ASSESSMENT OF BENTHIC MACROINVERTEBRATES AS BIOINDICATORS OF WATER QUALITY IN RIVER NAKA, CHUKA, THARAKA-NITHI, KENYA

Chamia, L.K. and Kutuny, G.K.
Department of Environmental Studies and Resource Development, Chuka University, P. O. Box 109-60400, Chuka
Email: chamialoice.lc@gmail.com

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 of River Naka in Tharaka-Nithi County, 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 their 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 in the laboratory(nitrates and phosphates). The highest EPT index values (28) at the upstream corresponded to good water quality, while the slightly low values (21) at the midstream indicated moderate water quality and the lowest values (15) recorded at the downstream showed fair water quality. The downstream water quality parameters exceeded World Health Organization limits, posing a health risk to water consumers. Continuous bio-assessment of rivers based on EPT biotic indicators should be conducted on a regular basis to establish a long-term profile of water quality state and ecological integrity of rivers.
Keywords: Bio-assessment, EPT index, Water quality, Biological integrity

INTRODUCTION

In order to identify and monitor water quality deterioration, appropriate monitoring tools are needed. It is these tools that will help identify and distinguish the cause and source of the loss in 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 evaluate the condition of ecosystem health; when the biological life is healthy, normally the chemical and physical parameters 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). Hence, 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 as bio indicators of water quality, benthic macro invertebrates are the the most commonly used (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 (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 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, leaf matter and woody material in the water body(Eckert *et al.,* 2020). 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 adults that will then reproduce and die. A macroinvertebrate life cycle can last from a month to 4 years, depending on the species (Readel, 2002). Macroinvertebrates are fairly immobile, only moving by swimming, crawling or drifting in currents. Due to this immobility, they move or relocate to avoid pollution.

Naturally occurring bio ndicators are used to assess the health of the environment and are also an important tool for detecting changes in the environment, and their subsequent effects on human society. Through the application of bio indicators, it is possible to predict the natural state of a region or the level/degree of contamination (Khatri & Tyagi, 2015). Macroinvertebrates are classified into three groups based on their vulnerability to pollution (Voelz et al., 2000); *Group I* taxa, that consist of pollution sensitive organisms, such as stonefly nymphs, mayfly nymphs and caddisfly larva (Mophin kani& Murugesan 2014). *Group II* taxa, that are moderately intolerant of pollution include Crayfish, clams, crane flies and scuds (Guimaraes et al., 2009)and *group III* taxa that are tolerant to 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). Different groups of macroinvertebrates are excellent indicators of human impacts, especially contamination. Most of them have quite narrow ecological requirements and are very useful as bioindicators in determining the characteristics of aquatic environments (Maul et al., 2004 ; Fernández-Díaz et al., 2008; Pérez-Bilbao & Garrido, 2009), to identify the segments of a polluted river where self-purification of organic inputs is under process (Chatzinikolaou & Lazaridou 2007).

To assign a biotic index value, macroinvertebrates are collected and then separated into groups of families using a macroinvertebrate identification key. EPT Index (Ephemeroptera, Plecoptera, Trichoptera group) is used to determine macroinvertebrates collected in the sample. The index value given is based on types of macroinvertebrates found in each tolerance category (Plafkin et al., 1989). A stream health rating (excellent, good, fair or poor) is assigned to the water body sampled. 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 values obtained from 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 1: EPT richness index ranges and corresponding water quality ratings (NCDEHNR, 1997)

Water quality rating	Excellent	Good	Good-fair	Fair	Poor
EPT Index	>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 attempted to describe the structure and composition of macroinvertebrates in lotic systems (Barnard, and Briggs 1988, Kinyua and Pacini 1991, Makanga and Tumiwesigye 2000). Further, none of these studies relate macroinvertebrates assemblages to land use impacts or to water quality and did not establish a bio indicator or a bio monitoring procedure for evaluating water quality in rivers studied.

