Assessing Ecosystem Integrity And Macroinvertebrates Community Structure: Towards Conservation Of Small Streams In Tanzania

Fredrick Ojija, Mesfin Gebrehiwot, Neema Kilimba

Abstract: This study attempts to use biological indices such as Biological Monitoring Working Party (BMWP), Average Score Per Taxa (ASPT) and Hilsenhoff Family Biotic Index (FBI) in order to determine the ecosystem health and water quality of Nzovwe stream in Mbeya, Tanzania. Macroinvertebrates were sampled from Nzovwe stream using semi-quantitative techniques from March to June, 2016. About 500 meters of Nzovwe stream was divided into 5 sampling sites, each site was 100 meters apart. The macroinvertebrates were collected from all the possible microhabitats of each site using a 250µm mesh size D- frame kick net. Macroinvertebrate specimens were preserved in the 70% ethyl alcohol in the polyethylene bottles. The samples were identified to the family level using standard identification keys. The BMWP score and ASPT score indicated good and moderate stream water quality respectively. The FBI showed the stream had possibility of some organic pollution. The Shannon-Wiener diversity index shows the sampling sites were moderately polluted or possibly impaired. Macroinvertebrates in pollution class II were abundant, suggesting moderate pollution. Moreover, the % Midge, % Insects, % Diptera and % Snail indicated the stream water quality or ecosystem health is between unimpaired and possibly impaired. Based on these results, the study concludes that the stream ecosystem is moderately polluted, and therefore the study recommends a regular stream monitoring.

Index Terms: Aquatic ecosystem, Biomonitoring, Ecosystem health, Macroinvertebrates, Streams, Water pollution, Water quality

1 INTRODUCTION

Monitoring and management of ecosystem integrity of freshwater bodies (such as streams, rivers, and lakes) is a topic of growing scientific and public concern [1]. Freshwater ecosystems are among the most threatened ecosystems in the world. They are affected by water pollution, habitat degradation, climate change, overexploitation, species invasion and flow modification [2]. These factors impend sustainable management and utilization of water resources, also disturb macroinvertebrates community structure of these freshwater bodies [3], [4]. For example, modern farming near freshwater bodies, which employs the use of synthetic fertilizers, pesticides, weedicides and hormones with the aim of quick profits; and development of infrastructures as a result of urbanisation that demands space, infrastructures and facilities contributes to pollution of the aquatic environment [1]. In Mbeya city, for instance, farms and households neighbouring Nzovwe stream release their wastes into the stream, which discharge in other small streams and eventually into rivers in the city [5]. Monitoring of aquatic ecosystems could be achieved by using different biological indicators [2], [4], [6], [7]. Among those are aquatic macroinvertebrates, which are organisms lacking a backbone, yet are large enough to be seen with the naked eye.

