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Habitat preference of benthic macroinvertebrates in highland rivers of Ethiopia

Getachew Senbete
Oromia Agricultural Research Institute, Batu Fishery and Other Aquatic Research Center Zeway, Oromia, Ethiopia

Abstract
Study on microhabitat preference of Benthic Macroinvertebrate (BMI) was conducted on two rivers (Meribo and Leliso) in Ethiopia. Sample was collected in post rainy season, October 2010 with objectives to document taxa-habitat relationship of less affected rivers in relation to substrate type. After ecological integrity assessment, a stretch of the rivers were selected and substrate specific BMI samples were collected from the available in-stream habitats using hand net of 500 µm mesh size. Twenty one out of 38 taxa were subjected to statistical analysis and found all taxa, except Baetidae and Chironomidae, showed clear narrow range of habitat preference when analyzed with PCORD5 (final stress=15.68). However Baetidae and Chironomidae did not show clear preference to substrate which could be due to their taxonomic diversity and wide range of adaptability. Mud & sand, microhabitat and megalithal were preferred by few taxa whereas majority of the BMI taxa preferred macrolithal, mesolithal, woody debris, microlithal and roots. Therefore, river modification, climate change, and other anthropogenic impacts that have access to modify these in-stream microhabitats could highly affect the BMI diversity. In conclusion this work will help as reference document for the future study.

Keywords: Africa, Ethiopia, macroinvertebrates, microhabitat

1. Introduction

Benthic macroinvertebrate assemblage varies spatially and temporally in relation to different biotic and abiotic environmental factors like substrate type, water current, water depth and habitat availability [11]. For instance, discharge creates different stream morphologies as a result of deposition and/or erosion [21, 24, 22]. These substrate type and composition forms different in-stream habitats such as mud, sand, gravel, pebbles, stones, cobbles, boulders, as well as organic habitats like macro-algae, exposed root networks, and coarse particulate organic matter which finally contribute to habitat diversity.

Availability of favorable habitat is the basic criteria for existence of biodiversity. Since different organisms need different habitat types, the in-stream habitat diversity positively discriminate the diversity of BMI and a positive correlation often exists between in-stream habitat diversity and BMI species richness [6]. Habitat diversity may provide not only a greater number of niches, but also a greater number of refugees during disturbance and/or predation [20]. However, [21] states that excessive sediment loading results in habitat homogeneity and hence negatively affects BMI diversity and currently, loss of diversified in in-stream habitat is becoming a risk in freshwater ecosystems.

Disturbance from flood has different degrees of pressure in temperate and tropical stream BMI communities since the rainfall frequency and intensity, which triggers flooding, are different in the two regions [16]. A flood in aquatic ecosystems is an important organizing factor of benthic communities [22, 17, 24]. Some studies showed that large floods caused substantial reduction in the abundance, taxa richness, and diversity of BMI compared to small floods caused by medium frequent precipitation [8, 9, 11]. However, invertebrate assemblages in temperate and tropical streams showed only slight differences [13]. Although intensive studies conducted in temperate areas could be the base for tropical ecology, similarities and differences among the various types of tropical and temperate streams need to be further studied for better understanding. Understanding and knowledge about habitat loses because of ecological degradation is limited and there are only few studies available on the short comings of these disturbances in the tropical streams and rivers [16]. As in developed countries, BMI are the organisms most widely used as bio monitoring in some of the developing countries. Although direct transfer of approaches used from developed to developing countries are often appropriate, techniques dependent on pollution-tolerance values are often region specific and not transferable [23]. Zoogeographical aspects like faunal differences intensify these problems and underlie the need for basic knowledge regarding the ecology of BMI.

Reference conditions which represent the physical, chemical, and biological status of nearly non-impacted or slightly impacted site are very important in ecosystem restoration and management [6]. It is important that management assess the magnitude and direction of these changes, not only between a previous and a present condition but also between a present and a future prediction [4]. Thus, reference in terms of a previous (historic) or future condition can differ. Therefore, knowledge of what organisms are found in these streams, their distribution and the overall status of the ecosystem at a certain time is critical to understand the trend of changes and the extent of disturbance, and to plan for mitigation measures [16]. Despite several anthropogenic related disturbances, only few researches are available on the taxonomy, distribution, and habitat preference of BMI in Ethiopia [3, 12]. Although the research gaps are wide in this area, this paper focuses on the microhabitat preference of the BMI of the reference sites in highland rivers of Bale Mountain, Ethiopia.