This study investigated macroinvertebrate communities in River Naka in Tharaka-Nithi, Kenya in relation to water quality and established a macroinvertebrate index of biotic integrity as a bio monitoring tool. The river 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 (Jones-Lepp et al., 2012).

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.

METHODOLOGY

Study Area

River Naka which is in Meru-South District, Chuka Division of Tharaka Nithi County in Kenya, originates in the slopes of Mt. Kenya (approximately 5,200 a.s.l). 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 passes next to Chuka Town located on the eastern slopes of Mount Kenya(0° 19' 60.00" N and a longitude 37° 38' 59.99" E) about 65km south of Meru town. Tharaka Nithi County isan 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.

Population of Study

More than 100 (Lenat, 1988) macroinvertebrates were collected at all sampling sites. Where it was established 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. Where 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 of 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 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 (Belal, 2019). 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(APHA, 2005). A combined pH, temperature and D.O meter probe was used to take measurements on site while a Turbidity meter probe was also used to take turbidity measurements. Nitrates and Phosphates were measured in the laboratory using Ultra Violet Spectrophotometer.The analytical methods of water quality parameters were followed by the Standard Method for the Examination of Water and Wastewater(APHA, 2005).

Sampling of benthicmacroinvertebrates

For benthic macroinvertebrates, kick sampling method (Višinskienė & Bernotienė, 2012) that ensures the dislodgement of attached organisms from the substrate into the scoop-net was used. Sampling was carried out with a kick net(model specifications) 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 the collectors feet and a D-frame kick sampling aquatic net (5cm×20cm) 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 researcher avoided kicking course debris into the net but allowed the macroinvertebrates to 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 (Carter & Resh, 2001).

During collection of macroinvertebrates, the researcher 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, macroinvertebrates were sorted 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 (Višinskienė & Bernotienė, 2012). All the specimens were identified to order levels (Quiley, 1977; Contreras-Ramos, 2010; IFM, 2006).

RESULTS AND DISCUSSION

Water Quality Characteristics and Macroinvertebrates

The upstream site had the highest index of 47 followed by the site midstream with an index of 40. The site at the downstream recorded the lowest index of 34 as shown in Table 1 below. Just like the EPT indices physical and chemical characteristics at the three sampling sites were noted to change along the course of the river as shown in Figure 1,2 and 3 below. Results obtained indicated that fewer species were found in the downstream which was characterized by serious impairment of river water quality due to increase in water quality stresses as result of burgeoning anthropogenic activities.

