Macroinvertebrate Index of Biotic Integrity for Assessing the Water Quality of Rivers Kipkaren and Sosiani, Nzoia River Basin, Kenya.

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Moi University

2008
DECLARATIONS

Declaration by the candidate

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Signature ..................................... Date.............................................
Aura Mulanda Christopher
(NRM/PGFI/01/06)

Declaration by the Supervisors

This thesis has been submitted with our approval as supervisors.

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Signature........................................ Date.............................................
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ABSTRACT

Globally, IBI is being applied as an integrity tool in monitoring and bioassessment of aquatic ecosystems such as rivers. The study set out to investigate the possibility of establishing an Index of Biotic Integrity (IBI) using macroinvertebrates to assess the water quality with special reference to nutrient levels of Rivers Kipkaren and Sosiani in the upper reaches of River Nzoia Basin, Kenya. Physical water quality parameters like pH, conductivity, temperature, water velocity and discharge were measured in situ while chemical parameters such as DO, TP and TN were determined calorimetrically in the laboratory using standard methods. Habitat and land use characteristics were also recorded. Triplicate macroinvertebrate samples were collected semi-quantitatively on a monthly basis from December 2006 to May 2007 using a 0.5 mm mesh size scoop net in the riffles, pools and runs. Macroinvertebrates were analyzed for abundance and diversity and related to the nutrients (TP and TN) using the Spearman’s correlation analysis. Statistical tests of Mann-Whitney U and Kolmogorov-Smirnov tests were used for pairwise comparison in all the stations and provided 9 macroinvertebrate metrics that contributed significantly (p<0.05) to the final IBI. SPSS for Windows version 10.0 and Microsoft Excel computer packages were used for statistical analyses. A total of 31 macroinvertebrate genera for River Kipkaren dominated by the EPT and 19 macroinvertebrate genera for the lower River Sosiani dominated by dipterans were recorded. Significant differences in the mean abundance (F= 16.371; df = 6; p = 0.000) and diversity (H=7; df=7; p=0.0032) between the stations were found that indicated differences in water quality. A significant positive correlation for TN and TP and macroinvertebrates was obtained (p=0.00; r =0.39). In the final IBI, River Kipkaren
stations had better water quality with IBI ranging from 27 to 39 points, while River Sosiani stations fell in classes of fair to poor water quality and IBI ranging from 19 to 22 points out of the total 45 points due to variations in anthropogenic impacts. The study recommends the use of IBI in biomonitoring and bioassessment of rivers to improve the river health and thus biotic integrity because the IBI delineates impacted from less impacted sites along the rivers. An alternative preliminary IBI using fish and algae assemblages should also be explored for comparison in the Nzoia River Basin.
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<th>Full Form</th>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>APHA</td>
<td>American Public Health Association</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>EPT</td>
<td>Ephemeroptera, Plecoptera and Trichoptera groups together</td>
</tr>
<tr>
<td>Fig.</td>
<td>Figure</td>
</tr>
<tr>
<td>GoK</td>
<td>Government of Kenya</td>
</tr>
<tr>
<td>IBI</td>
<td>Index of Biotic Integrity</td>
</tr>
<tr>
<td>mgL⁻¹</td>
<td>Milligrams per liter</td>
</tr>
<tr>
<td>IBI</td>
<td>Index of Biotic Integrity</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>pH</td>
<td>Potential hydrogen or acidity level</td>
</tr>
<tr>
<td>S</td>
<td>Station</td>
</tr>
<tr>
<td>SEM</td>
<td>Standard error of the mean</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for Social Sciences</td>
</tr>
<tr>
<td>sp.</td>
<td>Species</td>
</tr>
<tr>
<td>TN</td>
<td>Total Nitrogen</td>
</tr>
<tr>
<td>TP</td>
<td>Total Phosphorous</td>
</tr>
<tr>
<td>µgL⁻¹</td>
<td>Microgram per liter</td>
</tr>
<tr>
<td>µScm⁻¹</td>
<td>MicroSiemens per centimeter</td>
</tr>
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DEDICATION

To my dad, mum, brothers and sisters.
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CHAPTER 1

1.0 INTRODUCTION.

1.1 Background Information on Rivers.
Running waters provide a plethora of utilities for mankind, including a source of water for domestic, industrial and agricultural purposes, a means of power generation, waste disposal, fishing, bathing and for aesthetics and recreation (Young et al., 1994). This great utility of running waters to mankind has also proven its undoing, as they have acted as magnets for human settlement and there are now very few river catchments that are unaffected by human activities.

Only a small proportion (0.006%) of the world’s fresh water is present in streams and rivers at any one time (Shiklomanov, 1993), but this statistic is subtle to the significance of lotic systems to mankind and the biosphere. In terms of their biological value however, rivers contain a rich and varied biota, including a high diversity of fish and other emblematic vertebrates such as crocodiles, birds and snakes, and an even greater diversity of invertebrates plants and algae, many of which are still not described. Because of the lack of a basic taxonomic knowledge of many taxa in tropical regions, like Kenya, and only rudimentary data for the functional role of biodiversity in running waters (Covich 1996; Jonsson et al., 2001), it is difficult to gauge the relative importance of lotic diversity or its ecological significance. But, with the global human population predicted to increase by approximately 2 billion (to 8 billion) in the next 25 years (Ward, 1998), the pressure on lotic systems will increase dramatically and the current importance of riverine biota may become too apparent.
Running water ecosystems encompass a wide spectrum of habitats spanning a continuum from small mountain springs to immense lowland rivers. The relative narrowness of lotic systems means that they have an intimate contact with their surrounding catchments and the terrestrial ecosystems they contain (Hynes, 1975). The trophic dynamics of many low-order streams, for example, is driven primarily by inputs of terrestrial leaf litter (Junk et al., 1989), in the low-order streams. Riparian vegetation has an important role in buffering potential impacts from the catchment (Osborne & Koviacic, 1993) and interactions between large rivers and their floodplains serve to maintain the biodiversity and ecological importance of rivers (Ward, 1998).

In addition to their linear form, running waters are amongst aquatic ecosystems in their unidirectional flow. This characteristic flow shapes the morphology of river channels, makes running waters inherently variable in space and time and has led to a biota that is highly adapted to mic conditions (Giller & Malmqvist, 1998). Land use activities occurring within a watershed such as urbanization, agriculture, mining, deforestation, road construction and impoundments often severely alter stream morphology and water quality of individual catchment areas as well as complete river ecosystems. These activities impact the physical, chemical and biological processes that occur within a river ecosystem. Among the causes of streams’ habitat degradation such as excessive nutrients, lack of diverse habitat complexity, sedimentation occurrence and turbidity, offers poor habitat for biota. Unfortunately, the ability to predict precisely the rate of species loss in these watercourses is hampered by a lack of knowledge of how many species there are and the impossibility of tracking changes in individuals of genera other than large, high-
profile organisms that are very few to come across. Data from the tropics suggest that habitat destruction may have severe implications for biodiversity (Reid, 1992), such as extinction of species, particularly in areas with high endemism, although such predictions suffer from a general lack of knowledge in species turnover.

The Lake Victoria North Catchment area is situated in the western part of Kenya. The three major water towers in the region include Cherang’ani hills, Mt. Elgon and Nandi hills. The most prominent rivers in the area are the Nzoia and Yala Rivers. River Nzoia is the longest (334 km) and has the largest catchment area of 12,903 km² and annual discharge of 1777x 10⁶ m³yr⁻¹ (GoK, 2007). It originates from Chereng’ani hills, which forms the northern part of the watershed dividing the Keiyo Valley from the Lake Basin and traverses Trans Nzoia, Lugari, Bungoma, Butere-Mumias, Siaya and Busia districts. The main upper course tributary is Moiben River. Many other rivers feed the Nzoia River before it discharges into Lake Victoria. The most notable rivers are the Kipkaren, Kwoittobus, the Little Nzoia, the Ewaso Rongai and the Kibis. The other tributaries in the Nzoia basin are the Kuywa, the Chwele and the Khalaba discharging into Nzoia from the north, and Rivers Lusumu and Viratsi flowing into the Nzoia from the southern part of the Lusumu River. The Nzoia River empties into the Lake Victoria in the south western corner of the Lake Victoria North Catchment area (GoK, 2007). This catchment is generally rich in water resources stocked in rivers. However, there are environmental issues that the region must address as a matter of urgency in order to conserve the water resources from further depletion and degradation.
Information on anthropogenic impacts on streams and rivers in this catchment and Kenya as a whole is patchy. There are vital gaps in knowledge concerning the impacts of many pollutants and a paucity of data for developing regions; areas that may be particularly vulnerable in the near future (Ward, 1998). There are also limited studies that attempt to predict future changes in the status and ecology of such running waters (Raburu, 2003). The ultimate aim of this research is to provide data on macroinvertebrates and nutrient levels in Rivers Kipkaren and Sosiani, on the upper reaches of Nzoia Basin, and thereby attempt to show the main threats to running water systems in the region and possible management options. This is because macroinvertebrate assemblages are integrally linked to in-stream physical and chemical characteristics and have been frequently used as indicators of water quality (Roy et al., 2001). This study set out to develop an Index of Biotic Integrity for Rivers Kipkaren and Sosiani ecosystems in the upper reaches of River Nzoia Basin. Hence, this study is aimed at bridging the existing knowledge gaps of lack of a suitable bioindicators for assessing the riverine integrity and health in Rivers Kipkaren and Sosiani, and for predicting future environmental changes. This may provide necessary data for managing the watercourses from human activities that threatens the diver of aquatic fauna and health in the riverine environments within the Lake Victoria Basin.

1.2 Statement of the Problem and Justification.

The susceptibility of lotic systems to any man’s activity is exacerbated by their linear or unidirectional nature. Almost any anthropogenic activity within a river catchment has the potential to cause environmental change and any pollutant entering a river is likely to exert effects for a long distance downstream. The nature of the threats to running waters differ from region to region. Whereas pressure on water resources is
extremely high in Eastern Africa, lotic systems are abundant at high latitudes or in tropical areas with high precipitation, a condition similar to the study area. However, running waters are not high priority ecosystems for conservation efforts (Ward, 1998). The destruction of running water habitats is becoming so extensive in some developing countries that it is now a perceived necessity to protect what is left or restore degraded systems. In other countries where industrial development has been slower, like in Kenya, the destructive processes are in a rising phase, but may present an immediate threat (Dudgeon, 2000).

The high population densities, intensive cultivation, repeated subdivision of farmlands and rapid decrease in land available for farming are some of the major causes of soil erosion and nutrient enrichment in aquatic ecosystems within the Lake Victoria basin (Ngugi & Brabley, 1986). These problems, together with declining tree cover resulting from conversion of forests to settlement areas, are causing increasing concern about sustainable development of Lake Victoria Basin. To remedy this situation, there is need to study the impacts of nutrient enrichment within the basin on biodiversity so that necessary measures may be put in place. In Kenya, Mt. Elgon, Cherengani, Kakamega, North and South Nandi and Tinder forests are special catchment areas as they act as the sources of Rivers Nzoia, Yala and Nyando, draining into the Lake from the north. From the south, the Mau complex and Transmara forest blocks are the major catchments for Rivers Sondi, Kuja and Mara. In addition to River Kagera, these two catchments contribute immensely to the total water flowing into the Lake Victoria. This may imply that if these inlets are polluted by anthropogenic inputs, they may keep on altering the functioning of Lake Victoria. Given the importance of these catchments to Lake Victoria, it is imperative that
environmental impacts in these areas are studied and a equate data for use in formulating management advice.

Increased nutrient inflow from the catchment of Lake V toria has led to eutrophication of the lake triggering international attention (GEF, 2004). Agriculture is implicated as the main source of nutrients into Lake Victoria. Food shortages coupled with high poverty rates that diminish people’s ability to afford the ever-increasing food prices has resulted into increased agr icultural activities within the Lake Victoria basin. Apart from this, both domestic and industrial wastewaters also contribute a significant proportion of nutrients into this lake. Coupled with the destruction of natural wetlands fringing Lake Victoria Basin further contributes to the increased nutrient flow (GEF, 2004). Inevitably, a major challenge to economic development in Kenya is therefore the sustained increase of food production without compromising the integrity of the environment on which that much required food depends.