Methodology

Description of the study area

This study was conducted on two perennial rivers, Meribo (6059’17N, 39021’06E) and Leliso (6058’36N, 39023’19E) south eastern central highland of Ethiopia. It is 345 km South of Addis Ababa, the capital of Ethiopia. Both Meribo and Leliso rivers are found in the uppermost of Wabe Shebele basin. The two rivers originate from altitude of about 3400 m a.s.l. and drain the northern side of Bale Mountains. The altitude at the sampling sites was 2394 m a.s.l and 2429 m a.s.l. for Meribo and Leliso rivers respectively.

The study area is characterized by bimodal rainfall, with the main rainy season from July to September. The dry season lasts from October to February, followed by the short rainy season occurring between February to April with annual average rainfall about 890mm. Meribo and Leliso have an average annual discharge volume of $3.28M^3s^{-1}$ and $1.58M^3s^{-1}$ and catchment area of 185 km^2 and 135 km^2 respectively [2].

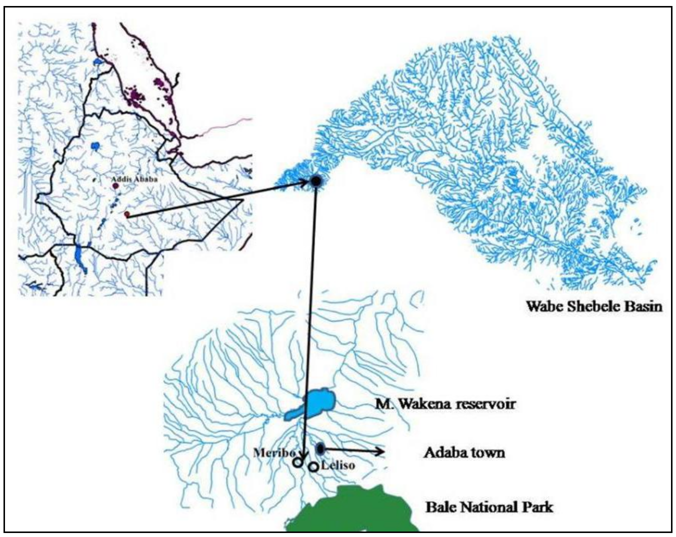

Fig 1: Map of the study area

The existing traditional land use of the area is mixed farming (agro-pastoral) type of which crop production and livestock take the major part [1]. Barely, wheat and some other leguminous plants are the major crop types [27]. From the total 162,152 hectares available land in the district, 34.58 % is forest and shrubs, 24% agricultural land, 27.64% mountains and gorges, 2.84% settlement, 2.02% water bodies, 1.76% for other uses and 7.18% is grazing land [1].

Materials and methods

Meribo and Leliso rivers were selected and a river stretch was investigated for its habitat diversity. Site protocol was filled to document land use practices in the catchment area, available in-stream habitats, riparian vegetation, hydrologic conditions and flow regulation, physico-chemical and biological conditions. Available in-stream microhabitats, organic and mineral habitat types were described and their association with organic and biotic habitat was assessed. Mineral and organic habitats were defined according to pro-rata multi-habitat-sampling of benthic invertebrate [19].

Table 1: Characterization of habitats

Mineral habitat	Particle size class
Megalithal	>40 cm large cobbles, boulder, blocks, bedrock
Macrolithal	20cm-40cm; coarse blocks
Mesolithal	6cm -20cm fist to hand sized cobbles
Microlithal	2cm-6cm coarse gravel
Akal	0.2cm -2cm fine to medium sized grave
Psammal	6µm -2mm sand
Psammolpelal	Mixture of sand with mud
Pelal	6µm mud/organic mud and sludge
Argyllal	Silt; loam, clay(inorganic)
CPOM	Coarse Particulate Organic Matter
Submerged macrophytes	Totally immersed macrophytes
FPOM	Deposition of particulate organic matter, Fine Particulate Organic Matter
Woody debris	Fallen dead trees and remains of large branches

Megalithal, macrolithal surface and bottom, mesolithal, microlithal, mud &sand, woody debris, different root types such as tree roots, marginal fibrous roots, and root bunch in shallow pool were identified as different in-stream habitats.

Table 2: Habitat availability in Meribo and Leliso river at the sampling stretch in %.

