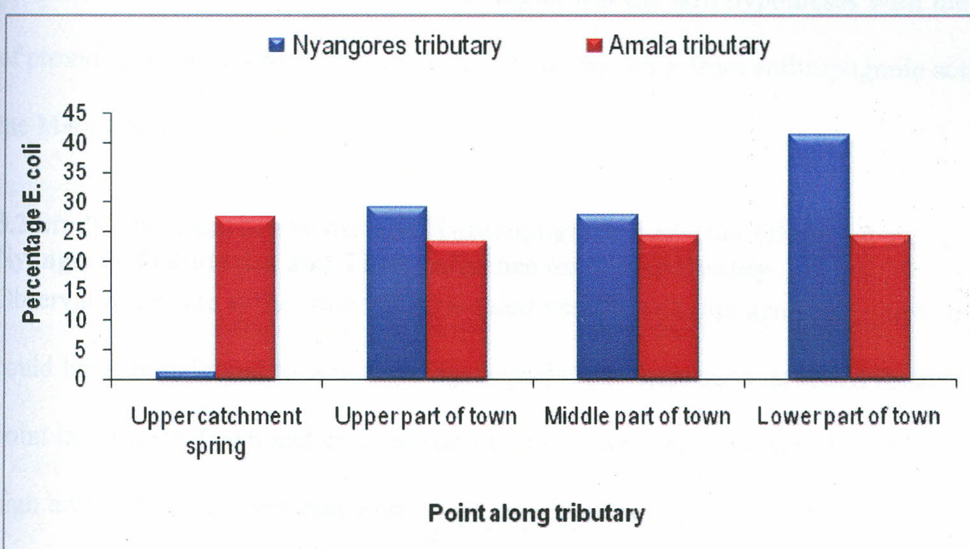

Figure 4.14. Percentage *E.coli* levels along Nyangores and Amala tributaries

Regression analyses showed that total nitrogen ($R^2=0.6886$, n=8, P=0.01), total suspended solids ($R^2=0.8100$, n=8, P=0.002), and pH ($R^2=0.8634$, n=8, $P<0.0001$) were predictive of *E. coli* abundance along both tributaries combined, while all the other parameters were not.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

The Mara River tributaries serve as valuable sources of water for various uses key among them domestic use. However, increased anthropogenic activities continue to impact negatively on the water resources through disposal of waste (solid and liquid), into the river channel, especially at the urbanized sections, flowing through Mulot and Bomet Towns. This contributes to water quality degradation thus making the water unsafe for human consumption. The overreliance on the waters of the Mara River by the local inhabitants therefore continues to expose them to waterborne diseases necessitating regular monitoring of changes in water quality. This chapter gives an in depth discussion of the study findings, based on the study objectives, while seeking to test the null hypotheses with the overall aim of providing solutions to water quality problems resulting from anthropogenic activities along the Mara River.

5.2 Study Site Characteristics and Anthropogenic Activities Observed along Amala and Nyangores Tributaries and Their Influence on Water Quality

Observations made at the study sites revealed various anthropogenic activities some of which could have contributed to water quality degradation. Sites such as AUM located at the entry point into Mulot Town and characterized by high anthropogenic activities recorded relatively high levels of solid waste that were harphazardly strewn along the banks with some spoted in the river channel, thus contributing to the high suspended solids and turbidity levels compared to the low TSS and turbidity levels recorded at the relatively undisturbed upper catchment spring (NS) draining into Nyangores tributary. Sections of the two tributaries that served as livestock watering points were also characterized by degraded river banks probably due to the trampling effect of livestock during their numerous trips to the river, thus contributing to increased sediment load into the river. Consistent with the current study findings, Meehan and Platts (1978) also reported that livestock trampling and grazing near river banks increased bank sloughing and downstream sedimentation and had the capacity to reduce the quantity and quality of riparian vegetation needed as food, shade, and cover for fisheries and other aquatic biota.

Livestock waste along the banks as observed at various points along the two tributaries could have influenced the water quality with regards to nutrient and coliform bacteria levels. Consistent with the current findings, earlier studies by Schepers and Francis (1982) also reported that animal waste, deposited in or near rivers or entrained or dissolved in runoff often contributed to nitrogen (N), phosphorus (P), and other nutrients in streams. Doran *et al* (1981) also reported that livestock wastes may influence the bacteriological quality of stream water, while Meehan and Platts (1978) noted that large herds of livestock, mainly cattle, had more impact on the physical, chemical and bacteriological properties of water than most watershed uses.

Harphazardly discarded waste along the gently sloping banks, and in open surface drainages could have led to their subsequent deposition in the river channel thus resulting in water quality degradation. The close proximity of latrines to the river, poor human waste disposal in bushes next to the river and allowing livestock access to watering points right inside the river, as observed at several sections of the two tributaries, could have resulted in an increase not only in nutrient levels but also microbial levels, potentially contaminating the water sources, which also serve as the main source of water for most of the inhabitants of the two towns. Consistent with the current study findings, Krhoda, (2002) identified the main sources of pollution of the Motoine/Ngong River as uncontrolled disposal of excreta from the major slum areas along the river continuum, uncontrolled disposal of solid waste from human settlements areas, inappropriately sited disposal pits along the river continuum, blockages and/or breakages of sewer lines at major junctions and surface runoff from the nearby town.