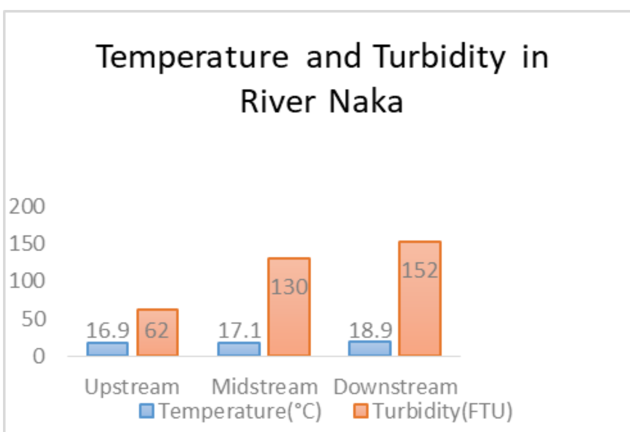

Figure 1: Temperature and Turbidity in River Naka

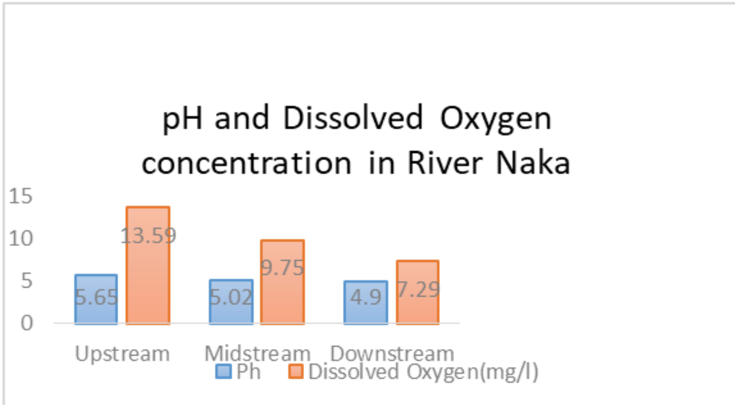

Figure 2: pH and Dissolved Oxygen concentration in River Naka

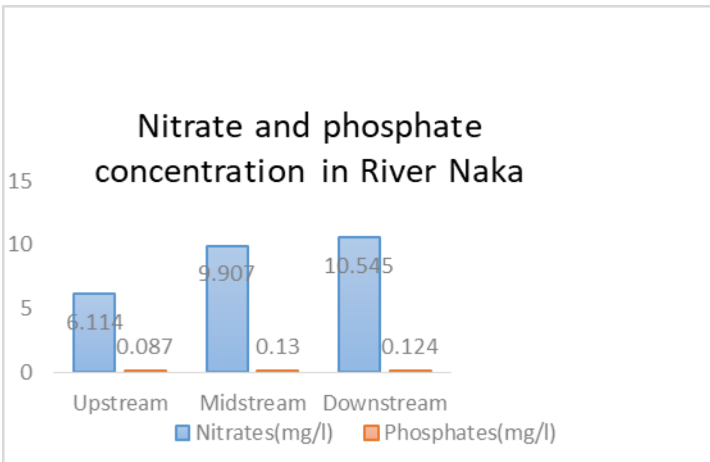

Figure 3: Nitrate and Phosphate concentration in River Naka

Macroinvertebrates

Table 2: 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 from three selected sites along the river. 47 were collected upstream, 40 midstream and 34 downstream. 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.

Comparisons within the EPT genera richness showed variations (Table 1). This is why the upstream was assigned water quality status of being excellent water quality; midstream of being Good water quality and downstream of having Fair water quality. The EPT richness index assigns water status values as follows: ≤ 6 = Poor water quality; 7 – 13 Fair water quality; 14-20 Good to Fair; 21 - 27 Good water quality and ≥ 27 as excellent water quality (NCDEHNR, 1997).

Therefore, according to the results obtained from the study research: upstream was mildly polluted; midstream was moderately polluted and downstream had very serious impairment.

The decrease of EPT richness index in the downstream direction of rivers was directly proportional 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 species richness comprising 36% of the total samples that were collected, while the Order Trichoptera had slightly low species richness with 34% and Plecoptera had a species richness of 30%. This indicated that the species richness among the three sites was not very different. 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.

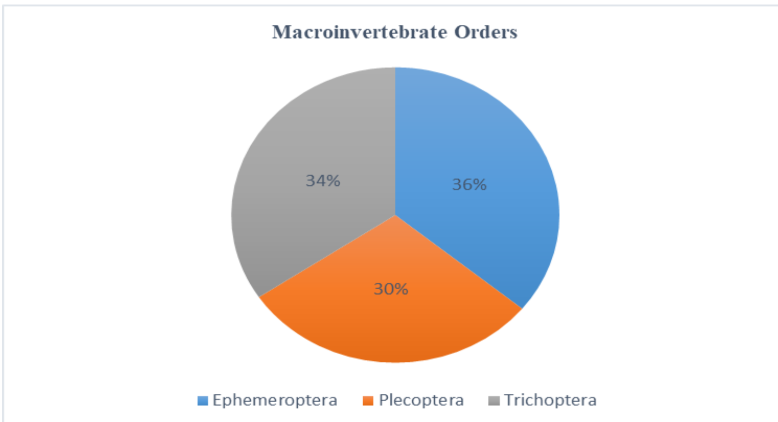

Figure 4: Proportions of EPT Orders of Macroinvertebrates in River Naka.

