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ASSESSMENT OF BENTHIC MACROINVERTEBRATES AS BIOINDICATORS OF ON WATER QUALITY IN RIVER NAKA, CHUKA

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ABSTRACT
Freshwater ecosystems worldwide have been progressively deteriorating leading to a decrease in aquatic biodiversity. Conventionally, evaluation of water quality uses single physical-chemical parameters which may be insufficient to fully assess the quality of freshwaters. This study used bio-indicators to assess water quality River Naka in Tharaka-Nithi, Kenya. Fluvial ecosystems support rich and diverse assemblages, making them vulnerable to possible alterations in the habitat. The study assessed the diversity and abundance of benthic macroinvertebrate communities and use as bioindicators of water quality. Grab sampling was used to collect water samples, a kick sampler and D-frame aquatic net was used to collect 121 benthic macroinvertebrates from three selected sites and determined using EPT Index (Ephemeroptera, Plecoptera and Trichoptera group). The data obtained was used to determine the index of the sampling sites. Physico-chemical factors were analyzed in-situ (temperature, turbidity and pH) and (nitrates and phosphates) in the laboratory. The highest EPT index values at the upstream corresponded to good water quality, while the slightly low values at the midstream indicated moderate water quality and the lowest values recorded at the downstream showed fair water quality. The water quality parameters downstream exceeded the World Health Organization standards posing health hazard to water users. Continuous bio-assessment based on EPT biotic indicators of rivers should be conducted oftenly to develop long-term profile of water quality status and ecological integrity of rivers.
Keywords: Bio-assessment, EPT index, Water quality, Biological integrity

INTRODUCTION
In order to identify and monitor water quality deterioration, the appropriate monitoring tools are needed. It is these tools that will help identify and distinguish the cause and source of the integrity. The most common tool used to evaluate the biological condition of a water body are biological assessments (Kaaya et al, 2015). Biological assessments include surveys and direct measurements of aquatic life in the water body. Aquatic life reflects the collective effects of stressors such as chemicals, changes in temperature, and excess nutrients and allows us to measure the impact of these stressors (Borisko et al., 2007). Physical and chemical measurements such as pH, dissolved oxygen and organic carbon can be useful in determining the source of water contamination (Ojija, 2015). However, these assessments only indirectly measure the health of the aquatic ecosystem because they don't examine the reaction to pollution in the ecosystem. Biological assessments provide a more dependable and consistent assessment of long-term changes in the water body (Bellucci et al., 2013). These assessments directly assess the condition of ecosystem health; when the biological life is healthy, normally the chemical and physical sectors of the water body are in good condition (United States Environmental Protection Agency, 2018).

Aquatic organisms are time-integrated indicators of stream health because they deal with chemical, physical and biological influences in their habitat over their lifecycle, which can last for several years (Borisko et al, 2007). A chemical test is only a glimpse of ecosystem health at that specific time, and the stream can vary from day to day (Raescu et al., 2011). Biological communities combine all of the responses to environmental stressors caused by natural and man-made activity over a long period of time (Cheimonopoulouet al., 2011). It is because of this that the type and number of organisms present in a stream reflect the quality of their habitat. By collecting and inventorying aquatic communities and then comparing those numbers to a pollution-free area, it can be determined if pollution is impacting the species richness and diversity (Uhurek et al., 2014). Biological monitoring of the same stream(s) over time also gives an indication of whether the overall health of the stream is improving or deteriorating. Knowledge about the health status of aquatic ecosystems and the value of the potential services that they can provide to humans allows optimal and sustainable use of the available resources.

Among the communities that are considered bio indicators of water quality, the most commonly used are the benthic macro invertebrates (Chadwick et al., 2012), because they have several characteristics that make them easy to study and show clear responses when faced with adverse environmental conditions. The structure of the benthic communities in an aquatic ecosystem reflects its ecological conditions, including habitat heterogeneity and water quality (Hepp et al., 2010). Some macro invertebrates cannot survive in polluted water while others can survive or even thrive in polluted water. In a healthy river, the benthic macro invertebrates will include a variety of pollution sensitive macro invertebrates. In an unhealthy stream, there may be only a few types of non-sensitive macro invertebrates present (Hepp et al., 2010). It may be difficult to identify stream pollution with water analysis, which can only provide information for the time of sampling. Even the presence of fish may not provide information about a pollution problem because fish can move away to avoid the polluted water and return when conditions improve. However, most benthic macro invertebrates cannot move to avoid polluted water (Mophin kani & Murugesan 2014). A macro invertebrate sample may thus provide information about polluted water that is not present at the time of sample collection. Some abiotic factors such as temperature, pH, electrical conductivity, dissolved oxygen among others, determine the distribution of benthic macro invertebrate communities (Raescu et al., 2011).