In contrast to all the other sites along the two tributaries, the relatively undisturbed site (NS) located at the upper catchment spring and draining into Nyangores tributary was characterized by well vegetated banks effectively protecting the spring from pollutants that are normally transported by surface runoff. In addition, since the spring was protected, livestock were not able to reach the source of the spring thus protecting it from livestock disturbance and contamination. The relatively high water quality at this site was exemplified by the low turbidity and suspended solid levels, low total coliforms levels as well as very low *E. coli* levels. Based on the findings, it is therefore, clear that both instream anthropogenic activities and those carried out on the river banks especially within the urbanized areas have an influence on the water quality. These findings were consistent to those of other researchers like Bernstein (2004) which also reported that rivers flowing through urbanized areas are highly prone to pollution mainly due to their proximity to numerous pollutant sources like waste water discharge points, solid waste disposal sites, raw sewage spills, urban runoffs, among others.

5.3 Solid Waste along Amala and Nyangores Tributaries as Influenced by Anthropogenic Activities

The most common waste disposal method among residents of Bomet and Mulot Towns was open dumping, owing to a general lack of clearly demarcated waste disposal sites in both towns. As such, solid waste was disposed off harphazardly by residents on open lands and steep terrains along the banks of the Mara River tributaries. Such actions do not give prior consideration of the waste's potential impact on aquatic ecosystems, the surrounding environment and subsequently on public health. Kim (1998) also reported that most urban areas in Kenya neither have the financial nor physical ability to provide effective waste management services for the urban populace, especially the urban poor, who form the majority of those living in informal settlements. Lack of these vital services in Bomet and Mulot Towns could have triggered the harpharzard disposal of solid waste by the locals, as was evident at various sections along the two tributaries of Mara River.

According to Wetherall (2003), poor waste disposal and collection inefficiency in most parts of Africa can be attributed to a rapidly growing population and high rate of urbanization, which gives rise to large amounts of waste, to the extent that they have outstripped the capacity of most local authorities to collect and discard in a safe and efficient manner. In addition, studies by Bernstein (2004) showed that populations living in informal settlements that lack refuse collection facilities tend to either dump their generated solid waste at the nearest vacant lot, public space, storm drains, rivers, or simply burn it in their backyards.

Poor garbage collection efficiency is not, however, limited to Bomet and Mulot Towns alone as many other urban areas in Kenya also face similar problems. Studies carried out in Kisumu City for instance estimated a collection efficiency of 20% leaving the bulk of the 500,000 tons of solid waste generated annually in the city uncollected (Carl Bro Report, 2001). Almost similar inefficiencies were also reported in the capital city - Nairobi, where only 25% of the 2000 tonnes of solid waste generated daily was collected (CCN, 2007). It is, therefore, clear that solid waste generated in most urban centers in Kenya, has not been accompanied with an equivalent increase in capacity by the relevant urban authorities to deal with it and the problem might worsen considering the ever increasing human population and a corresponding increase in demand for manufactured goods (CCN, 2007).

Dumping of garbage along the river banks and in storm drains as was evident at the upper part of Mulot Town (AUM) along Amala tributary facilitates their transportation and subsequent deposition in aquatic systems, resulting in water quality deterioration. The current findings were consistent with those of the World Resources Institute (1996), which estimated that one to two thirds of solid waste generated within most urban centres is left uncollected and instead finds its way into nearby aquatic systems. Many researchers including Lnanc *et al.* (1998) and Martin *et al.* (1998) all attributed surface water contamination within urbanized areas to solid and liquid waste resulting from anthropogenic activities and deposited either along the banks, in storm drains or directly into the river channel.

Polythene grocery bags and polythene product wrappers were the most frequently encountered solid waste, followed by plastic bottles and recyclable office paper, along the banks of both tributaries. These findings were consistent with those of Ikiara *et al.* (2004) and Peters (2009) carried out in Nairobi, Kenya and Accra, Ghana, respectively, which also reported that polythene bags and plastic bottles were the most dominant of all the waste generated within the urban areas. In the current study, the site located at the upper catchment spring (NS) along Nyangores tributary, recorded the least amount of solid waste (0.8%), compared to 16.4% recorded at the upper catchment spring (AS), draining into Amala tributary. Large proportions of solid waste were however reported at sites located within the urbanized areas especially at water collection and animal watering points; an indication of the strong anthropogenic influence on water quality, through daily activities like washing and bathing in the river, cultivation along the banks, watering of livestock among others.

Consistent with the present findings, Scoullos and Tomassini (2003) reported that anthropogenic activities were the main threats to water resources in the Mediterranean, primarily through direct discharge of solid waste and untreated sewage into surface waters. Takova-Arsova (1996) also linked contaminated surface water of Axios/Vardar River in the Mediterranean basin to solid waste disposed in unrestricted landfills along the river bank. The type of solid waste encountered along the banks of the two Mara River tributaries was typical of the ongoing activities in their immediate vicinity. This could be an indication that most of the waste was likely to have been deposited at the site by the locals and not transported from elsewhere as was also reported by Munala and Mirongo (2011). For instance, the upper catchment spring (AS) draining into Amala tributary and characterized by elevated anthropogenic activities among them washing and bathing had detergent/soap wrappers, tattered clothing and confectionary wrappers, as the most prominent waste types. On the other hand, soft drink and mineral water plastic bottles, grocery polythene bags, detergents and confectionary wrappers were dominant at the middle part of Bomet Town (NMB), along Nyangores tributary, where motor vehicle washing, bathing and water collection activities were dominant.