Microhabitat	% Availability in Meribo	%Availability in Leliso
Megalithal	5	30
Macrolithal	65	45
Mesolithal	5	5
Microlithal	<5	5
Mud-sand	5	5
roots	15	<5
Woody debris	0	5

Sampling design

103 single standardized substrate specific BMI samples were collected from 21 sampling points. Each sampling point had 5 replications except for two sampling points at megalithal and one point at root in Meribo, which had 4 replications each. The sampling points were purposely allocated to address all the available habitats in the active channel. Each sample was treated separately to evaluate reproducibility or consistency of each point in BMI assemblage whereas similar sampling points were grouped under respective microhabitat. A total 58 samples were taken from Meribo and 45 samples were collected from Leliso

BMI samples were collected using D frame net of 500µm mesh size and area of 25cm*25cm area. Sample collection was done against water current, to avoid early disturbance. The hand net was firmly placed on the sediment against the water current and sediments were disturbed up the net for about one minute to a depth of 5cm-20cm to dislodge all the organisms into the net. For megalithal, the surface was brushed and scraped to sweep the animals into the net. Different positions of the megalithal (opposite and front to current) were also sampled. The surface of macrolithal was brushed but immediately the bottom of the same macrolithal was also sampled independently by turning the stone and brushing the underside area while it is in the net. Woody debris was taken to bucket to wash the animals. Roots were shacked vigorously to remove the organisms. Bigger leaves were thoroughly washed and inspected for attached organism. All the samples were transferred to pre-labeled plastic containers with the necessary collection information and preserved using 4% formaldehyde and transported to laboratory for sorting and identification.

In the Laboratory, samples were repeatedly washed under gently flowing tap water through a series of sieves of different mesh size. The washed samples were put on white trays to sort the animals from debris. Sorted BMI were identified by using hand lens and Olympus compound microscope. Aquatic Invertebrates of South African rivers field guide booklet and illustrations [10] was employed as basic identification key. The identified organisms were enumerated and transferred to vials and preserved using 70% alcohol. Detail identification of the samples was done in Vienna Museum of Natural History, Austria

Results & discussion

The study area is characterized by bimodal rainfall, with the main rainy season from July to September. The dry season lasts from October to February, followed by the short rainy season occurring between February to April with annual average rainfall about 890mm. Meribo and Leliso have an average annual discharge volume of 3.28M^3s^{-1} and 1.58M^3s^{-1} [2].

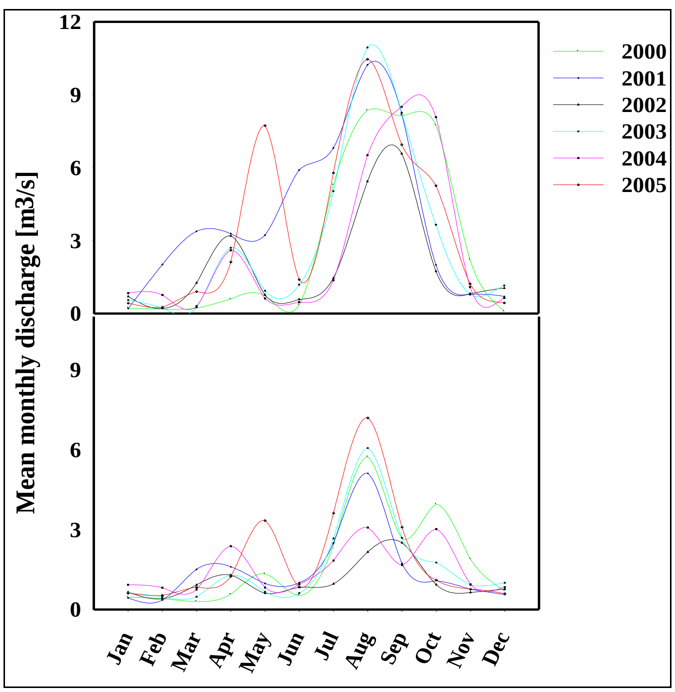

Fig 2: Mean monthly discharge [M^3s^{-1}] of the two rivers from 2000-2005. Top is Meribo and bottom is Leliso.

Meribo and Leliso are different in their discharge regime although they are adjacent and share similar season. They differ in discharge volume, but have similar discharge pattern lowest in December and the highest discharge hit in August. Ten years discharge data indicated a slight decrease from1998 to 2006 as indicated below in figure 3 which could be attributed to gradually changing land use, and emerging climate change issues.