Macroinvertebrates are organisms that do not have a backbone and that can be seen with the naked eye. Aquatic macroinvertebrates inhabit lakes, rivers and streams and live around, on or under rocks. These organisms are called “benthos” because they live at the bottom of substrates for all or part of their lifecycle (Resh & Rosenberg, 1993). Benthic macroinvertebrates include insect larvae such as stonefly and mayfly nymphs, aquatic worms, crustaceans such as crayfish and gastropods such as snails. Insect larvae are the most common in freshwater ecosystems. Macroinvertebrates are capable of living in any freshwater body, as long as the water isn't extremely deep or highly polluted (Strayer, 2001).

Macroinvertebrates feed on bacteria and algae and eat leaf matter and woody material in the water body. When macroinvertebrates die and decay, they deposit nutrients that are then reused by other aquatic organisms and plants. Without the input of plant material and macroinvertebrates the entire food chain for the ecosystem would be compromised. Most benthic macroinvertebrates spend the majority of their lives in water, only emerging as an adult where they will reproduce and die. A macroinvertebrate life cycle can last from a month to 4 years, varying among species (Readel, 2002). Macroinvertebrates are fairly immobile, only moving by swimming, crawling or drifting in currents. Due to this immobility, they cannot move or relocate to avoid pollution.

Naturally occurring bio ndicators are used to assess the health of the environment and are also an important tools for detecting changes in the environment, and their subsequent effects on human society. Through the application of bio indicators, we can predict the natural state of a region or the level/degree of contamination (Khatri & Tyagi, 2015). Macroinvertebrates are divided into three categories (Voelz et al., 2000). *Group I* taxa consist of pollution sensitive organisms, meaning these invertebrates are delicate and intolerant of pollution. Examples of group one taxa include stonefly nymphs, mayfly nymphs and caddisfly larva (Mophin kani& Murugesan 2014). *Group II* taxa are moderately intolerant of pollution; these organisms can exist under a wider range of water quality conditions than *Group I* organisms. Crayfish, clams, crane flies and scuds are examples of *Group II* taxa (Guimaraes et al., 2009). *Group III* taxa are tolerant of pollution and can exist and survive in poor water quality conditions; these taxa include leeches, aquatic worms, blackfly larvae and pouch snails (Merritt &Cummins, 1997).

In order to assign a biotic index value, collectors first collect the macroinvertebrates and then separate them into groups of families. Collectors use a macroinvertebrate identification key such as the EPT Index (Ephemeroptera, Plecoptera and Trichoptera group) to determine which macroinvertebrates they have collected in their sample. The index value given depends on how many types of macroinvertebrates are found in each tolerance category (Plafkin et al., 1989). A stream health rating is assigned to the water body sampled: excellent, good, fair or poor. These bio classifications are subsequently used to assess the numerous impacts of point source and non-point source pollution (Beaven et al., 2001). Biotic index values can be calculated by assigning each species a number by using the EPT index values. Total index values of streams are calculated by counting the number of each species found in Group I taxa and multiplying it by three, multiplying Group II taxa by two and Group III taxa by one. Adding the three totals from each of the groups will give the stream’s total index value. The index value is then compared to a water quality rating chart. Water quality rating charts differ by states and regions (North Carolina Department of

Environmental Health, and Natural Resources, 1997).

Table 11: EPT richness index ranges and corresponding water quality ratings (NCDEHNR, 1997)

Index	Excellent	Good	Good-fair	Fair	Poor
EPT	>27	21-27	14-20	7-13	0-6

Macroinvertebrates are widely used as bioindicators in many developed countries and are included in national and technical standards of water quality monitoring. However, in Kenya and to large extent the whole of Africa, the use of macroinvertebrate assessment and monitoring of stream conditions is still uncommon. In east Africa, only few studies have attempted to describe the structure and composition of macroinvertebrates in lotic systems. For instance, in Kenya, Barnard, and Briggs, (1988) studied macroinvertebrates in the catchment streams of Lake Naivasha whilst Kinyua, and Pacini, (1991) surveyed macroinvertebrates of Nairobi River. Makanga and Tumiwesigye (2000) investigated the structure, taxonomic composition and the temporal distribution of benthic macroinvertebrates in Nyamweru River in Uganda. These studies did not however, relate macroinvertebrates assemblages to land use impacts to water quality and did not establish a bio indicator or a bio monitoring procedure for evaluating water quality in rivers studied. This study will seek to investigate macroinvertebrate communities in River Naka in relation to water quality and to establish a macroinvertebrate index of biotic integrity as a bio monitoring tool.