Contrary to studies by JICA (1998) which reported food remains to be the most prominent of all the solid waste generated in Nairobi, the current study found only a small proportion of food remains among all the solid waste encountered along the two tributaries. The general absence of food remains from the other solid waste encountered along the two tributaries was probably due to their easily decomposable nature, and perhaps because they make ready meal for livestock such as cattle, goats, sheep and poultry, which feed on them while scavenging for food as was seen around the area surrounding site NLB at the lower part of Bomet Town, along Nyangores tributary. These findings were consistent with those of Peavy *et al.* (1985) which also reported that food waste are putrescible, therefore, can deteriorate rapidly especially in warm weather, making them rare among other solid waste. Absence of food remains from most sections of the river banks could also be attributed to the relatively wide distance between the human dwellings and the river channel, as most households were located more than 30 metres from the river channel, effectively excluding any food waste that may have been discarded near human dwelling places. These findings were consistent with those of Otieno *et al.* (2004) carried out in Yala Division within Siaya County, Kenya, in which they reported that more than half (57%) the households simply threw away kitchen / food waste in the open to dogs, cats, pigs among others, while only a small percentage had safer ways of handling food waste.

Considering the large quantities of the recyclable waste encountered along the banks of the two tributaries, it was clear that most residents had not adopted the general waste reduction strategies. Kibwage (2002) reported that efforts to solve solid waste management problems in many developing countries, including Kenya, focus more on waste collection and disposal, rather than waste recycling and re-use which can significantly reduce the waste. According to Seik (1997), waste collection and disposal is only one component of a more comprehensive waste management strategy.

A high population growth will always trigger an equally high demand for produced goods, whose consumption results in increased waste generation. It is therefore important that basin inhabitants take steps towards reducing the amount of waste they generate probably through recyling and reuse. Studies by Kaseva and Mbuligwe (2000) concur that solid waste recycling is currently acceptable as an appropriate approach towards solid waste management and is highly desirable from the environmental, economic and social persectives. Apart from the solid waste, poorly disposed human waste observed at various sites along the banks of the two Mara River tributaries were also a major concern with regard to water quality, as they could easily be swept into the river channel and result in water contamination. This has the potential to trigger waterborne diseases among the locals residing within the basin and who rely on this water for their domestic use. Cumulative effects of solid and liquid waste will most likely exacerbate the pollution problem in the Mara River if left unabated, as has been observed in many other rivers flowing through urban areas in Kenya, a case in point the Nairobi River (JICA, 1998).

5.4 Influence of Anthropogenic Activities on Various Water Quality Parameters

Physico-chemical water quality parameters (dissolved oxygen, pH, conductivity and turbidity) are influenced by anthropogenic activities along and within the river channel, which in turn influence the biological and biochemical reactions within the aquatic systems (USEPA, 1998). Sudden changes in physico-chemical parameters are indicative of changing water conditions in the river system and have the capacity to influence aquatic biota including benthic macroinvertebrates differently (USEPA, 1998).

5.4.1 Influence of anthropogenic activities on physico-chemical parameters

Evaluation of Dissolved Oxygen (DO) is vital in establishing the status of water quality and thus the survival of aquatic organisms (Fakayode, 2005). Dissolved oxygen levels varied significantly between sites along Amala and Nyangores tributaries, ranging between 6 and 8.23mg/l. However, contrary to expectations, lower DO levels were recorded at the upper catchment springs draining into the two tributaries compared to the relatively disturbed sites located within the urbanized sections (Bomet and Mulot Towns). This could have been due to increased biodegradation of organic waste resulting from human and livestock activities at the upper catchment springs. The organic waste decomposition process results in high uptake of the oxygen dissolved in the system leading to oxygen deficit as was also reported by Okbah and Tayel (1999).

Consistent with the current study findings, Majule (2010) also established that human, wildlife and livestock activities had significant implications on the quality of Mara River through organic matter deposition into the river channel, thus resulting in low dissolved oxygen levels. The high concentration of dissolved minerals as exemplified by the high conductivity levels at the upper catchment spring (AS) draining into Amala tributary could also have resulted in a lowered capacity of the water to hold oxygen. In addition, the low atmospheric pressure characteristic of higher altitudes could have led to a slight decrease in oxygen solubility, at the two springs located at the upper catchment compared to all the other sampling sites downstream. Likewise, the focal nature of the springs and their typical low flow rate could have hindered effective aeration of water with atmospheric oxygen thus contributing to low dissolved oxygen levels compared to the rapidly flowing downstream sites.

These findings were consistent with those of Araoye (2007), which reported that the amount of oxygen dissolved in water is dependent on the rate of flow of streams/rivers, with swiftly flowing water having more dissolved oxygen than slow-flowing streams/rivers. According to Okbah and Tayel (1999), low DO concentrations of less than 3mg/L in fresh water ecosystems is considered very stressful to most aquatic organisms and is indicative of highly polluted systems, with the WHO limits for DO in fresh water set at between 10-12 mg/l (EPA, 2002). This implies that dissolved oxygen levels across all sampled sites along the two tributaries were below the acceptable WHO limits for fresh water bodies, probably because of increased anthropogenic activities within the Mara River basin.

Conductivity levels varied significantly between sites along Nyangores as well as Amala tributary. Though springs draining into both tributaries had relatively higher conductivity levels compared to other sampling sites located downstream within the urbanized areas, the value recorded at spring AS draining into Amala tributary was however extremely high, recording upto 4 times that recorded at the other spring (NS) and close to 6 times higher than those recorded at other sites located within the urbanized sections.

The significantly high conductivity at site AS could have been influenced by the composition of the bedrock material through which the water flows before recharging the spring and not by anthropogenic activities, which were nevertheless taking place not only at this particular site but at other sites as well. Studies show that clay soils have materials that tend to ionize when washed and therefore surface waters in regions composed mainly of clay soil can exhibit high conductivity levels (Jordao *et al.*, 2007). This study did not however investigate the soil composition of the area.