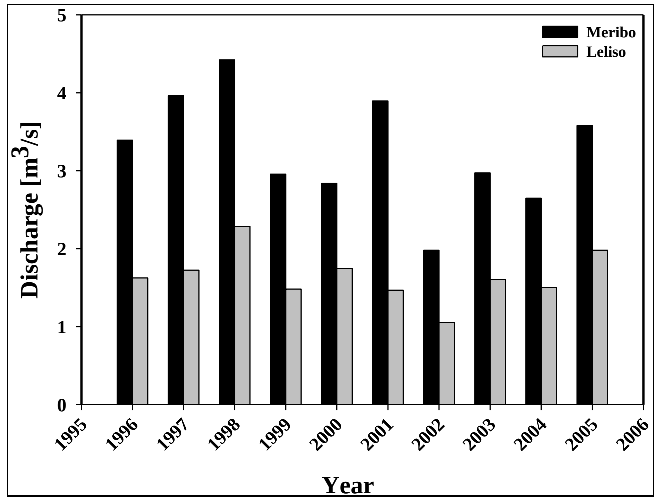

Fig 3: Yearly mean discharge, River Meribo and Leliso.

The land use of the area is mixed farming (agro-pastoral) type of which crop production and livestock take the major part [1]. Barely, wheat and leguminous plants are the major crop types [27]. From the total 162,152 hectares available land in the district, 34.58 % is forest and shrubs, 24% agricultural land, 27.64% mountains and gorges, 2.84% settlement, 2.02% water bodies, 1.76% for other uses and 7.18% is grazing land [1].

BMI communities of the investigation area

A total of 103 samples were collected from 21 different sampling points during October 2010, which is post rainy season in the region. A total of 12,201 BMI individuals belonging to 38 taxa and 11 taxa groups were identified from the samples. Numerically, Diptera was the dominant taxa group with relative abundance 65.5% followed by Ephemeroptera (23.2%), and Heteroptera (3.7%) of the total BMI individuals counted. Of five taxa built Diptera, Simuliidae and Chironomidae contributed 33.35% and 29.17% of the total count respectively. The frequency of occurrence for Chironomidae was 96% and for Simuliidae 32%. Therefore the species rich Diptera family Chironomidae was the most ubiquitous and abundant taxa across all the substrates whereas, the Simuliidae is limited to few habitat compared to Chironomidae, but highly abundant in number [5]. Has also reported similar dominancy of dipteral taxa. Ephemeroptera, the second dominant taxa group, was dominated by Baetidae which had relative abundance of 18.84% from the total BMI individuals, and it was the second widely distributed taxon next to Chironomidae with the frequency of occurrence 89%. However, EPT taxa accounts 26% of the total count which indicates better abundance of the sensitive taxa in these rivers.

Of the 38 taxa found in the total sample, only 16 taxa (42%) were found common for both rivers. Almost all taxa of

Heteroptera, some taxa of Coleoptera such as Psephenidae larvae were found almost exclusively in Meribo whereas, majorities of the Coleoptera families, Lepidostomatidae, and nearly all Perlidae were found in Leliso. This indicated that Meribo and Leliso rivers are different in most of their BMI community composition although, the two rivers are under the same land use and have similar physico-chemical parameters. Macroinvertebrate communities of the Meribo River.

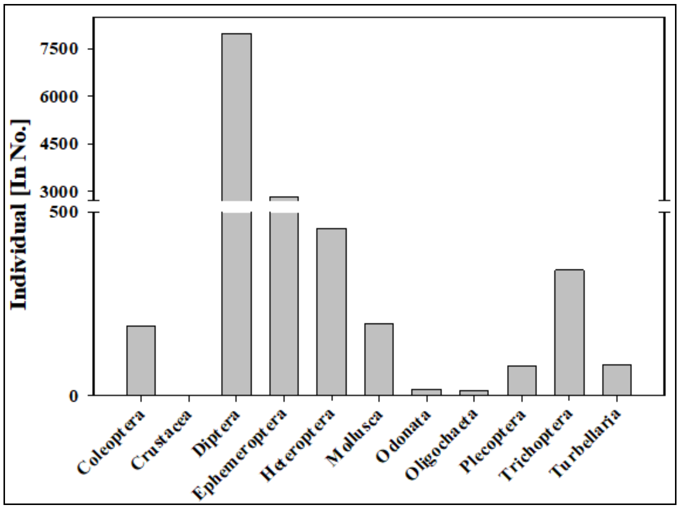

Fig 4: Abundance of taxa groups in the whole sample.