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Macroinvertebrates inhabit diverse types of aquatic ecosystem, they can be found in running waters, both in fast or slow flowing streams, and in muddy rivers. Moreover, they live around living or dead plants, on the surface or in the sediments of water bodies. Some live attached to submerged rocks, woods, and plants. They feed on living and dead plant matter, and on each other [3]. They are important food for various vertebrates, for example, fishes, amphibians, reptiles, mammals and birds. Aquatic invertebrates include insects such as dragonflies, caddisflies, mayflies, stoneflies, water penny, water striders and their larvae or nymphs. Other common examples of aquatic invertebrates include crustaceans (such as crayfish), snails, worms and leeches. Even if aquatic macroinvertebrates are used as bioindicators of ecosystem health, they also help in nutrient recycling and completion of food chain and hence energy flow. Such bioindicator mirrors the abiotic or biotic state of an environment, represents the impact of environmental change on a habitat, community or ecosystem [1]. They are regarded as good bioindicators of stream because (i) they show the effects of short and long term pollution events (ii) they are affected by the physical, chemical, and biological conditions of the stream (iii) they can indicate the cumulative impacts of pollution (iv) they are critical part of the stream's food web (v) some are very intolerant of pollution and (vi) they are relatively easy to sample and identify. The objective of this study is to present the status of water quality and ecosystem health of Nzovwe stream using the most commonly used community structure indices such as Biological Monitoring Working Party (BMWP), Average Score Per Taxa (ASPT) and Hilsenhoff Family Biotic Index (FBI) developed in temperate regions, primarily in Europe and in the United States [7]. Other indices used were Shannon-Wiener diversity index (H'), % Midge, % Insects, % Diptera, % Snail and % EPT and the abundance of three classes of aquatic macroinvertebrates (Class I: Pollution sensitive, Class II: Moderately tolerant and Class III: Pollution tolerant). Macroinvertebrates are recommended for use in river and stream pollution surveys because they are simple and easier to use and reduces the costs when compared to physico-chemical analysis which could require sample processing in laboratories. Moreover, they involve a limited effort to yield precise and repeatable results of environmental monitoring [6], [7]. Furthermore, Family Biotic Index (FBI) is the modified biotic index which initially was developed by Hilsenhoff [8]. The modified Hilsenhoff FBI was developed to detect organic pollution [9]. It estimates the total tolerance of the community in a sampled site, weighted by the relative abundance of each taxonomic group. FBI tolerance values range from 0 to 10 for known sensitivity of families to organic pollutants. Normally, 0 is the most sensitive and 10 the most tolerant and increase as water quality decreases [1], [10].

2 Materials and Methods

2.1 Study area.

Field studies were conducted in Nzovwe stream (8°53′24″S33° 25′48″E) found in Mbeya city (08°54′S 33°27′E), Tanzania [5]. The stream supplies water for domestic uses, mainly laundry, bathing and irrigations. It receives pollutants mostly from farms, domestic or residential wastes that originate from private homes. Very common wastes observed around the stream include garbage and rubbish such as food scraps or leftovers, food packaging, bottles, cans, clothing, dung, disposables, magazines and newspapers. These wastes may affect the health of local people, water quality and stream ecosystem health. Five sampling sites were identified along the river (Fig.1). Sampling sites were selected because were easily accessible and allowed a sampling of all representative habitats

2.1.2 Macroinvertebrates sampling and identification

Macroinvertebrates were collected from Nzovwe stream using semi-quantitative techniques [11]. About 500 meters of Nzovwe stream was divided into 5 sampling sites, each site was 100 meters apart. Sampling was done every Monday, Wednesday and Friday for three months, from March to June 2016, and each site was sampled two times a day, starting from 10am to 12am and 3pm-5pm. Macroinvertebrates were collected using D-frame kick net with a mesh size of 250µm. The stream bottom substrates were disturbed with the feet of a person, facing the water current, for three minutes to dislodge macroinvertebrates adhering to debris and stones found within a ten-meter stretch. The collected macroinvertebrates and other contents were emptied into bucket. During sampling, all the microhabitats in each sampling site were considered. The specimens were preserved using ethyl acetate (70%) and were taken to the biology laboratory at Mbeya University of Science and Technology (MUST). All macroinvertebrates were sorted, identified to the family level using standard systematic identification keys and counted using a binocular dissecting microscope [12], [13].

Figure 1. *Sampling sites at the Nzovwe stream*

2.1.2 Data analysis

Assessment of Nzovwe stream integrity was based on the Biological Monitoring Working Party score (BMWP) [14], Average Score Per Taxa (ASPT) and Family Biotic Index (FBI) [15]. BMWP requires taxonomic identification of the invertebrates to the family level, however can take order or class for some groups [6]. The analytical procedures were identification of macroinvertebrates to family level and assign them with the scores following BMWP scoring system. The BMWP score equals the sum of the tolerance scores of macroinvertebrates families in the sample [10]. A higher BMWP score is considered to reflect a better water quality [16]. ASPT equals the average of the tolerance scores of all macroinvertebrates families found, or average tolerance score of all taxa within the community [10]. The ASPT score ranges from 0 to 10 [16], [17]. It was calculated by dividing the BMWP by the number of families represented in the sample [17-19]. The main difference between both indices is that ASPT does not depend on the family richness [16]. The Average Score Per Taxa (ASPT) is given as:

