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HEADWATER STREAMS AND VALUES OF BIO-ASSESSMENT FOR SUSTAINABLE RIVER MANAGEMENT IN HIGHLANDS OF ETHIOPIA

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Abstract

Headwater streams are important component of riverine ecosystem comprising the majority of the catchment area. These streams are densely networked in the highlands of Ethiopian river basins. Organic and inorganic materials and invertebrates are transported from the headwater streams and they have potential effect on downstream river habitat, water quality and living organisms. In recent years, the understanding of applying biological monitoring system for assessing the ecological health of streams, rivers and associated wetlands is increasing in developing countries including Ethiopia. At a time when anthropogenic activities are increasingly destroying the ecological integrity of riverine ecosystems, monitoring of biological communities is central to assess the health and function of streams for sustainable management. In this study, selected headwater streams in five river basins of Ethiopia were assessed using selected environmental parameters and benthic macroinvertebrate based score system (ETHbios). Streams in the upper section showed near natural ecological condition while after few kilometers in the downstream moderate to bad ecological degradation were measured. The major stressors causing degradation in the downstream sections include continuous human in-stream activities, nutrient loading from farm lands, presence of numerous cattle watering points, and organic and inorganic wastes from industries. Environmental parameters and biotic indices indicated traditional practices of local communities including river bank afforesting and production of perennial fodder grass along river side protect the streams from direct impact of nutrient enrichment.

Key Words: *Headwater, Ecological integrity, Biomonitoring, Pollution, Biotic score*

Introduction

Headwater streams are the origin of most rivers and they are important component of riverine ecosystem comprising the majority of the catchment area. Some studies estimated that headwater streams consist 90 percent of the length of river network (Benda and Dunne, 1997). This implies that a substantial proportion of water volume acquired by the downstream reaches is obtained from the total catchment of a drainage basin. First and second-order streams are generally considered as headwater streams (Gomi *et al*., 2002; Haggerty *et al*., 2002). Headwater streams are extremely heterogeneous ecosystems with high spatial and temporal variation and they are main sources of water, sediments, and organic materials that are transported downstream (Meyer *et al.,* 2001, Gomi *et al.,* 2002). The abundance of headwater streams has advantage to create contact with terrestrial ecosystem and sustain aquatic organism through food web dynamics including allochthonous input. Furthermore, they are essential for sustaining the structure and function in the catchment and their presence offers valuable habitats and services for unique and diverse communities of aquatic and terrestrial flora and fauna.

Headwater streams are among the most threatened ecosystems worldwide (Hering *et al.,* 2006), affected by increasing water demands by the human population and a variety of development pressures. Such anthropogenic activities generally alter stream morphology, hydrology, water quality and aquatic biota that consequently affect the overall ecological integrity of aquatic ecosystems. Currently the problem of stream health deterioration is the main concern of environmental issue that increased from point source pollution to climate change. An increase in scale of threats and challenges in stream ecosystem implies the need for application of scientific knowledge for realistic assessment and sustainable management.

The practice of maintaining healthy ecological integrity in headwater streams is crucial to avail aquatic ecosystem services in the downstream reaches. Aquatic ecosystem services are the processes by which the environment produces resources we often take for granted, such as clean water, habitat for fisheries, and water for various production and development activities. The health and well-being of human populations depend on the services provided by ecosystems and their components including organisms, soil, water, and nutrients (Barbour and Paul, 2010). Healthy ecosystem ensures that services are intact, and the required biological, physical, and chemical components of overall ecological integrity are maintained (Barbour *et al.*, 2000; Moog and Chovanec, 2000). In this regard, biological assessment has been increasingly recognized as the most supporting procedure to determine the level of impact before setting management options.