Macroinvertebrate communities of the Meribo River

From Meribo, 5425 BMI individuals (44.5 % of the total 12201BMI individuals) belonging to 29 taxa recovered from the 58 samples collected from the river. Relative abundance of Simuliidae and Chironomidae was 31.29% and 19.61% respectivel. The family Baetidae with 21.35% relative abundance was the second abundant taxa whereas Naucoridae contributed 7.3% and Hydropschidae 4.9% to the total count from River Meribo. The remaining 24 taxa contributed only 15.55% to the BMI of Meribo. On the other hand, 13 taxa were found exclusively in Meribo River. All Heteroptera families except *Hebrus* sp., all Odonata and Mollusca were found only in Meribo.

Macroinvertebrates communities of the Leliso River

Forty five samples from different microhabitats in the river Leliso had 6776 BMI individuals belonging to 24 taxa which are 55.5% of the total 12201 BMI individuals. Similar to the total sample, samples from Leliso River were also dominated by Diptera of which Chironomidae with relative abundance of 36.82% and Simuliidae (34.92%) numerically dominated the samples from Leliso. The family Baetidae was dominant from the Ephemeroptera with 16.84% relative abundance from Leliso. The remaining 21 taxa contributed 11.4% of total BMI count from Leliso. Nine taxa were found exclusively in Leliso. Some of the taxa found exclusively in Leliso include all the Dytiscidae except *Rhantus sp*., and *Stenelmis sp*, a Heteroptera taxa group, Hebrus sp. Despite the fact that the number of samples from River Leliso is less in number than that of Meribo, the number of BMI found in this river was greater than Meribo. BMI density was found 1496 ind.m^{-2} and 2409 ind.m^{-2} on average in Meribo and Leliso respectively.

Despite similar land use and comparable value for their physico-chemical parameters, BMI communities of Meribo and Leliso were found different for most of the taxa. The result shows only 16 taxa (42%) were found common for both rivers. Almost all taxa of Heteroptera (5 out of 6 families), some taxa of Coleoptera (Psephenidae larvae, Rhatus sp. and Aulonugyrus sp.) were found almost exclusively in Meribo whereas, the remaining Coleoptera families, Lepidostomatidae, and nearly all Perlidae were found exclusively in Leliso. This indicates that the two rivers are distinct in their BMI communities.

The habitat share of the BMI communities was analyzed using PCORD5 software. PCORD5 software uses log+1 transformed data of each sample to produce an output as a form of Non-metric Multidimensional Scaling (NMS) scatter plot. The fact behind NMS is that it calculates matrix of item-item similar and assigns a position for each item in a low-dimensional space [26] so that each point can be observed in 3D visualization. Therefore, similar sites are near each other and dissimilar sites become far apart. NMS scatter plot (Figure 4) also revealed that the BMI communities of the two rivers are distinct (final stress =15.68) although they are comparable regarding size, land use and almost similar in their physico-chemical parameters.

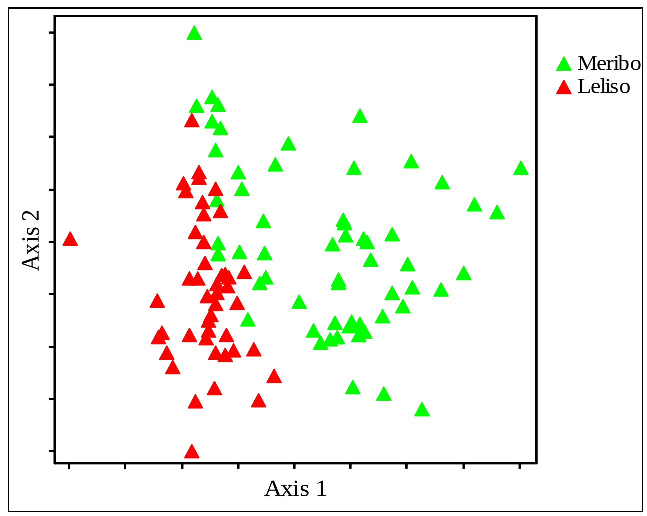

Fig 5: NMS scatter plot showing distinct BMI assemblage in Meribo and Leliso rivers

The reasons for deviation in BMI communities could be attributed to Variation in discharge regime and variation in vegetation and land use: The influence of discharge regimes on BMI abundance and richness was reported by several authors [22, 24, 25]. also reported that streams with steady flow had more BMI abundance and taxa richness while the BMI abundance and richness were found to be influenced by high discharge regime, which could be either through directly dislodging the animals by current or modification of habitat structure and the associated Fine Particulate Organic Matter (FPOM) and Coarse particulate Organic Matter (CPOM) in the stream. Compared to Meribo, Leliso has a lower discharge (Figure 3). Furthermore, single discharge measurement during the sampling period showed higher discharge volume and strong current in Meribo.