$$ASP = \frac{BMWP}{Total\ number\ of\ families\ counted}$$

FBI score of the stream and each sampling site was calculated using the tolerance value of different macroinvertebrate taxa. Modified Hilsenhoff Family Biotic Index (FBI) tolerance values range from 0 to 10 for families and increase as water quality decreases [1]. FBI was calculated as:

$$FBI = \Sigma \frac{x_i t_i}{n}$$

Where xi is the number of individuals in the ith taxon, ti is the tolerance value of the ith taxon, and n is the total number of specimens in the sample [9].

Table 1. *Tolerance values assigned to aquatic macroinvertebrates taxa collected from Nzovwe stream.*

Order	Family	Tolerance values
Coleoptera	Psephenidae	4
	Elmidae	4
Odonata	Gomphidae	1
	Libellulidae	9
	Calopterygidae	5
	Coenagrionidae	9
Diptera	Tipulidae	3
	Chironomidae	6
	Ceratopogonidae	6
Plecoptera	Chloroperlidae	1
	Leuctridae	0
	Capniidae	1
Ephemeroptera	Baetiscidae	3
	Caenidae	7
	Polymitarcidae	2
Gastropoda	Physidae	8
	Lymnaeidae	6
Tubificida	Tubificidae	8

Calculated BMWP and ASPT scores of Nzovwe stream were compared with threshold values and assessment interpretation indicated in table 2, while FBI values were compared with the criteria in table 3 to determine the status of water quality. Furthermore, the diversity of aquatic macroinvertebrate in each site was described by means of Shannon-Wiener diversity index (H') [20]. The Shannon diversity formula is given as:

$$H = -\varepsilon\left(\frac{n}{N}\right)\log_2\left(\frac{n}{N}\right)$$

The relative dominance (RD) was calculated using the formula below [21].

$$RD = \left(\frac{n}{N}\right) * 100$$

Where n = is the total number of individuals of one species and N is the total number of all individuals in the sample. Other indices used to assess the Nzovwe stream health and water quality constituted % Midge, % Insects, % Diptera, % Snail and % Ephemeroptera, Plecoptera and Trichoptera (%EPT); these were calculated as their proportional abundance relative to the total number of organisms in the sample [22], [23]. The result of these indices were compared with the criteria explained in David et al. [22] and Griffiths [23]. Macroinvertebrates were counted for the number of individuals, and gathered into three classes or groups based on pollution tolerance in order to assess the water quality and ecosystem health of the stream. These classes are; class I (Pollution sensitive), class II (Moderately tolerant) and class III (Pollution tolerant) [24-26]. Bray-Curtis clustering method was computed using Biodiversity Professional 2 (The Natural History Museum, London, UK) [27] to compare similarity among sites taking the density of macroinvertebrates into account.

Table 2. *The BMWP and ASPT threshold values and assessment interpretation used (Adapted from Aquilina [16])*

BMWP score	ASPT score	Quality or diversity interpretation
>150	>6	Very good
101-150	>5	Good
51-100	>4	Moderate
16-50	<4	Poor
0-15		Very poor

Table 3. *Evaluation of water quality using the family level biotic index (Adapted from Hilsenhoff, 1988)*

Family Biotic Index (FBI)	Water quality	Degree of Organic Pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very poor	Severe organic pollution likely

