ASSESSMENT OF WATER QUALITY STATUS OF RIVER KIBISI, KENYA USING THE EPHEMEROPTERA, PLECOPTERA AND TRICHOPTERA (EPT) INDEX

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AUGUST, 2013
DECLARATIONS

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This thesis is my original work and has not been presented for a degree in any other university or any other award.

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We confirm that the work reported in this thesis was carried out by the student under our supervision.

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DEDICATION

I would like to dedicate this thesis to my dear wife Elizabeth Bonzemo together with my children, my mother for their support and inspiration.
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1.1 Background information

The term water quality is applied universally to refer to the water status that meets the universal standards set for legitimate and vital water use at any scale i.e. local, regional and international levels (WHO, 2000). The evolution of the term water quality has been due to the expansion of water requirements and ability to measure and interpret water characteristics. The definition of water quality depends on the factors that determine it, and other variables that affect the nature of water resource. The introduction of harmful substances in river water (pollution) results in deterioration water quality standards (degradation), and this interferes with legitimate and vital water use at any scale i.e. local, regional and international levels (Meybeck et al., 1989). However, water quality standards have been established for regulatory purposes and are determined based on the criteria involved depending on domestic, agricultural uses and aquatic life systems (WHO, 2004).

River water quality status is generally affected by many physical, chemical and biological parameters introduced by natural forces and human (anthropogenic) activities. Water quality criteria, standards and related legislation are often used as the main administrative means to manage water quality status in order to achieve user requirements. Water quality standards for surface water vary significantly due to different environmental conditions, ecosystems and intended human uses. Different uses of water raises different concerns and therefore different standards must be considered. The most common national requirements for drinking water of suitable quality for many countries are based on the standards of the World Health Organization guidelines for drinking water (WHO, 1993).
Water quality is an important factor influencing the distribution and abundance of stream fauna and flora. Species richness is the number of different species represented in an ecological community and species composition is the relative abundance of different species in a region. High water quality streams have the greatest species composition, richness and diversity. Many of the aquatic insects are intolerant to pollutants and they are hardly found in polluted waters. The greater the pollution, the lower the species richness expected because only a few species are able to tolerate such conditions. Highly polluted rivers have less oxygen content, and the absence of this gas inhibits the survival of aquatic biota. Land use has always had an effect on water quality and aquatic biota (Lenat and Crawford, 1994).

Traditionally water quality had always been determined by measuring the quantity of chemicals dissolved in it. There is a lot of subjectivity to data interpretation when traditional methods are applied in quality water assessment. Sometimes results obtained when these methods are applied in the assessment of water quality are unreliable, not precise and fallacious (SWRP, 1996). In addition, the traditional methods of water quality assessment are not cost efficient and are time wasting. Another setback about these traditional methods is that they are never used in measuring the ecological integrity of an ecosystem. These methods have minimal use in the world of modern scientific river water quality assessment because they have been overtaken by events (Teferell and Perfetti, 1996).

Biotic metrics (biological methods) which have long been embraced in the developed world in evaluating and monitoring water quality status are lagging in application in poor countries. Biotic metrics are nowadays used because aquatic organisms are very sensitive to presence of pollutants in the water (Teferell and Perfetti, 1996); and secondly, these organisms spend their whole or
entire lives in water (Lenat, 1988). Other advantages are that biological metrics are easily applicable and the results obtained are reliable and precise (SWRP, 1996). Further, benthic assemblages i.e. chironomidae, odonata, crustaceans, worms, molluscs, coleoptera, porifera, fish, and sponges are good biological indicators because they are sensitive to disturbances, stress (both natural and human induced), have limited mobility, are highly exposed and integrate impacts over time. Their populations and life cycles are directly affected by human (anthropogenic) activities leading to impaired or un-balanced community.

The response of the aquatic insects to pollution gives an early warning to possible harm of the water resources. Because the benthic macro-invertebrates spend nearly the entire life in water or in aquatic systems, they show and indicate the effects of physical habitat alteration, point and non-point contaminants and cumulative pollutants over their life cycles. Fundamentally, benthic assemblages are sensitive to water quality status alteration, hence, they are justifiably the most frequently used biological parameters in monitoring water quality (Morse et al., 2007).

Biotic indices are largely developed to measure the stresses and health of ecosystems. The advantage of the bio-monitoring of aquatic depends on the ability of biological communities to reflect not only the water quality status but also the overall ecological state of the entire ecosystem. Most of the biotic indices which are applied in the assessment of water quality of streams also measure the sensitivity of the macro-organisms and their responses to pollution (Lennat, 1988). Benthic macro-invertebrates are known to be useful in monitoring water quality status because they exhibit a relatively wide range of exposes to chemical and the physical water quality stress. In addition, these organisms have long life cycles which enable researchers examine impacts of stresses/contaminants on them. Different benthic macro-
invertebrates have different habitat preferences and various levels of pollution tolerance (Plafkin et al., 1989).

Numerous biotic techniques have been developed over the last three decades, varying in complexity and region of implementation. Foremost examples of bio-assessment techniques include: Macro-invertebrate Water Quality Index (MWQI) (Plafkin et al., 1989); Water Quality Index (WQI) http://kancrn.org/stream/cp4wqi.cfm; Ephemeroptera, Plecoptera and Trichoptera richness index (EPT) (Lennat, 1988); Average Score Per Taxon (ASPT) (Chutter, 1994); North Carolina Biotic Index (NCBI) (Lennat, 1988); Watershed Pollution Potential Index (WPPI); Index of Biotic Integrity (IBI) (Karr, James 1981); Beck’s Biotic Index (BBI) (Teferell and Perfetti, 1996); Field Biotic Index (FBI) (Hilsenhoff, 1988); Hilsenhoff’s Biotic Index (HBI) (Hilsenhoff, 1988); Benthic Index of Biotic Integrity (BIBA) (Fore et al., 1996).

Four examples are hereby reviewed because they are commonly embraced and used in water quality assessment. They include: The Integrity Biotic Index (IBI); the South African Scoring Index (SASS.5); Macro-invertebrates Water Quality Index (MWQI) and the Water Quality Index (WQI).

The Integrity Biotic Index (IBI) concept was formulated for multiple assemblages including benthic macro-invertebrates, periphytons, fish, algae, chironomidae, vascular plants, and combinations of these (Karr, 1981; Karr and Chutter 1999). The index uses attributes termed metrics of selected biotic assemblages, such as taxonomic richness, feeding guilds composition and density to calculate an index score for impaired/stressed and compared to an index score for an unimpaired/pristine site (Karr, 1981; Karr and Chutter, 1999). The IBI uses the reference
condition approach which involves assessing an ecosystem exposed to a potential stress. The rationale for such a biotic metric index is that the responses of different indices to human disturbances are displayed naturally by patterns of variations in their differences. The assessment of biota in rivers is a widely recognized means of determining the condition or ‘health’ of rivers. Benthic macro-invertebrates, in particular, are recognized as valuable organisms for bio-assessments, due largely to their visibility to the naked eye, ease of identification, rapid life cycle often based on the seasons and their largely sedentary habits stressors (Silveira et al., 2005). This necessitates the use of different metrics to account for natural variability before the analysis of anthropogenic disturbances (Marques and Barbosa, 2001).

The Macro-invertebrates Water Quality Index (MWQI) considers both the number of different species in the ecological community (species richness), the measure of the amount of a species in a sample (abundance) and taxon’s pollution sensitivity score. This bio-assessment technique is considered to be more robust than any other known biotic index because it is widely applied besides providing the information on the community structure of an aquatic ecosystem. It is universal in application and has better accuracy in the description of water quality. The index is influenced by the relative abundance of taxa in a given sample. The index is cost effective in terms of time and it does not involve the use of expensive equipment and chemicals. With a slight modification, this index can be extended to other bio-indicators like fish and diatoms which are basically used in bio-monitoring. The MWQI can also be a good tool for estimating the health a freshwater aquatic ecosystem and its biotic complexity. The MWQI use can as well be extended up to generic and specific levels with better results, if pollution sensitivity scores are assigned to these taxa (Bhatt et al., 2005).
The Water Quality Index (WQI) is the latest or the newest biotic index proposed for the evaluation of water quality in freshwater rivers. This water quality index provides a single number (like a grade) is obtained and expressed as an overall value of water quality at a certain location, and time based on several water quality parameters. The objective of this index is to turn complex water quality data into information that is understandable and useable by the public. This type of index is similar to the index developed for air quality that shows if it is red or blue air quality day. The use of an index to "grade" water quality is a controversial issue among water quality scientists. Some scientists argue that a single number cannot tell the whole story of water quality status because there are many other water quality parameters that are not included in the index. The index presented here is not specifically aimed at human health or aquatic life regulations (Brown et al., 1970). However, this water quality index based on some very important parameters can provide a simple indicator of water quality. It gives the public a general idea of the possible problems with lotic water bodies in the region. In the past researchers used several types of water quality indices but they have found out that this particular water index can be used by many communities in characterizing overall water quality. To use this biotic technique, sampling sites are chosen such that they include the river stretches with moderately disturbed and undisturbed catchment areas. The proposed index is then calibrated against the Water Quality Index (WQI) of National Sanitation Foundation (NSF) of USA and other known biotic indices (http://kancrn.org/stream/cp4wqi.cfm). The Water Quality index gives better results of water quality compared to other biotic indices because:

1. It takes into account the abundance of taxa and reflects even the minor changes in abundance and community structure of the river ecosystems;
2. It is flexible in use and gives the researcher freedom to select any pollution ecosystem based on generic or specific levels; and

3. It is universally applicable and it is not affected by the geographical location of a river.

This index was originally developed by the National Sanitation Foundation (NSF) in the USA (Brown et al., 1970).

However, a method that is commonly applied in the assessment of water quality is the use of (EPT) richness index. The EPT index has three orders of aquatic insects (Ephemeroptera, Plecoptera, Trichoptera) that are easily sorted and identified and thus, it is commonly used as an indicator of water quality status. The Ephemeroptera, Plecoptera and Trichoptera (EPT) index uses the insect taxa to assess or evaluate the water quality status. These insects are also known as benthic macro-invertebrates. The term benthic macro-invertebrates mean bottom-dwelling (benthic) animals which do not have backbones (invertebrates). They are well adapted to living in stream water where they utilize all the available habitat niches. The EPT richness index is based on the presence or absence of the benthic macro-invertebrates. This index reflects the changes in water quality, changes in the watershed of lotic systems and also takes into account the quantitative estimation like the density and abundance of the taxa. The EPT richness index is universal in application and is greatly influenced by the relative abundance of taxa in the river systems as well as reflects land use in the watershed (Lenat, 1988). The EPT richness index will vary from region to region, but, naturally within a region, the greater the number of taxa from these orders, the better the water quality status. For example, some benthic macro-invertebrates are adapted to live in higher velocity portions of the stream, others live at the
bottom of the stream, some crawl for food, while others let the food come to them by the help of the water current (Lenat, 1988).

The EPT index is used to determine between site differences in water quality or watershed studies with a large number of sites. This method is applicable because benthic macro-invertebrates are sensitive to stress both which are natural and human induced. Their populations are directly affected by human (anthropogenic) activities leading to an impaired or an imbalanced community. Because these organisms spend their entire lives in water, they show the effects of physical habitat alterations that take place in the aquatic systems including point and non-point contaminants and cumulative pollutants over time (Lenat, 1988).

It can be used for emergency sampling where it is desirable to rapidly assess the effects of spills and unusual discharges. It can also be used in areas that are naturally known to have a low EPT species richness (either inherent or human induced) or in areas where pollution tolerant groups are of interest. This method is a technique that has a direct application in conducting rapid resource assessment. The EPT index can be used to monitor water quality status and prioritize resource management (Lenat, 1988).

It is also used because it is reliable, precise and it is applied in the establishing reference conditions; setting protection and restoration of goals; identifying disturbances; choosing control measures; evaluating the effectiveness of Biological Monitoring Program (BMP) improvement measures and monitoring watershed condition change in the all stages of the river. Undisturbed aquatic environments may support high populations of benthic macro-invertebrates which are important food sources for the aquatic organisms which are associated with unpolluted environmental conditions (Griffiths, 1998).
1.2 Statement of the Problem and Justification

The use of the water resource of rivers originating from Mt. Elgon forest has proved fatal because of the use of contaminated river water resulting in waterborne diseases to local residents. Ministry of Health statistical records available in Bungoma and Trans Nzoia County hospitals and health centers indicate rampant waterborne diseases that attack mostly children in the riparian communities. Each year many people especially children aged between one to fifteen years succumb to waterborne diseases such as cholera, amoebic dysentery, diarrhoea and typhoid. Use of contaminated river water by residents in the region is the cause of waterborne diseases resulting in fatal consequences (Matumbai, pers.comm.).

However, water quality assessments have not been tested in the region yet existing chemical methods are laborious and expensive. Therefore, there is need to apply the biotic EPT index in the assessment of river water quality status due to its reliability and low costing. The application of the EPT index which has been widely used in the temperate countries including South Africa and the USA would be a useful pollution indicator in the tropical world. This study aimed at testing the EPT richness index method in the assessment of the water quality status of the River Kibisi in Mt. Elgon region.

1.3 Research Questions

i. What was the water quality status among the three sampling sites along River Kibisi as indicated by the EPT index?

ii. What was the relationship between water quality status and the macro-invertebrates abundance at the three sampling sites along River Kibisi watercourse?
iii. How did water quality status influence the distribution, abundance and composition of benthic macro-invertebrates along River Kibisi?

1.4 Hypotheses

i. There was no water quality variation among sampling sites along River Kibisi.

ii. There was no relationship between water quality and macro-invertebrate abundance at the three sampling sites along River Kibisi.

iii. Water quality had no impact on the distribution, composition and abundance of benthic macro-invertebrates along River Kibisi.