In line with this finding, BMI density per microhabita was higher in Leliso compared to Meribo except for Megalithal habitat which was mainly inhabited by rheophilic Simuliidae. Therefore, discharge regimes play pivotal role in structuring BMI community structure and the in-stream habitats through influencing the available resource distribution in the stream which ultimately determine the distribution and abundance of BMI. As reported in [22] flood in aquatic ecosystems is an important organizing factor of benthic communities and hence affects the abundance and availability of food and habitat. Moreover [17, 24] indicated the substantial reduction in BMI abundance and taxa richness following high flood.

The abundance and diversity of EPT taxa is crucial in biological water quality monitoring because of their sensitivity to stress. EPT-taxa richness was the lowest at mud & sand microhabitat in Meribo (Table 3) and at megalithal in Leliso. In conclusion woody debris, macrolithals, mesolithals, roots and microlithals showed better taxa richness than mud &sand microhabitat and megalithal. Similarly, [21] states that excessive sediment loading results in habitat homogeneity and hence negatively affects BMI diversity. The mean number of total BMI individuals per sample was the highest at the megalithal and more diversified habitates like woody debris. Study conducted by [11] also reveals similar result that benthic macroinvertebrate assemblage directly relates to biotic and abiotic environmental factors like substrate type, water current, water depth and habitat availability. Moreover [6] and [20] also stated the correlation between habitat diversity and species richness, because diversified habitat not only serve as niche, but also a help as refuge during disturbance and predation.

Table 3: Distribution and abundance of EPT compared to total BMI across the microhabitats.

River	MiHa	(n)	BMI TI	BMI TI/sample	Eph	Ple	Tri	EPT TI	EPT TI/sample
Meribo	Megalithal	4	151	378	38	0	5	43	11
	Macrolithal bottom	15	115	77	394	1	238	633	42
	Macrolithal surface	15	810	54	163	0	18	181	12
	Mesolithal	5	671	134	426	0	0	426	85
	Mud & Sand	5	146	29	12	0	0	12	2
	Roots	14	112	81	481	0	9	490	35
Leliso	Megalithal	15	300	200	315	1	2	318	21
	Macrolithal bottom	5	477	95	310	31	9	350	70
	Macrolithal surface	5	636	127	144	0	0	144	29
	Mesolithal	5	740	148	128	4	4	136	27
	Microlithal	5	730	146	245	42	5	292	58
	Mud &Sand	5	630	126	84	1	11	96	19
	Woody debris	5	561	112	93	2	40	135	27

MiHa=microhabitats, (n) = number of samples, TI=total individuals, Eph=Ephemeroptera, Ple=Plecoptera, Tri=Trichoptera, EPT=Ephemeroptera, Plecoptera, Trichoptera

From the total 12201 BMI individuals found in the sample, the contribution of EPT was 26.68% despite the fact that more than 60% of the EPT individuals were composed of Ephemeroptera across all the microhabitats. Among the EPT, Plecoptera more preferred microlithal and macrolithal habitats in Leliso but were generally less abundant in the EPT composition and almost absent from river Meribo. Study conducted in USA, by [15] on stream of large agricultural catchment dominated by clay and sand soil showed reduced BMI abundance and EPT taxa were dominated by Plecoptera, and Ephemeroptera and concluded that increase in agricultural intensity upstream significantly affected the BMI composition. In his study he found that pasture draining streams and forest draining streams showed differences in water chemistry and BMI. Therefore, the variation in BMI composition of both rivers could be attributed to the difference in land use and variation in discharge regime which have the power to structure habitat availability.

Each BMI taxa have its own affinity to microhabitat and current (Table 4) although it is inconvenient to present all the result for each taxa graphically. To identify microhabitat and current preference only taxa with a frequency of occurrence greater than 3% and total abundance greater than 10 were considered to avoid occurrences by chance. Based on these criteria, 21 taxa (55%) of the total taxa found in the samples were subjected to statistical analysis and their abundance and frequency of occurrence is shown below.

Table 4: Summery of microhabitat and current preference of BMI communities.