3. Results and Discussion

A total of 985 macroinvertebrates belonging to 8 orders and 27 families were collected from Nzovwe stream (Table 4). St1 had more number of individuals (n =310), followed by St2 (n =202), St4 (n =179), St5 (n =158) and St3 (n =136) (Table 5). On the basis of diversity, St5 showed high Shannon diversity (H' =2.617) followed by St4 (H' =2.478), St3 (H' =2.243), St1 (H' =2.102) and St2 (H' =1.954). The overall stream Shannon diversity was 2.654 (Table 4). The most abundant family was Psephenidae, Tipulidae, and Gomphidae (Table 4). The order Coleoptera (30.558%), Odonata (25.482%) and Diptera (20.711%) indicated high relative abundance of macroinvertebrates (Fig.2). Macroinvertebrates in class II were the most abundant 554 (56.244 %) in the stream. The other two classes were as follows, class I 226 (22.944%) and class III 206 (20.812%) (Table 5). The Family Biotic Index (FBI) values of St1-St5 are indicated in table 6. St1, St2, St3 and St4 showed good water quality except St5 which indicated fair water quality. Overall FBI value of Nzovwe stream showed that the stream had organic pollution with a score of 4.40. Moreover, the overall BMWP score (122) and ASPT score (4.88) of Nzovwe stream indicated good and or moderate stream water quality respectively (Table 6). ASPT score of St1-St5 were as follows; St1 =4.9, St2 = 4.54, St3 = 5.33, St4 = 5.14 and St5 = 5.04 (Table 6). The BMWP score of St1, St2, St3, St4 and St5 are 98, 59, 96, 108, and 116 respectively (Table 6). Moreover, the % Midge, % Insects, % Diptera, % Snail and % EPT were 2.74%, 97.26%, 22.54% and 0.61% respectively. Sites classification based on the macroinvertebrate abundance as a result of cluster analysis is presented in Fig. 3. The results indicated that the similarities between ST4 and ST5 was the highest (73%) followed by ST1 and ST2 (68%).

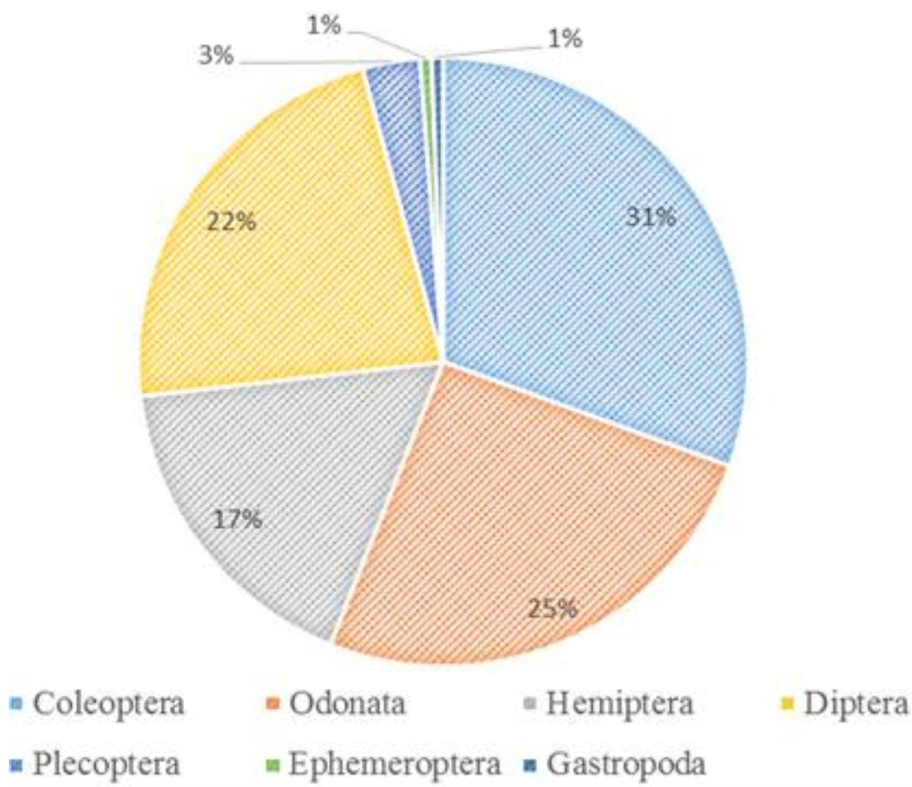

Fig. 2. *Relative abundance of macroinvertebrates order collected from Nzovwe stream*