1.5 Objectives

1.5.1 General Objective

To assess the water quality status of River Kibisi, Mt. Elgon area, using the EPT richness index method

1.5.2 Specific Objectives

i. To evaluate the effectiveness of the EPT richness index in the assessment of the water quality status of River Kibisi in Mt. Elgon area

ii. To determine the effects of changes in river water quality on the river’s benthic macro-invertebrates

iii. To compare the effectiveness of the EPT richness index and physico-chemical parameters for water quality assessment of River Kibisi
CHAPTER 2: LITERATURE REVIEW

2.1 Factors that affect distribution of benthic fauna

A multiplicity of factors regulate the occurrence and the distribution of stream dwelling benthic macro-invertebrates, most important being the current (velocity); temperature; altitude; season; total suspended solids; the substratum; and vegetation. Other factors which affect the occurrence of these benthic fauna include substrates; vegetation; pH; dissolved oxygen; availability of food; turbidity; transparency; total dissolved solutes; conductivity; competition; liability to droughts and floods (Reid, 1961; Hynes, 1970; Odum, 1973).

During base flows, benthic macro-invertebrates are assumed to select patches most suited to their hydraulic requirements. These patches may change as discharge declines and as near bed hydraulic regimes alter. Though due to light floods caused by heavy rains cause displacement of the benthic macro-invertebrate assemblages downstream (hydrological disturbance), many of the biotic indicators display distinct velocity preferences and are influenced by turbulence regimes (Wetmore et al., 1990; Jowett et al., 1991; Horne et al., 1992; Collier, 1993). Low flows /discharges are usually seasonal and a normal part of river’s hydrograph while droughts result from less than normal precipitation for an extended period of time although the beginning of the drought period is hard to define (Humphries and Baldwin, 2003). Substrate is one of the most important factors in the micro-distribution of the macro-invertebrates in lotic systems (Tolkamp and Both, 1979). The relationship between the two is however, very complex. The sediment particle size is a principle determinant of the distribution of stream benthic fauna (Watson, 1978).

Various methods are used to determine the type of substrates that exist in the rivers or streams.
Gore (1978) had developed a surface profiler with a six-to-six matrix of steel rods on a 0.1 m² frame. The frame is levelled and the rods pushed gently down until an obstacle is reached, producing a map of substrate profile. Other approximate methods are (techniques) based on substrate size classification which include visual methods (Statzner, 1987).

Substrates that are found in streams are either inorganic or organic in nature. Bed materials of most streams consist primarily of inorganic particles which range from clays, silts to boulders and stream bedrock. Organic substrates (less than 1 mm.) serve as food materials rather than habitats for the benthic macro-invertebrates. Larger organic materials from some parts of the streams and submerged logs function as substrates rather than food for the benthic macro-invertebrates (Hynes, 1970). Large substrates trap fine detritus food materials while being transported in the water column. Substrate composition size decreases downstream with large stones and boulders found in mountain areas, and sandy bottoms in lowland rivers. Even “muddy” rivers have mainly sand and fine gravel in their substratum, and silts are found in backwards or during periods of greatly reduced flow (Hynes, 1970).

Each macro-invertebrate taxon occupies a certain niche according to its feeding group: for instance, some are shredders, while others are collectors-gatherers, scrapers, filterers or predators. Shredders prefer to feed on larger particles of organic matter such as leaves and twigs, and in the process they churn the materials into smaller organic matter which can then be fed upon by collectors and gatherers. Collectors feed on small organic particles that are found at the bottom of the river. Scrappers feed on diatoms and algae that are attached to the underwater surfaces. Filterers feed by straining small organic matter particles out of the water. Filterers have fanlike appendages on the insect’s body or built externally by the insect to resemble little underwater nets (http://www.Epa.govowowwtr/monitoring).
Predators feed on other macro-invertebrates. Stream impairment may be indicated when one or more feeding groups are missing from a river. In healthy streams all the feeding groups should be present. Generally, stoneflies are predators; mayflies are scrapers and collectors while caddis flies are collectors, scrapers or shredders (Hynes, 1970).

The ratio and the number of these macro-invertebrates change with the stream food resources and human impacts and hence, they can be used as a tool for assessing the ecological status of the biotic and water quality status. Mayflies and caddisflies prefer low current environments but the stoneflies prefer riffle parts of the stream and they live in crevices of the boulders, stones, rocks, cobbles and logs on whom they adhere. The selection of the substratum of a particular type is both common in both lotic and lentic water systems, and may be related to feeding requirements, but sometimes no reason for the choice of a micro-habitat is apparent (Macan, 1974; Tolkamp and Both, 1979).

Most of the causes of poor water quality arise from land based and human (anthropogenic) activities making the evaluation of the ecological status of rivers to represent trends in man’s impacts on river systems. The deterioration of water quality represents the presence of stressors and its improvement represents progress towards attaining ecological integrity due to better management and conservation efforts. It is important that water quality should be maintained to the recommended levels of World Health Organization (WHO, 2006).

Almost every anthropogenic activity affects the biophysical environment in some way very often destroying the existing equilibrium or accelerating natural rates of change (Nadakavukaren, 1986). This has had profound effects on the ecology of the benthic macro-invertebrates, especially their diversity, spatial-temporal distribution, sizes and composition (Griffiths, 1998;
Shivoga, 1999). There are several biological metrics which have long been embraced in other countries the world over especially in the developed countries. These biotic indicators are used in the assessment and water quality and ecological integrity of the environment. A biotic index is simply the scale for showing the quality of the water resource of the environment by measure or against the type of organisms present in it.

2.2 Methods of evaluating water quality of river systems

Lotic ecosystems are among the most important biological ecosystems on earth (Dudgeon et al., 1996). However, these are the most threatened resources today in the world because of the irresponsible anthropogenic activities and un-relented increase in human populations. It is therefore a big priority to conserve rivers and water streams and to manage those that are already threatened with degradation to ensure their preservation and ecological integrity respectively.

There are many approaches of carrying out estimates of richness of individuals, similarity and diversity of a biotic community (Fausch et al., 1990). The multi-metric approach which takes into account several metrics such as the structural, functional and compositional metrics of biota assemblages is useful in evaluation of water quality. Also of use is the Index of Biotic Integrity (IBI) (Karr et al., 1996). The River Invertebrate Prediction and the Classification System (RIVPACS) can also be used to assess water quality (Wright et al., 1993).

Another example is the multivariate approach is a measure of mathematical relationship among samples (e.g. the similarity in structure of two communities) for two or more variables (e.g. qualitative presence-absence of species or the quantitative abundance or biomass of species) are selected. Conceptually, this technique is good because it is dependent on sample size,
ecologically sound, easy to understand, interpret and apply by aquatic water managers (Johnson, 2001). Though the multivariate approach has higher precision than the micrometric approach, it is more difficult method to understand, interpret and apply by aquatic resource managers and hence, it is less preferred.

2.2.1 Physico-chemical approaches

Water quality status is affected by many physico-chemical and biological parameters which are introduced naturally or by human (anthropogenic) activities into the river systems. However, benthic indices are most appropriate as they remove much of the subjectivity associated with data interpretation. They also account for habitat differences. These indices provide simple means of communicating complex information to managers, tracking trends over time and correlating benthic responses with stress (Ranasinghe, 2003).

This approach is based on the qualitative measurement of parameters derived from the abiotic components of the lotic environment. The parameters measured range from oxygen, temperature, pH, electrical conductivity, salinity, transparency, Biological Oxygen Demand (BOD) and mineral nutrients ranging from nitrates, phosphates and sulphates (Wetzel and Likens, 1991). The physico-chemical assessments are based on the comparison of the measurements made with the water quality criteria or with the standards derived from such criteria. These are founded on set national standards on water, sewage and other effluent discharges normally set by the Ministry in charge of the environment (Norris and Norris, 1995).

The physico-chemical techniques have the merit of being precise, discriminatory, and quantitative, and thus they are important for determining the type of chemicals pollutants
present in a river and their concentrations (Tebbut, 1992). However, the technique of physico-
chemical approach to assess water quality in all the water bodies the world over is rather expensive. This is because water samples would be required to achieve a health assessment to acceptable confidence standards (Woodiwiss, 1978).

Furthermore, the knowledge of chemical monitoring and the type of pollutants likely to be present in river water can be used as a pre-requisite for effective assessment (APHA, 1995). Increasing complexity of agro-chemical discharge as well as domestic discharge can prove to be very difficult to completely assess the quality of water in these rivers. When chemical discharge are irregular in nature, it becomes hard to be monitored or detected (Hart et al., 2007). Physico-chemical measurements alone cannot be used to effectively assess water quality of streams because their status keep changing too often and their ecological influence are too complex to be understood (Tebbut, 1992).

2.2.2 Use of biotic indices in monitoring water quality

Water quality monitoring is the sampling of the conditions of water including sediments, physico-chemical parameters, fish tissues and the macro-invertebrates in order to determine the pollution level of lotic and lenthic water systems. We monitor to characterize water and identify the changes in trends in water quality over time; identify specific existing or emerging water quality problems; gather information to design specific pollution prevention or remediation programs; determine whether programs, goals e.g. compliance of population implementation have been met; and to respond to emergencies for instance flash floods and spills. Thus, water monitoring is a fundamental tool in water quality resource management.
The principle of biological monitoring as a tool is that the incidence and intensity of environmental stressors is based on the degree to which the chosen endpoint organism association deviates from the expected natural diversity (Hynes, 1972). This approach helps to detect ecological changes which are indicative of the water quality though it does not specify the causes of the change making the physico-chemical approach a more viable technique. This method is often applied because it is cheaper in term of costs and since river sample are easy to collect and analyze for inferences of health status (Nixon et al., 1996).

2.3 The rationale of biological monitoring programs

The purpose of developing biological monitoring programs is to enable researchers to be able to assess water quality of lotic and lentic systems. This is a useful approach because it makes use of aquatic biota to evaluate complex river water qualities. Overall biotic communities are generally affected by the multi-presence of chemicals and physical factors that influences the conditions in aquatic biota reflecting the total conditions of the river ecosystems. This approach which is called bioassay uses biota as endpoint to represent the general environmental conditions and assess environmental qualities. The aquatic biotic assemblages include the macro-invertebrates, the phytoplanktons, the zooplanktons, phyto-benthic macro-invertebrates and the fish communities (Depauw and Vanhooren, 1983).

The ecological indicators are used on the basis of biological diversity to portray species and community structures and thus water quality, hydrology and the overall health of a stream. Indicators are used to monitor the levels of toxins and the chemical content i.e. the physical and chemical parameters and the overall nature of the water resource (Nixon et al., 1996). Biological monitoring is a protocol that is designed of monitoring surface and groundwater water quality.
The presence or the absence of biota groups are used as biological indicators and the whole living community reflect the overall environmental conditions (Karr, 1981).

2.4 Macro invertebrates prediction and classification system
This system consists of statistical models which are used to predict the expected presence of aquatic macro-invertebrates fauna at sites with no environmental stressors (Simpson and Norris, 2000). These assessment techniques are based on a stepwise progression of multivariate and univariate analysis. A comparison of the samples predicted to occur at test sites and those actually collected provides a target invertebrate community to measure the effectiveness of remediation actions at impaired sites (Wright et al., 1993). These models have the advantage of having a high turnout of results, hence, their use in rapid bio-assessment programs because they are easy to understand and apply by natural resource managers (Hawkins and Norris, 1997).

2.5 Ecological integrity
Ecological integrity refers to a concept that seeks to incorporate the biotic and abiotic components of an ecosystem with regard to how they relate in their functions, goods and service output and their regeneration rates (Maddock, 1999). Within the context of a water ecosystem, ecological integrity is the maintenance of all internal and external processes and attributes that interact with the environment in such a way that the biotic community corresponds in the natural state of specific aquatic habitats (ONORM, 1995).

High river water quality is reflected by good ecological integrity in the river watershed and poor water quality is as a result low ecological integrity in the watershed. Disturbance in the river watershed e.g. farming on the river banks causes poor ecological integrity. The absence or
the presence of the biota groups are used as biological indicators and the whole entire living community reflect the overall environmental conditions (Karr, 1981).

For many decades the trend had been to concentrate on the physico-chemical quality aspects in the assessment of water quality of rivers. As much as there has been a rapid development of geomorphological and physical methods of river assessment, riverine morphology, hydrology and connectivity still continue to deteriorate. It is thus pertinent to develop biologically based methods, and to look at all these methods from a biological perspective (Zalewski, 2002).

Increase in the reduction of the water quality in Mt. Elgon Rivers has had serious ecological implications especially in the ability to support human life, livestock and wildlife. There is all the likelihood that rivers in the region are going will face more pollution in the future because the demand for the water resource is on the rise due to un-relented human population increase. Thus, water will continue to diminish in quality as well as in quantity due to the unabated destruction of the forests, the degradation of Mt. Elgon water tower and conversion of the forest cover to land use.

The integrity of the quality and the quantity of the rivers in Mt. Elgon will potentially continue to face pressure due to the increase in commercial activities in the mushrooming urban centers in the region. This may also be due to the poor agricultural practices that have led to enormous discharge of the agrochemical wastes both in the upland and lowland areas of the rivers in the region. For unknown reasons, no assessment of water quality status of Mt. Elgon rivers region has ever been carried and hence, there is no source of reference. Therefore, the pollution status and ecological integrity of rivers in the region is unknown. There is no baseline data to be used to monitor pollution levels in rivers in relation to environmental degradation in the region.
Thus, it is imperative that the ecological status of the rivers in Mt. Elgon be known. This will give an insight of the quality and quantity integrity levels of river basic characteristics that are critical to maintenance and resource conservation and management of the river lifeline of Mt. Elgon. If they continue to remain unattended and unaddressed, the threats to water quality in Mt. Elgon Rivers will continue to have long term negative impacts on the survival of human beings, livestock and wildlife in the region.