Level of Macroinvertebrate Tolerance to Pollution

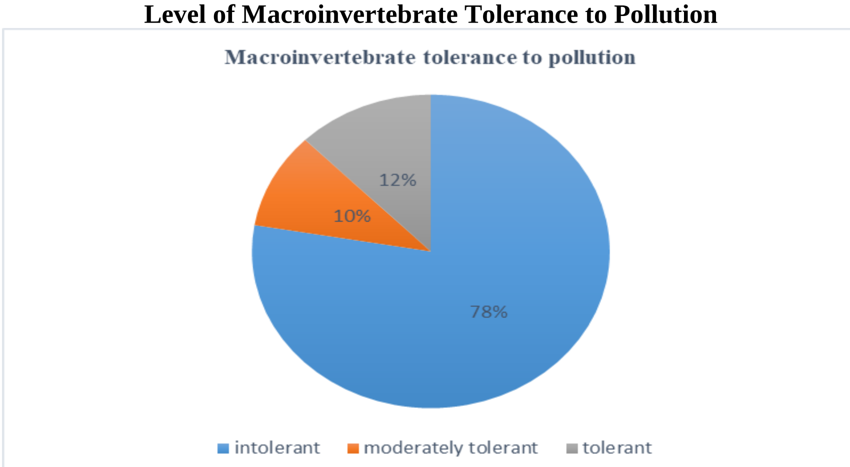

Figure 5: Proportions of Macroinvertebrates in different pollution tolerance categories

When grouped in the order of pollution tolerance, the intolerant organisms comprised of 78% (mayfly nymph, stone fly nymph, caddis fly larva and water penny), the moderately tolerant comprised of 10% (dragon fly and damsel fly) while the tolerant ones comprised of 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 effect while the Plecoptera taxa is the most sensitive to high degree of pollution and hence, very rare.

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 that unhealthy biological aquatic communities are normally dominated by a few tolerant taxa (Sutcliffe and Hildew, 1989).

CONCLUSIONS AND RECOMENDATIONS

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 upstream due to limited 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 downstream stations which indicated good quality of the river water. The decrease in the EPT index downstream indicated 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 moderately good 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 consistent with other similar findings in other parts of the world (Abdel, 2019; Bonzemo, 2013; Xu *et al.*, 2014). This study indicates 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.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 should be conducted as oftenly to develop a long-term profile of water quality status and ecological integrity of rivers.

REFERENCES

Abdel-Gawad, S.S. 2019. Using benthic macroinvertebrates as indicators for assessment the water quality in River Nile, Egypt. Egyptian Journal of Basic and Applied Sciences, 6(1):206-219.

Barnard, P.C. and Briggs, J. 1988. Macroinvertebrates in the catchment streams of Lake Naivasha, Kenya. In: *Rev. Hydrobiol. Trop.*, 21:127-131.

Beavan, L., Sadler, J., and Pinder, C. 2001. The invertebrate fauna of a physically modified urban River. Hydrobiologia, 445:97-108.

Belal, A.A.M. 2019. Macro-benthic invertebrates as a bio-indicator for water and sediment quality in Suez Bay, Red Sea. Egyptian Journal of Aquatic Research, 45(2):123–130. https://doi.org/10.1016/j.ejar.2019.03.003

Bellucci C.J., Becker M.E., Beauchane, M. and Dunbar L. 2013. Classifying the health of Connecticut streams using benthic macroinvertebrates with implications for water management. Environmental Management 51:12741283.

Bonzemo, S. 2013. Assessment of water quality status of River Kibisi, Kenya using the Ephemeroptera, Plecoptera and Trichoptera (EPT) index (Doctoral dissertation, Master's Thesis. Kenyatta University, Kenya).

Borisko, J.F., Kilgour, B.W., Stanfield, L.W. and Jones, F.C. 2007. An evaluation of rapid bioassessment protocols for stream benthic invertebrates in southern Ontario, Canada.

Water Quality Research Journal Canada, 42:184–193.

Carter, J. L., & Resh, V. H. 2001. After site selection and before data analysis: sampling, sorting, and laboratory procedures used in stream benthic macroinvertebrate monitoring programs by USA state agencies. Journal of the North American Benthological Society, 20(4):658–682. doi.org/10.2307/1468095

Chadwick M.A, Thiele J.E, Huryn A.D, Benke A.C and Dobberfuhl D.R. 2012. Urban Ecosystems, 15(2):347-365.