Table 4. *The BMWP score, list of order and family of aquatic macroinvertebrates collected from Nzovwe stream*

Macroinvertebrate taxon		Sampling sites						BMWP
Order	Family	St1	St2	St3	St4	St 5	Total	Score
Coleoptera	Psephenidae	80	45	30	22	13	190	4
	Haliplidae	3	5	2	9	8	27	3
	Hydrophilidae	1	5	0	24	3	33	5
	Elmidae	3	0	0	2	1	6	3
	Dytiscidae	1	3	4	18	16	42	8
Odonata	Gomphidae	50	16	11	22	16	115	8
	Libellulidae	31	13	11	9	20	84	8
	Calopterygidae	6	4	7	5	3	25	8
	Coenagrionidae	4	2	2	10	9	27	3
Hemiptera	Gerridae	33	18	11	17	14	93	3
	Belostomatidae	2	2	3	1	2	10	3
	Corixidae	2	0	1	1	2	6	3

	Notonectidae	1	0	1	0	1	3	3
	Naucoridae	20	16	8	2	14	60	5
Diptera	Tipulidae	37	45	14	11	8	115	2
	Chironomidae	10	5	9	8	9	41	10
	Ceratopogonidae	11	21	8	2	6	48	10
Plecoptera	Chloroperlidae	1	0	3	2	4	10	10
	Leuctridae	0	0	4	5	2	11	4
	Capniidae	1	0	3	3	2	9	4
Ephemeroptera	Baetiscidae	1	0	1	0	1	3	5
	Caenidae	1	0	0	0	1	2	3
	Polymitarcidae	0	0	0	1	0	1	3
Gastropoda	Physidae	0	0	0	1	1	2	3
	Lymnaeidae	0	0	0	0	1	1	1
	Planorbidae	0	0	0	2	1	3	4
Tubificida	Tubificidae	11	2	3	2	0	18	3
Total		310	202	136	179	158	985	122
Shannon diversity index (H)		2.102	1.954	2.243	2.478	2.617	2.654	

Table 5. *Groups and classes of macroinvertebrates indicators from Nzovwe stream*

Macroinvertebrates group		Sampling sites					Total
Pollution sensitive (Class I)	Order	St1	St2	St3	St4	St5	
Stonefly	Plecoptera	2	0	10	10	8	30
Mayfly	Ephemeroptera	2	0	1	1	2	6
Water penny	Coleoptera	80	45	30	22	13	190
Total		84	45	41	33	23	226
Moderate pollution (Class II)							
Beetles	Coleoptera	8	13	6	53	28	108
Cranefly	Diptera	59	70	32	20	14	195
Dragonfly	Odonata	81	29	22	31	36	199
Damselfly	Odonata	10	6	9	15	12	52
Total		158	118	69	119	90	554
Tolerant pollution (Class III)							
Water strider	Hemiptera	33	18	11	17	14	93
Backswimmer	Hemiptera	1	0	1	0	1	3
Midges	Diptera	10	3	2	3	9	27
Pouch snail	Gastropoda	0	0	0	3	3	6
Water bug	Hemiptera	24	18	12	4	18	76
Tubifex	Tubificida	11	2	3	2	0	18
Total		68	39	26	27	45	205

Table 6. *Family Biotic Index (FBI) values, Biological scores (BMWP) and Average Score Per Taxa (ASPT) values obtained*

	Sampling site					
	St1	St2	St3	St4	St5	Overall
FBI values	4.31	4.30	4.34	4.17	5.07	4.40
Water quality	Good	Good	Good	Very good	Fair	Good
BMWP score	98	59	96	108	116	122
Category	Moderate	Moderate	Moderate	Good	Good	Good
ASPT score	4.9	4.54	5.33	5.14	5.04	4.88
Quality/Interpretation	Moderate	Moderate	Good	Good	Good	Moderate