2.6 Biological indicator organisms used to determine ecological integrity

Biological Indicator Organisms (BIO) include the macro-invertebrates, micro-organisms, algae and fish (Rosenberg and Resh, 1993). Biotic Indicator Based Assessment (BIBA) can also be used to generate information about the abundance of species taxa and their diversity. Also to be assessed are the physico-chemical conditions of the rivers including conductivity, pH, turbidity, oxygen concentration and salinity levels (Fausch et al., 1984).

The biological assessment of biota present in an aquatic system is the only best way to measure the ecological status of a biological community based on environmental functional stresses. Community composition keep altering because of the stresses within the system itself and the impact of pollution on the individual organisms, and this may act as an early warning of degradation in a biological community. The benthic macro-invertebrates are the assemblages most widely used in the bio-assessment of lotic environments because they are a diverse mixture of species exhibiting a range of pollutant levels and are abundant in most of the streams (Barbour et al., 1999).

Benthic macro-invertebrates spend most of their lifecycles between sediments and water spheres of lotic environments and this way they are capable of indicating cumulative changes
of the external environment. They are important linkages in food chains and food webs as they can be fed upon by other organisms and they also feed on other organisms. They are easy and affordable to collect, and this makes them be most preferred assemblages for biological monitoring.

The EPT richness index method can be used to directly assess the cumulative effects of all activities in the watershed of a lotic water system. These results allow for the establishment of baseline or reference conditions for watersheds to characterize their overall condition, identify potential nonpoint and point source pollutants, target resource efforts in impaired watersheds, and evaluate the effectiveness of pollution control measures. The EPT index uses three orders of the aquatic insects that are easily collected, sorted and identified; it is commonly used as an indicator of water quality.

It is used because it is reliable and it is applied in the establishing reference conditions; setting protection and restoration of goals; identifying disturbances; choosing control measures; evaluating the effectiveness of Biological Monitoring Programs (BMP) improvement measures and monitoring watershed condition change in the early stages of the project (Lennat, 1988).
CHAPTER 3: MATERIALS AND METHODS

3.1 Location of study area

River Kibisi originates from Mt. Elgon (Figure 1) which is situated at altitude of approximately 2,200 meters above sea level. The study area is found at longitude $0^\circ 45'N$ and latitude $34^\circ 45'E$. It then flows downstream through a natural forest dominated mainly by indigenous trees/vegetation cover. The river leaves the forest edge and flows through a rich upland agricultural area of extensive and intensive human farming activities and settlements. In the lower reaches it passes through a floodplain before it eventually coalesces with River Sosio, and together they form a tributary that pours its waters into River Nzoia. The larger River Nzoia which has its origin in the Cherang’ani hills and Mt. Elgon water tower flows in the southern direction ending up in Lake Victoria. The erratic weather changes due to climate change and the removal of the riparian vegetation from the river watershed have greatly affected the discharge of River Kibisi causing its volume to dwindle tremendously in recent years. The floodplain in the lowland is dominated by anthropogenic activities that include human settlements, farming, urbanization and grazing. Mt. Elgon is the eighth highest mountain, and it has the largest base than any other mountain in the world (Boys and Allan, 1988).

Along its watercourse especially in its upland reaches, River Kibisi watershed is dominated by indigenous trees and other riparian vegetation that include the following:

*Bridelia micrantha* (Horchst.) Baill; *Hagenia abyssinica* (Bruce) J. F. Gmel.; *Cardia africana* (Lam.); *Teclea nobilis* (Del.); *Podocarpus milanjianus* (Rendle); *Olea capensis* (L.); *Olea africana* (Mill.); *Maesopsis eminni* (Engl.); *Markhamia lutea* (Benth.); *Warbugia ugandesis*
(Sprague); *Podocarpus falcatus* (Thumb); *Juniperus procera* (Hochst. ex. Endl.); *Acocarpus flaxinifolius* (Weight et. Arn.); *Elaeodendron buchananni* (T. Mutanga); *Croton megalocarpus* (Hutch.); *Kigelia africana* (Lam.) Benth; *Trichilia emitica* (Vahl); *Ethrina abysinnica* (Lam. Ex. Dc. ); *Vitex kiniensis* (Turill.); *Acacia xanthophlea* (Benth.); *Prunus africana* (Hook f.) Kalkman; *Calotropis procera* (Aiton) A.W. Aiton.

Plate 3.1: A photograph of site I (Forested area) at the edge of Mt. Elgon Forest along River Kibisi showing excellent water quality with little human disturbance
Figure 3.1: Map of Mount Elgon area showing sampling sites 1, 2, and 3 along River Kibisi representing forested, agricultural and urban sites respectively.
The floodplain is dominated by human settlements and farming activities. In the lowland reaches, the color of the river turns brown because of the extensive deposition of soil sediments from open farmlands especially during the rainfall seasons. In the lowland reaches more than the upland reaches, intensive anthropogenic activities are dominant because of the increase in human population. Obviously anthropogenic activities are to blame for the decline of the river water quality degradation. Mt. Elgon is the eighth highest mountain with the largest base area than any other free standing volcanic mountain in the world (Boys and Allan, 1988).

3.2 Hydrology and geomorphology

The hydrology of Mt. Elgon region is greatly influenced by Lake Victoria and the natural forest vegetation both which influences the process of evapo-transpiration that eventually produces precipitation in the region. The resulting precipitation replenishes the underground water content that feeds rivers and the streams that originate from the water catchment area. These rivers include River Kibisi which is one of the tributaries of the larger River Nzoia which ends up in Lake Victoria. In recent years rainfall has become unevenly distributed, unpredictable and unreliable due to climate change, and this in turn has greatly influenced the discharge of rivers in the region. The southern and the western slopes of Mt. Elgon receive (about 2,000 mm. annually) while northern and the eastern slopes receive (about 1,500mm. annually) respectively (van Heist, 1994).

Water imbalances and runoffs have greatly been due to reasons above. Temporal differences in weather patterns are a cause of river water discharge being greatest during the wet periods and lowest during the dry spells. Increased anthropogenic activities that include poor agricultural practices, human settlements and massive removal of riparian vegetation from the river
watershed has led to large scale erosion. Lack of the riparian vegetation along the river watercourse has accelerated evaporation from the river water surface. This has in turn resulted in the reduction of water discharge into rivers, and hence, less discharge of soil and groundwater which sustain river flow systems.

Global warming which results from release of green gases into the atmosphere has had bad effects on weather and rain patterns as well as river runoff regimes. Understanding the hydrology of this particular region is vital because it will help put in place strategies to help alleviate problems associated with both water quantity and quality. What is required is good planning and sound water resource management in the region in order to help resolve water quality problems. Mitigation and restoration processes of the ecosystem should be achieved for the purpose of water quality and ecological integrity recovery.

The abstraction of the water resource at Kamtiong’ water supply station from River Kibisi by Nzoia Water and Sewerage Company (NZOWASCO) is one other major reason which is why the discharge of this river has greatly dwindled especially in the lowland reaches. Furthermore, the removal of riparian vegetation from the river’s watershed to give way to farming activities and human settlements has tremendously accelerated the rate of evaporation surface water thereby reducing its water discharge.

Overall, the region receives bimodal pattern of rainfall with the wettest period occurring April to October, and the major dry season occurring in the months of November to February (van Heist, 1994). The southern and the western slopes receive (about 2,000 mm. annually) while northern and the eastern slopes receive (about 1,500mm. annually). The highest amounts of rainfall occur on the slopes while light rainfall is experienced at high altitude (van Heist,
1994). The mean maximum annual temperatures in the area ranges from 27\(^{0}\)C to 30\(^{0}\)C while the minimum range from 16\(^{0}\)C to 18\(^{0}\)C. The soils in the region are mainly nithosols and andisols (Wesche, 2002).

In the upper areas, Mt. Elgon forest remains relatively undisturbed except for a few human perturbations that include settlements and agricultural practices at its margins. Though at the forest margins human disturbance is minimal, at certain places exotic trees have been planted to replace indigenous trees removed for considered reasons. However, the ecosystem and lotic water systems that originate from it are under threat due to anthropogenic activities. For example, the ecosystem suffers mans; economic activities that include removal of timber, charcoal harvesting, removal of wood fuels, poor agricultural practices, human settlements and conversion to pastureland.

Parts of the main physical features in the region are the protruding volcanic rocks which were formed millions of years ago by the process of vulcanicity. The landforms and structures of Mt. Elgon landmass are changing due to landform evolution and the process of weathering. Landform and weathering processes are controlled by forces that include earth movements or plate tectonics and climate change. Plate tectonics are responsible for the creation of the existing steep slopes associated with a volcanic mountain such as this. Continual fault movements and longtime effects of erosion have been responsible for the shaping of the landscape as seen today. Mt Elgon landscape is also subject to climate change and different types of weathering. The annual alternating wet and dry climatic conditions are the main conditions that are responsible for shaping of the landscape. However, water is the major weathering agent in the region. Water in rivers transport sediments, silt, sand and clay particles
which are later deposited in the lowland areas. Flows of rivers create land forms through erosion and deposition. Most of the erosion takes place upstream and deposition takes place downstream on the floodplain (Wesche, 2002).

River erosion is caused by water dissolving rocks, and by the abrasion of cobbles, pebbles and sand grains that rub along the base of the river valley and against each other. The moving, eroding fragments are known as river’s load. The amounts of loads depend on the strength of the river current. Deposition of sediments downstream creates a flat area of land called a flood plain as a result of periodic flooding of River Kibisi. Flashy floods mainly that occur during rainy periods play a vital role in renewing the sediment and water flow that helps in soil formation. The floodplain is continually being re-shaped as a result of growth of vegetation, erosion and deposition of new sediments as the river flows across the floodplain. Though river floods are known to be both constructive and destructive, however, they have not caused any real damage in the region. Mini-floods are a common scene especially during the rain periods when rivers overflow their banks but damage is minimal.

Large scale soil erosion in River Kibisi watershed has increased the turbidity within its waters especially in the lowland reaches. The erosion of sediments and pollutants is directly related to the anthropogenic activities where for example the removal of vegetation has resulted in an increase in amounts of erosive materials that end up in the river. Movement of materials due to the nature of land has increasingly been modified by human activities which in turn have tremendously increased the pollution levels of River Kibisi. Therefore, anthropo-geomorphology which is the study of human impacts on landforms must be considered important due to an increase in human population, and changing rainfall patterns.
3.3 Anthropogenic impacts

Exponential population increase in Mt. Elgon Ecosystem (MEE) has in recent years put a lot of pressure on the available natural resources resulting in resource-use conflict. Increased anthropogenic activities due to increase in population has caused degradation and decimation of this particular important biotic system. Expansion of the human settlements in the region is as a result of human population surge. Incision and conversion of land under the natural forest to farmlands and pastureland is a bad policy by the government in order to produce additional required food, settle the landless and provide grazing for domesticated animals. Agricultural activities in the region have been intensified to produce adequate food to feed the increasing population. This means that there is need in the application of chemical fertilizers in farms to enhance farm output though these chemicals eventually end up in the rivers causing increased pollution.

Plate 3.2: A photograph of site III (Urban area) along River Kibisi showing agricultural activities in its watershed with scarce riparian vegetation
Illegal logging especially of the indigenous trees takes place due to impunity. In the middle reaches, the river watercourse is completely awash with agricultural activities. In the lowland region, the riparian vegetation in the river watershed has completely been removed with conversion to farmland and pastureland. River Kibisi like any other lotic system in the world is under a big threat as a result of anthropogenic activities practiced in its watershed. For instance, the ecosystem suffers encroachment by human beings in search of timber, charcoal, wood-fuel, farming activities and human settlements (Plate 3.2).

Anthropogenic activities have led to increased river pollution as manmade solid and fluid waste materials of adverse impacts on living and non-living resources in the region. Erosive forces including running water carry chemicals from open farmlands contaminating the rivers in the region which become health insecurity to residents in the region. Most of the residents in the region depend on river water for survival. Contamination of water, air and soil resources affects standards of human life by lowering its quality and normal functioning.

Thus, the use of contaminated river water has proved fatal to human life and that of other biota in the region. Though river pollution is a result of increased anthropogenic activities, it is now imperative that we have as little river pollution as possible to improve health security of human livelihoods in the region. Microbial river pollution is a real health security problem in the region because it causes diseases such as cholera, typhoid fever, leptospirosis and amoebic dysentery.

The communities living in both the upland and lowland regions of Mt. Elgon Ecosystem have continued to blame each other over resource-use conflict. These communities are equally using the available resources for their livelihoods; hence, they are exerting the same pressure on the
resources regardless where they live. The degradation and decimation of Mt Elgon Ecosystem is really a big threat to those who depend on it for various supplies and needs. It would be a dignified idea to save the available resources instead of plundering them to exhaustion. Whereupon, there is need to strike a balance between resource harvesting and population growth rates both in the upland and lowland regions. If this is not achieved, this can result into serious consequences should these resources suffer a setback in future.