Biological assessment methods characterize the current status of stream ecosystems by monitoring changes in the aquatic communities associated with short and long time anthropogenic disturbance. These methods have been developed largely to assess the health and level of stresses on an aquatic ecosystem (Birk *et al.*, 2012). Unlike chemical monitoring, the advantage of biomonitoring lies in the ability of biological communities to reflect not only the quality of the water, but also the overall ecological status of the ecosystem (Rosenberg and Resh, 1993; Hering *et al.*, 2006). Several countries in developed world have programs devoted to assessing aquatic ecosystems using biomonitoring methods through the application of biological indicator organisms as a sensor. However, in other countries like Ethiopia, bioassessment is in its infancy although it is increasing gradually as a scientific foundation to establish the method and evaluate indicator organisms is going on by concerned scientific institutions. Among aquatic organisms used as bioindicator, benthic macroinvertebrates (BMI) are often the taxa group of choice for biomonitoring in streams and rivers. Many investigators have shown the macroinvertebrate assemblage to have the capacity of detecting various alterations and multiple stressors, owing to their sensitivity to environmental change (Hering *et al.*, 2006; Aschalew and Moog, 2015). Currently, BMI have received considerable attention in the study of running water ecosystems and have been the subject of numerous studies on links between assemblage characters and environmental variables elsewhere. Recently, BMI received considerable attention by researchers and environmentalist for evaluation of aquatic ecosystem especially streams and wetlands connected to rivers in highlands of Ethiopia as effective bioindicator for surface water assessment (Tesfaye, 1988; Aschalew, 2007; Getachew and Seyoum, 2010; Solomon *et al.*, 2011; Mereta *et al.*, 2013, Aschalew and Moog, 2015).

The ecological, social and economic contribution of densely networked streams and rivers in the highlands of Ethiopia are poorly studied and there ecological health status is not known. In different rural parts of the country where 85% of the population live, streams are the main sources of drinking water and are the only sources of water to satisfy household and development needs. These streams also convey water into local storage compartments such as ponds and shallow aquifers which are important sources of water for maintaining base flow in rivers. In the contrary, streams and rivers flowing through urban and industrial areas of Ethiopia are abused and used for transporting domestic, industrial, municipal, clinical, and other types of liquid and solid wastes. To understand the level of degradation in these streams and rivers, it is important to implement reliable assessment and monitoring tools and procedures. In this paper, a recently developed biotic score for assessing the ecological health of highland streams and rivers of Ethiopia is tasted in the headwater streams of five major rivers of the country to provide assessment methods.

Methodology

Study Area

The samples for this study were collected from selected representative headwater streams in Abay, Awash, Genale, Gibe and Wabe basins. Streams of Abay basin originate in the west, south-west and north highlands of Ethiopia draining a catchment area of 199,812 km^2 and flowing to west to Sudan. Streams of Awash basin originate in the central highlands of Ethiopia and flow to north-east to Djibouti draining a catchment area of 112,696 km^2. Streams of Wabe-Shebele and Genale- Dawa basins originate in Bale and Sidama highlands flowing in the direction of east to Somalia by draining a catchment area of 202,220 km^2 and 171,042 km^2 respectively. Streams of Rift valley basin originate in central and Arsi highlands draining a catchment area of 57,739 km^2 flowing to major lakes in the country.

The sampling sites are located with altitude ranging from 1900 to 3300 m above sea level. Rainfall distribution in the study area is bimodal, short rainy season from February to April while the main rains occur from June to September (NMA, 2012). Headwater streams originated in the protected forests and national parks, and flowing through rural–agricultural areas and urban-industrial sites were sampled to represent different degradation gradient. Samples were collected in the most upper and lower section of each stream to show downstream degradation level. Figure 1 indicate five river basins and streams considered for this study and short description was given for each streams in table 1.