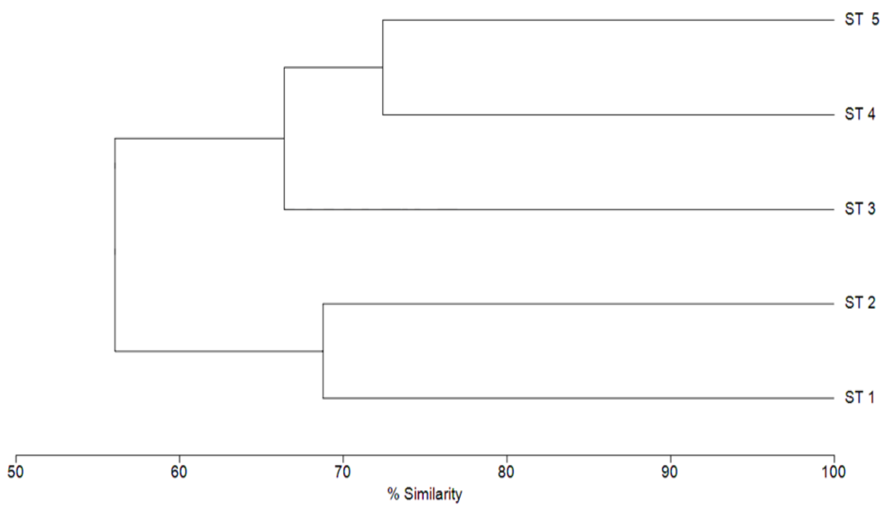

Fig. 3. *Dendrogram showing similarity among sites (St1-St5) based on the abundance of macroinvertebrates: Bray Curtis clustering method*