3.4 Selection of study sites

The Kibisi River was selected for this research study because it is one of the perennial rivers out of the expanse Mt Elgon area, and for the fact that it is one of the most polluted, and a source of water supply to most of the homes, institutions and urban centers. Sampling sites were selected randomly based on a number of factors: accessibility, physical proximity, habitat diversity and riparian land uses. The sites selection was also based on the fact that River Kibisi is the source of piped water to urban centers, homes, institutions, and animal watering. The sampling sites were representative by both the mildly polluted and highly polluted sites in the upper and lowland areas. The selected sampling sites included: Forested area (site I), Upland agricultural area (site II) and Lowland agricultural area (site III) plates 3, 4 and 5 respectively.
Plate 3.3: A photograph of site I (Forested area) at the edges of the Mt. Elgon Forest showing clean water with little human disturbance and dense riparian vegetation

Plate 3.4: A photograph of site II (Upland agricultural area) along River Kibisi Mt. Elgon showing moderate river degradation due to anthropogenic activities
Plate 3.5: A photograph of site III (Urban area) along River Kibisi Mt. Elgon showing high turbidity of river water due to anthropogenic activities

3.5 Sampling

Sampling was done for a period of four months starting from 15\textsuperscript{th} March 2011 to 30\textsuperscript{th} June 2011. The collection of samples was carried out in a systematic order at three sites which were selected based on ease in accessibility and anthropogenic activities along the river. The first data sampling site I was located near the margins of the forest, the site II was located in an upland agricultural area and the site III at the lowland agricultural area. Each sampling site was marked using a Geographical Positioning System (GPS) to ensure that samples were collected from the same place at each sampling time. The sampling was chosen such that they had to include the river sheds with mild, moderately disturbed and seriously disturbed/impaired catchment areas.
At each sampling site, the data was collected from both the pools and the riffles which were 1 metre off the river banks. Considerations were given to different biotopes namely stones, vegetation, gravel, sand and mud both in and out of the current. Disturbance Removal Sampling Technique (DRST) was used, and this involved defining specific sampling areas and then disturbing the substrate within the defined area to dislodge the benthic macro-invertebrates which were then washed down into a Hess sampler net. The samples were processed in the field to remove organic debris. This was meant to reduce the volume of the sample, and to clean the composite sample that was taken to the laboratory for identification and analyzes. The collected macro-invertebrates and organic debris components and samples were then stored in containers or sample bottles with 70% ethanol ready for laboratory analysis and classification whereas the inorganic debris components were discarded away in the field. The containers were carefully labeled to maintain identity giving details such as river name, site, date, code and location.

3.6 Physico-chemical characteristics

Significant variations in the physico-chemical characteristics were noted from the forested, agricultural and urban areas throughout the sampling period.

3.6.1 Physical characteristics

The physical parameters such as temperature, turbidity, conductivity, water depth, width of the river channel, transparency, the velocity of water flow and Total Suspended Solids (TSS) were measured in situ using standard methods at sampling stations.
Temperature – Ordinary air temperatures were measured with the help of a mercury glass thermometer with a precision of ± 0.1°C. A mercury glass thermometer was dipped into the water and left for about three minutes after which it was withdrawn and readings were taken and recorded.

Transparency was estimated as the mean of the depths at which the secchi disk disappeared when lowered into water and reappeared after being raised (Wetzel, 1983).

Depth of the water was measured using a meter rule while the width of the river channel was measured using a tape measure. Measurement of Total Suspended Solids (TSS) was measured by the use of TSS probe meter (model PCT: 40). Pick the number of holder at random, label each holder to a particular station e.g. S1 = 0.5, S2 = 2, S3 = 9. Before filtering the sample, heat the holder and the filter paper in the oven for approximately 10 minutes to drive off all the moisture. Weighing was done with the help of an electrical balance. Filtration process is done with the help of a filter pump. The samples are then transferred to the oven and dried for about 2 hours at 100°C. Then compute the difference and tabulate the results in milligrams per litre (mg/l.).

Water velocity was measured by observing the time required for a floating object to transverse a known distance downstream. This method was appropriate for coarse estimates of discharge particularly during floods, and required a little time or equipment. A floater was introduced at a short distance upstream along the river so it could travel the speed of the water before passing the first mark. A stopwatch was used to measure the time of travel between the marked sections. Turbidity – a Cecil spectrophotometer CE 323 units of turbidity being Nepherometric Turbidity Units (NTUs) (Owen, 1975);
To measure suspended sediments it was important to obtain samples which accurately reflected the stream’s sediment load. Samples were taken during high and low flow periods to develop long-term averages. Samples were taken in such a way that concentration represented an average for a section depending on the particle size. Normally variability was found to be higher towards the centre than towards the edges. Preferably suspended sediment samples were used to measure suspended solids.

The general classification of surface sediments was often done by eye when assessing the distribution of substrate types in a stream reach. Sediments could be classified visually into boulders, cobbles, gravel, sand, silt or clay. Sometimes it was hard to distinguish silt and clay, and hence, they may just be given one name as “mud” as proposed by (Brakensiek et al., 1979).

### 3.6.2 Chemical characteristics

The pH was measured by the use a corning 105 pH probe meter. The appropriate probe was dipped into collected water in a sample container in turns and the reading taken and recorded after equilibration. Conductivity was measured by use of the probe conductivity meter. Conductivity can also be determined by use of chemtrix type 700 conductivity meter with a temperature compensator.

Dissolved Oxygen (DO) was measured by use of a calibrated portable DO meter. The DO meter probe was dipped into the river water and the meter left to equilibrate before the reading was made and recorded. Dissolved oxygen was measured by use of PT1 401 dissolved oxygen
meter. The azide modification of the iodometric (Winkler method) method of oxygen
determination as described by APHA (1975) could also be used.

Measurement of Total Dissolved Solutes (TDS) was measured by the use of TDS probe meter
(model PCT: 40). The measurement of the Total Dissolved Solutes procedure is exactly the
same as that of the measurement of the Total Suspended Solids. To measure the amount of
water (filtration), the solid is put in the oven. The filtrate and the container and are left in the
oven for approximately 10 – 12 hours. They are then removed and reweighed using the
analytical balance. The results are calculated in terms of milligrams per litre (mg/l.).

The concentration of Total Suspended Solids (TSS) was estimated gravimetrically on Whatman
GFC filters. The river water (a volume of 150 ml) was filtered on site for onwards nutrients
analysis in the laboratory. The filter papers used then were carefully folded and wrapped in an
aluminum foil for onward drying in the oven at 95°C for at least three hours. The suspended
solids weight was thereafter calculated using the formula below (Wetzel and Likens, 1991).

\[
TSS = (W_r \text{mg/l.}) - (W_c \times 10^6) V^{-1}
\]

\(W_r = \text{Weight of pre-combusted filter in grams.}\)

\(W_c = \text{Weight of filter + residue in grams.}\)

\(V = \text{Volume of water sample.}\)

3.7 Biological assessment of water quality

One sample was collected from a pool and one was collected from a riffle at each of the three
selected sampling sites at a distance of 1m from the shoreline. In total six samples were
collected from the upstream to downstream sites on each of the sampling dates. Therefore, for the whole sampling period forty eight samples were collected. Samples were collected using a modified Hess sampler with an area of 0.0284 m² and a mesh size of 100 µm. The sampler was placed in the stream and large rocks cleaned by hand, and the remaining substrate thoroughly agitated for about three minutes to a depth of about 10cm where possible. The dislodged animals passed through a conical net of mesh size 100µm.

The organisms were thereafter washed into the sample bottles and preserved in 70% ethanol solution. In the laboratory, the samples were analyzed with the aid of a dissecting microscope whereby the animals were sorted out to various orders, identified to the lowest possible taxonomic unit using the appropriate keys where possible and there relative abundance determined.

In the laboratory, the benthic fauna were carefully unpacked from the labeled plastic bottles before being sorted out using different sieve of > 1 mm., 0.5 mm., and < 0.5 mm. Each of the replicated samples was washed down the 3 set of sieves to remove ethanol and to separate the benthic macro-invertebrates. The insects were correctly identified and enumerated up to the genus level by the help of a dissecting microscope set at X50 magnification and identification keys provided by Merrit and Cummins (1996). The specimen were then fixed with the help of 4% ethanol and stored in well labeled vials with indication of dates, sites and sieve sizes.

3.8 Application of the EPT index method

The EPT richness index method is the total number of species in the following order of benthic macro-invertebrates: Ephemeroptera, Plecoptera and Trichoptera. For example, if ten (10)
genera of Ephemeroptera (mayflies), eight (8) Plecoptera (stoneflies), and five (5) Trichoptera (caddisflies) are found at a site, the total number EPT index would be twenty three (23). The total EPT index will then be compared to values on an EPT rating chart to determine the water quality of the rivers under study. High quality water supports a greater number of EPT insect taxa. Ratings are tailored to account for differences in species pollution tolerance between regions (NCDEHN, 1997).

Table 3.1: An example of EPT richness index ranges and their corresponding water quality ratings (NCDEHN, 1997).

<table>
<thead>
<tr>
<th>Ratings</th>
<th>Excellent</th>
<th>Good</th>
<th>Good – Fair</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>&gt; 27</td>
<td>21 – 27</td>
<td>14 – 20</td>
<td>7 – 30</td>
<td>0 - 6</td>
</tr>
</tbody>
</table>

3.8.1 EPT index score development

The EPT index increases with improving water quality i.e., there should be a greater number of EPT insects species in cleaner water. Ratings are tailored to account for differences in species pollution tolerance between regions. (NCDEHN, 1997). Table 1 above shows an example of EPT richness index criteria developed for Mt. Elgon region in Bungoma County, Kenya.

The EPT richness index can also be used to directly assess the cumulative effects of all activities in the watershed of a lotic water system. The results allow for the establishment of baseline or reference conditions for watersheds to characterize their overall condition, identify potential
nonpoint and point source pollutants, target resource efforts in impaired watersheds, and evaluate the effectiveness of pollution control measures. It is used because it is reliable and it is applied in the establishing reference conditions; setting protection and restoration of goals; identifying disturbances; choosing control measures; evaluating the effectiveness of Biotic Monitoring Programs (BMP) improvement measures and monitoring watershed condition change in the early stages of the project (Barbour et al., 1996).

3.8.2 Determination of taxa richness

The diversity of the collected samples was determined by the number of distinct taxa and this involved taxa identification to the genus level. According to Barbour et al., (1996) this entailed laboratory identification with the aid of a dissecting microscope at X50 magnifications.

i. Total number of taxa; an indication of the variety of macro-invertebrate assemblage.

ii. The number of EPT taxa of the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies).

iii. The number of Ephemeroptera taxa.

iv. The number of Plecoptera taxa.

v. The number of Trichoptera taxa.

3.9 Determination of macro-invertebrate species composition

The composition measures were used in the determination of the relative abundance of benthic macro-invertebrate assemblages. They were used to serve as an indicator of their role in the collaborative energy and food cyclic processes in the river. The collected samples
compositional metrics were obtained through laboratory identification using a dissecting microscope at X50 magnification of:

i. The % of EPT taxa i.e. the percentage of the mayflies, stoneflies, and caddis flies larvae.

ii. The % of Ephemeroptera taxa.

iii. The % of Plecoptera taxa.

iv. The % of Trichoptera taxa.

3.10 Data analysis

Different statistical methods were used in the analysis of the data from the three sampling sites along River Kibisi. The abundances of the collected benthic macro-invertebrates were compared using Kruskall Wallis H which is a two sample non-parametric test. This sampling technique was also used to compare variations of physico-chemical characteristics between sampling sites. Pearson Rank Correlation ($r^2$) analysis was used to assess the relationship between benthic macro-invertebrate abundance and physico-chemical factors. Differences were considered significantly at p < 0.05. All data were analyzed using the Statistical Program for Social Sciences (SPSS).
CHAPTER 4: RESULTS

4.1 Morphological Characteristics

4.1.1 River Widths

River widths of the river Kibisi site I were 4.1 ± 0.33m; site II 5.0 ± 0.51m; and site III 4.1 ± 0.72; during the entire sampling period at the forested (site I), agricultural and urban sites respectively. Mean river widths at the three sampling sites, however, did not vary significantly (Kruskall-Wallis H test, $K = 1.715$, $p > 0.05$). Two sites (site I and III) had equal mean widths for the entire sampling period of 4.1 ± 0.33m. and 4.1 ± 0.72m. respectively while site II recorded the highest mean width of 5 ± 0.51m. The rocky bottom riverbed at site II made water to spread out and hence, increased its width (Plate 4). River width at different sampling sites during sampling periods differed significantly. The river widths at site I had minimal variations that ranged from 2.26 – 7.15m. (Table 4.2).

4.1.2 Water Depths

Water mean depths varied from a low of 0.9 ± 0.04 m., 0.7 ± 0.05 m. and 1.5 ± 1.15 m. at sites I, II, and III. respectively. Mean water depth however, did not differ significantly at sampling sites Kruskall Wallis H test, $K = 1.24$; $p < 0.05$) (Table 2). However, expected results were that the depths of the river should have increased in the downstream direction as is always with other lotic bodies in other parts of the world.
Table 4.2: The table shows physico-chemical characteristics measured at the three sampling sites along River Kibisi Mt. Elgon area

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Site I (Forested)</th>
<th>Site II (Agriculture)</th>
<th>Site III (Urban)</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>15.3 ± 0.46</td>
<td>17.9 ± 0.67</td>
<td>19.7 ± 0.55</td>
<td>***</td>
</tr>
<tr>
<td>pH</td>
<td>7.7 ± 0.07</td>
<td>7.7 ± 0.10</td>
<td>7.2 ± 1.16</td>
<td>n.s.</td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>7.5 ± 0.59</td>
<td>6.9 ± 0.54</td>
<td>5.0 ± 0.62</td>
<td>***</td>
</tr>
<tr>
<td>Conductivity (µScm⁻¹)</td>
<td>134.9 ± 7.03</td>
<td>157.0 ± 10.76</td>
<td>166.0 ± 12.69</td>
<td>**</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>13.1 ± 1.86</td>
<td>26.0 ± 6.82</td>
<td>44.8 ± 8.62</td>
<td>n.s.</td>
</tr>
<tr>
<td>Turbidity (NTUs)</td>
<td>78.0 ± 27.1</td>
<td>112.0 ± 40.9</td>
<td>182 ± 39.2</td>
<td>**</td>
</tr>
<tr>
<td>Width (m)</td>
<td>4.1 ± 0.33</td>
<td>5.0 ± 0.51</td>
<td>4.1 ± 0.72</td>
<td>n.s.</td>
</tr>
<tr>
<td>Transparency (m)</td>
<td>0.6 ± 0.10</td>
<td>0.6 ± 0.11</td>
<td>0.23 ± 0.05</td>
<td>*</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>1.2 ± 0.10</td>
<td>0.4 ± 0.12</td>
<td>1.5 ± 1.15</td>
<td>**</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>0.9 ± 0.04</td>
<td>0.7 ± 0.05</td>
<td>1.5 ± 1.15</td>
<td>**</td>
</tr>
<tr>
<td>TDS (mg/l)</td>
<td>257.8 ± 21.7</td>
<td>291.8 ± 25.2</td>
<td>348.0 ± 22.9</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Key: * p < 0.05; ** p < 0.01; *** p < 0.001; n.s. = not significant
4.1.3 Water Velocity

Water velocity at the three sampling sites on River Kibisi did not differ significantly (Kruskall Wallis H test, $K = 4.820, P > 0.05$). Site II had the lowest water velocity averaging $0.4 \pm 0.12 m/s$ compared sites I and III that mean velocities of $1.2 \pm 0.10 m/s$ and $1.5 \pm 1.15 m/s$ (Table 4.1). All sampling sites were characterized by almost constant velocities during sampling period (Table 4.1). Site II had the lowest water velocity averaging $0.4 \pm 0.12 m/s$ compared with sites I and III had mean velocities of $1.2 \pm 0.10 m/s$ and $1.5 \pm 1.15 m/s$ respectively (Table 4.2).