There has been an over-reliance on the use of chemical tests as the sole method of water quality analyses for all water bodies in Kenya. The method is very expensive making it difficult to generate time series data often needed for the management of water quality in the basin. Since large scale agriculture which contributes large amounts of nutrients is the major land use in the catchment of Lake Victoria, the study focused on their impact on macroinvertebrate assemblage in an effort to come up with a biomonitoring scheme. In Kenya, little effort has been invested in the use of biological indicators such as macroinvertebrate index of biotic integrity (IBI), as a result, little information is available on the same. The rivers in this study are found in agricultural dominated areas, urbanized localities, forested stations and swampy areas.
This study set out to investigate the possibility of establishing a macroinvertebrate index of biotic integrity in assessing the water quality of Rivers Kipkaren and Sosiani in the upper reaches of River Nzoia Basin, Kenya. This was to provide systematic information on the use of macroinvertebrates to monitor the water quality in Rivers Sosiani and Kipkaren catchment.

1.3 Research Objectives.

1.3.1 Overall Objective.

- To develop a Macroinvertebrate Index of Biotic Integrity for assessing the water quality of Rivers Kipkaren and Sosiani in the upper reaches of Nzoia River Basin, Kenya.

1.3.2 Specific Objectives.

- To determine the abundance and diversity of macroinvertebrate assemblages in the Rivers Kipkaren and Sosiani.

- To determine selected water quality parameters in the Rivers Kipkaren and Sosiani.

- To investigate the spatial differences in nutrients, and in particular total phosphorus and total nitrogen, in the Rivers Kipkaren and Sosiani.

- To establish the relationship between diversity and abundance of macroinvertebrates in the rivers and nutrient enrichment within the sub-catchment.

- To derive an Index of Biotic Integrity for assessing water quality of Rivers Kipkaren and Sosiani.
1.4 Research Hypotheses.

- H1: There is no difference in the occurrence, abundance and diversity of macroinvertebrate assemblages in the Rivers Kipkaren and Sosiani.

- H2: There are no spatial differences in total phosphorus and total nitrogen in Rivers Kipkaren and Sosiani.

- H3: There is no relationship between the diversity and abundance of macroinvertebrates and nutrients levels (total phosphorus and total nitrogen) in Rivers Kipkaren and Sosiani.

- H4: There is no difference in the Index of Biotic Integrity along Rivers Kipkaren and Sosiani.
CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Background Information on Rivers

Running waters are perhaps the most impacted ecosystems on the planet as they have been the focus for human settlement and are heavily exploited for water supplies, irrigation, navigation, electricity generation, and waste disposal. Lotic systems also have an intimate contact with their catchments and so are directly affected by land use alterations. The ultimate factors forcing change in running waters include ecosystem destruction, physical habitat and water chemistry alteration, and the direct addition or removal of species. These stem from proximate influences from urbanisation, industry, land use change and watercourse alterations (Buttle & Metcalfe, 2000). Any one river is likely to be subjected to several types of impacts, the management of which is complicated by numerous links between different forms of anthropogenic effect.

A number of natural environmental factors influence the ecology of running water ecosystems. At large scales, several models have been proposed that highlight factors that are of prime importance in shaping the fundamental ecology of lotic systems, including the River Continuum Concept, supply of trophic energy and organic matter transport (Vannote et al., 1980). Others are the spiralling like longitudinal cycling of nutrients (Newbold et al., 1982), lateral expansion and contraction of floodplains (Junk et al., 1989) and hydraulic regime (Statzner & Higler, 1986). There are also numerous regional and local-scale studies demonstrating the importance of water chemistry, hydrology, microhabitat structure, and biotic interactions in lotic ecosystems (Giller & Malmqvist, 1998). But changes in the features in relation to
man’s activities and how they affect stream biodiversity remains a very important issue to address.

Anthropogenic influence on river systems can alter the balance of the natural factors that influence the river health. For example, changing the proportional abundance of different streambed substratum types or altering the annual temperature regime can alter the biota present in such areas (Dudgeon, 2000). Alternatively, such impacts can cause changes that are beyond the normal condition expected for any given lotic ecosystem. Examples would include an influx of toxic metals to, or the complete removal of a microhabitat type from a stream reach of which the ultimate impact would be the destruction or removal of the ecosystem, in whole or in part. The source and effect of an anthropogenic impact may be obvious, or example, a point-source discharge from sewage works containing high concentrations of organic compounds (Buttle & Metcalfe, 2000). However, the water chemistry alteration caused by nutrient enrichment forms the basis of this research.

2.2 Macroinvertebrates Composition, Abundance and Diversity.

The diversity of macroinvertebrates in local streams can be measured and the patterns compared with the information of relative human activities like urbanization in order to test the biodiversity changes with human development (Roy et al., 2001). The observation of these species is particularly useful in testing stream quality because most of them are good indicator species. There are many reasons why most macroinvertebrates are such excellent indicator species. They are important members in the food web of a stream ecosystem, and when a pollutant enters the stream or there is some damaging disturbance, they will inevitably be affected. In almost all cases
they are too small to be able to get away from these times of human disturbance. Therefore, if they are intermediately tolerant species they will survive but so stressed that they lose time and energy to fight against the circumstances and eventually they die off. However, if they are more tolerant, then they will thrive in the absence of competition. Furthermore, they are relatively easy to sample and identify (Herrmann, 1991; Karr & Chu, 1997).

For example, if a bio-survey were to demonstrate that stoneflies are no longer present where they once were, then one could hypothesize that the streams dissolved oxygen content has decreased (Roy et al., 2001). This however touches on the primary disadvantage of this type of biological assessment. While observing these creatures gives us a fairly certain affirmation of the health or sickness of a stream, it does not tell us why certain species are present or absent. In other words, it does not tell us why the oxygen levels have decreased, and furthermore, it is still possible that there is another factor altogether, which is impacting stonefly population. When studying across 30 streams in the piedmont of Northern Georgia, Roy et al., (2001) found that the diversity of macroinvertebrates decreased with increasing urbanization. A primary conclusion that they drew was that macroinvertebrate diversity is an excellent indicator of stream health and development impacts and that limiting development in a stream catchment is necessary to preserve the integrity of the stream.

Several factors can contribute to changes in the composition and abundance of macroinvertebrate community. For instance, high frequency and long duration of flooding and altered sediment transport dynamics favour species adaptable to unstable
habitats such as chironomids and oligochaetes. In addition, excess sedimentation limits refugial space, so invertebrates are more susceptible to drift (Sarkar et al., 2002). This study targeted the response of macroinvertebrate nutrient levels and water quality to verify such results.

2.3 Water Quality Parameters in Rivers.

Macroinvertebrates are abundant and easily sampled. The species living in virtually any water body like in streams and rivers have a diversity of morphological, ecological, and behavioral adaptations to their natural habitat (Herrmann, 1999). Being a diverse component of riverine habitats, they respond quickly to changes in physical, chemical or biological parameters. The structure and function of macroinvertebrate communities reflect physical or chemical conditions, and change with increased human influence (Herrmann, 1999).

For example, natural differences in pH and alkalinity may be important determinants of certain macroinvertebrate assemblages. Highly acidic water generally results in impoverishment of fauna, and low acidities generally reflect better buffering and higher productivity. Generally, river acidification can alter community structure by being acutely or chronically damaging tissues of invertebrates particularly for species that easily lose sodium ions when pH is reduced. It also alters algal communities, upon which some invertebrates depend for food and shelter, altering predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians, and by altering the bioavailability of some other potential stressors, such as heavy metals. Such effects may reduce invertebrate species diversity, increase in abundance of tolerant species and changed community composition (Shieh & Yang, 2000).
On the other hand, temperature and oxygen levels usually fluctuate seasonally and aid in the structuring of benthic communities, which vary from species to species (Shieh & Yang, 2000). Turbidity, oxygen levels, conductivity and total suspended solids are affected by human activities (Ndiritu et al., 2003). According to Ndaruga et al. (2004), subsistence agriculture was evident in the upper stream where low turbidity, conductivity and moderate oxygen readings were recorded in River Gaitaini in Kiambu District in Central Kenya. On the contrary, lower stream sites had high conductivity levels and turbidity with low dissolved oxygen concentrations that were attributed to point source pollution by Kamiti Tannery Factory.

Therefore, macroinvertebrates respond to changes in water quality parameters negatively (decrease) or positively depending on the environmental factors surrounding the stream such as human activities (Hermann, 1999).

2.4 Nutrients Occurrence in Rivers.

Most of the water entering rivers must first pass through terrestrial catchments, which differ markedly in their geology, soils, and vegetation and, hence, contribute to a large natural range of river chemistry. The chemistry of running waters also varies substantially between small streams and large rivers (Meybeck & Helmer, 1989). This natural variability means that impacts of different forms of chemical alteration introduced by human activities are likely to vary dramatically. However, as well as acting against a backdrop of natural variability in water chemistry, the understanding of how chemical alterations are impacting river ecosystems is complicated further because the pollutants are seldom present in isolation and most forms of pollution actually concern more than one chemical or effect (Roy et al., 2001).
Nutrient concentrations have increased in rivers globally and less than 10% of the rivers can be classified as pristine in terms of their nutrient status as defined by WHO (Heathwaite et al., 1996). For example, recent increases in the nitrate concentrations in streams in the Catskill Mountains (eastern USA), were concomitant with increased population size in this region, but not land use change and sewage inputs (Heathwaite et al., 1996). Trends in nitrate concentrations were not synchronous with increased deposition of nitrates in acid rain, which had increased from the start of the nineteenth century (Roy et al., 2001).

When assessing the nutrient concentrations of forested and agricultural streams, Sabater et al. (2004) discovered that concentrations of nitrogen and phosphorus were within the same range. However, continuous reception of nutrients caused high chlorophyll concentrations and high community metabolism in the agricultural streams. They found out that these high levels of nitrogen and phosphorus were only altered by shear stress provided by abrasive floods and the process of recovery of the stream experience. The agricultural stream shared the characteristics of eutrophic rivers where the fungus Cladophora was a dominant organism. They further argued that the mass of Cladophora altered the stream habitat community and constrained the diversity of macroinvertebrates.

On the other hand, nutrient enrichment in the forested rivers caused a moderate increase in the chlorophyll and bacteria density, as compared to those observed in the unenriched stretch. Moreover, these changes in the structure of the microbial components did not significantly affect the macroinvertebrate community where only
a few genera showed changes due to nutrient addition or for the overall stream metabolism (Sabater et al., 2004). The absence of response by the macroinvertebrate community could have been due to the short duration of the experiment, which may have been conflicted with the life history and generation time of some macroinvertebrate genera. Slight changes in metabolism can probably indicate slower response to nutrient enrichment due to low nitrogen and phosphorus levels or because of less efficiency in the uptake of such nutrients. According to Sabater Op cit., the existence of riparian zone in this forested stream intercepted the light intensity reaching the streambed, which caused it to be “sub-saturated” with the primary producers. Dodds et al. (1998) believed that the riparian zone has such a strong influence on structural and stream characteristics that inorganic nutrients show a restricted capacity to speed up the process covering the system. Hence, protecting the riparian vegetation enhances the ability of the system to resist effects of nutrient inputs from anthropogenic sources.

Stream ecologists have noted that water quality of surface runoff, streams and rivers varies seasonally. During wet periods and storm events, water is contributed primarily by recent precipitation that becomes stream flow very quickly without coming into contact with soil and subsurface minerals. During low low, some or much of the stream flow originates as groundwater and has higher concentrations of dissolved materials (Harding et al., 1998). This inverse relationship is not always the case. Concentrations of nitrogen and phosphorus increase with discharge in disturbed watersheds because of increased erosion but decrease with stream flow in natural watersheds because of reduced erosion and increased dilution (Harding et al., Op cit).
There are two principal sources of water pollution: point sources, where pollutants are discharged from easily identifiable industries and from sewage plants which remove some but not all pollutants, and non-point sources, which are difficult to trace. But nutrients from small households can be classified either as point or non-point sources. Non-point sources of pollution originate from spatially diffuse areas where water is polluted by runoff, subsurface flow, or deposition from the atmosphere. According to Davies & Hirji (2003), non-point source pollutants are a result of anthropogenic activities that take place in the catchment areas of a water body, the most common result of sediment transportation. Sediments can originate from any activity that disturbs the soil surface such as construction, tilling, or forestry operations. Nutrients, salts, pathogens from farms and heavy metals and acid inage from agricultural projects form contaminants coming from diffuse sources especially in rural areas. Since the industrial revolution, other sources of non-point source pollution include pesticides, and agrochemicals in runoffs from farms, oils, metals and chemicals from urban areas, and deposition of airborne pollutants from vehicles, factories, and other atmospheric sources that cause eutrophication of rivers and lakes.