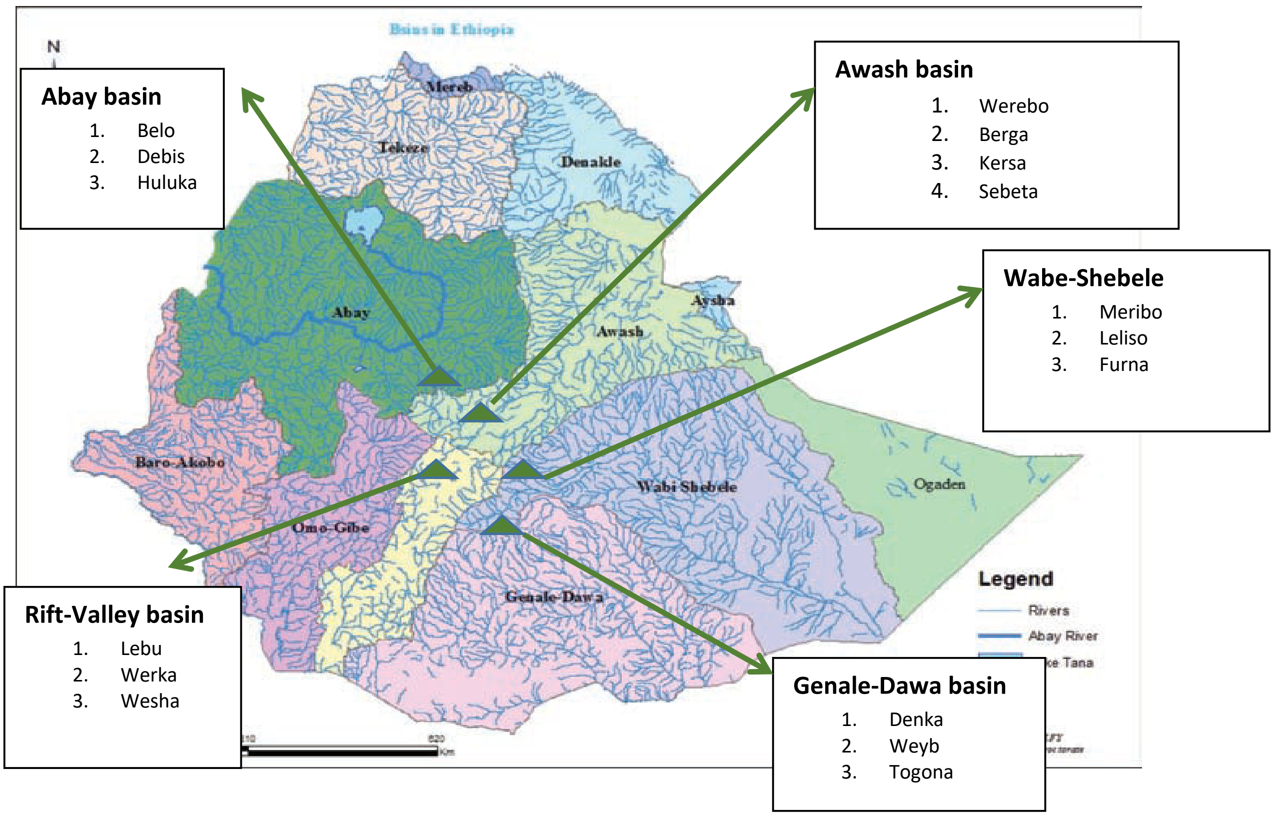

Fig. 1: Map showing river basins and streams considered in the study

Table 1: Sampling streams, geographic location and short description on land use around the sampling sites

Basin	Stream	Altitude (m a.s.l.)	Coordinate	Short description
Abay	Belo	2547	$8^0$44.10N $37^0$37.40E	Protected natural forest in upstream, open grazing and watering points in the downstream
	Debis	2178	$9^0$05.57N $37^0$50.15E	River bank vegetation in the upstream and extended crop farming and cattle watering points in downstream
	Huluka	2208	$8^0$56.30N, $37^0$47.30E	River bank vegetation in upstream, agricultural runoff and domestic waste from Ambo town in downstream
Awash	Werebo	2358	9°03.96N, 38°07.936E	Protected dense natural forest in upstream and extended crop farming in downstream
	Berega	2126	9°01.44N, 38°21.13E	Shrubs and trees in the upstream, intensive mixed crop farming and cattle watering points in downstream
	Kersa	2871	8°57.99N 38°34.46E	Dense protected natural forest in upstream and irrigation supported crop farming in the downstream
	Sebeta	2174	$8^0$54.41N $38^0$37.81E	Eucalyptus plantation with mix of agricultural activities in upstream and various industries in the downstream
Genale-Dawa	Denka	3254	$7^0$04.60N $39^0$47.85E	Upstream in Bale National park with dominant *Erica arborea*, minimal human intervention in downstream