4.2 Physical Characteristics

Physical variables determined at study sites are presented as in Table 4.2. Among the variables that were measured included temperature, turbidity, Total Suspended Solids (TSS) and transparency. These parameters varied significantly at sampling sites according to prevailing conditions in the river watershed and in the water column during the study period as evidenced from the study findings. Other reasons for variations in results during the period were anthropogenic activities and natural forces.

4.2.1 Water Temperature

Mean water temperatures, however, differed significantly between sites (Kruskall Wallis H test, $K = 0.001; p < 0.05$), averaging $15.3 \pm 0.46^0 C$, $17.9 \pm 0.67^0 C$ and $(19.7 \pm 0.55^0 C)$. The average temperatures varied greatly throughout the study period with lowest temperatures being recorded in the month of June since the sampling period coincided with the long rainy season between the months of March and July (Fig. 4.1).
4.2.2 Water Turbidity

Turbidity varied between sampling sessions, though not significantly, ranging from as low as $112.0 \pm 40.9$ at site II, to a high $182.0 \pm 39.2$ at site III (Fig. 4.2). All the three sampling sites, however, generally did not show high levels of turbidity during the study period. Serious levels of water degradation were evident in lowland reaches of the river which had high concentrations of sediments turning the river water brown in colour (Plate 3.5).
Figure 4.2: Variations in Turbidity at sampling sites I, II and III along River Kibisi, Mt. Elgon area.
Plate 4.1: High water turbidity evident to river water pollution in the lowland area of River Kibisi as a result of increased anthropogenic activities

Heavy pollution was observed in the lowland reaches of River Kibisi was evidenced by the photograph graph (Plate 4.1). The brown color of the water is as a result of sediment and silt deposition of organic and inorganic materials from the open agricultural farmlands and the river watershed that end up in the river. The situation has recently been aggravated by increased anthropogenic activities and the natural forces along the watercourse of River Kibisi especially during the rainy periods.
4.2.3 Water Transparency

Water transparency was significantly lower (Kruskall-Wallis H test, $K = 7.291$, $P > 0.05$) at site III with mean transparency $0.23 \pm 0.05m$ (Fig. 4.7). Water transparencies at site I and II had mean of $0.6 \pm 0.11m$, respectively. Like water turbidity, water transparencies were generally high at all the three sampling sites along River Kibisi on 15th April 2011 and declined throughout the rest of the sampling period. The lowest transparency of 0.03m was recorded at site III while the highest transparency was 1.2 m was recorded at site II (Fig. 4.1).

![Figure 4.3: Variations in Water Transparency at three sampling sites I, II and River Kibisi, Mt. Elgon area](image)

4.2.4 Total Suspended Solutes (TSS)

Total Suspended Solids (TSS) similarly increased though not significantly from site I to site III averaging $13 \pm 1.86mg{l}^{-1}$, $26 \pm 6.82mg{l}^{-1}$ and $(44 \pm 8.62mg{l}^{-1})$ respectively. However, site III
showed the greatest variation in TSS during the study period, rising as from low in late March 5.6 to 68mg/l (Fig. 4.6) due to high inflow of sediments from the watershed or the catchment (Plate 3.5).

![Graph showing TSS variations at three sampling sites I, II, and III](image)

**Figure 4.4: Variations in Water TSS at three sampling sites I, II and III between the months of along River Kibisi, Mt. Elgon area**

### 4.3 Chemical Characteristics

#### 4.3.1 pH

Water pH varied from a low of 6.6 at site I to a high of 8.03 between sites during the study period. At the forested site, pH ranged from 7.3 to 7.9 and from 7.1 to 8.03 at the agricultural site. At the urban site, pH varied from 6.6 to 7.8 (Fig. 4.5). The mean water pH, however, varied significantly among sampling sites (Kruskall-Wallis H test, $K = 6.98$, $P < 0.05$ at particular sampling dates $7.2 \pm 0.07$, $7.6 \pm 0.10$ and $7.6 \pm 1.16$, at forested, agricultural and urban sites
respectively. pH also varied greatly through time with low pH values recorded at the urban site reaching a low of 6.6 as compared to the agriculture and forested sites, where pH of 7.10 and 7.3 respectively, were recorded. Though the river water pH remained relatively stable at sites I and II, the indication is that the river became more increasing acidic in the downward direction.

![Figure 4.5: Variation in Water pH at three sampling sites I, II and III along River Kibisi, Mt. Elgon area](image)

4.3.2 Dissolved Oxygen (DO)

Dissolved oxygen decreased significantly from site I to site III (Kruskall-Wallis H test, $K = 8.05$, $P < 0.05$) averaging $5.0 \pm 0.62 \text{ mg l}^{-1}$ while those of sites I and II were $7.5 \pm 0.59 \text{ mg l}^{-1}$ and $6.9 \pm 0.62 \text{ mg l}^{-1}$, respectively. The lowest concentration of oxygen was recorded at site III ($2.26 \text{ mg l}^{-1}$), and the highest at site I ($8.94 \text{ mg l}^{-1}$) (Fig. 4.6). Dissolved oxygen (DO) concentration at site III
through the study period was highest at site I, moderate at site II and lowest at site III which was consistent with the water quality status at each site (Fig. 4.6)

![Graph showing variation in dissolved oxygen (DO) at three sampling sites I, II, and III along River Kibisi, Mt. Elgon area.](image)

**Figure 4.6 Variation in Dissolved Oxygen (DO) at three sampling sites I, II and III along River Kibisi, Mt. Elgon area**

### 4.3.3 Conductivity

Conductivity increased though not significantly from the forested site to the lowland sampling site averaging $134.9 \pm 7.03 \mu \text{S/cm}$, $157.0 \pm 10.6 \mu \text{S/cm}$, $166.0 \pm 12.69 \mu \text{S/cm}$, respectively, at the three sampling sites I, II, and III of River Kibisi (Kruskall Wallis H test, $K = 4.54$, $P > 0.05$) (Fig. 4.1). During the study period, conductivity of the river water rose significantly at all the three sampling sites after the onset of the rain period in the month of April (Fig. 4.5) due to...
increased inflows from the catchment. Surprisingly, conductivities decreased significantly as the season progressed reaching a low 135-245 µS cm⁻¹, 127-203 µS cm⁻¹ and 110 ± 60 µS cm⁻¹ at sites I, II and III respectively by the month of May 2011.

![Variations in Water Conductivity at sampling sites I, II and III along River Kibisi, Mt. Elgon area](image)

**Figure 4.7:** Variations in Water Conductivity at sampling sites I, II and III along River Kibisi, Mt. Elgon area

### 4.3.4 Total Dissolved Solutes

The concentration of Total Dissolved Solutes (TDS) varied significantly (Kruskall-Wallis H test, \(K = 7.215, P < 0.05\)), among the three sampling sites along River Kibisi (Fig. 4.8). Site III had the highest TDS concentration averaging 348 ± 22.9 mg/l, while sites I and II recorded lower mean TDS concentrations of 257.8 ± 21.7 mg/l and 291.8 ± 25.2 mg/l respectively. Minimal differences in TDS concentration between the three sampling points occurred in March, after
which subsequent months were characterised by greater differences. This observation is considered to have been influenced by changes in weather patterns especially that of rain.

![Figure 4.8: Relative changes in TDS at sampling sites I, II and III along River Kibisi, Mt. Elgon area](image)

**4.4 Benthic community structure**

Out of the collected 48 samples collected during the study, 759 benthic macro-invertebrate individuals were enumerated, analyzed and identified to the level of genera (Table 4.3). The sampled macro-invertebrate individuals at the three sampling sites comprised a total of 17 genera of which 9 belonged to the order Ephemeroptera, 1 to the Order Plecoptera and 7 to the Order Trichoptera (Table 3). Of the three Orders of interest, the Ephemeroptera Order had the highest species richness comprising 53% of the total samples that were collected, while the Order Trichoptera had slightly low species richness with 42% and the Plecoptera had the lowest species
richness with only 5%. The Orders Ephemeroptera and the Trichoptera were observed at all the three sampling sites along River Kibisi though River isn’t comprised of only three Orders. The other Orders were not of interest as of now.

Table 3 below also shows the Relative Abundance (R/A) of the various taxa of benthic macro-invertebrate individuals as a result of the study. However, not all the macro-invertebrates are shown in the table. The genus *Rhithrogena*, for instance had the highest relative abundance value of 29.59% while the genus *Kogotus*, had the lowest relative abundance of 5.2% of the individual specimens. *Limnephilus*, *Branchycentrus*, *Trianodes*, *Nectopyche* and *Chimarra* were among the taxa that had the lowest relative abundances (0.14%). The families Heptageniidae, Baetidae and Caenidae were found at all the sampling sites.
Table 4.3: Relative abundance of Ephemeroptera, Plecoptera and Trichoptera Orders of benthic macro-invertebrate genera richness in River Kibisi, Mt. Elgon area

<table>
<thead>
<tr>
<th>ORDER</th>
<th>FAMILY</th>
<th>GENUS</th>
<th>RELATIVE ABUNDANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ephemeroptera</td>
<td>Heptageniidae</td>
<td><em>Epeorus</em></td>
<td>14.37%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Rhithrogena</em></td>
<td>29.59%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Stenonema</em></td>
<td>4.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Heptagenia</em></td>
<td>1.2%</td>
</tr>
<tr>
<td></td>
<td>Baetidae</td>
<td><em>Baetis</em></td>
<td>9.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Cloeon</em></td>
<td>10.12%</td>
</tr>
<tr>
<td></td>
<td>Isonychiidae</td>
<td><em>Isonychia</em></td>
<td>18.6%</td>
</tr>
<tr>
<td></td>
<td>Epherellidae</td>
<td><em>Ephemerella</em></td>
<td>4.5%</td>
</tr>
<tr>
<td></td>
<td>Caenidae</td>
<td><em>Caenis</em></td>
<td>0.24%</td>
</tr>
<tr>
<td>Plecoptera</td>
<td>Perlolidae</td>
<td><em>Kogotus</em></td>
<td>5.2%</td>
</tr>
<tr>
<td>Trichoptera</td>
<td>Hydropsychida</td>
<td><em>Hydropsyche</em></td>
<td>2.5%</td>
</tr>
<tr>
<td></td>
<td>Limnephilidae</td>
<td><em>Hesperophylax</em></td>
<td>0.14%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Limnophilus</em></td>
<td>0.14%</td>
</tr>
<tr>
<td></td>
<td>Branchycentridae</td>
<td><em>Branchycentrus</em></td>
<td>1.5%</td>
</tr>
<tr>
<td></td>
<td>Leptoceridae</td>
<td><em>Trianodes</em></td>
<td>0.14%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Nectopyche</em></td>
<td>0.14%</td>
</tr>
<tr>
<td></td>
<td>Philopomidae</td>
<td><em>Chimarra</em></td>
<td>0.14%</td>
</tr>
</tbody>
</table>
4.4.1 Occurrence and Relative Abundances of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa

The relative abundances of the sampled Orders varied greatly along River Kibisi with the commonly occurring genera being genus *Rhithrogena* (29.59%), genus *Baetis* (21.74%) and genus *Epeorus* (14.37%). Contrary to this, a few species were also recorded with low relative abundances. These include genus *Caenis* (0.24%) and *Hesperophylax* (0.14%) and genus *Nectopsyche* (0.14%) (Table 4.2).

During the rainy period benthic macro-invertebrates were swept by mini floods from the upland reaches to the lowland reaches. Thus, increasing their numbers increased downstream (Table 4). In the dry spell season only moderate numbers were recorded compared to the wet season. Human (anthropogenic) disturbances that destabilized micro-habitats in the lowland reaches might have caused the migration to the upland reaches of the river. This is as a result of the fact that these organisms completely avoid seriously impaired (polluted) river waters and only the pollution tolerant are found in river beds in the lowland reaches.