Nevertheless, eutrophication has been worsening since 1960s and currently has reduced the Lake Victoria volume by 25% (Davies & Hirji, 2003). Increased levels of algae decomposition utilize the available dissolved oxygen concentrations. This means that a quarter of this lake’s volume is not available to most fish species including Nile Perch due to low oxygen levels. The extent of the eutrophication is controlled by the amount of phosphorus entering the lake. It is estimated that 25 thousand tonnes enter the lake from the atmosphere each year and another 5700 tonnes per year from the inlets (mainly from agriculture), e.g. River Nzoia. The large
atmospheric input of phosphorus is a consequence of the large surface area of the Lake and the prevalence of dust and smoke associated with the poor agricultural practices in the region (Davies & Hirji, Op cit).

Studies by Kerugara and Nevejan (1996) reported agricultural activities as the main non-point source of pollution in the catchment area of Nyando Basin. This is due to the fertilizers and pesticides loading to the watercourses. However, there are few studies that document long-term trends on the effect in biota in relation to increased nutrient loadings in rivers in Kenya. It is likely that any such effects will impact other biota such as macroinvertebrates that rely on aquatic plants for habitat (Raburu, 2003). The lack of enough data for nutrient enrichment in streams in Kenya in relation to anthropogenic stress creates a scientific gap that requires detailed studies.

2.5 Macroinvertebrates Composition, Abundance and Diversity versus Nutrients in Streams.

Benthic organic matter, a major food source for invertebrates, has the capacity to bind many heavy metals and organic contaminants such as mercury, thus exposing the fauna to potentially toxic and inhibiting effects (Sarkar et al., 2002). These authors further noted that an increase in nutrients, organic matter, or contaminant concentrations in surface waters, sediments or food sources result in low diversity of macroinvertebrates, with an increase in abundance of stress tolerant species. However, excessive nutrients can cause long-term or short-term shifts in invertebrate community richness, abundance, and species composition. These changes are typically triggered when excessive nutrients lead to greater growth of aquatic plants, and in particular the increased dominance of certain kinds of algae. This means that invertebrate species that are specialized feeders of algae, or which characteristically
find shelter and attachment stations in aquatic plants are then favoured. At
decomposition of such plants, oxygen depletion may occur, affecting oxygen-
dependent macroinvertebrates negatively (Welch, 1992).

Macroinvertebrate species composition is a function of responses to the trophic state.
For example, tubificid oligochaetes increase in number of individuals with organic
enrichment. The number of species seems to relate negatively (reduce) or positively
(increase) to the amount of available nutrients. It is however, unclear whether this
relation is positive or negative, although it is on record that slight eutrophication
seems to favour increased diversity (Herrmann, 1999). However, excess amounts of
nutrients resulting in increased primary production and consequently oxygen
depletion, probably affects diversity negatively. Studies on the upper paint Greek
watershed, singled out that nutrient enrichment stands out to be the main factor
affecting water quality, and thereby macroinvertebrate diversity in the watershed
(Harding et al., 1998). They eventually subjected this macroinvertebrate trend to the
final IBI to show the strength of nutrient enrichment on macroinvertebrate metrics.
This study targeted similar relationships for macroinvertebrate metrics in relation to
nutrient levels to verify such results.

2.6 Macroinvertebrate Index of Biotic Integrity (IBI).

Karr and Chu (1997) defined biotic integrity as the capability of supporting and
maintaining a balanced, integrated, adaptive community of organisms having species
composition, diversity and functional organization comparable to that of a natural
habitat of the region. Index of Biotic Integrity (IBI) encompasses attributes of
communities, populations, and individual organisms to assess biological integrity on
the basis of accurate measures of relative abundance. The major advantage of IBI is that it is a broadly based ecological index that is sensitive to different sources of perturbations and degradation, thus producing biologically meaningful and reproducible result (Karr and Chu, Op cit). This implies that the assessment of water resource quality by sampling biological communities in the field such as macroinvertebrates is a promising approach that requires expanded use of ecological expertise (Schindler, 1998).

There is a wide spectrum of biotic indices for assessing ecological health of a running water ecosystem, but an IBI stands out as the best (Sabater et al., 2004). They proposed five criteria to define a suitable index at a given time of ecosystem degradation that favours the IBI. These guidelines highlights that the index should be relevant, simple and easily understood by laymen, scientifically justifiable, quantitative and acceptable in terms of cost. When using the IBI to assess the ecosystem health of a river, researchers can gain a well-grounded perspective of the chemical, physical and biological conditions of a particular stream station. Schindler (1998) affirms that this comprehensive assessment is critical for evaluating disturbance and land use practices such as urbanization, agriculture and forestry. The variables to be used may include the tolerant and intolerant genera, other biotic indices and the abundance of macroinvertebrates in a given station; hence in line with this study (Griffith et al., 2005).

The question of precision of macroinvertebrate IBI was tested by the Wyoming Benthic IBI scores in the stream classes. This study showed that 95% confidence
interval around a single sample was ± 8 points on a scale of 100. A triplicate sample, that is in line with this study, required a 95% confidence interval of less than 5 points. This is an indication that the measurement area was normally distributed and not affected by sub-ecoregion or impairment (Barbour et al., 1999). Hence, there is need for the use of an IBI as a water quality index of macroinvertebrate community to assess the effect of land use activities causing ecosystem degradation (in relation to nutrient enrichment) in rivers as a way of assessing stream health.

When assessing the relative sensitivity of community metrics for an IBI in 86 stream reaches, Griffith et al. (2005) established an environment gradient that correlated with agricultural effects and stream size. He further noted that fish, macroinvertebrates and periphyton, differ in their sensitivity to different stressors, and combining metrics for these assemblages into a mixed assemblage index of biotic integrity may increase utility of the multimetric approach to diagnose environmental stressors at impaired reaches. However, their study depicted better performance of macroinvertebrate metrics as compared to fish and periphyton.

The development of biological criteria to assess the biological integrity of an ecosystem is based on regionalization, multi-metric approach and the use of reference conditions (Barbour et al., 1999). Regionalization categorizes ecologically discrete units based on a number of characteristics such as soil type, climate and land use. This is because, according to Karr and Chu (1997), geographic separation of within region-homogeneity and between region-heterogeneity (discrete units) has become integral part of bioassessment. On the other hand, Babour et al. (1999) denotes that multi-
metric indices are composed of ecologically sound measurements that have known responses to anthropogenic impacts. This implies that metrics are organized and selected systematically within a regional framework, multi-metric indices measure changes along disturbance gradients (Karr and Chu, 1997) such as agricultural, urbanization and forestry. Reference conditions are a suite of sampling points or sites, that are chosen to represent regional expectations, regardless of the degree of expectations (Barbour et al., 1999). Probability-based sampling designs, in concert with knowledge of metric responses to human impact, are appropriate for the random selection of reference conditions (Griffith et al., 2005). This affirms the use of macroinvertebrate metrics, stations and reference site that were used in this study.

However, in Kenya and to large extend the whole of Africa, the use of macroinvertebrate assessment and monitoring of stream conditions is still uncommon. In east Africa, only few studies have attempted to describe the structure and composition of macroinvertebrates in lotic systems. For instance, in Kenya, Barnard and Briggs (1988) studied macroinvertebrates in the catchment streams of Lake Naivasha whilst Kinyua and Pacini (1991) surveyed macroinvertebrates of Nairobi River. Tumiwesigye et al. (2000) investigated the structure, taxonomic composition and the temporal distribution of benthic macroinvertebrates in Nyamweru River in Uganda. These studies did not however, relate macroinvertebrates assemblages to nutrient levels and did not establish a bioindicator or a biomonitoring procedure for evaluating water quality in rivers studied. This study sought to investigate macroinvertebrate communities in Rivers Kipkaren and S ni in relation to nutrient levels and to establish a macroinvertebrate index of biotic integrity as a biomonitoring tool.
CHAPTER 3

3.0 MATERIALS AND METHODS.

3.1 The Study Area.

The study was conducted on Rivers Sosiani and River Kipkaren, both of which are tributaries of River Nzoia that lies between latitudes 1° 30’N and 0°05’S and longitudes 34° 15’W and 35° 45’E at an altitude of between 2000 m to 2180 m above sea level (Fig. 1 ). Served with 7 tributaries, River Kipkaren has a maximum depth and maximum width of 3.6 m and 17 m while River Sosiani has 3.2 m and 15 m respectively. River Kipkaren which originates from Kipchamo swamp in Kenya’s Rift Valley is 50 Km long and is joined by River Sosiani, about 6 Km before confluencing near Kipkaren Town downstream. Rivers Kipkaren and Sosiani catchments present a variety of human activities such as urbanization, agriculture, deforestation and afforestation. The rainfall in the Rivers Kipkaren and Sosiani catchments is bimodal with a mean annual rainfall of about 1500 mm (Jaetzold and Schmidt, 1983). The mean annual temperature is 18°C with a maximum of 24°C. The topography of the area is mainly undulating and soils are mainly oxisols on the hill slopes and luvisols on the valley bottoms. The area experiences four seasons in a year as a result of the inter-tropical convergence zone. There are two rainy seasons and two dry seasons with dry seasons occurring from October to December and the short rains from March to May. The dry seasons occur in the months of January to February and from June to September. However, short rains were experienced throughout the study period from December 2006 to May 2007.

A total of 7 sampling stations were established along Rivers Kipkaren and Sosiani and sampled from December 2006 to May, 2007 (Fig. 2). The sampling stations were
chosen after considering human activities along the rivers. The Global Positioning System (GPS model, etrex VISTAC) was used to mark the coordinates of the sampling stations.

**Fig. 1:** Showing the map of River Nzoia Basin and its tributaries (Source: GoK, 2007).
Fig. 2: Showing the sampling stations on Rivers Kipkaren and Sosiani.
In the preliminary survey, characteristics of the sampling stations were noted as shown below.

**Station S1**

Station S1 was located at the source of River Kipkaren (Plate 1) at latitudes and longitudes of N00°51.235’ and W035°23.107’ respectively. The riffles at the station had substrates made of stones, pools consisted of mud and detritus material, while runs had mud substrates. The station had an average depth of 0.6 m with an average width of 3.5 m. The riparian zone is swampy with black clay soils dominating the area. Human activities around the station were minimal except for a plantation of eucalyptus trees at the edge of the swamp. The station was used as a reference station in the development of an IBI because of its minimal anthropogenic disturbance observed. This choice was supported by this stations threshold for physico-chemical parameters and Shannon-Wiener diversity for macroinvertebrates. One single household was located at a distance of about 1 km from the station.

![Plate 1: Station S1 located at the Source of River Kipkaren showing the water flow and the riparian vegetation.](image)

**Station S2**

Station S2 was located on River Kipkaren, 100 m away from the bridge on the way to Eldoret Airport (Plate 2). The station has latitudes and longitudes of N00°23.235’ and
W035°54.110’ respectively. The substrate of the riffles was made of boulders while pools were dominated with sand and detritus. The runs were dominated by sandy substrate. The station had an average depth of 0.9 m and an average width of 5 m. Within the riparian zone is a small swamp, a forest with a tarmac road passing across the River. Black clay soils dominate the riparian zone.

Plate 2: Station S2 showing the River channel and bank vegetation located on River Kipkaren.

Station S3

The station was located 100 m before the confluence of Rivers Kipkaren and Sosiani at latitudes and longitudes of N00°61.235’ and W035°59.112’ respectively. The substrate in the riffles were dominated with bedrock and boulders, whereas, the runs and pools had small stones and sandy substrates (Plate 3). The average depth and width was 1.3 m and 12 m respectively with a forested riparian zone, dominated by black-clay-type soils.
Plate 3: Instream characteristics of station S3 located before the Confluence of Rivers Kipkaren and Sosiani.