	Weyb	2991	$7^0$07.34N $39^0$46.05E	Upstream in Bale national park, afro-alpine vegetation and open cattle grazing mainly in the downstream
	Tegona	2968	$6^0$58.24N $39^0$57.33E	Dense natural forest in Bale National Park in the upstream, and eucalyptus plantation and agricultural activities in the downstream
Rift - Valley	Lebu	2001	$8^0$14.33N $38^0$27.98E	Shrubs and natural trees in upstream and irrigation supported agricultural activities in the downstream
	Werka	1908	$7^0$04.78N $38^0$38.53E	Dense broadleaved vegetation in upstream and irrigation farming by diversion in the downstream
	Wesha	1978	$7^0$05.19N $38^0$36.59E	Dense broadleaved vegetation in the upstream and irrigation farming by diversion in the downstream
Wabe-Shebele	Meribo	2498	6°57.56N 39°21.98E	Protected dense natural forest in upstream and mixed agricultural activities in the downstream
	Leliso	2408	6°58.94N 39°23.154E	Protected dense natural forest in upstream and mixed agricultural activities in the downstream
	Furna	2436	7°07.13N 39°25.38E	Protected dense natural forest in upstream and mechanized crop farming in the downstream

Sample Collection and Laboratory Analysis

Environmental and BMI samples were collected in November, December and January (dry months of the year) in 2016 and 2017 as recommended in previous studies (Aschalew and Moog, 2015). Environmental variables were measured from each sampling sites. Substrate composition was visually estimated in accordance with particle size: akal (0, 2 – 2 cm), microlithal (2-6 cm), mesolithal (6-20 cm), macrolithal (20-40 cm), megalithal (>40 cm and bed rock). Flow velocity and water depth were measured using velocity meter. Water quality parameters including temperature, pH, dissolved oxygen and conductivity were measured *in situ* using a portable WTW multi-parameter probe (Model HQ40D, HACH Instruments). A liter of water were collected from each investigation site and stored in ice box until return to National Fishery and Aquatic Life Research Center for laboratory analysis. In the laboratory, total phosphorus (TP) was measured following the standard methodology described in APHA (1997).

BMI were collected using standard square frame (side 25 cm) hand net with mesh size of 500µm following multi-habitat approach (Barbour *et al.*, 1999; Moog, 2007). In the laboratory, each sample was passed through a set of sieves (5000, 3000, 2000, 1000 and 500 m mesh size) to separate size class of BMI groups. Identification was performed to the lowest possible taxonomic level based on the available keys with the help of expert.

Calculation of ETHbios Score

The ETHbios score is calculated by adding up the individual sensitivity score of benthic BMI assigned for assessing Ethiopian highland streams and rivers (Aschalew and Moog, 2015). The corresponding average score per taxon (ASPT) was calculated as ETHbios divided by total number of taxa considered in the calculation. Potential relationship between environmental variables identified as important in structuring BMI and ETHbios was explored in SPSS version 18.

Table 2: Taxonomic names and sensitivity scores of benthic macroinvertebrates used in ETHbios score calculations (Aschalew and Moog, 2015).

Common name	Taxon	Score
Crabs	Potamidae	7
Worms	Oligochaeta	1
Leeches	Leeches	3
Snails	Physidae, *Bulimus* sp.	3
	Limpets	6
	Pisidum sp.	7
Mayflies	Baetidae 1 spp	4
	Baetidae 2 spp, Caenidae	6
	Baetidae> 2 spp, *Acanthiop sp.* , Heptageniidae (*Afronurus sp.),*Leptophlebiidae	9
	Tricorythidae	8
Stone flies	Perlidae	10
Caddisflies	Hydropsychidae 1sp	5
	Hydropsychidae 2spp	6
	Hydropsychidae> 2 spp	9
	Lepidostomatidae , Philopotamidae	10
	Leptoceridae, Ecnomidae	8
Dragonflies/	Aeshnidae, Lestidae	7
Damselflies	Gomphidae	6
	Coenagrionidae, Libellulidae	5
Bugs	Naucoridae	6
	Mesoveliidae, Veliidae,Gerridae	5
	Corixidae, Pleidae	4
	Belostomatidae, Notonectidae, Nepidae	3
Beetles	Scirtidae	10
	Psephenidae, *Stenelmis* sp.,*Microdinodes* sp.	8
	Elmidae	7
	Hydrophilidae, Dytiscidae, Gyrinidae, Haliplidae	5
Flies	Tipulidae	7
	Tabanidae	6
	Ceratopogonidae excl. Bezzia-Gr.,	5
	Bezzia-group,	3
	Musidae, Chironomidae with predominantly Tanytarsini and Tanypodinae	2
	Psychodidae, Ephydridae, , Culicidae, *Chironomus sp.,*Syrphidae	1
Water Mites	Hydrocarina	8