Increased anthropogenic activities among them bathing, washing and water collection around the unprotected spring (AS), could also have contributed to the high dissolved solid and contaminants especially electrolytes in the spring through backflows and surface runoff. Jordao *et al.* (2007) observed that discharges into a river channel from various sources along its continuum can change the conductivity levels depending on their make up with sewage discharges likely to increase the conductivity while oil spills could decrease it. Such inflows could therefore have influenced the conductivity levels especially at sites located within the urbanized areas along Nyangores and Amala tributaries. The permissible conductivity limit for domestic water supply is 200µS/cm according to WHO (2004), implying that conductivity levels at the upper catchment spring (AS) draining into Amala tributary were high above the acceptable WHO limits for a domestic water supply source, thus making this spring a source of concern.

Most natural water pH values range between 5.0 and 8.5 (WHO, 1993). In the current study, pH values were close to neutrality along both tributaries but varied significantly between sites along Nyangores tributary but not along Amala tributary. Nevertheless, the pH values recorded for the two tributaries fell within the WHO (1993) maximum allowable range of 6.5-8.5 for a drinking water source. The highest pH value recorded in this study was 8.13 at the relatively undisturbed upper catchment spring (NS) draining into Nyangores tributary. This could have been attributed to natural minerals such as calcium and magnesium in water as well as surface runoff as was also reported by Surindra *et al.* (2010). However, the low (< 7) pH levels recorded at some sites along the two tributaries may have been as a result of sulphur and amino acid compounds contributed by human excreta and animal waste, as was also reported by Efe *et al.* (2005).

The slightly alkaline pH recorded in most sites sampled, is however, preferable in surface waters. Since the metabolic activities of most aquatic organisms are pH dependent, the right pH is critical in fresh water bodies as it determines the suitability of water for the survival of aquatic biota (Wang *et al.*, 2002). The WHO maximum acceptable pH limit for a drinking water source is 6.5 – 8.5 (WHO, 2004), implying that pH values recorded at all the sites along the two tributaries fell within the acceptable limits. Additionally, the fact that pH levels remained relatively within a close range throughout all sites was an indication that changes in the concentration of other water quality parameters could not possibly be associated with it.

Turbidity levels varied significantly between sites along Amala tributary, with highest levels recorded at the highly disturbed sites located within the urbanized section (Mulot Town) and lowest at the less disturbed sites. Nevertheless, turbidity levels across all the sites were unusually high, exceeding the allowable turbidity limit of 0 - 1.0 NTU for domestic water source as determined by WHO (2004). Some of the factors that could be attributed to the high turbidity levels include increased sediment load originating from agricultural lands, livestock activities, and urban surface runoff among others sources. High concentration of particulate matter in surface waters interferes with the passage of light through water thus inhibiting important ecosystem processes such as photosynthesis (APHA, 1998). Since the degree of water turbidity is an approximate measure of the intensity of pollution (Siliem, 1995), highly turbid water is unsuitable for domestic and industrial use and is often associated with microbial contamination (DWAF, 1996).

5.4.2 Effect of anthropogenic activities on TSS and TDS levels along Amala and Nyangores tributaries

The levels of TSS and TDS are a general indication of the suitability of water for a particular purpose or use (McCutheon *et al.,* 1993). TSS levels varied significantly between sites along both tributaries with higher levels recorded in areas characterized by high anthropogenic activities and lower levels at less disturbed sites like spring NS at the upper catchment of Nyangores tributary. Increased anthropogenic activities within the Mara River basin could have influenced the rate of sediment load from various sources among them agricultural lands and urban centres, thus contributing to the high TSS and TDS levels recorded in surface waters.

These findings were consistent with previous studies done in different river basins including those by Jaji *et al.* (2007) along Ogun River in South West Nigeria, Jordao *et al.* (2007) in the Turvo Limpo River in Minas Gerais State, Brazil and Surindra *et al.* (2010) in the Hindon River in India, in which increased TSS and TDS levels were observed in sections of the three rivers flowing through agricultural and urbanized areas. Nevertheless, TSS and TDS levels recorded along the two tributaries in the current study were below the maximum permissible limits for surface water used for domestic and recreational purposes, which are set at 500mg/l and 1,000mg/l, respectively, by the WHO (2004).

Monitoring TSS and TDS levels in aquatic systems is important since their continued accumulation can destroy critical aquatic habitats and spawning grounds for aquatic fauna, thus interfere with their life-cycle and the general ecology of the entire system (Omoleke, 2004). In addition, high concentration of suspended solids can reduce transparency, thus hinder the photosynthetic process, and as a result interfere with the natural productive capacity of aquatic ecosystems.

5.5 Nutrients (Phosphorus and Nitrogen) Concentration as Influenced by Anthropogenic Activities

Total nitrogen (TN) and total phosphorus (TP) levels varied significantly between different sites along Nyangores tributary, with highest levels of both nutrients recorded at the more disturbed sections particularly those located within the urbanized area (Bomet Town), while the lowest were recorded at the relatively undisturbed upper catchment spring (NS) that discharges its waters into Nyangores tributary. Likewise, TP levels varied significantly between sites along Amala tributary, with highest levels recorded at the highly disturbed sites located within the urbanized area (Mulot Town).

Sources of nitrogen and phosphorus into Amala and Nyangores tributaries are numerous and may range from livestock and agricultural activities at the upper catchment areas to urbanization and daily anthropogenic activities like washing of clothes and utensils, bathing, swimming and poor human waste disposal methods along the banks and within the river, especially at the urbanized sections (Bomet and Mulot Towns) through which the tributaries flow. Extensive use of detergents during the various cleaning activities within the urban areas could also have contributed to high levels of nutrients at those sites. Khan and Ansari (2005) reported high phosphorus levels in aquatic systems which they attributed to detergents used in daily cleaning activities by households residing along those rivers.