METHODOLOGY

Study Area Characteristics

River Naka originates from the slopes of Mt. Kenya which is situated at an altitude of approximately 5,200 metres above sea level. It then flows downstream through a natural forest dominated by indigenous trees and vegetation cover. The river leaves the forest edge and flows through a rich agricultural area of extensive and intensive human farming activities and settlements. It is in Meru-South District, Chuka Division. It passes next to Chuka Town located on the eastern slopes of Mount Kenya about 65km south of Meru town. It lies on a latitude of 0° 19' 60.00" N and a longitude 37° 38' 59.99" E. This river is found in Tharaka Nithi County, Kenya in an area with diverse land uses including semi pristine forest cover, agriculture and urban settlement. These land uses lead to pollution of the river water through surface run off. It plays an important role in the water cycle since it acts as a drainage channel for surface water and is a source of water for many people that live within its reach. It also provides excellent habitat and food for many organisms. However, water quality status is affected by many physico-chemical and biological parameters which are introduced by human (anthropogenic) activities into the river system. In Kenya, little effort has been invested in the use of biological indicators such as macro invertebrate index of biotic integrity (IBI), as a result, little information is available on the same. There has been an over-reliance on the use of chemical tests as the sole method of water quality analyses for all water bodies in Kenya. The method is very expensive because the equipment required is costly, making it difficult to generate time series data often needed for the management of water quality, compared to the use of biological tests which are relatively cheap. In addition, previous studies conducted on River Naka investigated the concentration of heavy metals in the water and assessed the general state of the river. These studies did not however investigate the impact that these heavy metals could be having on aquatic organisms, neither did they investigate the source of these heavy metals. This study was therefore able to assess the water quality of the river by the use of benthic macroinvertebrates and linked them to the adjacent land uses, which is a relatively cheap way compared to chemical testing.

Research Design

Ecological research design was used in this study. This is because it is mainly used when collecting data from a natural environment where variability is investigated across various zones or altitude.

Population of Study

More than 100 (Lenat, 1988) macroinvertebrates were collected at all sampling sites. The net contents were inspected to ensure that more than 100 macroinvertebrates had been collected. If it was determined that insufficient numbers of macroinvertebrates were captured after initial sampling efforts, sampling was extended for a second period of equal duration and noted on the field sheet. If insufficient numbers existed after completion of the second sampling effort, collection stopped and the sample was preserved. Low numbers of organisms were indicative of water quality or habitat problems and was noted on the field sheet.

Sampling Procedure

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 was located near the margins of the forest, the second site was located in an area near the urban center and settlement area and the third site at the agricultural area. The sampling was chosen such that the river sheds with mild, moderately disturbed and seriously disturbed/impaired catchment areas as per the land use were included. Water sampling on river Naka was carried out at three points. Grab sampling method was adopted. Three samples were collected about 20cm below the water surface. Sample container preparation, storage and transport procedures followed the recommended standard methods for the examination of water and waste water. A range of water quality parameters were measured at all sampling locations, with key parameters being dissolved oxygen (DO), pH, temperature, nitrate, turbidity, and phosphates. The analytical methods of water quality parameters were followed by the Standard Method for the Examination of Water and Wastewater.

Macroinvertebrates

For benthic macroinvertebrates, kick sampling was used to ensure the dislodgement of attached organisms from the substrate into the scoop-net. Sampling of macroinvertebrates was done with a kick net by holding the net frame firmly against the stream bottom and disturbing the substrate upstream (approximately a full arm's length) from the net with my feet and D-frame aquatic net for sampling non-riffle areas This was followed by digging deeply into the substrate with the heel or toe to dislodge macroinvertebrates from the streambed. The collector avoided kicking course debris into the net (let the macroinvertebrates wash downstream into the net). Care was taken to ensure that the plume of silt that resulted from disturbing the substrate was flowing into the net, as this plume also contained the dislodged invertebrates. In sections that lack riffles, vegetation (twigs, leaves, grass) or riparian vegetation overhanging into the stream were sampled by jabbing the net into the vegetation to dislodge the clinging invertebrates. The net was inspected often to make sure the invertebrates that were being dislodged were washing into the net. (Wisconsin department of natural resources June, 2001).