Station S4

Station S4 was located near Eldoret Municipal Sewage Treatment Plant on River Sosiani (Plate 4) at latitudes and longitudes of N00°73.435’ and W035°65.108’ respectively. The riffles substrate was composed of bedrock and pools with sand and mud while runs had stones and boulders. The station had an average depth and width of 1.0 m and of 7 m respectively. The human activities around this station include human settlements, quarrying and crop farming on both sides of the river channel. The riparian zone has bedrock on one side of the river bank, whereas, the soils are of loamy type.

Plate 4: The River channel and the River bank vegetation at station S4 located after Huruma sewage on River Sosiani.
**Station S5**

Station S5 was located near Turbo Town (Plate 5) at latitudes and longitudes of N00°85.535’ and W035°87.214’ respectively. The instream site consisted of riffles, runs and pools. The riffles had bedrock and the runs consisted of boulders and stones, while the pools were made of sand, mud and detrital material. The station had an average depth of 1.0 m and an average width of 9 m. The riparian zone consisted of urban settlements and crop farming activities with volcanic soil types dominating the riparian areas.

![Image](image.png)

**Plate 5: Station S5 located on River Sosiani after Turbo Town showing the River channel and riparian vegetation in the background.**

**Station S6**

The station was located 100 m after the confluence of rivers Sosiani and Kipkaren, after the Kipkaren Training Institute (Plate 6) at latitudes and longitudes of N00°89.635’ and W035°95.716’ respectively. The station had bedrock in the riffles, and the runs consisted of boulders and stones, whereas, the substrate in the pools was made of sand. The station had an average depth of 1.2 m and average width of 8 m. Dominated by fertile loamy soils, the predominant land use in the riparian zone consisted of organic farming and agro-forestry on one side, with about 20% vegetation cover (shrubs) on the other side of the river.
Plate 6: Organic farming practiced around sampling station S6 on the left side, vegetation on the right side of the River and the River channel around the area.

Station S7

Station S7 was located near Kipkaren Town on River Kipkaren (Plate 7) at latitudes and longitudes of N00°88.335’ and W035°86.818’ respectively, about 100 m after Kipkaren Town. The streambed of the riffles was composed of bedrock while the substrate in the runs was composed mostly of cobbles and gravel, but the substrates in the pools were composed of sand and detrital material. The station had an average depth of 0.6 m and an average width of 11 m. The human activities around this station include urban settlements (Town), crop farming, cattle rearing and a slaughter house, horticulture activities, agro-forestry and cultivation at the river banks. Tertiary volcanic soils dominate the riparian zone.
Plate 7: River channel, bank vegetation and cultivation at the River banks in the background of station S7 located downstream of Kipkaren Town.

3.2 Data Collection.

Data collection of physico-chemical parameters, nutrients and macroinvertebrates was conducted once in a month, for 6 months from December 2006 to May 2007. Triplicate samples for the riffles, pools and runs in each station in all the 7 stations were collected for physico-chemical parameters, nutrients and macroinvertebrates analyses. The riffles, pools and runs were haphazardly picked from each station basing on their proximity to each other to have an equal chance of each macrohabitat to be selected per station. The whole stretch of land use characteristics in both sides of the rivers was recorded.

3.2.1 Physico-chemical Parameters.

Temperature was measured in situ using a mercury thermometer, at a depth of approximately 10 cm below the water surface for about 5 minutes. Dissolved oxygen was determined approximately 10 cm below the water surface by a calibrated oxygen meter (model, YSI 555). At the same depth of 10 cm, conductivity was measured using a conductivity meter (model, HI 8033) where similar triplicate readings for each
of the macrohabitats were recorded. Average water depth was determined by making
triplicate cross-sectional measurements at the riffles, pools and runs using a tape
measure across the river. The surface velocities of the river water were determined
from each of the randomly picked riffle, pool and run in each station using a float (an
orange) and a stopwatch to determine the time taken to float a given distance.
Velocities in meters per second were calculated using the following formula and
averaged for each station (APHA, 2000).

\[ \text{Velocity (m s}^{-1}\text{)} = \frac{\text{Distance taken by the float (m)}}{\text{Time taken by the float (s)}} \]

The stream discharge was estimated as 

\[ Q = A \times V \]

where 

\[ Q = \text{stream discharge, in m}^3\text{s}^{-1} \]

\[ A = \text{cross sectional area, in m}^2 \]

\[ V = \text{average velocity, in m s}^{-1} \]

3.2.2 Nutrients.

Sampling for nutrients (total phosphorus and total nitrogen) was done by collecting
triplicate samples from riffles, pools and runs in each sampling station using plastic
sampling bottles before sampling for macroinvertebrates to prevent contamination.
The samples were fixed with 3 drops of concentrated sulphuric acid in the field and
transported in ice cool-box (to preserve the sample) to the laboratory for further
analyses.

3.2.2.1 Total Nitrogen (TN).

Total Nitrogen was determined using the Kjeldahl method (APHA, 2000). A 50 ml
water sample was taken in a conical flask to which 2 ml of ammonium chloride
solution was added. The solution was then mixed well and the first 10 ml of the
sample were run through the cadmium column and discarded. The following 25 ml of
solution was collected in a conical flask to which 0.5 ml of sulphanilamide solution
was added. After about 5 minutes, 0.5 ml of n-1 naphthylene diamine dihydrochloride was added and the solution was mixed well. After 1.5 hours, the absorbance of the solution was measured at a wavelength of 543 nm in a Spectrophotometer (Pharmacia Biotech model, 65455). A 50 ml of distilled water and different standard samples were also treated as above. Total nitrogen was calculated using the formula:

\[ \text{TN in mgL}^{-1} = F (E_1 \text{ sample} - (E_0 + E_{B1})) \]

where: 

- \( F \) = Sample concentration (of NO\(_3\)-N in mgL\(^{-1}\))
- \( E_1 \) = absorbance of sample with reagent
- \( E_0 \) = absorbance of sample without reductant
- \( E_{B1} \) = absorbance of distilled water + reagent

### 3.2.2.2 Total Phosphorus (TP)

Total phosphorus was measured using the Persulfate digestion method (APHA, 2000). A 100 ml of mixed reagent was added to a flask with 100 ml of sample. Simultaneously, 10 ml of mixed reagent without reductant was added to another flask with 100 ml of sample and the sample thoroughly mixed. After 1.5 hours, extinction coefficient of the solution was measured at a wavelength of 885 nm in a spectrophotometer (Pharmacia Biotech model, 65455). The absorbance of the reagent and distilled water blank was also measured. The total phosphorus content of the sample was calculated as follows:

\[ \text{TP in } \mu \text{g/L} = F (E_1 \text{ sample} - (E_0 + E_{B1})) \]

where: 

- \( F \) = Sample concentration (of PO\(_4\)-P in \( \mu \)gL\(^{-1}\))
- \( E_0 \) = absorbance of sample without reductant
- \( E_1 \) = absorbance of sample with reductant
- \( E_{B1} \) = absorbance of distilled water + reagent
3.2.3 Macroinvertebrates.

Macroinvertebrates were sampled using a scoop-net of 0.5 mm mesh size with a 0.4 m diameter opening on a monthly basis for a period of six months from December 2006 to May 2007. Triplicate random samples of macroinvertebrates in each of the riffles, pools and runs were taken from each station. During sampling in the littoral areas, three standard sweeps from around the sediments along the plant stems to the water surface in a one-square metre were made for two minutes at each locality. The net was moved back and fourth and to and fro during these eps. For benthic macroinvertebrates, kick sampling was used to ensure the dislodgement of attached organisms from the substrate into the scoop-net. Macroinvertebrate samples were sorted live in a white plastic tray and placed into vials and preserved with 70% ethanol after which they were transported to the laboratory for further sorting, counting and identification that was done using identification keys (Quigley, 1977; Merritt & Cummins, 1997; IFM, 2006). All the specimens were identified to genera levels. The samples were further analyzed for composition, abundance and diversity and related to nutrient levels in both rivers. The data obtained from macroinvertebrates was ranked using the Shannon-Wiener Index:

\[ D = -\sum p_i \ln p_i; \]

where \( D \) = Shannon-Wiener diversity of macroinvertebrates

\( S = \) Sum

\( \ln = \) Natural logarithm

\( p_i = \) Proportion of the ith species (Roy et al., 2001).

Values of Shannon-Wiener closer to 4.5 indicate high diversity.

Relative abundance (R.A.) was calculated as the proportionate percentage (by numbers) of each taxon in a sample. The relative abundance was calculated according
to Roy et al. (2001) as:

\[ R.A = \frac{n * 100}{N} \ ( = p_i \times 100); \]

where \( n \) = Number of individuals of one taxon

\( N= \) Total number of individuals in a station

\( p_i = \) Proportion of the ith species

\( 100 = \) Percentage conversion

The EPT index for each station was calculated as (Taylor & Francis, 2005):

\[ \text{EPT index} = \frac{\text{Abundance of all EPT genera} \times 100}{\text{Total composition per station}} \]

where \( 100 = \) Percentage conversion

EPT = Ephemeroptera, Plecoptera and Trichoptera group.

### 3.3 MacoInvertebrate IBI.

#### 3.3.1 Reference Station Identification.

Reference station was defined as an area with minimal anthropogenic disturbance, based on thresholds established in this study for water chemistry, physical habitat, and land use within the catchment upstream of sampled stations (Robert & Rankin, 1998). In this case, the station at the source of River Kipkaren was selected as the reference station. However, completely undisturbed stations are virtually nonexistent and even remote waters are impacted by factors such as atmospheric pollution and presence of households (Mason, 2002). This study utilized the best values observed in this study to set the baselines of expectation for each metric attribute (Karr & Chu, 1997) and hence delineate degraded stations from nondegraded ones basing on the data from water chemistry and physical characteristics observed at each station. To validate this approach, a classification of stations was further developed after sampling on nutrient levels, DO and conductivity data using the Multivariate analysis of variance.
(MANOVA) at p<0.05 to show significant differences of macroinvertebrate assemblages.

3.3.2 Compiling Candidate Metrics.

A metric in this context, is defined as an attribute with empirical change in value basing on one's study, along a gradient of human disturbance or environmental condition change (Mason, 2002). In this study, various metrics were selected that acted as indicator attributes in assessing the status of macroinvertebrate assemblages in response to perturbation in the study area. The metrics that were considered for this study were obtained from literature in relation to data obtained from this study on occurrence of genera in the stations.

Taxa richness refers to the total number of species at a specific station in a stream. This is the simplest way to measure the macroinvertebrate diversity at a station in a stream. The orders sensitive to organic pollution of Ephemeroptera, Plecoptera and Trichoptera (EPT) were used (Hermann, 1991; Karr & Chu, 1997). The numbers of genera belonging to the EPT were evaluated in relation to each station. These measures have been identified as an effective metric for use with macroinvertebrates studies, with the purpose of IBI development (Robert & Rankin, 1998).

Composition attributes involved relative abundance and dominance to provide information on the make-up of the assemblage by assessing relative contribution of the macroinvertebrates to the total fauna (Roy et al., 2001). According to Griffith et al. (2005), it is assumed that there are changing patterns of dominance associated with pollution, the few dominant genera contributing with a larger proportion out of the total at the polluted station. In this respect the percentage 5 dominant genera in every
order is commonly used as a measure of dominance and evenness. Genera percentage composition measures as metrics tested here included those of % Ephemeroptera, % Plecoptera, % Trichoptera, % Diptera, % Mollusca, % Oligochaeta, % Odonata, % Hemiptera and the ratio of % EPT to % Diptera. As an order, Diptera is considered to be pollution-insensitive taxa while the EPT group is said to be pollution intolerant since they can not withstand the stress caused by pollution (Merritt & Cummins, 1997). High numbers of EPT relative to Diptera at a station will, therefore, indicate better water quality with regard to extreme nutrient levels and vice versa (Harding et al., 1998).