In addition, untreated waste water and sewage discharge from urban areas and informal urban settlements along the banks of the two Mara River tributaries could have contributed to the high nutrient levels recorded at sampling sites located within the urbanized areas (Mulot and Bomet Towns). These findings were consistent with those of Bashir and Kawo (2004) and Ibrahim, (2003) which also linked effluent discharge to increased nutrient levels in aquatic systems. High protein intake by humans can increase the amount of nitrogen in human waste (WHO, 2002), which can also contribute to the high levels of total nitrogen in water when such human waste is improperly disposed. Liu *et al.* (2008) established that human waste constituted the second biggest source of nitrogen load into aquatic systems after agricultural fertilizers. Insufficient provision of septic tanks and lack of sewage treatment plants as observed in Bomet and Mulot Towns could have resulted in the high levels of total nitrogen and total phosphorus recorded within the urbanized areas along Nyangores and Amala tributaries, respectively.

Likewise, the large herds of livestock grazing along the two tributaries and using some sections of the tributaries as their watering points could have increased TP and TN levels in the water through their waste as was also reported by Shindo *et al.* (2006). The increase in total nitrogen downstream along Amala tributary could have been due to the cumulative nature of nutrients originating from various sources along the river continuum. Based on the current study findings, Nyangores and Amala tributaries clearly contain elevated nutrient levels whose origin could be through anthropogenic activities within the basin particularly from urban centres and agricultural activities.

High nutrient input into aquatic systems is a cause for concern as elevated nitrogen and phosphorus levels can trigger excessive growth of aquatic weeds including algae, reduce dissolved oxygen among other negative effects, all of which can interfere with the ecological balance of aquatic system, thus inhibit the river's natural processes like self purification (Fakayode, 2005; Minareci *et al.*, 2009).

5.6 Macroinvertebrate Community Structure and Diversity

A total of 678 individual benthic macroinvertebrates comprising of eight taxa were encountered along the two perennial Mara River tributaries during the study period. There were significant differences in benthic macroinvertebrate abundance between Amala and Nyangores tributaries. The varying pollutant load into the two tributaries probably contributed by anthropogenic activities could have led to the differences in benthic macroinvertebrate species diversity and abundance between sites along both tributaries. Generally, the significantly low species diversity recorded along Amala tributary could be attributed to elevated anthropogenic activities along its course, while the relatively less impacted Nyangores tributary had a higher benthic macroinvertebrate diversity. Bogi *et al.* (2003) reported that alteration of the physical and chemical characteristics of river systems by anthropogenic activities influences not only the species diversity, but also their abundance as well as the overall stream productivity.

Significant variations between benthic macroinvertebrate taxa were observed at different sites along Nyangores as well as Amala tributary. For instance, pollution tolerant taxa (Chironomidae and Oligochaetes) were dominant (82.6%) over the non tolerant taxa (17.4%). The differences could have been due to small-scale variability in nutrient level and physico-chemical parameters probably arising from anthropogenic activities, which might have impacted on the diversity and abundance of benthic macroinvertebrates at the sites.

Consistent with the current study findings, Cortes *et al.* (2002) observed a clumped distribution among benthic macroinvertebrates which they attributed to small scale variability in a variety of water quality parameters.

Likewise, Chatzinikolaou *et al.* (2006) established that pollution and excessive nutrient enrichment from anthropogenic sources can affect benthic macroinvertebrate trophic relationships as well as their habitats and thus change their community structure and composition. In the current study, the Arthropods, comprising of class Insecta, and dominated by order Diptera which were mainly contributed by the *Chironomous* spp. - a pollution tolerant species, were numerically abundant compared to all other macroinvertebrates. These findings were consistent with those of Epler (2001) which reported that chironomids are often the most abundant macroinvertebrates and account for the majority of aquatic insects in freshwater. Likewise, Phylum Annelida, represented mainly by the Oligochaetes of *Tubifex* spp. - also pollution tolerant species, were present in most sites sampled though slightly fewer in numbers compared to chironomids. The prominence of Chironomidae larvae and Oligochaetes (both pollution indicator species), in many tropical assemblages has also been acknowledged by other researchers like Ogbeibu and Oribhabor (2002), and Osemwegie and Olomukoro (2004). Their importance as biological indicators of water quality, which determines their distribution, has also been stressed by Williams and Feltmate (1992).

Other macroinvertebrate taxa encountered along Amala and Nyangores tributaries combined included: the Ephemeroptera (0.6%), Plecoptera (0.3%), Mollusca (7.2%), Coleoptera (0.9%), Tricoptera (6.0%) and Odonata (2.4%). Presence of pollution indicator species in large numbers, along Amala and Nyangores tributaries, and a general absence or low abundance of other taxa across all sampling sites, was an indication of increased pollutand levels at some sections along Nyangores and Amala tributaries, which could have been contributed by the increased anthropogenic activities that charcterized various points along the two tributaries. Contrary to expectations, *Chironomous* spp., (a pollution tolerant species), showed its peak at the upper catchment spring (AS), draining into Amala tributary - a site thought to contain clean water as exemplified by the large number of locals who depended on it as their main source of water for domestic use.

The high numbers of pollution tolerant species was an indication that the site could possibly be polluted. Increased anthropogenic activities (mainly bathing and washing) observed at this site (AS), owing to the presence of hot springs at the site, could have contributed to water quality degradation resulting from anthropogenic activities within its' surroundings. In addition, the fact that the spring (AS) was located in a depression and was not protected, could have facilitated the swift flow of storm water runoff as well as waste water back-flow into the spring resulting in water contamination.