4 DISCUSSION

In earlier study on abundance and diversity of aquatic macroinvertebrates of Nzovwe stream, about 584 macroinvertebrates under 7 orders and 22 families were collected [28]. In the present study, a total of 985 macroinvertebrates belonged to 8 orders and 27 families were collected. This difference could be influenced by sampling efficiency and methods used in the two studies. In the current study, water quality of each sampling site (St1-St5) was inspected using biotic indices, and the results indicate a good to moderate water quality for all five sampling sites. However, there was a small variation between the biotic index score levels. This variation may be due to different taxa, insufficient habitat and substratum in some sites. Shannon-Wiener diversity index (H') indicated all five sampling sites were moderately polluted as their H' values was between 1.954 and 2.617. This is according to Wilhm and Dorris [29] and Mason [30] who recommended that H' values between 1 and 3 indicate moderately polluted stream. They further explained that, H'-values approaching 4 suggest unpolluted streams, while values lower than 1 are indications of a stressed community affected by heavy organic pollution. Therefore, according to this study, the Nzovwe stream experience moderate pollution with the overall diversity index value of 2.654. In addition, St1-St5 had more number of individuals belonging to class II revealing these sampling sites were moderately polluted [24]. High relative abundance of organisms in the order Coleoptera (i.e. Predaceous diving beetles, Crawling water beetles, Water scavenger beetles), Odonata (i.e. Dragonfly, Damselfly), and macroinvertebrates in class II indicate that the stream support macroinvertebrates that live in a good or moderate polluted aquatic ecosystem. These organisms are moderately pollution-sensitive macroinvertebrates which need fair water quality to survive unlike pollution-sensitive organisms such as mayfly (Ephemeroptera) and Stonefly (Plecoptera) that strictly found in a good stream water quality (i.e. clear or non-turbid waters with high dissolved oxygen levels) to survive [24], [31], [32]. The FBI values of St1-St3 and St4 indicate good and very good stream water quality, respectively, whereas St5 fair water quality. Hence, basing on the evaluation of water quality using the family level biotic index indicated in table 4 shows that St1-St3, St4 and St5 indicate possibility of some organic pollution, possible slight organic pollution, and fairly substantial pollution respectively [1], [9], [10], [33]. Kilgour [34] explained that FBI less than 6 indicates unimpaired stream quality, similarly, the FBI value of the current study indicates the Nzovwe stream has good water quality as the overall FBI value is 4.40. Biological scores (BMWP) of St1-St3 indicated moderate water pollution while St4 and St5 indicated good water quality. Overall BMWP score indicates the stream had good water quality. This result is similar to the previous study by Ojija and Laizer [5] which showed that the ecosystem health of the Nzovwe stream is in the category of 'good' in class I with BMWP score of 115, indicating unimpaired ecosystem [35], [36]. Furthermore, Average Score Per Taxa (ASPT) values of St1 and St2 indicated moderate pollution while St3, St4 and St5 indicated good water quality. The overall ASPT value indicated that the stream is moderately polluted ecosystem. Furthermore, according to David et al. [22], Dipterans are known to be important part of community structure of benthic macroinvertebrates. They are found in all stream types, ranging from clean streams to polluted streams. Very low and high Dipteran index values show poor stream quality. Unimpaired stream is indicated by 20-45% Dipteran and anything outside of this range is considered impaired [37]. In the current study, it was found that Diptera index value is 20.711%, indicating the Nzovwe stream being unimpaired aquatic ecosystem [22], [38]. Like the % Dipteran index, very low and high % Insect values indicate deprived stream quality [38]. Mostly, an unimpaired condition is indicated by 50-80% Insects [37]. Insect index value of Nzovwe stream was found to be 98.173% indicating unimpaired stream [22]. Also, high percentage of midges (% midges) in aquatic ecosystem is an indications of poor water quality. The % midge in Nzovwe stream was 4.162%. This % midge value in the stream is an indication of unimpaired ecosystem health of Nzovwe stream and therefore support aquatic macroinvertebrate community [23]. Moreover, the % Snails index value of Nzovwe stream is 0.61% indicating that the stream is possibly impaired [38]. Based on these indices, the present study indicates that the water quality of Nzovwe stream is slightly polluted. Additionally, cluster analysis using Bray-Curtis similarity indicated that there are similarities between sampling sites based on the abundance of macroinvertebrates. St1 and St2 showed a close similarity of number of macroinvertebrates of about 68%. St4 and St6 showed a similarity of macroinvertebrates abundance of about 73%. St3 had a similarity of abundance of macroinvertebrates with the rest of other sites at less than 68%. Similarity and differences between sampling sites could be attributed to different types of pollutants, concentration of organic matter, and loads of garbage within a site that influenced the macroinvertebrates abundance. For instance, at St1 and St2 neither garbage nor farms were seen, however there were people bathing and washing their clothes. Heaps of garbage and rubbish were seen at St4 and St5, for instance, leftovers, food packaging materials, bottles, clothing, compost, and disposables. St3 was seen affected by human activities especially collection of gravels, stones and extraction of soil from the stream. In addition to these, wastes from farm lands and garbage near the stream are suspected to enter the stream through this site. Garbage as well as extraction of soils and pebbles from the stream destroy the size and depth of the stream. They also disturb and pollute the stream ecosystem, by increase turbidity in the water and decreasing light penetration; hence reducing the growth of photosynthesizing plants that provide oxygen to aquatic organisms.

CONCLUSION AND RECOMMENDATION

From this current study, it can be established that ecosystem health of Nzovwe stream is moderately polluted based on the abundance of moderately pollution-sensitive macroinvertebrates, FBI values, BMWP and ASPT score. Thus, this study recommends that pollutant sources should be effectively monitored and isolated from Nzovwe stream; and any increases in rubbish and other garbage near the stream over time should be prevented. In addition, education and policy implications on management and conservation efforts of stream water quality and aquatic creatures should be enhanced.

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