Taxa tolerance attributes were intended to be representative of sensitivity to perturbation and included numbers of pollution tolerant and intolerant genera or percentage composition of macroinvertebrates (Karl et al., 2003). Only those species that were considered as tolerant or intolerant by consensus of most researchers were designated as tolerant and intolerant in this study (Merritt & Cummins, 1997; Karr & Chu, 1997), although there is still a huge debate on the taxa tolerance of macroinvertebrates to pollution. Taxa that were considered intolerant to perturbation include genera from the orders of Ephemeroptera, Plecoptera and Trichoptera (EPT group). Those considered tolerant included most genera belonging to orders Diptera, Oligochaeta and Hirudinea. This was evident in the study area as the two groups (tolerant and intolerant) appeared in large numbers at degraded stations. The metrics under the “tolerant attributes” included, % tolerant taxa, and % 5 dominant taxa in each station. Intolerant species disappear in early stages of degradation due to high suspended solids, increased nutrient levels, and decreased dissolved oxygen (Griffith et al., 2005).
Trophic function encompasses functional feeding groups and provides information on the balance of feeding strategies in macroinvertebrate assemblages (Karr & Chu, 1997). According to Rankin & Robert (1998), pollution of, for example, increased nutrient levels may influence occurrence per station and relative abundance of these groups by altering the availability of various food types or the action of various toxins associated with food types. These functional feeding groups are surrogates of complex processes such as trophic interaction, production, and food resource availability (Karr & Chu, 1997). Trophic measures as metrics considered included percentage filterers, predators, gatherers and shredders. Table 1 shows the full list of candidate metrics that fell into four groups of taxa richness, composition attributes, taxa tolerance and trophic function.

Table 1: Macroinvertebrates metrics considered for assessing index of biotic integrity.

<table>
<thead>
<tr>
<th>Taxa richness</th>
<th>Composition Attributes</th>
<th>Taxa Tolerance</th>
<th>Trophic Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Ephemeroptera taxa</td>
<td>% Diptera</td>
<td>% Tolerant taxa</td>
<td>% Filterers</td>
</tr>
<tr>
<td>No. Plecoptera taxa</td>
<td>% EPT; % Diptera</td>
<td>% 5 Dominant taxa</td>
<td>% Predators</td>
</tr>
<tr>
<td>No. Trichoptera taxa</td>
<td>% Mollusca</td>
<td>-</td>
<td>% Gatherers</td>
</tr>
<tr>
<td>-</td>
<td>% Hemiptera</td>
<td>-</td>
<td>% Shredders</td>
</tr>
<tr>
<td>-</td>
<td>% Odonata</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>% Oligochaeta</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

3.3.3 Testing Candidate Metrics.

Statistics tests of Mann-Whitney U test and Kolmogorov-Smirnov test were used to eliminate the macroinvertebrate metrics that did not show significant differences at p<0.05 that involved pair wise comparison in all the stations. The 9 metrics out of 15 tested, showed significant differences and were used in subsequent analyses. Metrics
at degraded stations were then compared to the reference station (Barbour et al., 1999) in the scoring criteria.

3.3.4 Scoring Criteria.

During the comparison, the IBI approach involved scoring each metric as 5, 3 or 1, depending on whether each value at a station approximates, deviates slightly from, or deviates greatly from conditions at the best reference station (Karr & Chu, 1997; Barbour et al., 1999). The trisection criterion was based on Karl et al., (2003). Here, threshold values for each selected metric were established as approximately the 20th and 50th percentile (median) to the reference station. For each metric expected to decrease with degradation and nutrient levels, values below the 20th percentile were scored as 1, as they showed greatest deviation from the reference station. Values between the 20th and 50th percentiles were scored as 3, as they fell short of median expected values for the reference station. Values above the 50th percentile were scored as 5. Scoring was reversed for metrics expected to increase with degradation and nutrient levels (e.g., values below the 50th percentile were scored as 5, values above the 80th percentile were scored as 1).

To arrive at the final IBI value for each station, scores for each metric were summed. The highest expected value of 45 points served as a benchmark for ranges for qualitative assessments of the final IBI scores that was done according to Barbour et al. (1999) and Griffith et al. (2005), but modified to suit local conditions. The ranges used to classify the stations in this study were as follows (Table 2):
Table 2: Integrity classes for final IBI development.

<table>
<thead>
<tr>
<th>Class of integrity</th>
<th>Ranges for IBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>36-45</td>
</tr>
<tr>
<td>Good</td>
<td>28-35</td>
</tr>
<tr>
<td>Fair</td>
<td>21-27</td>
</tr>
<tr>
<td>Poor</td>
<td>12-20</td>
</tr>
<tr>
<td>Very poor</td>
<td>&lt;12</td>
</tr>
</tbody>
</table>

3.4 Data Analyses.

The data obtained was analyzed statistically using the Statistical Package for Social Sciences (SPSS for Windows version 10.0) and Microsoft Excel packages. Descriptive analysis of mean, median, Percentage and Standard Error of the mean for water quality, genera abundance and diversity, nutrient levels in stations and for sampling dates were carried out. For determining spatial and temporal variations for nutrients and other selected water quality parameters, ANOVA test was used. Kruska Wallis ANOVA was used to determine the significant differences for macroinvertebrate abundance and diversity between stations. Spearman`s rank correlation was used to determine significant differences for the relationship of macroinvertebrate abundance and diversity to nutrient levels (log-transformed) and in the hypotheses testing at $p = 0.05$. Multivariate analysis of variance (MANOVA; at $p = 0.05$) was used to show statistically different macroinvertebrate assemblages in sampled stations. The Mann-Whitney U test and Kolmogorov-Smirnov test were used for eliminating the metrics with no significant differences after pair wise (subset) comparison in all the 7 stations, before arriving at the final IBI.
CHAPTER 4

4.0 RESULTS

This chapter presents the results for macroinvertebrates abundance and diversity, selected physico-chemical parameters, nutrients, the relationship between macroinvertebrates abundance and diversity with nutrient and the IBI scores per station over the six months study period.

4.1 Macroinvertebrates Abundance and Diversity.

4.1.1 Macroinvertebrates Composition and Abundance.

Three phyla of stream macroinvertebrates were found in 7 study stations (Table 3 & 4). They were Arthropoda, Mollusca and Annelida. Arthropoda was the richest phylum consisting of class Insecta that had seven orders (Ephemeroptera, Diptera, Coleoptera, Trichoptera, Plecoptera, Odonata and Hemiptera) and Crustacea that had the order Isopoda. The phylum Mollusca had the class Gastropoda consisting of orders of Pulmonata, Prosobranchiata and Bivalvia. The phylum Annelida had the class Clitellata that had Oligochaeta and Hirudinea as its orders. A total of 1499 macroinvertebrates belonging to 13 orders, 28 families and 31 genera were sampled. The orders Ephemeroptera, Hemiptera and Coleoptera were the most diverse taxa, consisting of four families each. The order Coleoptera had 5 genera, hence the most diverse in the study stations.
Table 3: List of macroinvertebrates sampled in Rivers Kipkaren and Sosiani during the study period.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
<th>R. Kipkaren</th>
<th>R. Sosiani</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ephemeroptera</td>
<td>Baetidae</td>
<td>Baetis sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Caenidae</td>
<td>Caenis sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Heptagenidae</td>
<td>Heptagenia sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ephemerecellidae</td>
<td>Ephemeralis sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hemiptera</td>
<td>Gerridae</td>
<td>Gerris sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Notonectidae</td>
<td>Notonecta sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Velidae</td>
<td>Velia sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Corixidae</td>
<td>Corixa sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Nepididae</td>
<td>Nepus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Belostomatidae</td>
<td>Belostoma sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>Dryopidae</td>
<td>Derenectes sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Elmidae</td>
<td>Elmis sp., Limnius sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Gyrinidae</td>
<td>Gyrinus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Hydraenidae</td>
<td>Hydraena sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Diptera</td>
<td>Chironomidae</td>
<td>Chironomus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Culicidae</td>
<td>Culicida sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Prosoconchialat</td>
<td>Valvatidae</td>
<td>Valvata sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Hydrobididae</td>
<td>Bithynia sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Odonata</td>
<td>Aeschenidae</td>
<td>Aeschenia sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Gomphiidae</td>
<td>Gomphus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Agridae</td>
<td>Agrion sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>Lumbriculidae</td>
<td>Lumbricus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Tubificidae</td>
<td>Tubifex sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Plecoptera</td>
<td>Nemouridae</td>
<td>Nemoura sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Leuctridae</td>
<td>Leuctra sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Bivalvia</td>
<td>Unionidae</td>
<td>Pisidium sp., Sphaeri um sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Bithynidae</td>
<td>Gabriella sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Isopoda</td>
<td>Asellidae</td>
<td>Asellus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pulmonata</td>
<td>Lymnaidae</td>
<td>Lymnaea sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Polycerapididae</td>
<td>Polycercopus sp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hirudinea</td>
<td>Erpobelliidae</td>
<td>Erpobellia sp., Glossiphonia sp.</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**Baetis** sp. was dominant in stations S1 and S2 with a relative mean abundance of 29.10 ± 0.21 and 27.78 ± 0.95 respectively, while **Chironomus** sp. had the lowest relative mean abundance value of 0.33 ± 0.01 (Table 4a). Station S3 experienced a high relative mean abundance of **Caenis** sp. (23.12 ± 0.63) and lowest mean relative abundance of **Pisidium** sp. (0.86 ± 0.02). **Lumbricus** sp. recorded the highest relative mean abundance of 19.34 ± 0.09 and 26.73 ± 0.96 in station S4 and S5 respectively.
(Table 4b). In the same stations, *Heptagenia* sp. and *Elmis* sp. were the least dominant with relative mean abundances of 0.56 ± 0.05 and 0.87 ± 0.03 respectively. Station S7 was dominated by *Chironomus* sp. with a mean relative abundance of 26.1 ± 0.12 whereas *Heptagenia* sp., had the lowest mean abundance of 0.74 ± 0.31. *Tubifex* sp., with a relative mean abundance of 27.56 ± 0.07 dominated station S6 and *Elmis* sp. had the lowest mean abundance (0.74 ± 0.01).
Table 4a: Mean (±SEM) macroinvertebrate abundance in different sampling stations in River Kipkaren during the study period.