Table 4 below shows the presence (+) and absence (-) of benthic macro-invertebrates at the three sampling sites along the watercourse of River Kibisi. The insects belonging to the Orders Ephemeroptera and Trichoptera were found at all the three sampling sites while the Order Plecoptera was found at both sites I and II. The genera *Rhithrogena, Stenonema* and *Isonychia* were found at all the sampling stations. The genera *Heptagenia, Baetis, Cloeon, Kogotus, Hydropsyche, Hesperophylax* and *Limnephilus* were recorded at two sampling sites.
Table 4.4: The presence (+) and absence (-) of Ephemeroptera, Plecoptera and Trichoptera benthic macro-invertebrates at sampling sites I, II and III along River Kibisi in Mt. Elgon area

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
<th>Site I</th>
<th>Site II</th>
<th>Site III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ephemeroptera</td>
<td>Heptageniidae</td>
<td><em>Epeorus</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Rhithrogena</em></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Stenonema</em></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Heptagenia</em></td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Baetidae</td>
<td>Baetidae</td>
<td><em>Baetis</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Cloeon</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Isonychiidae</td>
<td></td>
<td><em>Isonychia</em></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Ephemerellidae</td>
<td></td>
<td><em>Ephemerella</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Caenidae</td>
<td></td>
<td><em>Caenis</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plecoptera</td>
<td>Perlolidae</td>
<td><em>Kogotus</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Tricoptera</td>
<td>Hydropsychidae</td>
<td><em>Hydropsyche</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Limnephilidae</td>
<td><em>Hesperophylax</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Limnophilus</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Branchycentridae</td>
<td>Branchycentrus</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Leptoceridae</td>
<td></td>
<td><em>Trianodes</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Nectopyche</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Philopomidae</td>
<td></td>
<td><em>Chimarra</em></td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Totals: 15 12 5
The benthic macro-invertebrates community at sites I, II and III was equally rich comprising a total of the three orders (Fig. 4.9). However, only two benthic macro-invertebrates Orders were found to be more abundant and accounted for over 90% of the sampled individuals. They were Orders Ephemeroptera with a relative abundance of (60%) and Order Trichoptera with a relative abundance of (40%) respectively. Both these Orders were dominant at all the three sampling sites while the Order Plecoptera occurred at sampling sites I and II but completely disappeared at sampling site III.

The benthic macro-invertebrates fauna had the richest abundance at sites I and II with 15 and 12 genera respectively (Table 4). On the contrary this biotic community at site III had the lowest generic richness comprising only 5 genera (Fig. 4.10). The most common genus was *Isonychia* which appeared at all the three sampling sites whose relative abundance was 54.81%. Similarly, *Rhithrogena* genus was noted to occur commonly at all the three sampling sites. The genus that recorded the lowest occurrence at all the three sampling stations was genus *Hydropsyche*. 
Figure 4.9: Relative abundance of benthic macro-invertebrate Orders at sampling sites I, II and III along River Kibisi Mt. Elgon area.
Figure 4.10: Comparison of the relative abundance of the benthic macro-invertebrates genera among sampling sites I, II and III along R. Kibisi in Mt. Elgon area
4.4.2 Variations in EPT species richness index

Comparisons of the EPT richness index values of the three sites showed high significant differences (Kruskall-Wallis H test, $K = 20.16, P < 0.05$), with site III recording the lowest index of $10 \pm 0.71$ (Fig. 4.11). However, site I had the highest mean index of $34 \pm 1.33$ and it was followed by site II with a mean index of $25.0 \pm 1.22$. Just like other physical and chemical characteristics, EPT indices at the three sampling sites were noted to change with time. Results obtained indicated that fewer species were found in the lowland agricultural station which was characterized by serious impairment of river water quality due to increase in water quality stresses as result of burgeoning anthropogenic activities.

Comparisons within the EPT genera richness showed tremendous variations (Table 4.4). This is why site I was assigned water quality status of being Excellent water quality; site II of being Good water quality and site III of being Fair water quality. The EPT richness index assigns water status values as follows: $\leq 6$ = Poor water quality; $7 - 13$ Fair water quality; $21 - 27$ Good water quality and $\geq 27$ as excellent water quality (NCDEHNR, 1997). Therefore, according to the results obtained from the study research: site I was mildly polluted; site II was moderately polluted and site III had very serious impairment.
Table 4.5: The Ephemeroptera, Plecoptera and Trichoptera species richness index (NCDEHN, 1997) at sampling sites I, II, and III along River Kibisi, Mt. Elgon area

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>Site I (Forested)</th>
<th>Site II (Agricultural)</th>
<th>Site III (Urban)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15th March</td>
<td>40</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>30th March</td>
<td>29</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>15th April</td>
<td>20</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>30th April</td>
<td>30</td>
<td>60</td>
<td>17</td>
</tr>
<tr>
<td>15th May</td>
<td>12</td>
<td>32</td>
<td>48</td>
</tr>
<tr>
<td>30th May</td>
<td>10</td>
<td>35</td>
<td>53</td>
</tr>
<tr>
<td>15th June</td>
<td>8</td>
<td>36</td>
<td>59</td>
</tr>
<tr>
<td>30th June</td>
<td>6</td>
<td>37</td>
<td>59</td>
</tr>
</tbody>
</table>

| Mean± SE      | 34±1.33           | 25±1.22                | 10±0.71          |

| Water Quality | Excellent        | Good                   | Fair             |

4.4.3 Correlation analysis of EPT richness indices

The results of correlation (Spearman’s Rank Correlation test (P > 0.05, Rho = 0.6143) between EPT index and physical characteristics showed significant negative correlation for temperature and water velocity, transparency, and non-significant negative relationship with turbidity. Correlation results between EPT indices and chemical characteristics, however, showed
significant positive relationship with dissolved oxygen concentrations, and non significant positive relationship with water pH. Contrary to this, a significant negative relationship was noted between EPT indices and conductivity values, while a non significant negative relationship was recorded between EPT indices and total dissolved solids concentration. Further, comparisons between water temperature and dissolved oxygen concentration did not show any significant correlation $r^2 = -0.7753$; d.f. = 2; $p < 0.01$. (Table 4.6).

Table 4.6: The correlation between Ephemeroptera, Plecoptera and Trichoptera richness index and physico-chemical parameters among sampling sites along R. Kibisi, Mt. Elgon area

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPEARMAN’S (Rho)</th>
<th>P-VALUE</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>-0.7753</td>
<td>0.0001</td>
<td>Significant</td>
</tr>
<tr>
<td>Turbidity</td>
<td>-0.3298</td>
<td>0.1156</td>
<td>Not significant</td>
</tr>
<tr>
<td>Transparency</td>
<td>0.4081</td>
<td>0.0476</td>
<td>Significant</td>
</tr>
<tr>
<td>Velocity</td>
<td>-0.5843</td>
<td>0.0027</td>
<td>Significant</td>
</tr>
<tr>
<td>pH</td>
<td>0.3503</td>
<td>0.0933</td>
<td>Not significant</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>0.6587</td>
<td>0.0005</td>
<td>Significant</td>
</tr>
<tr>
<td>Conductivity</td>
<td>-0.5398</td>
<td>0.0065</td>
<td>Significant</td>
</tr>
<tr>
<td>Total Dissolved Solutes</td>
<td>-0.295</td>
<td>0.1618</td>
<td>Not significant</td>
</tr>
</tbody>
</table>
CHAPTER 5: DISCUSSION

5.1 Morphological characteristics

River Kibisi recorded small differences in its width between the three sampling sites I, II and III respectively but they did not differ significantly. The differences were probably caused by the nature of the surface of the riverbed. For example, site II which had the largest width than sites I and III had its bottom surface lined with rock (Plate 4). At site II, the rocky bottom of the river was responsible for the spreading out of water over a large surface area, which increased the width of the river. The variation observed in river width at various times was caused by changes in water volume during the study period. For example, the three sampling sites recorded increased river width but they differed significantly with site II being wider (0.87 ± 0.0376m) than sites I and III. The great depth at site I was perhaps due to the presence of the hard rock at the bottom of the river (Plate 3.4).

Water velocity in (rivers) lotic ecosystems is normally influenced by the elevation of the land, water volume and the width of the river. Site I located at the highest altitude of the river did not record the highest velocity as expected. This could be attributed to the presence of the pool of water at the site that greatly contributed to decrease in water velocity. This can also supported by the fact that site I had the greatest depth than the other two sampling sites. On the contrary, river waters at site III which is located in the lowland reaches and at low altitude had the highest velocity. This observation was not in line the expectation of water velocity known to prevail at lower reaches of most river systems. Site III had the least water depth, and hence, water had to flow faster than at sites II and III so as to discharge the large volume of water received from the higher reaches of the river (Hynes, 1970).
The velocity of water had a direct and indirect effect on the aquatic benthic macro-invertebrate community. High river velocity supports more oxygen content and thus, more aquatic organisms. However, the discharge of River Kibisi varies seasonally imposing seasonal changes on the biological communities. During the rainy periods the discharge is high than during the dry seasons. There is a tendency of the populations of the macro-invertebrates being high in the upland areas than in the lowland areas especially during the rainy seasons (Weatherly and Ormerod, 1990).

The water quality of River Kibisi had been compromised at the upland sampling sites but more so at the lowland sampling site III due to high levels of pollution. The degradation of the water status of River Kibisi was due to a diversity of causes including point and non-point pollution sources making mitigation and adaptation to be more difficult. Pollution of river water by human and animal wastes has made the foul of rivers in the region especially in low land reaches. Disposal of large volumes of organic sewage into the river due to agricultural activities, urbanization and institutions results in a decrease in the quality of river water. Increase in human population has translated into increased human activities resulting in the generation of hazardous wastes causing high river pollution levels. It is imperative to reduce human activities because they are impacting negatively on the river water quality status thereby affecting human health and lowering living standards.

The forested area (sampling site I) had good water quality, and at this point the river was only mildly polluted or degraded. Anthropogenic activities were absent at this sampling point or if present are very minimal. The site had good oxygen supply, low temperatures and good organic and inorganic substrate composition. The site also had the greatest species composition, richness
and diversity of mayflies, stoneflies and the caddisflies. This can be attributed to the excellent river water quality and good ecological integrity (Hynes, 1972).

Stoneflies temporal changes in the macro-invertebrate communities can be linked to heterogeneity and stability of the habitat, possibly reflecting the availability of refugia from disturbance events and predator and prey interactions, intrinsic population’s processes such as succession, and the random events like chance extinction (Weatherly and Ormerod, 1990; Brown, 2003).

At the upland agricultural sampling area (site II), the river water was moderately degraded or impaired with moderate pollution levels but with a fairly good oxygen supply. There were however, continuous human disturbances at the site. Intensified anthropogenic activities including poor agricultural practices were responsible for the degradation of the river water quality as well as that of the watershed. The color of the water was averagely brown, an indication of sedimentation and siltation. Thus, at this point the river water was moderately degraded. It had moderate species richness and diversity of the benthic-invertebrate fauna with the order Ephemeroptera being dominant and the Trichoptera being less dominant while the Plecoptera being least dominant (Armitage et al., 1983).

At the lowland sampling station (site III), the river water was highly polluted with sediments and organic materials. The river had low oxygen content due to deposition of sediments, chemicals from open agricultural fields, homes, institutions and urban centers. At this sampling site, benthic macro-invertebrates were fewer in richness and diversity as evidenced from the findings (Table 4.3). Their numbers increased slightly in the months of May and June, a fact attributed to
the increase of rainfall and hence, increases in river discharge. The high river discharge must have been responsible in the transfer of the benthic fauna from the upland to the lowland reaches.

Fundamentally, the lowland reaches experience intensive and extensive anthropogenic activities that include removal of riparian vegetation from the river watershed, river bank farming, conversion to farming and pastureland as well as human settlements. These activities have resulted in rise of river water pollution and increase in environmental stress downstream. The main representatives at sampling site III of the benthic macro-invertebrate assemblages were the most pollution tolerant species (Armitage et al., 1983).

The natural flow of lotic or running water ecosystems is usually high and this provides water with a natural cleansing ability (Hynes, 1970). Also, the regular supply of prop gules delivered from upstream to downstream locations except in the most drastically degraded situations helps improve the water quality status. As a consequence, rivers have some natural recovery capability which facilitates the restoration of river ecosystems (Gore, 1978).

Big volumes of sewage and solid wastes have become a big nuisance especially in the lowland reaches of the River Kibisi in recent times. The solid wastes from various homes which are deposited haphazardly by area residents eventually end up in this river contributing enormously to its pollution. Recovery of the river regime is dependent on opportunities for colonization, and subsequent population growth of the aquatic fauna so the rapidity of organism’s life cycles, their dispersal capabilities, and the availability of refugia which has become significant. New adequate and strategic measures should be put in place in the nearest future to avert an increase in the contamination of the River Kibisi waters, and restore the riparian vegetation in its watershed to stop the diminishing water volumes.
5.2 Trends in physical variables

A number of physical characteristics are of great importance in the determination of the biological nature of lotic systems and the ecological integrity of their watersheds. These parameters include temperature, turbidity, transparency, Total Suspended Solids (TSS) and substrate and sediment deposition.

The physical parameters were measured in situ using standard methods at sampling stations during the study period. These characteristics varied at all the three sampling sites which were approximately five kilometres apart along the river. Water temperature for instance recorded a significant variation at all the three sites. Sampling site I located at the edge of the forest and at a higher altitude recorded the lowest temperatures (15.3 ± 0.46°C), while site III located far in the lowland reaches of the river recorded the highest temperatures (19.7 ± 0.55°C). High temperatures at site III was caused by the exposure of the river to the sun, complete lack of vegetation canopy and heat exchange with the atmospheric air. Low temperature record at site I may, however, be attributed to the cooling effects by the dense forest canopy and the low sun intensity which is associated with high altitude. This observation concurs with study findings by Swift (1983) who found forests to influence the temperature regime of rivers and their macro-invertebrate communities. Similarly, temperatures showed seasonal variations at all the three sampling stations on River Kibisi. Generally, the months of March and May recorded higher temperatures which were due to the dry and sunny conditions in the region. On the contrary, the end of the months of April, May and June recorded relatively low temperatures, a condition attributed to onset of cloudy and wet conditions in the region. Changes of temperature regimes of streams have an association with forest canopy cover.
Similar studies by Bryne and Dates (1997) noted that water temperature can affect the amount of dissolved oxygen in river water, the rate of photosynthesis of aquatic plants, the metabolic rates of aquatic organisms, the rate of decomposition, sensitivity of organisms to toxic wastes, parasites and spread of diseases. Temperatures of river waters have increased in the region because of deforestation and the removal of riparian vegetation from the river watersheds. Changes in temperatures can cause major shifts in the structures of lotic or aquatic biotic communities. Warm river water holds less oxygen than cold river water. Increase of river water temperatures normally accelerates rates of decomposition of dead remains of plants and animals thereby making nutrients recycled back into the atmosphere.