Chatzinikolaou, Y. and Lazaridou, M. 2007. Identification of the self-purification stretches of the Pinios River, Central Greece. Mediterranean Marine Science, 8(2):19. https://doi.org/10.12681/mms.151

Cheimonopoulou M.T, Bobori D.C, Theocharopoulos I and Lazaridou M. 2011. Assessing ecological water quality with macroinvertebrates and fish: A case study from a small mediterraneanriver. Environmental Management, 47:279-290.

Contreras-Ramos, A. 2010. Richard W. Merritt, Kenneth W. Cummins y Martin B. Berg (eds.). 2008. An introduction to the aquatic insects of North America, 4a edición. Kendall/Hunt Publishing Company, Dubuque, 1158 p. + CD con clave interactiva. Revista Mexicana de Biodiversidad, 81(002). doi.org/10.22201/ib.20078706e.2010.002.247

Duran, M. 2006. Monitoring water quality using benthic macroinvertebrates and physicochemical parameters of Behzat Stream in Turkey. Polish Journal of Environ. Stud. 15(5): 709-717.

Fernández-Díaz, M., Benetti, C.J. and Garrido, J. 2008. Influence of iron and nitrate concentration in water on aquatic Coleoptera community structure: Application to the Avia River (Ourense, NW. Spain). Limnetica, 27(2):285–298. doi.org/10.23818/limn.27.23

Guimarães, R.M., Facure, K.G., Pavanin, L.A. and Jacobucci, G.B. 2009. Water quality characterization of urban streams using benthic macroinvertebrate community metrics. Acta Limnol. 21(2):217-226.

Hellawell, J.M. 1986. *Biological indicators of freshwater pollution and environmental management.* Elsevier Biomedical Press, Repr.

Hepp, L.U., Milesi S.V., Biasi, C. and Restello, R.M. 2010. Effects of agricultural and urban impacts on macroinvertebrates assemblages in streams (Rio Grande do Sul, Brazil). Zoologia 27(1):106-113.

Institute of Fisheries and Macroinvertebrate Identification, IFM. 2006. Aquatic Ecology. Department of Biology, Sweden: Linkoping University Press. 21 pp.

Jones-Lepp, T.L., Sanchez, C., Alvarez, D.A., Wilson, D.C. and Taniguchi-Fu, R.L. 2012. Point sources of emerging contaminants along the Colorado River Basin: Source water for the arid Southwestern United States. Science of the Total Environment, 430:237–245. Doi.org/10.1016/j.scitotenv.2012.04.053

Kaaya, L.T., Day, J.A. and Dallas, H.F. 2015. Tanzania River Scoring System (TARISS): A macroinvertebrate-based biotic index for rapid bioassessment of rivers. African Journal of Aquatic Science. 40:2. doi:10.2989/16085914.2015.1051941.

Khatri N. and Tyagi S. 2015. Influences of natural and anthropogenic factors on surface and ground water quality in rural and urban areas. Front Life Sci. 8(1):23 39.

Kinyua, A.M. and Pacini, N. 1991. The impacts of pollution on the ecology of the Nairobi Athi River systems in Kenya. Journal of Bio-Chemical Physics, 1:57.

Kripa, P.K., Prasanth, K.M., Sreejesh, K.K. and Thomas, T.P. 2013. Aquatic macroinvertebrates as bioindicators of stream water quality: A case study in Koratty, Kerala, India. Research Journal of Recent Sciences. 2(ISC-2012):217-222.

Maul, J.D., Farris, J.L., Milam, C.D., Cooper, C.M., Testa III, S. and Feldman, D.L. 2004. The influence of stream habitat and water quality on macroinvertebrate communities in degraded streams of northwest Mississippi. Hydrobiologia, 518(1-3):79–94. doi.org/10.1023/b:hydr.0000025058.00605.6e

Mophin-Kani, K., & Murugesan, A.G. (2014). Assessment of river water quality using macroinvertebrate organisms as pollution indicators of Tamirabarani River Basin, Tamil Nadu, India. International Journal of Environmental Protection, 4(1):1-14.