<table>
<thead>
<tr>
<th>Genus</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S6</th>
<th>S7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baetis sp.</td>
<td>29.10±0.21</td>
<td>27.78±0.95</td>
<td>14.23±0.51</td>
<td>8.61±1.31</td>
<td>8.58±0.75</td>
</tr>
<tr>
<td>Caenis sp.</td>
<td>16.33±1.21</td>
<td>24.02±0.77</td>
<td>23.12±0.63</td>
<td>___</td>
<td>3.03±0.13</td>
</tr>
<tr>
<td>Ephemera sp.</td>
<td>5.21±0.38</td>
<td>11.34±0.93</td>
<td>4.11±0.33</td>
<td>1.32±0.61</td>
<td>2.82±0.34</td>
</tr>
<tr>
<td>Heptagenia sp.</td>
<td>___</td>
<td>___</td>
<td>12.35±0.09</td>
<td>0.78±0.02</td>
<td>0.74±0.31</td>
</tr>
<tr>
<td>Agrion sp.</td>
<td>___</td>
<td>___</td>
<td>1.83±0.74</td>
<td>___</td>
<td>2.52±0.23</td>
</tr>
<tr>
<td>Nepus sp.</td>
<td>5.21±0.03</td>
<td>6.60±0.09</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Belostoma sp.</td>
<td>___</td>
<td>4.34±0.01</td>
<td>___</td>
<td>___</td>
<td>4.74±1.21</td>
</tr>
<tr>
<td>Gabbelia sp.</td>
<td>0.94±0.40</td>
<td>1.03±0.13</td>
<td>4.78±0.67</td>
<td>3.3±0.98</td>
<td>4.34±0.97</td>
</tr>
<tr>
<td>Glossiphonia sp.</td>
<td>1.23±0.10</td>
<td>0.87±0.08</td>
<td>___</td>
<td>3.51±0.45</td>
<td>___</td>
</tr>
<tr>
<td>Notonecta sp.</td>
<td>3.11±0.042</td>
<td>2.23±0.012</td>
<td>3.35±0.06</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Valvata sp.</td>
<td>2.97±0.07</td>
<td>3.26±0.036</td>
<td>5.61±0.031</td>
<td>0.94±0.023</td>
<td>1.21±0.02</td>
</tr>
<tr>
<td>Velia sp.</td>
<td>4.12±0.02</td>
<td>___</td>
<td>0.97±0.1</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Dysticida sp.</td>
<td>2.91±0.02</td>
<td>___</td>
<td>2.84±0.145</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Elmis sp.</td>
<td>18.56±0.11</td>
<td>2.15±0.04</td>
<td>9.32±0.81</td>
<td>0.74±0.01</td>
<td>1.83±0.03</td>
</tr>
<tr>
<td>Limnus sp.</td>
<td>___</td>
<td>4.31±0.03</td>
<td>5.32±0.31</td>
<td>0.83±0.12</td>
<td>2.56±0.14</td>
</tr>
<tr>
<td>Gyrinus sp.</td>
<td>3.34±0.02</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Hydraena sp.</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>2.43±0.91</td>
<td>___</td>
</tr>
<tr>
<td>Chironomus sp.</td>
<td>0.33±0.01</td>
<td>0.45±0.045</td>
<td>1.02±0.76</td>
<td>10.7±0.23</td>
<td>26.09±0.12</td>
</tr>
<tr>
<td>Culicida sp.</td>
<td>0.77±0.31</td>
<td>0.64±0.02</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Aeshenia sp.</td>
<td>2.35±0.98</td>
<td>5.1±0.03</td>
<td>2.69±0.75</td>
<td>1.01±0.02</td>
<td>___</td>
</tr>
<tr>
<td>Gomphus sp.</td>
<td>___</td>
<td>0.56±0.04</td>
<td>___</td>
<td>3.23±0.91</td>
<td>1.32±0.05</td>
</tr>
<tr>
<td>Lumbricus sp.</td>
<td>0.45±0.02</td>
<td>0.76±0.03</td>
<td>1.35±0.08</td>
<td>15.7±0.92</td>
<td>20.43±0.05</td>
</tr>
<tr>
<td>Tubifex sp.</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>27.56±0.07</td>
<td>6.13±0.04</td>
</tr>
<tr>
<td>Nemura sp.</td>
<td>1.91±0.06</td>
<td>2.65±0.03</td>
<td>4.58±0.118</td>
<td>0.977±0.02</td>
<td>___</td>
</tr>
<tr>
<td>Leuctra sp.</td>
<td>1.21±0.02</td>
<td>1.78±0.92</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Pisidium sp.</td>
<td>0.45±0.08</td>
<td>0.63±0.043</td>
<td>0.86±0.02</td>
<td>3.01±0.03</td>
<td>2.002±0.01</td>
</tr>
<tr>
<td>Sphaerium sp.</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>1.42±0.02</td>
<td>___</td>
</tr>
<tr>
<td>Asellus sp.</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>3.17±0.17</td>
<td>___</td>
</tr>
<tr>
<td>Limnaea sp.</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Polycentropus sp.</td>
<td>0.95±0.02</td>
<td>0.28±0.056</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Erpobdella sp.</td>
<td>0.76±0.07</td>
<td>1.36±0.23</td>
<td>9.11±4.34</td>
<td>10.12±0.30</td>
<td>___</td>
</tr>
</tbody>
</table>
Table 4b: Mean (±SEM) macroinvertebrate abundance in different sampling stations in River Sosiani during the study period.

<table>
<thead>
<tr>
<th>Genus</th>
<th>S4</th>
<th>S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baeotis sp.</td>
<td>3.23±1.11</td>
<td>4.31±1.20</td>
</tr>
<tr>
<td>Heptagenia sp.</td>
<td>0.98±0.13</td>
<td>0.87±0.032</td>
</tr>
<tr>
<td>Agrion sp.</td>
<td>2.11±0.113</td>
<td>______</td>
</tr>
<tr>
<td>Gabbiella sp.</td>
<td>1.27±0.43</td>
<td>______</td>
</tr>
<tr>
<td>Elmis sp.</td>
<td>0.56±0.05</td>
<td>2.73±0.021</td>
</tr>
<tr>
<td>Hydraena sp.</td>
<td>3.24±0.06</td>
<td>1.36±0.31</td>
</tr>
<tr>
<td>Chironomus sp.</td>
<td>15.11±0.18</td>
<td>15.43±0.45</td>
</tr>
<tr>
<td>Culicida sp.</td>
<td>6.51±0.43</td>
<td>9.34±0.132</td>
</tr>
<tr>
<td>Aeshenia sp.</td>
<td>______</td>
<td>8.46±0.11</td>
</tr>
<tr>
<td>Gomphus sp.</td>
<td>3.33±0.45</td>
<td>______</td>
</tr>
<tr>
<td>Lumbricus sp.</td>
<td>19.34±0.09</td>
<td>26.73±0.961</td>
</tr>
<tr>
<td>Tubifex sp.</td>
<td>4.48±0.001</td>
<td>9.02±0.010</td>
</tr>
<tr>
<td>Leuctra sp.</td>
<td>______</td>
<td>0.94±0.06</td>
</tr>
<tr>
<td>Pseudium sp.</td>
<td>6.98±0.07</td>
<td>______</td>
</tr>
<tr>
<td>Sphaerius sp.</td>
<td>______</td>
<td>7.64±0.12</td>
</tr>
<tr>
<td>Asellus sp.</td>
<td>6.89±2.64</td>
<td>4.21±0.23</td>
</tr>
<tr>
<td>Limmatae sp.</td>
<td>11.29±0.71</td>
<td>9.78±1.57</td>
</tr>
<tr>
<td>Polycentropus sp.</td>
<td>______</td>
<td>1.97±0.02</td>
</tr>
<tr>
<td>Erpobdella sp.</td>
<td>15.45±0.45</td>
<td>8.40±0.89</td>
</tr>
</tbody>
</table>

The order Diptera were the most abundant macroinvertebrates in River Sosiani (35%) while the intolerant group of Ephemeroptera, Plecoptera and Trichoptera (EPT) decreased downstream in River Kipkaren (Fig. 3).
Fig. 3: Relative abundance of macroinvertebrate groups in Rivers Sosiani and Kipkaren during the study period.

The macroinvertebrate abundance in the stations of River Sosiani (S4 and S5) was high as compared to River Kipkaren stations (Table 5). The mean value of tolerant macroinvertebrate taxa was significantly different from intolerant taxa \( (F = 23.4; \text{df} = 1; p = 0.00) \) in the stations sampled. The mean number of macroinvertebrates differed significantly \( (F= 16.31; p = 0.00) \) among the stations, with station S4 recording the highest mean number \( (17.5 \pm 1.30) \) and stations S3, the lowest \( (7.03 \pm 0.70) \).
Table 5: Mean (± SEM) abundance of macroinvertebrates the sampling stations during the study period. The significant different is at P < 0.05.

<table>
<thead>
<tr>
<th>Station</th>
<th>Mean ± SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>8.7± 0.72</td>
<td>0.002</td>
</tr>
<tr>
<td>S2</td>
<td>10.6± 0.90</td>
<td>0.002</td>
</tr>
<tr>
<td>S3</td>
<td>7.03± 0.70</td>
<td>0.002</td>
</tr>
<tr>
<td>S4</td>
<td>17.5± 1.30</td>
<td>0.020</td>
</tr>
<tr>
<td>S5</td>
<td>12.3± 0.72</td>
<td>0.010</td>
</tr>
<tr>
<td>S6</td>
<td>7.84± 0.50</td>
<td>0.002</td>
</tr>
<tr>
<td>S7</td>
<td>10.91 ± 0.90</td>
<td>0.010</td>
</tr>
</tbody>
</table>

4.1.2 Macroinvertebrate Diversity.

Kruska Wallis ANOVA showed significant differences in Shannon-Wiener mean diversity index of macroinvertebrate genera recorded among the stations (H=7; p=0.00). Station S1 had the highest Shannon-Wiener diversity (3.08±0.90), followed by station S2 (3.02± 1.21), whereas, stations S7 and S6 had the lowest diversity of 2.9±0.90 and 2.94± 0.80 respectively. The species diversity was higher at station S5 (2.88± 0.96) than at station S4 (2.85± 0.91). The highest diversity was recorded in the month of May (3.02±1.10) and the lowest in the month of December (2.88±1.0). The taxa richness in River Kipkaren were higher (31 genera) as compared to those of River Sosiani (19 genera).
4.2 Physico-Chemical Parameters.

The highest temperature was recorded at station S2 with a mean of 22.2 ± 0°C while the lowest was recorded at station S3 with a mean of 19.8 ± 0°C. There was no significant difference between the stations and sampling dates. The lowest mean pH value of 6.8 ± 0.5 was recorded at station S3, whereas, the highest mean pH value was recorded at station S4 (7.1 ± 0.3). As noticed with temperature, there was no significant difference in pH between sampling stations and sampling dates. The highest mean conductivity of 121.8 ± 8 μScm⁻¹ was recorded at station S4 with the lowest recorded at station S1 (101± 4 μScm⁻¹). Whereas no difference was noted both spatially and temporally in temperature and pH, conductivity was significantly different between stations (F = 16.8; p<0.05) but not between the sampling dates.

The mean dissolved oxygen was significantly different among the stations (F = 3.6; p<0.05) with the highest mean observed at station S2 (7.6 ± 0.02 mgL⁻¹) and the lowest was recorded at station S4 (4.0 ± 0.01mgL⁻¹). Dissolved oxygen however, did not vary with time. The highest mean velocity was recorded at station S3 (1.58 ± 0.01ms⁻¹) and lowest at station S5 (0.01 ± 0 ms⁻¹). However, no significant differences were detected between stations and sampling dates. The highest mean discharge was recorded at station S3 (0.97 ± 0 m³s⁻¹) and lowest mean value at station S1 (0.001 ± 0 m³s⁻¹). No significant differences in discharge occurred between stations and sampling dates.

4.3 Nutrients.

The stations in River Sosiani (S4 and S5) recorded the highest TN and TP concentrations compared to River Kipkaren stations (Fig. 4). The amount of total phosphorus (TP) did
not differ spatially or temporally during the study. However, station S4 in River Sosiani recorded the highest TP of 0.54 ± 0.23 µgL⁻¹ while the lowest TP value of 0.05± 0.02 µgL⁻¹ was recorded at station S1 of River Kipkaren. Unlike TP, the total nitrogen (TN) significantly varied among the stations (F = 629.52; df = 6; p = 0.00) but not temporally. The highest TN of 0.72 ± 0.03 mgL⁻¹ was recorded at station S4 and the lowest at station S1 (0.07± 0.04 mgL⁻¹).

![Bar chart showing concentrations of TP and TN at different stations]

**Fig. 4:** Mean (± SEM) of TP and TN at the Sampling Stations in (a) River Kipkaren for S1, S2, S3, S6 & S7 and (b) River Sosiani for S4 & S5 during the study period.

### 4.4 Relationship between Macroinvertebrates Abundance and Diversity and Nutrients.

Figure 5 shows the values and the Spearman’s correlations respectively, indicating the strength of the relationships between macroinvertebrates Shannon-Wiener diversity, respectively, and nutrients. Station S2 had a significant correlation between macroinvertebrate Shannon-Wiener diversity, respectively, with TP and TN concentrations (r =0.49± 0.57). Whereas, station S4 in River Sosiani had the highest value (r = 0.95 ± 0.01). The overall correlation value for all the sampling stations was r =
0.39. All the stations indicated significant differences (p = 0.00) between macroinvertebrate Shannon-Wiener diversity and TP and TN concentrations as error bars at some stations did not overlap with others. Stations with the highest Shannon-Wiener diversity of macroinvertebrates recorded the lowest values of TP and TN concentrations. With a Shannon-Wiener value of 3.08±0.8, the source of River Kipkaren had 0.046 ± 0.02 μgL⁻¹ and 0.073 ± 0.01 mgL⁻¹ for TP and TN respectively. Station S4 that recorded the highest TP of 0.544 ± 0.2 μgL⁻¹ and TN of 0.72 ± 0.03 mgL⁻¹ had the lowest Shannon-Wiener diversity of 2.85 ± 0.97. Whereas, stations with increased abundance of macroinvertebrates recorded increased levels of nutrients. Two-way ANOVA showed significant differences between log-tranformed mean abundance per station and TP (F = 2.6; p = 0.00) and between log-transformed mean abundance per station and TN (F = 3.9; p = 0.00).