Taxa	most preferred microhabitat	preferred current
Turbellaria		
Planariidae	macrolithal, roots	in lentic current
Mollusca		
Ancylidae	mud & sand**, mesolithal**,macrolithal**	stagnant to lentic current
Oligochaeta		
Oligochaeta	mud & sand, roots, *	stagnant to lentic current
Crustacea		
Potamidae	macrolithal	under stones in riffle

Ephemeroptera		
Baetidae	ubiquitous	stagnant to very fast
Acanthiops sp.	macrolithal**, megalithal**	medium to very fast
Heptageniidae	macrolithal** mesolithal*, woody debris**,@	lentic to medium
Caenidae	All except megalithal	stagnant to medium
Plecoptera		
Perlidae	microlithal**, mesolithal**, macrolithal*,@	lentic to medium current
Odonata		
Anisoptera	roots*, macrolithal*@	stagnant to lentic
Zygoptera	Roots*	lentic current
Heteroptera		
Naucoridae	roots***, macrolithal**, mesolithal*,@	lentic current
Nepidae	roots *	lentic current
Gerridae	roots*	lentic current
Veliidae	roots*	lentic current
Corixidae	roots*	lentic current
Hebridae		
Hebrus sp.	woody debris*	lentic current
Coleoptera		
Dytiscidae	mud & sand*	stagnant water
Agabus sp.	mud & sand *	stagnant to medium current
Laccophilus sp.	woody debris*	lentic current
Rhantus sp.	roots*	lentic to medium
Cercyon sp.	woody debris*	lentic current
Aulonogyrus sp.	roots*, macrolithal*	lentic current
Elmidae		
Elmidae larvae	woody debris***, macrolithal**,@,	lentic to fast current,
Stenelmis sp.	megalithal*, macrolithal	medium to fast current
Microdinodes cf.jeanneli	macrolithal, megalithal*	medium to fast current
Dineutus gondaricus	roots*	lentic current
Psephenidae larvae	macrolithal**	under stones
Trichoptera		
Lepidostomatidae	woody debris*	lentic current
Hydropsychidae	macrolithal***, @, roots*	medium to very fast
Rhyacophilidae	macrolithal** woody debris*	lentic current
Diptera		
Chironomidae	ubiquitous	stagnant to very fast
Dixidae	woody debris*	lentic current
Ceratopogonidae	mud & sand**, mesolithal*, macrolithal*	stagnant to medium
Psychodidae	roots*	lentic current
Simuliidae	megalithal***, Macrolithal **	medium to very fast
Tipulidae	mesolithal	stagnant to medium
Limoniidae	macrolithal**	fast current

Conclusion

Despite the dominancy of Diptera taxa group in the BMI of the investigation sites, 26% of the individual composition was EPT taxa which can be taken as better taxa composition. The relatively higher diversity of taxa preferred the macrolithal, mesolithal, microlithal, woody debris and roots were a function of water current and available substrate which indicates BMI prefer not only the substrate, but also ambient water current. It was observed that each BMi taxa has its own range of habitat preference. However, more detail identification to the simplest and the lowest taxonomic level is very crucial in order to clearly point out habitat-taxa relationship. Nevertheless, Low taxa richness and low BMI abundance observed in the mud & sand showed that this microhabitat supports low BMI diversity. Therefore poor catchment management like deforestation and careless agricultural practices which induce massive erosion ending in streams as mud and sand deposition is eventually a threat for BMI diversity. Therefore, less frequent and more intensified tropical rain, particularly in mountainous countries like Ethiopia will significantly affect BMI diversity mainly though habitat modifications. On the other hand, climate change which is known in affecting shift discharge regime can affect the marginal habitats at the river bank and riffle sections of the river as both are vulnerable to seasonal discharge fluctuations. Riffles area is prone to drought or prolonged dry seasons in most tropical streams. Information about BMI diversity profile and their respective habitat is very important to evaluate the extent and direction of changes in ecological status, to compare the past with the present and make future forecast which is important for ecosystem management. Therefore, this paper will help as a reference document concerning habitat taxa relationship of high land streams under similar eco-regions and land use.