NCDEHNR. 1997. North Carolina Departmert of Environmental Health and Natural Resources. Standard Operating Procedures for Biological Monitoring. Envinronmental Sciences Branch Biological Assessment Group, Division of Water. Water Quality Section. North Carolina University Press.

Ojija, F. 2015a. Analysis of water quality parameters and ecosystem services of Nzovwe stream. IJBLST, 7(1):1-10.

Oliveira, A. and Callisto, M. 2010. Benthic macroinvertebrates as bioindicators of water quality in an Atlantic forest fragment. Iheringia, Sér. Zool., Porto Alegre. 100(4):291-300.

Pérez-Bilbao, A. and Garrido, J. 2009. Evaluación del estado de conservación de una zona LIC (gándaras de budino, red natura 2000) usando los coleópteros acuáticos como indicadores. Limnetica, 28(1):11–22. doi.org/10.23818/limn.28.02

Plafkin, JL., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M. 1989. *Rapid Bioassessment Protocols for use in Streams and Rivers: Benthic Macroinvertebrates and Fish*. US. Environmental Protection Agency.

Quiley, M. 1977. *Invertebrates of Streams and Rivers*. Key to Identification. Bedford Square, London: Academic Press. 21 pp.

Readel, K. 2002. Investigating your watershed: *Using Benthic Macroinvertebrates as a Measure of Water Quality*. Tested Studies for Laboratory Teaching, Volume 23:378.

Resende, P.C., Resende, P., Pardal, M., Almeida, S. and Azeiteiro, U. 2010. Use of biological indicators to assess water quality of the Ul River (Portugal). *Environmental Monitoring and Assessment, 170:535544.*

Rosenberg, D.M. and Resh, V.H. 1993. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman and Hall, New York.

Simic, V. 1999. Use of River macro-invertebrates of a Serbia River to formulate a biotic index. *Hydrobiologia*. 16, 51.

Strayer, D. L. and W. D. Hummon. 2001. *Ecology and classification of freshwater invertebrates of North America*. 2nd Edition. Academic Press, San Diego, California.

Strayer, D.L. 2006. Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society, 25:271-287.

Strayer, D.L. 2006. Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society, 25:271-287.

Sutcliffe, D. W. and Hildew, A. G. 1989. Invertebrate Communities in Acid Streams. In: Acid Toxicity and Aquatic Animals. Society for Experimental Biology Seminar Series, 34:13-30. Cambridge University Press.

Tumiwesigye, C., Yusuf, S.K. and Makanga, B. 2000. Structure, taxonomic composition and the temporal distribution of benthic macroinvertebrates in Nyamweru River in Uganda, Pp. 72-77.

Uherek, C.B. and Gouveia, P.B.F. 2014. Biological monitoring using macroinvertebrates as bioindicators of water quality of maroaga stream in the Maroaga Cave System, Presidente Figueiredo, Amazon, Brazil. International Journal of Ecology. http://dx.doi.org/10.1155/2014/308149.

United States Environmental Protection Agency, Basic Information on Water Quality Criteria. 2018. https://www.epa.gov/wqc/ basic-information-water-quality-criteria#aquatic.

Višinskienė, G. and Bernotienė, R. 2012. Use of benthic macroinvertebrate families for river quality assessment in Lithuania. Open Life Sciences, 7(4). doi.org/10.2478/s11535-012-0052-1.

Voelz, N.J., Shien, S. and Ward, J.V. 2000. Longterm monitoring of benthic macroinvertebrate community structure: A perspective from a Colorado river. Aquatic Ecology, 34:261–278.

Xu, M., Wang, Z., Duan, X. and Pan, B. 2014. Effects of pollution on macroinvertebrates and water quality bio-assessment. Hydrobiologia, 729(1):247-259.