![Graph showing WQZ and R value for different stations.](image)

**Fig. 5:** The strength of the relationship of Spearman’s correlations of macroinvertebrates occurrence with TP & TN (log-transformed) during the study period.
4.5 Macroinvertebrate Index of Biotic Integrity.

The reference station and the degraded stations showed significantly different (p<0.05) occurring macroinvertebrate taxa assemblages in the 9 metrics out of the total 15 macroinvertebrate metrics tested (Table 6). Poor performers were % Oligochaeta, % Hemiptera, % Odonata, % 5 dominant taxa, % shredders and % filterers.

Table 6: Results of Mann-Whitney U and Kolmogorov-Smirnov tests for the value in 7 stations after pair wise comparisons (+ indicates p<0.05).

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Mann-Whitney, p value</th>
<th>Kolmogorov-Smirnov, p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxa richness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. Ephemeroptera taxa</td>
<td>&lt;0.01 +</td>
<td>0.001 +</td>
</tr>
<tr>
<td>No. Plecoptera taxa</td>
<td>0.001 +</td>
<td>0.01 +</td>
</tr>
<tr>
<td>No. Trichoptera taxa</td>
<td>&lt;0.01 +</td>
<td>0.02 +</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Diptera</td>
<td>0.025 +</td>
<td>0.025 +</td>
</tr>
<tr>
<td>% EPT: Diptera</td>
<td>0.01 +</td>
<td>0.01 +</td>
</tr>
<tr>
<td>% Oligochaeta</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>% Mollusca</td>
<td>&lt;0.001 +</td>
<td>&lt;0.001 +</td>
</tr>
<tr>
<td>% Hemiptera</td>
<td>0.23</td>
<td>0.35</td>
</tr>
<tr>
<td>% Odonata</td>
<td>0.42</td>
<td>0.25</td>
</tr>
<tr>
<td>Tolerance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Tolerant taxa</td>
<td>0.01 +</td>
<td>0.02 +</td>
</tr>
<tr>
<td>% Dominant taxon</td>
<td>0.02 +</td>
<td>0.01 +</td>
</tr>
<tr>
<td>% 5 Dominant taxa</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td>Trophic function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Filterers</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>% Gatherers</td>
<td>&lt;0.001 +</td>
<td>&lt;0.001 +</td>
</tr>
<tr>
<td>% Predators</td>
<td>0.01 +</td>
<td>0.01 +</td>
</tr>
<tr>
<td>% Shredders</td>
<td>0.20</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Station S2 on River Kipkaren emerged with the highest overall Macroinvertebrate IBI (37 points), whereas station S4 recorded the lowest IBI (19 points), hence the significance differences in IBI among the stations (Table 7).
### Table 7: IBI score metrics for individual stations in the study area.

<table>
<thead>
<tr>
<th>Metrics for IBI</th>
<th>Stations</th>
<th>Scoring criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1  S2  S3  S4  S5  S6  S7</td>
<td>5   3  1</td>
</tr>
<tr>
<td>No. Ephemeroptera taxa</td>
<td>5  5  3  1  1  3  1</td>
<td>18-11 11-6 &lt;6</td>
</tr>
<tr>
<td>No. Plecoptera taxa</td>
<td>5  5  3  1  1  5  3</td>
<td>10-6  6-3 &lt;3</td>
</tr>
<tr>
<td>No. Trichoptera taxa</td>
<td>5  5  3  3  5  5  3</td>
<td>6-4  4-2 2-1</td>
</tr>
<tr>
<td>% Diptera</td>
<td>5  3  3  1  1  3  1</td>
<td>&lt;4.6 4.6-8.8 &gt;8.8</td>
</tr>
<tr>
<td>% EPT: Diptera</td>
<td>5  3  3  1  3  3  3</td>
<td>&gt;3.8 1.6-3.8 &lt;1.6</td>
</tr>
<tr>
<td>% Mollusca</td>
<td>3  3  3  3  3  3  3</td>
<td>&lt;5  5-10 &gt;10</td>
</tr>
<tr>
<td>% Tolerant taxa</td>
<td>5  5  5  1  1  3  3</td>
<td>&lt;35 35-42 &gt;42</td>
</tr>
<tr>
<td>% Gatherers</td>
<td>3  5  5  3  5  5  5</td>
<td>&gt;30 15-30 &lt;15</td>
</tr>
<tr>
<td>% Predators</td>
<td>3  3  5  5  5  5  5</td>
<td>&gt;10 6-10 &lt;6</td>
</tr>
<tr>
<td><strong>Total IBI Score</strong></td>
<td><strong>39</strong>  <strong>37</strong>  <strong>33</strong>  <strong>19</strong>  <strong>22</strong>  <strong>35</strong>  <strong>27</strong></td>
<td></td>
</tr>
</tbody>
</table>
 CHAPTER 5

5.0 DISCUSSION

5.1 Macroinvertebrates Composition, Abundance and Diversity.

5.1.1 Macroinvertebrates Composition and Abundance.

Macroinvertebrates in sampling stations were composed of insect orders of Ephemeroptera, Diptera, Coleoptera, Trichoptera, Plecoptera, Odonata, Hemiptera and other non-insect orders of Isopoda, Oligochaeta, Pulmonata, Prosobranchiata, Bivalvia and Hirudinea (Table 3 & 4). High altitude low order streams have been shown to be dominated by such orders and other similarly adapted species (Williams and Feltmate, 1992). The taxa composition of rivers is compared by two authors in which Heptageniidae, Baetidae, Erpobdellidae, Elmidae, Tubifidae, Lumbriculidae, that were also observed in this study, are shown to dominate and occur consistently in the tropical regions (Merritt & Cummins, 1997).

Generally, according to this investigation, lower River Sosiani had a total of 19 genera, while River Kipkaren had a total of 31 genera. This could be due to seasonal variation in the community structure of macroinvertebrates due to local land use rather than climatic conditions because both rivers belong in the same River Nzoia Basin. In another study in the same catchment, Matha (1995) identified 22 genera from River Sosiani and Micheni (1996) identified 20 genera from Sergoik River. The low abundance and composition of macroinvertebrates in Rivers Sosiani and Sergoik could be attributed to part of their catchment areas within the highly populated and comparatively industrially developed Eldoret Municipality. This is because pollution inflows have been shown to reduce
stream macroinvertebrate diversity (Welch, 1992). River Kipkaren has most of its catchment area covered with vegetation and less of agricultural practice at its riparian zones. This may however change as this vegetation that probably traps any terrestrial effluents into the river, is being cleared currently to pave way for human settlement.

Macroinvertebrate orders of Diptera, Oligochaeta, Hirudinea and Odonata dominated the lower Sosiani River stations in high abundance as compared to the orders of Ephemeroptera, Plecoptera, Hemiptera and Trichoptera that dominated River Kipkaren stations (Table 4). In addition, the total EPT group comprised only 19% in the lower River Sosiani (Fig. 3) which probably emphasizes their limited chances of survival in such areas. The relative abundance of this intolerant group in both rivers was believed to be influenced by allochthonous material and availability of food for consumption that may be triggered by nutrient enrichment. Tolerant species like Chironomus sp., Tubifex sp. and Lumbricus sp. dominated stations S4, S5, S6 and S7 probably because these animals have got high glycogen content and reduced activity which allows them to withstand increased conductivity levels in the macrohabitats (Welch, 1992) that could have been caused by discharges due to urbanization in areas. Chironomids were highly abundant in such areas probably because of high haemoglobin content in their blood (Welch, 1992). The general decline in abundance of intolerant taxa downstream in Rivers Sosiani and Kipkaren was evident indicated probably by DO, conductivity and nutrient levels, which according to Hawkers (1979), determine the occurrence of macroinvertebrate taxa. Hawkers Op cit further states that temperature and turbulence have been found to affect abundance of benthic macroinvertebrates. Nevertheless, as
predicted by Hawkers Op cit, the short rains that were experienced throughout the study period could have been the cause of no significant differences in the temperature and turbulence levels overtime and between the sampled stations, among other physical parameters of pH and water volume.

There were no significant differences in the total macroinvertebrate mean abundance among the sampling dates. The significant differences among the mean abundance of macroinvertebrates in the sampled stations could have caused by changes in human activities that included urbanization, agriculture, sewage discharge and afforestation along both rivers. This is in line with Margolis et al., (2001) who claims that changes in the benthic macroinvertebrate assemblages are not determined by changes in the type and availability of food but differences in the ability of resident genera to tolerate the environment around it. Urbanization of a watershed may significantly alter stream water quality even in the absence of direct industrial or municipal discharges (Kari et al., 1993). Station S4 had the highest mean value of macroinvertebrate occurrence evidenced by the high abundances of tolerant taxa (of Oligochaeta and some Diptera genera like Chironomidae) to the discharges and sewage from the Eldoret (Huruma) Municipality (Table 5). The presence of Kipkaren Town that experiences an amalgamation of activities such as farming, agro-forestry, and poor dumping of refuse could be the cause for increased levels of mainly organic matter, TN and TP in the river-water. River Kipkaren before and after the confluence, at the source and the station near the Eldoret Airport were dominated by intolerant species of the EPT group. This could be due to low pollution levels of organic matter or the dilution effect of water due to increased water
volume in such areas. However, contrary to Barbour et al. (1999), tolerant macroinvertebrates could be more of *Baetis* sp., which occurred in low abundances in such areas.

The organic farming at the River Kipkaren Training Institute may be a contribution to the low levels of pollution as an alternative to biocides, after the confluence, that tally with the low number of tolerant genera. The institution is lved in the use of mulching and manure solution use in farms (instead of fertilizers), pepper solution and ash filters (instead of pesticides and herbicides). On the other hand, the amount of organic pollution at the source could be relatively small probably due to the cleansing effect of the swamp. This therefore correlates with the presence of most of the EPT group of species that are sensitive to organic pollution. This could also be true for the forested area at station S2. This view was supported by Kari et al. (1993) who observed that the use of fertilizers, insecticides, herbicides, and fungicides on agricultural land have caused serious pollution problems in waters. Agriculture, as well as forestry, also caused considerable water pollution by suspended particles and nutrient enrichment that alter the stream functioning.

### 5.1.2 Macroinvertebrate Diversity.

There were minimal variations in Shannon-Wiener diversity between sampling stations. The minimal variations were probably due to anthropogenic impacts served along the rivers. Pollution tolerant species like *Chironomus* sp., *Tubifex* sp., *Lumbricus* sp., *Pisidium* sp., *Sphaerium* sp., *Erpobdella* sp. and *Lymnaea* sp. were more abundant in the lower Sosiani River and at station S7 in River Kipkaren. This could conform to the physical structure that could have provoked perturbations in stream invertebrate
communities with response to such events varying according to species. Kari et al. (1993) concluded that the distribution of aquatic macroinvertebrate occurrence is set by physical and chemical tolerance of the individual macroinvertebrates to an array of environmental factors. A lower value of the Shannon-Wiener diversity metric is generally interpreted as a characteristic of polluted conditions over time, where a few tolerant genera dominate the community while higher values are recorded from unpolluted waters. Therefore, stations that showed low Shannon-Wiener diversity index values received a lower score and vice versa. Shannon-Wiener diversity index has been suggested to have values usually ranging between 1.5 and 3.5, rarely rising above 4.5 (Magurran, 1988). Station S1 had a Shannon-Wiener diversity index of 3.08 ± 1.21 whereas station S4 in River Sosiani had a lower Shannon-Wiener index (H’=2.85 ± 0.97). Almost similar Shannon-Wiener values obtained could be due to moderately high conductivity values and DO levels that were significantly different and were related to such areas in this study. Increased conductivity influences the osmoregulation of the aquatic invertebrates leading to sensitive freshwater organisms either to adopt or are driven out (Spiels & Mitch, 2000). Notably, the index showed minimal variations over time and among the sampled stations in both rivers. This suggested that stable chemical load in both rivers, resulted in the loss of ecosystem health. Station S6 had a lower Shannon-Wiener genera diversity (H’=2.94± 0.87) probably due to few macrohabitats observed in the area. In addition, this station, together with station S7, had an open access for livestock invasion. Herbivory of aquatic vegetation and nutrient input via urine and fecal deposition and trampling of sediments which have direct impact on the river. Similar observations have been made by Cragg (1961) and Griffith et al (2005) in these areas.
The high taxa richness of 31 genera recorded in River ipkaren could be due to several macrohabitats, especially riffles and runs that may have favoured availability of more niches for macroinvertebrates existence and the absence of major human activities like industries that could cause hydrological perturbations due to discharges into the river from such areas. Studies conducted by Matthaei et al. (2000), indicate that the microdistribution of benthic macroinvertebrates in streams is dynamic and is strongly influenced by the hydrological disturbance regime. This seems to suggest that insects like Heptagenia sp., Baetis sp., Elmis sp. and Caenis sp. were most abundant in riffles. It is therefore concluded that diversity is a function of seasonal differences, substrate composition, width of the river, presence of riffles, pools and runs and pollution discharges of organic matter.