Earlier studies by Armitage *et al.* (1983) showed that the ecological ability and adaptation capability of chironomid larvae to extreme environmental conditions such as pH, salinity, depth, temperature, water velocity and productivity enables them to survive in a wide range of aquatic environments. Numerical abundance of *Chironomous* spp. and a general absence or low occurrence of sensitive taxa at sites located within the urbanized areas (Bomet and Mulot Towns) could have been indicative of poor water quality probably as a result of pollutant load from various human activities along the river continuum, key among them sewage and waste water discharge as was also observed by Chakraborty and Das (2006).

Peckarsky *et al.* (1990) reported that the ability of *Chironomus* spp. to withstand low oxygen levels is due to presence of haemoglobin which aids them in trapping oxygen from their surroundings, probably explaining their ability to survive in highly disturbed sites along the two tributaries, where other organisms were largely absent. However other studies have shown that pollution tolerant species can also occur in unpolluted waters in large numbers (Peckarsky *et al.* 1990).

The oligochaeta, also a pollution tolerant species, could have been favoured by the organic environment created by waste emanating from various anthropogenic and livestock activities as well as presence of abundant organic detritus matter, that were common along the two tributaries as was also observed by Callisto *et al.* (2005) and Manoharan *et al.* (2006). Mandaville (2002) observed that Chironomidae and Oligochaetes have a short life cycle which enables them build populations over a short period and colonize different sites easily thus outcompeting other taxa.

Pollution sensitive taxa such as Plecoptera (stonefly larvae), and pollution intolerant taxa such as Ephemeroptera were relatively rare representing only 0.9% of the total macroinvertebrates recorded in the two tributaries. Their rare or low occurrence along the two tributaries was a clear indication of increased pollution probably resulting from anthropogenic activities along the river continuum. Such skewed compositions in benthic macroinvertebrate have also been reported by Chatzinikolaou *et al.* (2006), in their study of Axios-Vardar River, where anthropogenic impacts were most pronounced.

The current findings also showed that benthic macroinvertebrates were neither uniformly distributed along the river continuum nor did they exibit consistent increase or decrease downstream of both tributaries. Instead, they varied significantly between sites along both

Nyangores and Amala tributaries. This was expected since highly disturbed areas often seem to favour pollution tolerant taxa over the sensitive taxa. These findings were consistent with those of Kibichi *et al.* (2007) carried out along the River Njoro watershed of Lake Nakuru drainage basin which also reported that benthic macroinvertebrate diversity and abundance, from the upper reaches to lower reaches were highly dependent on anthropogenic activities along the river continuum. Other studies have shown that human activities can alter the community structure of benthic macroinvertebrates as well as influence the abundance of specific taxa (Ogbeibu & Oribhabor, 2002).

Regression analyses revealed that only total dissolved solids was predictive of benthic macroinvertebrates along both tributaries in general. The findings imply that most physico-chemical water quality parameters within the two Mara River tributaries did not seem to influence benthic macroinvertebrates diversity and abundance. Mandaville (2002) also reported that benthic macroinvertebrates are a diverse group that display variations in their tolerance to contaminants ranging from tolerant to sensitive taxa, and that some are therefore able to survive in waters with wide ranging levels of physico-chemical parameters. The lack of a clear relationship between benthic macroinvertebrates and all physico-chemical parameters except TDS along the Mara River tributaries could have been as a result of their physiological adaptations to unfavourable environmental conditions as was also reported by Tyokumbor *et al.* (2002), in which weak relationships between Diptera, Odonata and Mollusca to water temperature were reported. This implies that most benthic macroinvertebrates have the ability to survive, adapt, migrate or die under favourable or unfavourable environmental conditions as was also reported by Tyokumbur *et al.* (2002).

Macroinvertebrate diversity indices yielded a higher (1.12) Shannon-Weiner diversity index (H^l) along Nyangores tributary than Amala tributary (0.64). Since the index values normally range between 0.0 – 5.0 and decreases with increasing stress of the aquatic ecosystem (Meschkowski, 1968), the values recorded in the current study along both tributaries were still far below the normal range. In addition, the Shannon Evenness Index which decreases with increasing stress to the ecosystem (Meschkowski, 1968), was also higher (0.4351) along Nyangores tributary than Amala tributary (0.3563). Consdidering the fact that the evenness metric gives a value of 1 when there are similar proportions of all species in the system, these values were still low, clearly indicating that the species composition in both tributaries were very dissimilar with some species (chironomids and oligochaetes) being dominant over others (Ephemeroptera and Plecotera). These findings could be an indication of disturbed systems. It may however be much more informative to establish the differences in the diversity and abundance of benthic macroinvertebrates between the two tributaries in a longitudinal study.

5.7 Coliform Bacteria Levels along Amala and Nyangores Tributaries

Total coliform bacteria (MPN/100mls) showed significant variations between sites along Nyangores tributary. High bacterial levels were recorded at more disturbed site particularly those located within the urbanized areas while the lowest coliform levels were recorded at the upper catchment springs. Coliform bacteria abundance especially at highly disturbed urbanized sites (middle part of Mulot and lower part of Bomet Towns) could be attributed to pollutant load from various human and livestock activities along the river continuum as well as contributions from the urban areas and also from the natural environment. Urban surface runoff enhanced by the vast impervious surfaces like pavements, roads and building roofs within Mulot and Bomet Towns could have contributed to the high coliform levels into the two tributaries especially along the sections of the river flowing through the urbanized areas. The significant variation in total coliform levels observed between sites along the two tributaries could have been due to localized small-scale variability in water quality that was largely driven by the levels of disturbance at the specific site. Regression analysis showed that pH and TSS were predictive of total coliforms, implying that these parameters could be influencing the total coliforms in the Mara River tributaries.