Ecological Class of Streams and Rivers

A combination of total taxa score and Average score Per Taxa (ASPT) was recommended to classify highland streams and rivers of Ethiopia in to five ecological quality class (high, good, moderate, poor and bad) (Aschalew and Moog, 2015). Accordingly, Total taxa score and ASPT were calculated for each stream sites and the values were converted to river quality class based on the conversation table below (Table 3).

Table 3: ETHbios conversion table according to Aschalew and Moog (2015)

River quality class	Color	Total score	ASPT-ETHbios	Interpretation
I	Blue	>115	>6.5	high water quality; low level of degradation
II	Green	65-114	5.01-6.4	good water quality; slight ecological degradation
III	Yellow	45-64	4-5	moderate water quality; significant ecological disturbance
IV	Orange	12-44	2.4-3.99	poor water quality; major degradation
V	Red	< 12	< 2.4	Bad water quality; heavily degraded

Results and Discussion

Environmental variables showed variation in upstream and downstream section of study streams (Table 4). Physico-chemical parameters mainly conductivity, oxygen and total phosphorus (TP), the upper section of each streams in all basins indicated good ecological river water quality and the values are in the range of permissible level for healthy streams (conductivity below 1000 µS/cm based on local geology; Oxygen above 6mg/l and TP less than 0.03 mg/l) (Sharma and Moog, 2005). However, the values for these parameters in the lower section of study streams showed variation based on the stressor type and level of degradation. For example, conductivity and TP increased in each streams indicating nutrient enrichment from the catchment and in-stream activities as one moves downstream. The major nutrient source in the rural areas include agricultural activities such as river bank farming, animal watering, washing, bathing and waste damping. Except streams in the Awash basin, streams in the other study basins showed insignificant variation with above listed parameters which can be explained in terms of river self-purification capacity and protection of buffer zones in the river side. Traditionally, the local community do not farm river side rather keep it for animal fodder production (mainly natural grass) during the rainy season in the study streams of Wabe and Genale basins which traps and use the nutrients before entering the river system (Cooper *et al.*,1986). In addition in-stream activities such as washing and animal watering are localized and the nutrients could be transformed in to useable form through bacterial activities and stored in the river channel (Peterjohn and Corell, 1984). On the other hand, streams considered in Awash basin showed high conductivity and TP values compared to their upper section due to over degradation and loading of nutrient from various sources including factories which release their waste directly to the river system. Optimum oxygen concentration ranging from 6.5-9.5 mg/l was recorded in the downstream section of study streams of all basins except downstream sites of Awash basin. Due to high organic load from nearby industries in sebeta stream, the oxygen goes down to 1.2mg/l in the riffle section of the stream which shows high decomposition process is going on in the stream bed (Table 4).

Table 4: Mean standard deviation and range of selected environmental variables for upstream and downstream sections of study streams

Parameters	Upstream n=15	Downstream n=17
Water temperature (°C)	16.7±2.3 (11.2-22.6)	18.9±3.2 (13-23.1)
pH	8.0±0.3 (7.7-8.6)	7.5±1.1 (6.8-8.4)
Conductivity(µS/cm)	156.4±66.5 (58.4-265)	371 ±457 (104.6-850)
DO (mg/l)	7.72 ±0.7 (6.7-9.1)	6.5±2.3 (1.2-10.2)
TP(mg/l)	0.028±0.004(0.022-0.031)	0.49±1.1(0.06-1.1)
Catchment size (km^2)	112±190 (58-494)	182±370 (128-794)
Depth (cm)	16.5±2.3 (12-21)	18.5±3.3 (15-22)
Velocity(m/s)	0.6±0.12(0.21-0.88)	0.55±0.2(0.1-1.05)
% Riffle	88.7±10.7(65-95)	83±18(45-97)
Dominant substrate type		
% Megalithal	23.6±15.9(0-50)	8.4±10.6(0-40)
% Macrolithal	37.8±10.8(20-55)	25±16.8(0-75)
% Mesolithal	27±9.5(15-45)	26.5±16.8 (0-70)
% Microlithal	10.7±11(0-35)	11.5±11.8(0-50)
% Akal/sand	1±2 (0-10)	10±23(0-100)
Land use		
% forest/bushes	82±25(55-100)	9±18(0-35)
% Crop farming	5±8(0-15)	60±35(20-100)
% Open grazing	25±19 (18-74)	55±25 (65-100)
% Urban/industrial	0.0	25±47(25-100)