During this collection, the collector moved around to different habitats in the stream such as shallow water, slow moving water, fast moving riffles and plant roots. After 3-5 minutes of kicking and collecting, the collector picked up the net and carried it to the stream bank. The net was turned inside out and shaken into a white bucket filled with water. Inspection of the net or bucket was done to ensure that at least 100 macroinvertebrates had been collected. If insufficient numbers occurred, sampling was extended until this quantity was reached. Once the net was stretched out or the contents emptied, the collector sorted the macroinvertebrates based on their physical appearance using a white ice cube tray for separating and then placed into vials and preserved with 70 % ethanol after which the station number and location description, date and time of collection, collection method, preservative used, estimate of number of individuals in sample and name of collector(s) was recorded on each sample container. The samples were then transported to the laboratory for further sorting, counting and identification. All the specimens were identified to order levels (Quiley, 1977; Merritt & Cummins, 1997; IFM, 2006).

RESULTS AND DISCUSSION

Macroinvertebrates

Table 12: Number of macroinvertebrates collected

Macroinvertebrate	Upstream	midstream	Downstream
Stonefly nymph	13	6	0
Mayfly nymph	10	5	8
Caddis fly larva	5	10	7
Water penny	17	7	6
Dragon fly nymph	2	6	2
Damselfly nymph	0	2	0
Aquatic worm	0	4	10
Blood midge	0	0	1
Total	47	40	34

A total of 121 macroinvertebrates were collected at the three sites. 47 were collected at the upstream, 40 at the midstream and 34 at the downstream. The site at the downstream had a high diversity of macroinvertebrates compared to the upstream. This could be attributed to some macroinvertebrates being washed downstream due to increased discharge, and also because some macroinvertebrates such as mayflies can thrive on all sites. Six orders of macroinvertebrates were collected, including Ephemeroptera, Plecoptera and Trichoptera, megalopteran, Odonata and Oligochaeta, but the ones of interest in this study were three, the Ephemeroptera, Plecoptera and Trichoptera. Ten genera of Ephemeroptera (mayflies), thirteen Plecoptera (stoneflies), and five Trichoptera (caddisflies) were found at the upstream. Five genera of Ephemeroptera (mayflies), six Plecoptera (stoneflies), and seven Trichoptera (caddisflies) were found at the midstream while eight genera of Ephemeroptera (mayflies) and seven Trichoptera (caddisflies) were found at the upstream. Plecoptera (stoneflies) completely disappeared in the downstream.

Ten (10) genera of Ephemeroptera (mayflies), thirteen (13) Plecoptera (stoneflies), and five (5) Trichoptera (caddisflies) were found at the upstream, the total number EPT index was twenty-eight (28). This index score of 28 represented excellent water quality. Five (5) genera of Ephemeroptera (mayflies), six (6) Plecoptera (stoneflies), and 10 (10) Trichoptera (caddisflies) were found at the midstream, the total number EPT index was twenty-one (21). This index score of 21 represented good water quality from the EPT rating chart. Eight (8) genera of Ephemeroptera (mayflies) and seven (7) Trichoptera (caddisflies) were found at the downstream, the total number EPT index was fifteen (15). The index score of 15 indicated good to fair water quality.

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 Naka River with increase in pollution levels of the water. The total index score of River Naka was 25 which indicated good water quality.

EPT Orders of Macroinvertebrates

Of the three Orders of interest, the Ephemeroptera Order had the highest species richness comprising 36% of the total samples that were collected, while the Order Trichoptera had slightly low species richness with 34% and the Plecoptera had the lowest species richness with only 30%. The Orders Ephemeroptera and the Trichoptera were observed at all the three sampling sites along River Naka though the River is not comprised of only three Orders. The upstream had the highest score of the EPT followed by the midstream and then the downstream.