Like total coliforms, *E. coli* levels varied significantly between sites along Nyangores tributary, with highest (41.5%) and lowest (1.2%) proportions recorded at the lower part of Bomet Town (NLB) and upper catchment spring (NS), respectively. This is a possible indicator of the influence that anthropogenic and livestock activities have on surface water quality. Frenzel and Couvillion (2002) also reported significant positive correlation between fecal indicator bacteria and human population density in urban watersheds, probably explaining the high *E. coli* proportions at the sites located within the urbanized area (Bomet Town) compared to the less disturbed upper catchment spring (NS) draining into Nyangores tributary. These findings were consistent with those of Chambers *et al.* (1997), and Adams and Papa (2000), which also reported higher concentrations of coliform bacteria in urbanized and urbanizing areas compared to natural systems, which they attributed to increased number of people, domestic animals and related anthropogenic activities. A report by WHO and UNICEF (2004), noted that high coliform counts are found in surface waters used in most rural and informal urban settlements that lack proper sanitation facilities.

In addition, Kelsey *et al.* (2004) attributed storm water runoff from urban land uses to faecal contaminants in surface waters, while a longitudinal study by Toothman *et al.* (2009) carried out in North Carolina, Wilmington, singled out urban storm water runoff as the major contributor of faecal coliform bacteria into surface waters. Therefore, the poor human waste disposal practices along the river banks, livestock watering, and sewage or waste water discharge into the two tributaries especially within the urbanized areas could have contributed to the high *E. coli* levels recorded at highly disturbed sites, along Amala and Nyangores tributaries.

However, *E. coli* proportions at different sites along Amala tributary were almost similar, ranging between 27.5% at the upper catchment spring (AS) to 23.5% at the upper part of Mulot Town (AUM). Contrary to expectations, the upper catchment spring (AS) characterized by high anthropogenic activities and which also served as a livestock watering point, had the highest *E. coli* proportions compared to the other 3 sites located within the urbanized area (Mulot Town) which ordinarily were exected to have much higher proportions. This was a clear pointer to the significant influence of anthropogenic activities like bathing, washing water collection, among others on water quality. A report by the Kenya Demographic Health Survey (2007), indicated that only 42% of women in the North Eastern Province of Kenya threw children faecal matter into a toilet or latrine; with the majority (58%) of them either rinsing away in water, or throwing the waste outside their dwelling places. Insufficient sanitation facilities or lack of them altogether, particularly among the urban poor living in informal settlements, have been attributed to the haphazard human waste disposal as was also evident along sections of the two perennial tributaries.

Studies by APHRC (2002) linked poor human waste disposal along the Nairobi River to insufficient sanitation facilities in informal settlements, resulting in pollution by pathogenic organisms. A report by WHO (2002) also showed that insufficient provision of septic tanks and sewage systems leads to surface water pollution. Like was the case in the current study, Okoko *et al.* (2012) also attributed increased levels of *E. coli* at some points along River Awach to localized disturbance by anthropogenic activities at those particular points. Apart from human influence, livestock activities around the upper catchment spring (AS) could also have contributed to the high *E. coli* levels through direct deposition of waste into the river water, either during livestock watering or indirectly when cow dung deposited on land or spread as manure on agricultural fields surrounding the spring is swept into aquatic system by surface runoff. Since *E. coli* bacteria from humans and other warm-blooded animal's enteric system tend to die rapidly outside the body, their presence in water is a clear indication of a localized and more recent contamination, further pointing to the major role that localized human activities play in water quality degradation along the Mara River.

The gently sloping topography of the area surrounding this particular spring coupled with the largely bare land around the spring could have accelerated the rate of flow of waste water back into the spring sweeping with them organic waste thus resulting in high *E. coli* levels. A report by USEPA (2002) linked surface runoff from degraded lands to water quality degradation in many watersheds world wide. The detection of *E. coli* in the Mara River tributaries was therefore a specific indicator of the possible presence of other enteric pathogens as was also reported by Mireille *et al.* (2011) in their study on the prevalence of pathogenic strains of *E. coli* in urban streams in Cameroon.

The distribution of *E. coli* along the Mara River tributaries was not uniform and did not increase or decrease exponentially downstream. Instead, the levels varied highly with more disturbed areas having relatively high *E. coli* levels compared to less disturbed areas. This was probably due to the small-scale variability in water quality, resulting from point source pollution. Noble *et al.* (2004) attributed the spatial changes in bacterial levels to initial loading and the disappearance rate which is a function of time and distance of travel from the source, and of other external and internal factors like temperature, competition, toxicity, predation and solar radiation. This could partly explain the fluctuating levels of coliform bacteria along Amala and Nyangores tributaries. Nevertheless, the unexpected high proportions of *E. coli* at the upper catchment spring draining into Amala tributary, that had all along been regarded a clean source of water for domestic use, implies that anthropogenic activities could greatly be impacting on the water quality of Amala and Nyangores tributary than previously thought.

Regression analysis showed that only pH, TSS and total nitrogen were predictive of *E. coli,* along the two Mara River tributaries. Consistent with the current study findings, Murray *et al.* (2001) also found a strong relationship between TSS and fecal coliform in the Rouge River in Ontario, Canada. However, according to Jamieson *et al.* (2005), the fact that most parameters did not show any significant relationship with *E. coli* could have been as a result of "confounding factors" that mask the influence of some physico-chemical parameters on bacteria metabolism. These findings were also consistent with those of Burkholder *et al.* (2007) and Mallin *et al.* (2000) which reported a significant relationship between fecal bacteria and nutrient concentrations due to a common source or a random arrival of nutrients and *E. coli* in the same area. All the sampling sites along Amala and Nyangores tributaries had bacteria levels exceeding the WHO domestic water standards ($0/100cm^3$) for a domestic water source (WHO, 1996). Based on the current study findings, the water of the two Mara River tributaries are impaired and therefore unsafe for human consumption without prior treatment.