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Reference

1. ADEPLO. Adaba District Environmental Protection and Land Use Office; Unpublished: Adaba, Ethiopia, 2009.
2. ADWME. Adaba District Water Mine and Energy Report, Unpublished Adaba, Ethiopia, 2007.
3. Ambelu BA. Biological monitoring based on macro invertebrates for decision support of water management in Ethiopia. PhD thesis, Ghent University, Belgium, 2009.
4. Armitage PD. Prediction of biological responses in: Calow, P. & Petts, G.E. (eds.), The Rivers Handbook. Hydrological and Ecological Principles: Blackwell Sci. publ. 1994; 2:54-275.
5. Aschalew LH. Applicability of Bioassessment Methods using Benthic Macroinvertebrates to evaluate the Ecological Status of Highland Streams in Ethiopia: MSc. thesis: Unesco-IHE, Delft, The Netherlands, 2007.
6. Barbour MT, Gerritsen J, Snyder BD, Stribling JB. Rapid Bio-assessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic macro invertebrates and Fish. EPA841-B-99-002 Second Edition, 1999.
7. Beisel JN, Polatera PU, Thomas S, Moreteau JC. Stream community structure in relation to spatial variation: the influence of meso habitat characteristics, Hydrobiologia. 1998; 389:73-88.
8. Boulton AJ, Lake PS. The ecology of two intermittent streams in Victoria, Australia. Freshwater Biology. 1992; 27:123-138.
9. Cobb DG, Galloway TD, Flannagan JF. Effects of discharge and substrate stability on density and species composition of stream insects: Canadian Journal of Fisheries and Aquatic Sciences. 1992; 49:1788-1795.
10. Gerber A, Gabriel MJM. Aquatic invertebrates of South African Rivers-Field Guide. Resource Quality Services Department of Water Affairs and Forestry, 2002.
11. Giller PS, Malmsqvist B. The biology of streams and rivers. New York: Oxford University Press, 1998.
12. Harrison AD, Hynes HBN. Benthic fauna of Ethiopian Streams and rives. Archiv fur Hydrobiologie. 1988; 81:1-36.
13. Harrison AD. Re-colonization of a Rhodesian stream after drought. Arch. Hydrobiology. 1966; 2:405-421.
14. Hartung J, Elpelt B. Multivariate Statistik. Lehr- und Handbuch der angewandten Statistik. 6. Auflage. R. Oldenbourg Verlag München, 1999, 815pp.
15. Host EG, Richards C. Identification of predominant environmental factors structuring stream macro-invertebrate communities within large agricultural catchment: Freshwater biology. 1993; 29:285-294.
16. Mathooko JM, Mavuti KM. Composition and seasonality of benthic invertebrates and drift in the Naro Moru River, Kenya. Hydrobiologia. 1992; 232:47-56.
17. Matthaei CD, Huber H. Microform bed clusters: are they preferred habitats for invertebrates in a flood-prone stream. Freshwater Biology. 2002; 47:2174-2190.
18. Moog O, Sharma S. Description of simple operative top-down stream Typology for the HKH region- Working paper within ASSESS-HKH project: ASSESS-HKH consortium (editor): Available from, 2005b.
19. Moog O. Guidline manual for pre-classifying the ecological status of HKH Rivers. Version, 2005.
20. Murdoch WW, Warbrick SL, Luck SRF, Walde S, YUD S. Refuge dynamics and meta-population dynamics: an experimental test, 1996.
21. Rahel FJ. Homogenization of fish faunas across the United States Science. 2000; 288:854.
22. Resh VH, Brown AV, Covich AP, Gurtz ME, LIHW, Minshall GW, *et al*. The role of disturbance in stream ecology. Journal of North American Benthological Society. 1988; 7:433-455.
23. Resh VH. Multinational, Freshwater Biomonitoring Programs in the Developing World: Lessons Learned from African and Southeast Asian River Surveys. Environ Manage. 2006-2007; 39:737-748.
24. Schreiber ES, Quinn GP, Lake PS. Distribution of an alien aquatic snail in relation to flow variability, human activities and water quality. Freshwater Biology. 2003; 48:951-961.
25. Shivoga WA. The influence of hydrology on the structure of invertebrate communities in two streams flowing into Lake Nakuru, Kenya. Hydrobiologia. 2001; 458:121-130.
26. Sørensen T. Method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Det. Kong. Danske Vidensk. Selsk. Biol. Skr. 1948; 5(4):1-34.
27. Tamene L, Park SJ, Dikau R, Vlek GLP. Reservoir siltation in the semi-arid highlands of northern Ethiopia: sediment yield–catchment area relationship and a semi quantitative approach for predicting sediment yield. Earth Surf Process Landforms. 2006; 31:1364-1383.