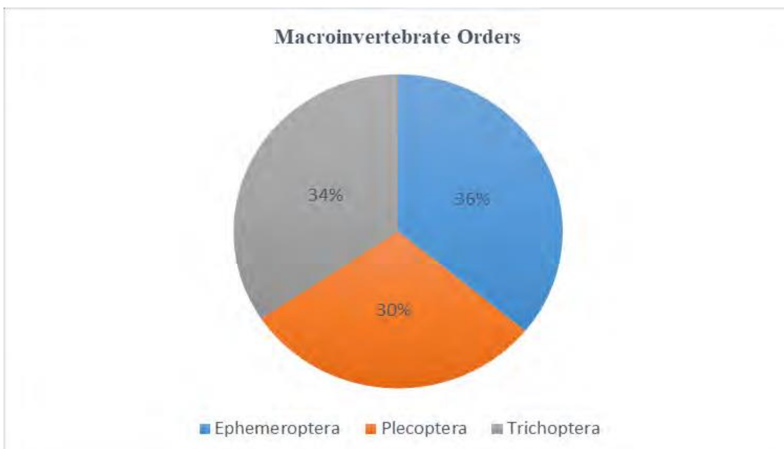

Figure 2: EPT Orders of Macroinvertebrates in River Naka.

Level of Macroinvertebrate Tolerance to Pollution

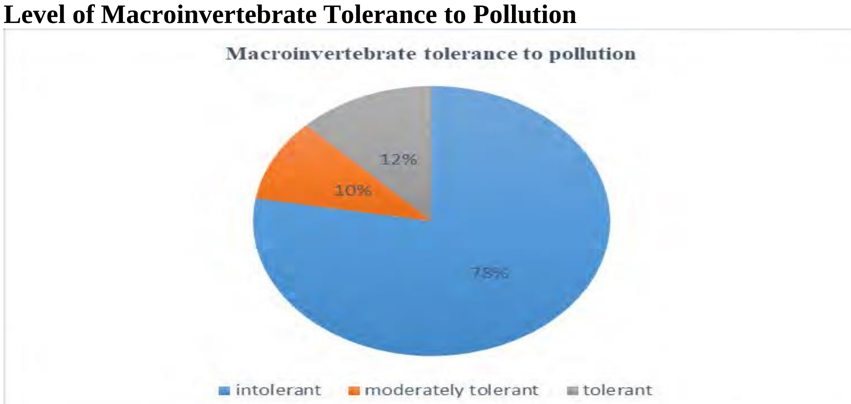

Figure 3: Macroinvertebrate tolerance to pollution

When grouped in the order of pollution tolerance, the intolerant organisms made 78% (mayfly nymph, stone fly nymph, caddis fly larva and water penny), the moderately tolerant made 10% (dragon fly and damsel fly) and the tolerant ones 12% (midges and aquatic worms). The benthic macro-invertebrates 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 downstream. 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. The Order Plecoptera or stoneflies are the most sensitive of all the benthic macro-invertebrate communities because they are on record of disappearing completely due to serious degradation of the water quality.

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. 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 invertebrate communities and the values of the EPT index indicate that the upper reaches of River Naka are of good ecological status, with high dissolved oxygen, high pH, low turbidity, low temperatures and low nutrient concentration. However, the lower reaches of the watercourse are of poor ecological integrity due to degradation largely due to human (anthropogenic) activities attributed by the high turbidity, low dissolved oxygen, increased temperatures and increased nutrients. These results agree with the findings for a study that found that unhealthy biological aquatic communities are normally dominated by a few tolerant taxa (Sutcliffe and Hildew, 1989).

CONCLUSION

Pollution from different land use activities have always impacted negatively on water quality status of rivers and streams as well as on benthic macro-invertebrate richness, composition and diversity. The water quality in River Naka was good at the upstream due to lack of or minimal human activities, while it reduced in the midstream due to the agricultural activities on both sides of the river and in the downstream it was because of the agricultural activities and the run off from the urban center that caused water quality to reduce. 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 decrease in the EPT index in the downward direction was an indication of the deterioration of the water quality towards the lowland reaches. The highest EPT index values at the upstream corresponded to good water quality, while the slightly low values at the midstream indicated moderate water quality and the lowest values recorded at the downstream showed fair water quality (NCDEHNR, 1997). The findings of the water quality assessment of River Naka by use of the EPT richness index were in consistence with other similar study findings in other parts of the world. 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.

RECOMMENDATIONS

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. 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.

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