Water turbidity was tested because of its effects on other parameters such as temperature, dissolved oxygen and primary productivity of the ecosystem. For example, high water turbidity can increase water temperatures, which in turn reduces the level of dissolved oxygen lotic waters. Drinking water is normally tested for turbidity because elevated amounts of turbidity can cause a breeding ground for micro-organisms. Water turbidity of River Kibisi was greatly affected by the anthropogenic activities along the river watershed. The lower reaches as represented by site III recorded high of 182.0 ± 39.2 NTUs, while the upper reaches located on the edge of the forest (site I) recorded the lowest turbidities averaging 78 ± 27.1 NTUs. These turbidities were generally higher than the guidelines proposed by Chapman et al., (2004) for freshwater systems. High turbidity within the river water was mainly caused by water runoffs that carried soil particles from the nearby farmlands into the river. Normally, high turbidities are mainly recorded during rainy seasons as these periods are characterized by high rates of soil erosion (Palamuleni et al., 2001), research report that concurs with the findings of this particular study. Lowest turbidities were noted to occur in the month of April. This was because this month
was characterised by dry weather conditions which in turn resulted in decrease in water turbidity in River Kibisi. Deforestation and clearance of the riparian vegetation near the river watershed was another possible cause for the high levels of turbidities and high transparencies.

Site III had the highest concentration of TSS that averaged 44.8 ± 8.62 mg l⁻¹. This was an indication of high rates of soil erosion in the lower reaches of the river. This was supported by the results of turbidity and water transparency which were both high and low respectively at site III. The study recorded a decrease in turbidity towards the upper reaches of the river with sampling site I having the lowest TSS concentration of 13.1 ± 1.85 mg l⁻¹. TSS of the Kibisi River did not show significant differences between sampling stations. The intensity of the Total Suspended Solids (TSS) is normally linked to soil erosion around the river channel. The high rates of erosion towards the lower reaches of the river are perhaps thought to have been caused by clearance of vegetation of the river watershed to pave way for human settlements or farming activities and conversion to pastureland as evidenced by (Plate 2). This observation is supported by findings by (Johnson et al., 2005) on various rivers in Southwest Ireland, whose results showed significant differences in suspended solids between different points of the rivers studied and attributed it to clearing of forests in the region.

Overall, transparency values increased downstream and this corresponded to the general increase in turbidity as revealed by the brown colour of the river water. Morris et al., (2003) found out that an increase in BOD downstream and a decrease in transparency therefore might have been caused by an increase in the runoff which transports organic matter and sediments from open agricultural fields. The situation was aggravated by the onset of heavy rains which tended to increase with time during sampling period. The combination of physical (sediments), organic
matter (animal faecal matter) and inorganic matter (nutrients) constituents, ultimately make their way into the local streams and rivers (Dallas and Day, 1993). Furthermore, increased organic matter or content had a significant bearing in the BOD (Rinne, 1988). Similarly, studies on water transparency, just like with turbidity showed significant lower transparency (0.23) at site III. The low transparency was mainly due to high rates of soil erosion especially in the lower reaches of River Kibisi. It is normal for high turbidities to conform to low transparency. Even if significant differences did not occur between sampling sites with respect to their water conductivities, they were observed to increase from sites I to site III. This was attributed to the increase in deposition of ions into the River Kibisi as it flowed downstream.

5.3 Trends in chemical variables

Like the physical characteristics, chemical characteristics are of great importance in the determination of the biological nature of lotic systems and the ecological integrity of their watersheds. These parameters include pH, dissolved oxygen (DO), conductivity and total dissolved solids (TDS).

Most of the chemical parameters measured at sampling stations on River Kibisi showed significant differences between the three sampling sites. There were significant differences in water pH among sampling sites. pH averaged 7.7 ± 0.07, 7.7 ± 0.10 and 7.2 ± 1.16 at sites I, II and III respectively. However, the level of pH at the three sampling stations ranged from 6.6 ± 8.03, values which were within the pH range recommended by Chapman et al., (1996) and World Health Organization WHO, (2000) for clean drinking water (pH: 6.5 – 9.5).
The slight decline in water pH noted at station III towards the end of the study period might have been caused by deposition of chemical elements into the river that had acidic qualities resulting in a decline of the water pH. From the study findings there was a slight shift of the pH towards the alkaline conditions. The rivers’ bedrock or the source of the water of the river could be a pointer to this (Dow and Zampella, 2000).

In their study findings, Kinyua and Pacini (1991) assert that the level of pH can have a direct effect on the physiology of the aquatic organisms. Any slight change of the river water to alkaline or acidic conditions would adversely impact negatively on the aquatic biota population. Under such conditions, benthic macro-invertebrates that are unable to keep up with or are unable to tolerate high pollution conditions tendency disappear downstream because they are unable to keep up with the competition for food or micro-habitats. These results or findings are true for unhealthy biological aquatic communities which are normally dominated by a few tolerant taxa (Sutcliffe and Hildew, 1989).

The usual pH ranges for freshwater aquatic systems are between 6.0 and 9.0 (Boney, 1989). Most aquatic biota is very sensitive to rapid environmental changes, and hence, survives within accepted pH ranges and disappears under the toxic effects of the pH. According to findings done in the Ruwenzori Mountains, the soils and the geology of the catchment largely determine the pH of stream waters under base flow conditions (Bailey et al., 1994). Kratz et al., (1994) observed that changes in mean pH affect benthic macro-invertebrates richness and diversity, and a short term exposure to acidic conditions might be lethal to several taxa groups.

High dissolved oxygen was recorded at site I presumably due to low discharge, high water quality and maximum canopy cover ( site I 7.5 ± 0.59; site II 6.9 ± 0.54; site III 5.0 ± 0.62)
respectively. A related study in the Cootamundra creek, Australia attributed high DO to the fact that these sections of the river had high riffle sections and eddying currents that could be used explain the high dissolution of oxygen in the water (ANZECC, 1997). Oxygen is a key limiting component in aquatic ecology as it influences the performance and community structure of the aquatic biota. However, oxygen saturation in aquatic ecosystems is temporarily and spatially much more variable than it is on land (Jacobsen et al., 2003). Lack of riffles and intermittent pools in the lowland reaches of lotic systems reduces the rate of water mixing with atmospheric oxygen. Dissolved oxygen is critical in the survival of aquatics organism (Chapman et al., 2004). Dissolved Oxygen (DO) concentration at the three sampling sites along river Kibisi ranged from 2.26 – 8.94 mg/l.

The minimum concentration of 5 mg/l is required for the survival of most aquatic organisms. Sampling site III for instance had an average of 5.0 ± 0.62 mg/l of DO which was low especially during the start of the sampling period. This was attributed to slightly higher processes of decomposition of organic matter at site III compared with sites I and II. Similarly, high water temperatures at site III may have contributed to low oxygen concentration at the site. Decomposition of dead decaying matter by bacteria removes dissolved oxygen from water to the detriment of other aquatic organisms. As oxygen gets depleted, species composition of the rivers or streams may change dramatically or die off or leave the area altogether and hence, low oxygen tolerant organisms may prevail in the same area. About half of oxygen demanding pollutants comes from non-point sources. Animal wastes used as fertilizers are the most conspicuous pollution point source.
According to Ebbert (2003), increased water temperatures reduce water dissolved oxygen solubility. The low DO concentration at site III might have resulted from high rates of respiration at the site as a result of high concentration of bacteria that cause decomposition of organic matter. The concentration of dissolved oxygen also depends on temperature, pressure and the concentration of various ions (Wetzel, 1983).

The highest conductivity recorded (Table 2) were attributed to the deposition of ions, nutrient and other elements into the river during sampling period as this concurred with the planting period in the region. Similarly, Total Dissolved Solids (TDS) did not record significant differences between the three sampling sites along River Kibisi. Its concentration ranged from 5.6 – 68 mg/l, values which were greatly below desirable concentration of 500 mg/l (WHO, 1996). Like water conductivity, TDS concentration was noted to increase from site I to site III, a characteristic attributed to increased deposition of ions and nutrients especially in the lowland reaches of River Kibisi. The results of this study noted a positive correlation between conductivity and TDS, an observation supported by Kutty (1987) whose findings showed an increase of ions and nutrients downstream. The concentration of light depends on the velocity of the river and the overall density of photosynthetic activities of aquatic flora that inhabits the entire water column from the surface of the bed.

5.4 Benthic macro-invertebrate community structures

Benthic macro-invertebrates were found in large numbers of riffles of sites I and II of River Kibisi than at pools. This was perhaps due to the factors that riffles had better oxygen concentration, less sediment deposition and water discharge was high at mentioned sites. Fundamentally, riffles normally have more food particles for the benthic macro-invertebrate
communities than pools. The substrates which are basically microhabitats for benthic assemblages were also found in large numbers in the upland reaches than in the lower reaches of the River Kibisi. This is perhaps the colonization of aquatic biota depends on the number of substrates present in the river. These substrates normally referred to as biotopes include stones, solid rocks, gravel, sand particles, roots, sludge, dead wood, reeds, submerged spermatophytes, filamentous algae and mosses (Cairns and Pratts, 1993). Benthic macro-invertebrates found in aquatic environments are less mobile than the rest of the aquatic organism, are easily collected and most have long periods of development in the aquatic environment. Thus, they reflect deleterious events that have occurred in the aquatic environment during the initial stages of their development (Cairns and Pratts, 1993).

Fundamentally, it was observed that benthic macro-invertebrates were in large numbers at the riffle sampling points than at the pools at sampling sites. This perhaps was because of the fact that the riffles had better oxygen concentrations and less sediment deposition because the water discharge was high. Incidentally, the riffles points have more food particles for the benthic macro-invertebrates than the pools. The substrates which are the micro-habitats for benthic assemblages were also many in this part of the river. This is because the colonization of aquatic biota depends on the number of substrates present in the river. These include stones, solid rocks, gravel, sand, sludge, roots, dead wood, reeds, submerged spermatophytes, filamentous algae and mosses (Hynes, 1972).

Apparently, the numbers of aquatic biota and their life cycles have completely changed due to an increase in pollution levels of River Kibisi. Some benthic macro-invertebrates might have become extinct or died or migrated to new micro-habitats due to alterations in pollution status of
the river water. This is especially true in reference to the lower reaches of the River Kibisi as a result of high levels of pollution due to increased human (anthropogenic) activities. Habitat restoration must be achieved in order that recovery can be realised. Though restoration is possible, it is hard to revert back to the original habitat that was originally there before because the destruction has already been done (Fig. 4.9).

By composition, the Ephemeroptera and the Trichoptera dominated the study sites accounting for almost about 90% of all the total individuals that were sampled at the three sampling sites along River Kibisi. Only, genus Kogotus of the Order Plecoptera was found at the upper and middle sampling stations which were associated with pristine waters, and these organisms completely disappeared downstream (Richards et al., 1997). This was perhaps because of the serious impairment of the river water quality in the lowland reaches. However, the genera Heptageniidae (Ephemeroptera), and Hydropsychidae (Trichoptera) were found the lowland areas of the river because they are able to colonize waters with low oxygen concentration due to the ability to oxidize mud on the river bottom to produce haemoglobin. Similar low numbers of the Plecoptera in tropical waters has been reported (Richards et al., 1997).

Higher taxa richness was recorded in the upper reaches of the Kibisi River. Otherwise, a decrease in taxa richness was observed in the downstream direction. This was most likely perhaps because of reduced food resources downstream, increase in environmental stress, fewer microhabitats and high levels of organic pollution. These findings are in agreement with the other studies where impaired sites with low numbers of species and high densities are as a result of inter-specific competition among taxa (Conell, 1978).
River Kibisi had the highest taxon richness in the uppers study stations but decreased in the lowland sampling station. This is the trend of expected results in most of the riverine ecosystems as they reflect the changes in stream order and other factors that influence aquatic community composition and structure (Vannote et al., 1980). Downstream changes in taxon richness can be attributed to changes in the physico-chemical factors which had different variations.

The highest diversity in the taxon richness at site I of River Kibisi can also be attributed to the excellent habitat quality. The rich vegetation canopy at the site is a good source of allochthonous organic matter for lotic stream biota. The heavy riparian canopy at the edge of the forest helps maintain low water temperatures and provide diverse micro-habitats for a variety of benthic macro-invertebrates leading to an increased diversity. This is in conformity with what is expected in un-impacted areas that contain some benthic communities (Jones et al., 2002).

Temporal changes in benthic macro-invertebrate fauna can be linked to spatial heterogeneity and the stability of the habitat that possibly reflects the availability of refugia from disturbance events and predator prey interactions, intrinsic populations processes for instance succession, random events like chance, extinction or colonization (Ormerod, 1990; Brown, 2003; Milner et al., 2006). The main representatives at sampling site III of the benthic community were the most pollution tolerant groups or species (Armitage et al., 1983). Stonefly assemblages consist of cold stenothermic representatives that are typical of higher altitudes (Miserendino, 2006). The caddisflies typically inhabit lowland reaches of streams or rivers because of the less organic load in comparison to the upland reaches which have high concentration of the organic load.

Predictably, the numbers of benthic macro-invertebrate genera were reduced tremendously in the downstream direction due to an increase in pollution levels of the waters of River Kibisi (Fig.
Some might have even become extinct or died or migrated to new habitats due to alterations in environmental conditions. This is very true especially in reference to the lowland reaches where increase in anthropogenic activities has led to an increase in serious pollution of the river water. Degradation of the quality of the micro-habitats due to increase in pollution has resulted in the reduction of the diversity of the benthic macro-invertebrate composition. The riparian vegetation had completely been removed from the river watershed with the aim of conversion to farm and pasture lands. Habitat restoration must be achieved so that recovery can be realized. Though restoration is possible, it is hard to revert back to the original habitat as it were because the massive and extensive destruction has already been done.