5.2 Nutrients.
Variations were recorded in the nutrient concentrations among the stations, with an increase in concentrations downstream in both rivers (Fig. 4). Sosian River at station S4 had the highest levels of TP (0.54 ± 0.22 μgL⁻¹) and TN (0.72 ± 0.03mgL⁻¹) possibly due to the high concentration of nutrients discharged from Eldoret (Huruma) Municipality. Robert & Rankin (1998) obtained almost similar results in a low order stream of >0.61 mgL⁻¹ for TN at a site that anthropogenic impact seemed to be absent. Nutrients availability in a river is primarily influenced by urbanization, like for the study, and urban and seasonal application of fertilizer (Carpenter et al., 1998). Total Nitrogen (TN) and TP concentrations at the source of Kipkaren River and at the station near the Eldoret Airport had low nutrient levels than the rest of the stations probably due
to absence of crop farming (Carpenter et al., 1998) and the cleansing effect of the swamps along their respective riparian zones. The lack of significant TP variations among the sampling stations was in conformity with the findings of Carpenter et al. Op cit, who found that phosphorus is the major limiting factor for the growth of algae in rivers. This is because of the clarity of water that showed no signs of chlorophyll presence. There were no significant differences in the concentrations of TP and TN among the sampling dates because of probably the dilution effect of the increased water levels due to short rains experienced throughout the sampling period.

5.3 Relationship between Macroinvertebrates Abundance and Diversity and Nutrients.

A positive significant correlation of macroinvertebrates Shannon-Wiener diversity with TP and TN variations occurred among the stations (Fig. 5). Station S2 recorded a low significant correlation value with TP and TN variations (0.453 ± 0.57) probably due to increased abundance of Ephemeroptera, Hemiptera and Plecoptera as at station S1. This could be probably due to tolerant to nutrient enrichment and low DO levels by the taxa. An overall weak positive correlation value of $r = 0.39$ between macroinvertebrates Shannon-Wiener diversity with TP and TN was registered in this study, indicative of a positive growth in the relationship between macroinvertebrate abundance and diversity and nutrient levels. This could be an indication that only 16% ($r^2 = 0.16$) of the variation in TP and TN can explain the variation in macroinvertebrates Shannon-Wiener genera diversity. This could be probably an indication of the low nutrient levels that were obtained in this survey may be due to the increased dilution effect of the high water volume because of the short rains experienced in the whole study period. In a similar
study, Griffith et al. (2005), obtained a negative value of $r = -0.309$ ($p = 0.001$) that showed a negative correlation of macroinvertebrate diversity with increased nutrient levels, but they noted high TN and TP flow into the Southern Montana streams.

Sabater et al. (2004) noted that changes in the structure of the microbial components did not significantly affect the macroinvertebrate community (where only a few taxa showed changes because of the nutrient addition) or the overall stream metabolism. Herrmann (1999) noted that slight eutrophication seems to favour increased diversity, however, excess amounts of nutrients resulting in increased primary production and consequently oxygen depletion, probably affecting macroinvertebrate diversity negatively. Harding et al., (1998) noted similar weak significant correlation results and suggested that high periphyton biomass due to nutrient enrichment and sedimentation in some of the stations that they sampled favoured Chironomids, Snails and Oligochaetes the expense of Ephemeroptera and Trichoptera. Thus they noted the decline in diversity of macroinvertebrates, with the low abundance or absence of Ephemeroptera and Trichoptera downstream due to increased nutrient levels because of agricultural activities and urbanization. The same phenomenon was depicted in this study (Fig. 5). Stations with high macroinvertebrate diversity (genera-based Shannon-Wiener values) recorded low levels of TN and TP. For example, the station at the source of Kipkaren River that recorded a Shannon-Wiener value of $3.08 \pm 1.21$ had the lowest TP and TN concentrations of $0.05 \pm 0.02 \mu g L^{-1}$ and $0.073 \pm 0.01 mg L^{-1}$ respectively. Station S4 in River Sosiani that recorded the highest TP ($0.54 \pm 0.219 \mu g L^{-1}$) and TN ($0.72 \pm 0.03 mg L^{-1}$) concentrations, had the lowest Shannon-Wiener diversity ($H' = 2.85 \pm 0.87$). The
suggestion by Harding et al. was evident in this study, in that the highest macroinvertebrate abundance of tolerant species such as *Chironomus* sp. occurred in areas of increased nutrient levels.

### 5.4 Macroinvertebrate Index of Biotic Integrity.

Mason (2002) confirms that bioindicators like macroinvertebrates used in this study, are organisms whose presence, absence or condition provides information about the river ecosystem quality. The presence, approximation or deviation of the macroinvertebrates occurrence to the reference station (the source of Kipkaren River, in this case) within the habitat is therefore a sign of particular environmental characteristics of anthropogenic impact. This means that the biological information contained within the Macroinvertebrate Index of Biotic Integrity (IBI) of this study and its component metrics has a potential towards informing on the conservation and restoration efforts needed for Rivers Kipkaren and Sosiani. Karl et al. (2003) used the metrics of EPT genera, that is the percentage composition of mayflies, chironomids, percentage of other dipterans and other insects, and the abundance of macroinvertebrates in relation to the same characteristics in the headwaters, small streams and large streams as reference stations. A few similar metrics were used in this study (Table 1 & 7), of percentage intolerant (EPT), percentage tolerant, abundance of macroinvertebrates and abundance of pollution tolerant oligochaetes and chironomids. Contrary to Karl et al (2003) study, the reference station was the source of the river studied (River Kipkaren). Both of these studies signified deleterious effects of nutrient enrichment into low order streams. This also compares with the studies done on other streams (Hawkers, 1979; Roy et al., 2001; Taylor & Francis, 2005) to come up with metrics and an IBI for evaluating the biotic integrity using
macroinvertebrate communities. The IBI obtained in this study has also shown a similarity with those IBI scores that have successfully correlated with human activities like urbanization and agriculture (Carpenter et al., 1998; Griffith et al., 2005), sewage effluent (Karr et al., 1997; Harding et al., 1998) and riparian destruction (Cragg, 1961; Griffith et al., 2005). This is an indication that the index could probably be a preliminary estimate of the current biotic integrity of all the stations and for both rivers, especially during the period of short rains.

Metric variability and response of metrics to impaired sites indicated that the IBI obtained in this study responded to the range of biological conditions found in the ecoregion. These metrics followed the predicted ecological-dose response relationships with perturbations using the subset (pair wise) of impaired sites (Barbour et al., 1999). For example, according to the calculated IBI (Table 7), station S4 scored 19 points while station S2 had 37 points out of the total 45 points. Basing on the integrity classes (Table 2), station S2 was within the first category (excellent water quality), while station S4 was in the fourth category (poor water quality). The difference in water quality between station S2 and stations S4 and S5 could be due to intense urban discharges (from Turbo Town, Huruma estates and Eldoret Town), industrial discharges (from Ken Knit, Cocoa Cola, K.C.C., Rupa and Rai-ply) into the lower Sosiani River and from agricultural farms. Station S3 scored 33 points indicating good water quality due to the dilution effect of pollutants because of increased water volume that was in the area. Another reason could be the uncultivated farm land and dense vegetation that forms the riparian zone of the area which to some extent buffers any runoffs into the river. Station S6
recorded (35 points) excellent water quality. This may be probably because of the organic farming and dense bank vegetation that minimized nutrient and other pollutant discharges into the River. The urban discharges at Kipkaren Town, together with agricultural runoffs in the area could probably be diluted by the increased water volume in the river (Carpenter et al., 1998). This could have led to the fair water quality (27 points) recorded.

The stations for the River Kipkaren were probably less affected by urbanization and agricultural activities due to the presence of a single urban centre (Kipkaren Town) that has no major industries and the presence of uncultivated riparian zones, swamps and vegetation closer to or around the River. The calculated IBI therefore depicts that River Kipkaren waters is of good water quality and the lower River Sosiani waters is of fair to poor water quality. Ogello (2005) scored 30 points for a high altitude area while the low altitude region obtained 17 points out of a total of 50 points, in small water bodies (wetlands) in the Lake Victoria catchment. A maximum of 50 points was noted by Ogello Op cit study because each individual metric was allocated a maximum of 10 points unlike in this study, in which a maximum of 45 points for each station was applied because each metric had a maximum of 5 points. This means that appropriate management techniques by lead agencies like National Environment Management Authority (NEMA) should be put in place to conserve aquatic ecosystems such as rivers. Even improved water quality levels could probably be realized if the role of Water Resources Management Authority (WRMA) under the Water Act of 2002 (GoK, 2006) is put into practice.
CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results of this study indicate that sampled stations in River Kipkaren had a macroinvertebrates taxa richness of 31 genera compared to that of the lower Sosiani River of 19 genera. The most abundant macroinvertebrate taxa in Kipkaren River were of the intolerant group, i.e. the EPT while the tolerant taxa such as Oligochaeta, Odonata, Hirudinea dominated the Sosiani River. The diversity (Shannon-Wiener values) decreased with an increase in nutrient levels, whereas, abundance of macroinvertebrates significantly increased with increased TP and TN levels. This indicated that macroinvertebrates abundance and diversity and nutrient levels covaried in this study, despite the low nutrient levels obtained probably due to the dilution effect caused by the short rains experienced during the study period. Therefore, the null hypotheses that stated the opposite of these findings were rejected. In addition, the results showed that TN, DO and conductivity indicated spatial differences spatially in both rivers with increased concentrations of TN and TP downstream for River Kipkaren and decreased concentrations of TN and TP downstream for River Sosiani. Hence the corresponding null hypothesis that there are no spatial differences for TN, DO and conductivity rejected.

Index of Biotic Integrity scores showed spatial differences along the two rivers. The results show that metrics derived from macroinvertebrate assemblages at the 7 stations have potential use in describing the biotic integrity of both river habitats, thus necessitating IBI development as a bioassessment and monitoring tool for both Rivers
Kipkaren and Sosiani, and for the upper reaches of River Nzoia Basin. Hence, the null hypothesis that IBI scores do not differ among the selected stations due to anthropogenic effect was rejected.

6.2 RECOMMENDATIONS
I would wish to recommend that:

- Macroinvertebrate Index of Biotic Integrity is preferable as a bioassessment and monitoring tool because it delineated impaired from less impaired stations with different degrees of degradation.

- A biological approach to ecosystem management in addition to the application of traditional monitoring to deal with point sources of contaminants should be the focus for river basin management since the IBI was found to be sensitive to the habitat quality deterioration.

- An alternative IBI for fish, algae and amphibians could be developed as a comparison assessment to determine the water bodies’ health within the upper reaches of River Nzoia Basin, and Lake Victoria Catchment as a whole.

- An Integrated Riverine Management Approach involving the physical, chemical, biological and land use aspects could be explored further to provide a wholistic management approach of the sub-catchment.

- The ministries of environment and water should put into practice the IBI concept to analyze and check the improper use of water catchments within the Lake Victoria Catchment by acting as a baseline data for policy formulation.
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