The composition and diversity of benthic macro invertebrates showed variability among and within streams under this study. Study streams in Wabe Shebelle, Genale-Dawa and Abay basins are dominated by highly sensitive and moderately tolerant taxa in both up and down stream sections, although Plecoptra taxa (Perlidae) is only found in the upstream section. In Awash basin, the downstream sections were dominated by tolerant taxa groups mainly Tubficidae, Chironomidae mainly *Chironomus* sp. and Syrphidae which have low sensitivity score (Aschalew and Moog, 2015) (Table 2).

Based on the calculated ETHbios score, the upstream section of each stream in all basins falls under high ecological status (total score greater than 115 and ASPT greater than 6.5) which indicates all streams near their source are in high ecological quality and low level of degradation. Depending on the level of degradation, the lower section of the study streams range from good to bad ecological status (Figure 2). From these findings, it is clear that ETHbios showed high discrimination efficiency to classify streams in to different ecological health based on the diversity of benthic invertebrates. Strong correlation between ETHbios and Total phosphorus (0.87, $p<0.05$, n=32) and Dissolved oxygen (0.71, $p<0.05$, n=32) indicates the sensitivity of the biotic score to nutrient loading and its direct effect on the overall health of the river system.

The most direct and effective measure of a river integrity, and of its place in the water cycle, is the status of life in the water. Living communities in streams and river reflect river catchment conditions better than any chemical or physical measure because they respond to the entire range of biogeochemical factors in the environment. When something alters the landscape of headwaters, life in the downstream reaches feels the effects. Actions that protect the biota tell us directly if we are protecting the water in the river system. Protecting the biological integrity of water with full range from its diversity to ecological processes will protect human uses of that water whether for drinking, fishing, washing, irrigating, generating electricity, or making money in countless ways. It should be clear that when stream and river waters do not support living things, they will no longer support human affairs.