Changes in both benthic macro-invertebrate communities and water quality parameters over time or between sites are commonly used in impact assessment on riparian land activities such as clear-felling in river catchment areas (Macdonald et al., 1991; Rosenberg and Resh, 1993). Collier (1993) while working on rivers in New Zealand recorded low EPT values for sites that had experienced clearing of forests and vegetation on the watershed of rivers. Similarly, he found out that clear-felling of forests is negatively correlated to river water quality. His observations support the findings of this study as the lowland watershed of river Kibisi has scanty vegetation cover and low benthic macro-invertebrate diversity. Benthic macro fauna especially the Ephemeroptera, Plecoptera and Trichoptera are reported to be very sensitive to pollutants such as sediments, heavy metals, chemicals and organic nutrients (Bryne and Dates, 1997). Similarly, it was observed that if a large sample of specimens belonging to the EPT orders are collected from a stream, the water quality is likely to be very good. These organisms are used in the assessment of water qualities because they are very sensitive to alterations in river water quality status, and
justifiably and most frequently employed biological parameters in water quality monitoring studies (Morse et al., 2007).

The benthic macro-invertebrates fauna investigated showed a variation in persistence and stability among sampling sites during the study period. The Ephemeroptera and Trichoptera taxa were found at all sampling sites because they are well adapted to survive even in the most polluted waters downstream. The Plecoptera order macro-invertebrates was absent from the highly polluted waters in the lowland reaches. The findings indicated that the Ephemeroptera taxa is more tolerant and most stable to pollution while the Plecoptera taxa is more sensitive to high degree of pollution and hence, very rare. However, all taxa respond rapidly to changes in the environment and they have diversity and effects that provide a variety of responses to changing environmental conditions (Hellawell, 1978; Rosenberg and Resh, 1993; Boothryod and Stark, 2000).

The composition and structure of the benthic invertebrates communities and the values of the EPT index indicate that the upper reaches of River Kibisi is of good ecological status. However, the lower reaches of the watercourse is of poor ecological integrity due to degradation largely due to human (anthropogenic) activities. Further extensive and intensive investigations should be carried out in the nearest future on rivers in the region to establish their ecological status.

There was a significant relationship between biotic indices and the levels of pollution of River Kibisi. The forested sampling site I was highly correlated with benthic macro-invertebrate indices than the sampling site III in the lowland reaches of the river because of the riparian buffer. This study result is supported by previous studies indicating the role of riparian buffers protecting the water quality status (Gregory et al., 1991). Some species are considered to be
stable and persistent while others are unstable and un-persistent. This phenomenon can be used to indicate whether a certain species has locally become extinct over a period of time span or reflect a short time disappearance from the micro-habitat. The presence of stable zoo-benthic assemblages and their persistence is highest where environmental conditions are relatively constant, and where the taxa are well adapted to prevailing environmental conditions or regimes (Townsend et al., 1989; Bradley and Ormerod, 2000).

The Order Plecoptera or stoneflies are the most sensitive of all the benthic macro-invertebrate communities because they are on record of disappearing completely downstream due to serious degradation of the water quality. Only tolerant EPT families (Baetidae and Hydropsychidae) are on record to survive under serious environmental stresses in the downstream direction of streams. According to Simic (1999), stoneflies, as most sensitive group immediately disappear under serious disturbance, while mayflies and caddisflies vanish in conditions of very high pollution stress (Figure 4.10).

Heptageniidae family with some exception inhabit mountainous and foothill streams. The results obtained concur with the observation of Ikonomov (1963) who found the presence of the Heptageniide family near the mouth of the Serbia river, one of the major tributaries of the river Vardar. Several species of the Hetagiidae family were found within the lower stretches of the River Serbia (Paunovic et al., 2007).

5.5 EPT index score

The decrease of EPT index of effectiveness for ecological status assessment in the downstream direction of rivers is directly proportion to the number of the EPT genera. This is due to the fact that changes in aquatic conditions are as a consequence of increase in pollution levels. Benthic
macro-invertebrates are known to be useful monitoring quality indicator organisms as they exhibit a relatively low range of responses to physical and chemical water quality stresses. The EPT index score decreased downstream of the Kibisi River with increase in pollution levels of the water. The upper reaches site I of the river had the highest score of the EPT followed by site II and then site III. The working principle based on the EPT index method is that with low index score have less biotic diversity and thus, a pointer to poor habitat quality (Dickens and Graham, 2002).

The EPT richness index is an effective tool for use only in rivers with hard bottom substrates. The index when used in the assessment of river water quality status will always reflect the quality of the aquatic environment (Bode et al., 1997). Nevertheless, the effectiveness of the EPT index decreases along the river continuum, and in the case of typical lowland rivers, the metric is not a good indicator of an environmental stress since the EPT index within which those river habitats naturally occur with a lower number of species and lower population densities (Paunovic et al., 2007). The situation of a decrease of the EPT effectiveness of ecological status assessment in the downstream direction was demonstrated in the study.

Though benthic community variations are due natural changes, the variations are mainly due to the increase in pollution levels along the river course in the downstream direction. The methods of ecological assessment based on the EPT richness index is a good approach to effective monitoring of aquatic ecosystem health in selected rivers because it is an effective indicator of environmental pollution. The method that was applied in this particular study was efficient and easy in application as it is cost effective and requires less time to sample the organisms.
5.5.1 EPT index as a measure of ecological integrity

The EPT index was found to be an effective assessment method mainly for rivers with hard bottom substrates. The index clearly reflects the quality of the aquatic environment (Bode et al., 1997). Nevertheless, the effectiveness of the index decreases along the river continuum and in the case of a typical lowland river, the metric is not a good conductor of environmental stress, since the EPT taxa within the river habitat naturally occur with a lower number of species and lower population densities (Paunovic et al., 2007).

The assessment of the impacts of land use activity in river catchment is an important component facing resource managers in the modern world. The benthic macro-invertebrate assemblages are widely used in the bio-assessment of lotic ecosystems because they of a diverse mixture of taxa that exhibit a range of responses to river pollution levels. The assessment of the water quality of river Kibisi showed significant differences between the three sampling stations along River Kibisi. The upland reaches of the river had the highest EPT index values compared to the two stations in the downward direction which indicated good quality of the river water. The EPT index values to decrease in the downward direction an indication of the deterioration of the water quality towards the lowland reaches.

The highest EPT index values at site I corresponded to good water quality, while the slightly low values at site II indicated moderate water quality and the lowest values recorded at site III showed poor water quality (NCDEHNR, 1997). Poor water quality is synonymous with high pollution levels of the river water. The EPT richness index is an appropriate approach to this study because it takes into account the abundance of the aquatic taxa, and reflects even the very minor changes in abundance and community structures of the river ecosystem. It is also a
flexible approach and gives the researcher freedom to select any pollution sensitive score system based on family, generic and specific levels. The EPT biotic richness index is universally applicable and it is usually affected by the geographical location of the river. Rehabilitation of the physical habitat and proper legislation are the two principal strategies of stream restoration measures for the purpose of the improvement of the water quality status of River Kibisi in order to enhance livelihoods in the region.
CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. From the results, the water quality of River Kibisi varied from excellent to fair in the downstream direction due to increase in pollution levels as evidenced by high water turbidity, poor transparency, low species richness, composition and diversity of the benthic macro-invertebrate fauna. This was as a result of natural forces and an increase in anthropogenic activities.

2. The results obtained were precise and reliable and thus they can be applied as a point of reference in future bio-assessments in the region. The results can also be used to make decisions on water quality and ecological integrity of rivers in the region.

3. The results showed variations in overall values of physico-chemical parameters and benthic macro-invertebrates communities throughout the whole sampling period due to differences in river water pollution levels and changes in weather patterns.

4. There was a significant relationship between the physico-chemical characteristics of River Kibisi with the benthic macro-invertebrate community and that of the water quality.

5. There was a decline of the benthic macro-invertebrates richness, composition, diversity and as well as water quality in the downstream direction due to increase in pollution levels.

6. The EPT % rates or values were highest at station I and lowest at station III. Sampling site I had an excellent water quality while site II had good water quality, and site III had fair water quality.
7. The findings of the water quality assessment of River Kibisi by use of the EPT richness index were in consistence with other similar study findings in other parts of the world. Pollution has always impacted negatively on water quality status of rivers and streams as well as on benthic macro-invertebrates richness, composition and diversity.

6.2 Recommendations

1. Poor farming practices along River Kibisi watershed associated with an increase in pollution levels should be done away with. New farming technology e.g. organic farming should be practised with an aim of protecting the water quality in rivers.

2. Residents in the region to plant indigenous trees especially in river watersheds to create more riparian vegetation to improve water quality statuses and ecological integrity of streams. The forest cover should be protected, conserved and sustained to improve the ecological integrity of rivers in the region.

3. The County and the National governments in collaboration with other stakeholders should put in place new laws and regulations to have the region operate under new management for the protection and sustainability of the water quality resource in the region.

4. An adequate monitoring strategy should be implemented on ecological integrity of river watersheds in future. Mitigation and adaptation programs should be embraced to improve water quality resources of river ecosystems in the region.

5. The study research has indicated that methods of ecological status assessment based on the selected macro-invertebrates would be a good approach for effective monitoring and screening of aquatic ecosystem health in selected river ecosystems.
6. Continuous bio-assessment process based on EPT biotic indicators of rivers in the region to be conducted as often as possible in order to develop a long term profile of water quality status and ecological integrity of rivers. A protective criterion should be established to reduce the toxic effects and negative impacts that compromise the water quality of River Kibisi.

7. The study research will provide key information for all government agencies, organizations and individuals responsible for provision of quality water in the region. The findings will be relevant to service providers, water quality regulators, area residents, stakeholders and the whole country at large. That it is now essential for anyone else to set up a water quality assessment and monitoring programme in rivers in Mt. Elgon region because the precedence has been achieved by this study.
REFERENCES


APPENDICES

**Appendix I: A Summary of the Physico-chemical Parameters for the three sites for sampling period along River Kibisi, Mt Elgon, Kenya.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SITE I</th>
<th></th>
<th>SITE II</th>
<th></th>
<th>SITE III</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Temperature(^0\text{C})</td>
<td>13.6-16.8</td>
<td>15.3±0.46</td>
<td>15-20.9</td>
<td>17.0±0.67</td>
<td>17.6-21.5</td>
<td>19.7±0.55</td>
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<tr>
<td>pH</td>
<td>7.3-7.9</td>
<td>7.7±0.07</td>
<td>7.1-8.03</td>
<td>7.7±0.10</td>
<td>6.6-7.8</td>
<td>7.2±1.16</td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>5.01-8.94</td>
<td>7.5±0.59</td>
<td>4.29-8.6</td>
<td>6.9±0.54</td>
<td>2.26-7.46</td>
<td>5.0±0.62</td>
</tr>
<tr>
<td>Conductivity(µS/cm)</td>
<td>110-160</td>
<td>134.9±7.03</td>
<td>127-203</td>
<td>157±10.76</td>
<td>135.0245</td>
<td>166±12.69</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>6-22</td>
<td>13.1±1.86</td>
<td>4.2-5.7</td>
<td>26.0±6.82</td>
<td>5.6-68.0</td>
<td>44.8±8.62</td>
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<tr>
<td>Turbidity(NTUs)</td>
<td>10.250.3</td>
<td>78.0±27.1</td>
<td>4.2-27.9</td>
<td>112±40.9</td>
<td>36.4-92.0</td>
<td>182±39.2</td>
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<tr>
<td>Width (m)</td>
<td>2.85-5.72</td>
<td>4.1±0.33</td>
<td>2.7-6.95</td>
<td>5.0±0.51</td>
<td>2.26-7.15</td>
<td>4.1±0.72</td>
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<tr>
<td>Transparency(m)</td>
<td>0.28-1.1</td>
<td>0.6±0.10</td>
<td>0.22-1.2</td>
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<td>0.09-0.46</td>
<td>0.23±0.05</td>
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<tr>
<td>Velocity (m)</td>
<td>0.13-7.82</td>
<td>1.2±0.10</td>
<td>0.2-1.19</td>
<td>0.4±0.12</td>
<td>0.01-9.55</td>
<td>1.5±1.15</td>
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<tr>
<td>Depth (m)</td>
<td>0.66-1</td>
<td>0.9±0.04</td>
<td>0.4-0.89</td>
<td>0.7±0.05</td>
<td>0.27-0.79</td>
<td>0.5±0.06</td>
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<tr>
<td>TDS (mg/l)</td>
<td>154-358</td>
<td>257.8±21.7</td>
<td>136-376</td>
<td>291.8±25.2</td>
<td>214-406</td>
<td>348±22.9</td>
</tr>
</tbody>
</table>
Appendix II: Sampling Protocol

Name of river................................................................. Site .........................

Date:..............................................................................................

Time:..............................................................................................

GPS:..............................................................................................

Sampling location:...........................................................................

Type of water:...................................................................................

Preservation method:........................................................................

Collector:...........................................................................................

General Description

1. Weather..........................................................................................

2. Water levels..................................................................................

3. River bank status...........................................................................
4. Water Status

5. Anthropogenic activities

6. Description of riparian vegetation

**Measurements**

1. Conductivity

2. River width

3. Water Temperature

4. Velocity of water

5. Turbidity

6. Dissolved Oxygen

7. pH

8. Transparency
9. Total suspended solids

10. River depth

**Sampling Benthic macro-invertebrates**

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Labeling</th>
<th>Totals</th>
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<tbody>
<tr>
<td>Mayflies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stoneflies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caddisflies</td>
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**Grand Total**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Totals</strong></td>
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