The continued use of water from the Mara River tributaries for domestic purposes without prior information of the sanitary quality with respect to microbial quality, coupled with lack of alternative sources of clean water, therefore continues to exposes the water users to risk of contracting waterborne diseases such as cholera, typhoid, and hepatitis among others (Esry and Habicht, 1986). It is against this backdrop that this study sought to determine the influence of anthropogenic activities on water quality of Amala and Nyangores tributaries of Mara River so as to inform policy makers on best options of protecting both the human health and the Mara River ecosystem.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Generally, sites that were located within the urbanized areas and characterized by high anthropogenic activities also recorded poor water quality compared to the relatively undisturbed sites like spring NS draining into Nyangores tributary, which had clean water.

Most of the solid waste along the two tributaries comprised of polythene bags, plastic bottles and office paper, though Amala tributary recorded significantly more waste than Nyangores tributary. Disturbed sites had relatively higher quantities of solid wastes than less disturbed sites, while most of the waste was inorganic and also recyclable.

Most physico-chemical parameters as well as nutrients varied significantly between sites along both tributaries, while nutrients (TP and TN) were higher within the urbanized sections compared to the upper catchment springs. Total phosphorus levels along Amala were significantly higher than those recorded along Nyangores tribuatry.

A total of 678 benthic macroinvertebrates were recorded during the study, with Nyangores tributary having a significantly higher macroinvertebrate species diversity compared to Amala tributary. Benthic macroinvertebrate taxa varied significantly between sites with pollution tolerant taxa (Chironomids and Oligochaetes) being dominant over sensitive taxa, especially in highly disturbed sites.

Total coliforms levels varied significantly between sites along Amala and Nyangores tributaries, with more disturbed sites recording higher levels than less disturbed sites. *E. coli* levels only varied significantly between sites along Nyangores tributary. However, along

Amala tributary, *E. coli* showed unexpectedly high levels at the upper catchment spring (AS) that was initially thought to be clean, compared to sites located within the urbanized section.

6.2. Conclusions

Based on the findings, it is clear that both instream anthropogenic activites and those carried out along the banks of Mara River tributaries or within the catchment area contribute significantly to water quality degradation, of Amala and Nyangores tributaries.

Solid waste abundance was driven by anthropogenic activites as exhibited by the large quantities recorded at sections of the river characterized by human activities like washing, bathing, swimming among others. The presence of large quantities of recyclable waste implied that the basin inhabitants had not embraced the waste minimization strategy of reduce, reuse and recycle.

This study established that anthropogenic activities could be influencing water quality as exibited by the significant variations in nutrients and most physico-chemical parameters between sites along the two tributaries. Generally, sites within urbanized areas characterized by high anthropogenic activities had poor water quality as indicated by the high nutrient levels and altered physico-chemical parameters, pointing to the close link between anthropogenic activities like urbanization, agriculture, livestock activities and water quality.

Benthic macroinvertebrate community structure was most likely affectd by the changing water quality parameters which were inturn influenced by anthropogenic activities as was evident by the dominance of pollution tolerant species over the sensitive taxa especially at highly disturbed sections of the two tributaries.

The study findings also suggest that there could be an increase in wastewater and raw sewage discharge into the two tributaries as exhibited by the elevated levels of total coliforms and *E. coli* especially within the disturbed sites. Livestock and agricultural activities also appear to influence the microbial load into the river including the spring as was seen at the upper catchment spring draining into Amala tributary, an indication of localized pollution sources.

6.3 Recommendations

Anthropogenic activities within the river channel, along the banks, and also within the entire Mara River catchment area should be controlled so as to curb increased pollutant load into the Mara River tributaries.

An Effective but practical solid waste management strategies, such as reduce, re-use and recycle, should be implemented in both Bomet and Mulot Towns to reduce the amount of solid waste discharged into the environment and subsequently into aquatic ecosystem thus uphold environmental quality and integrity.

A regular monitoring program of physico-chemical parameters should be carried out to help detect sources of pollution while nutrient loading from point and non point sources should be curbed to prevent eutrophication and water quality degradation along the two tributaries.

The ecological integrity of Amala and Nyangores tributaries should be maintained by controlling anthropogenic activities within the basin or along the river to enable the tributaries support a high biotic diversity including benthic macroinvertebrates as well as enable the river to effectively perform its natural self purification processes.

Proper sanitation and waste disposal should be given first priority, while all water collection points, particularly springs should be protected by embankments, to prevent backflows or runoffs that may cause source contamination. In addition treatment of water from the springs as well as the tributaries before use by the basin's inhabitants is highly recommended.

6.4 Suggestions for Further Research

The cumulative and possible long term effect of solid waste resulting from anthropogenic activities along the Mara River, on the water quality, needs to be established through a well structured longitudinal study to avert an imminent crisis in the future.

More extensive surveys are needed to monitor seasonal and spatial variations in water quality using a combination of physical, chemical and biological parameters in order to better monitor the effects of anthropogenic activities on the water quality.

The findings from this report are limited in that they are only snapshots of the water quality at specific points during the dry seasonons. It is therefore important that comprehensive longitudinal studies be carried out to establish any changes in water quality with respect to seasonality and changing flow rates. The differences observed in the two tributaries with respect to physical, chemical and biological factors also need to be established.

Further study are needed to establish the sanitary quality of the Mara River waters by use of several other indicators of microbial contamination so as to be able to detect the presence of other potentially pathogenic organisms such as viruses, protozoans, fungus, helminths among others that may be missed by the conventional *E. coli* and total coliform bacteria determination method.

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