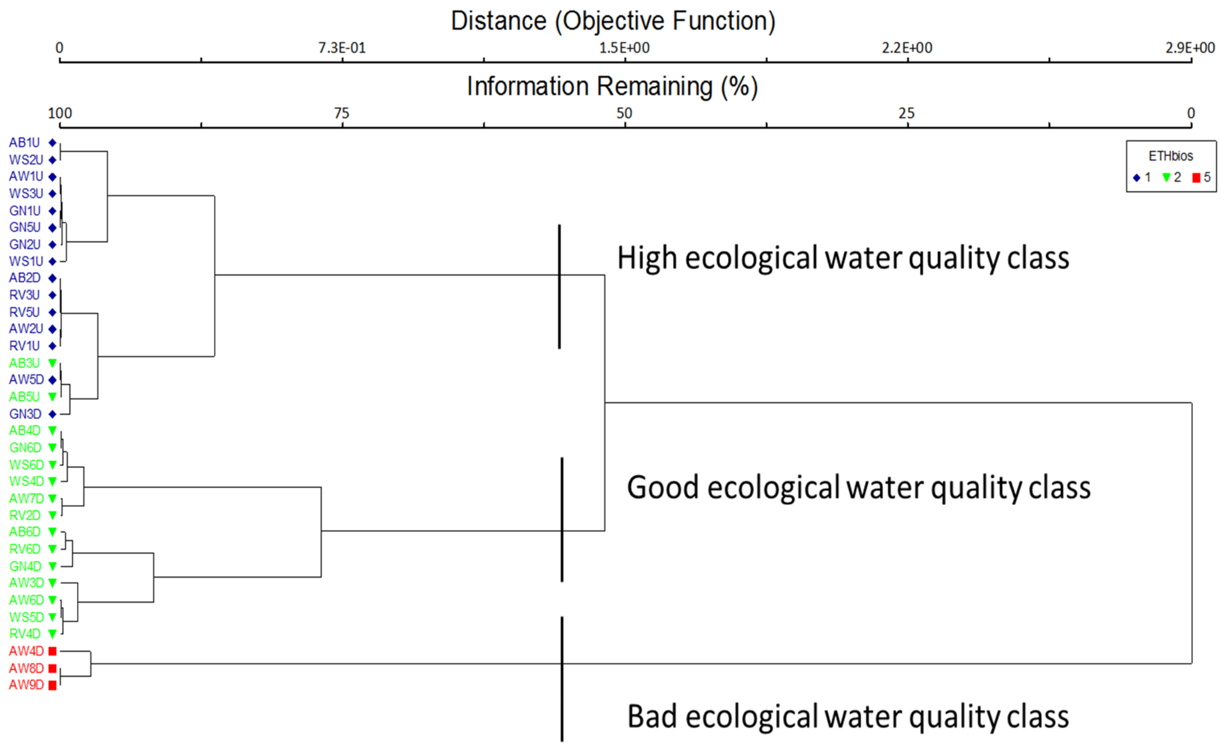

Fig. 2: Cluster analysis dendrogram showing the efficiency of ETHbios to classify upstream and downstream section of river in different ecological quality classes.
Site code description: Two first letters show basin code (AB-Abay,AW-Awash,RV-Rift valley, GN-Genale, WS-Wabeshebele), number indicate sampling sites and letter 'U' and 'D' shows upstream and downstream of same river.

ETHbios as stream monitoring kit

More than a century ago, people recognized that human activities produced pollution harmful to the aquatic biota. They therefore made an effort to track the extent of biological degradation which was considered as indicator for the presence of human activities that lead to the concept of biological monitoring. Currently biological monitoring become mandatory to river assessment in developed countries and its adaptation and application is rapidly growing in developing countries for detecting human caused biotic changes apart from those occurring naturally (Dickens and Graham, 2002). It is clear that a number of biotic scores based on benthic macroinvertebrates have been developed and widely applied for monitoring of wadable streams and rivers in different parts of the world (Birk *et al.*, 2012). ETHbios was developed for assessing Ethiopian highland streams and rivers based on sensitivity score provided for individual taxa (Aschalew and Moog, 2015). This score system is not sophisticated in terms of sampling procedure and processing of benthic invertebrates, and data analysis and interpretation. However, scores obtained through calculation must be care-fully interpreted as the diversity of BMI could be affected by several factors in the river system other than organic pollution. Therefore, when using ETHbios, the dominant stressor type in the area should be properly defined to provide more precise information on ecological status of streams and rivers under study. ETHbios uses a large number of family level indicators that simplify taxonomic complications. However, for specific taxa groups namely Baetidae and Hydropsychidae, family level identification was not sufficient for introducing effective ETHbios and thus a higher taxonomic resolution (genus–species level) is required although it is sufficient for calculation to note if there are different taxa among a family without giving scientific name.

Conclusion

Although there is variation in the level of stream degradation, human induced activities are causing ecological degradation in headwater streams of the country. The major pressures contributing to water degradation in streams are agricultural activities (crop and animal production) and in-stream human activities in all study streams. In streams flowing through urban and industrial areas, domestic waste and industrial pollutants are the major pressures that degrade water quality and aquatic biota as shown in downstream sites of Awash basin (e.g. Sebeta stream). The tradition of keeping the river side for animal feed production (natural grass) in Meribo, Leliso and Tegona streams contribute towards controlling the entrance of fertilizers and top soil to the river through runoff during the rainy season. This tradition could be more effective if the method is supported by scientific knowledge and technological inputs that improve nutrient holding and up taking capacity (e.g. planting improved animal feed which have fibrous root and high biomass). ETHbios considers taxa richness and taxon's specific sensitivity to pollution, thus sample collection is advisable in dry months of the year (November to February) than rainy months. This score system effectively detected and classified stream sites suffering from point and diffused source of pollution.

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