Biological monitoring of freshwater ecosystem health in Ethiopia: A review of current efforts, challenges, and future developments

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ABSTRACT

Aquatic resources are increasingly stressed primarily due to anthropogenic activities in Ethiopia. These anthropogenic stresses altered ecological integrities and compromised ecosystem services that could otherwise support the livelihoods of millions of people. Evidence-based management of the degradation of aquatic ecosystems requires quantifying ecologically significant changes and discriminating among impact levels and types. Apart from physico-chemistry, monitoring of aquatic ecosystems using biological organisms is progressing well in recent times both in the tropics and temperate regions. The majority of studies so far focused on macroinvertebrates and to a lesser extent on diatoms. Though the method is given less attention, individual initiatives have been increasing over time especially in developing countries, including Ethiopia. This paper reviews current efforts undertaken and major challenges facing the use of bioindicators in aquatic ecosystems as biological monitoring tools. The possible application of biomonitoring and its importance for Ethiopian aquatic ecosystems is also discussed and future improvements suggested.

Keywords: Anthropogenic pressures, Bioassessment, Ecological Integrity, Indicators, Pollution.
DOI: https://dx.doi.org/10.4314/ejst.v13i3.5

INTRODUCTION

Anthropogenic impacts on Ethiopian freshwater ecosystems

Ethiopia is endowed with many lakes and rivers supporting diverse freshwater ecosystems covering an estimated surface area of 18,587 km^2 (EEPA, 2010). The

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majority of lakes are concentrated in the Rift Valley basin, which is productive as well as rich in biodiversity (Tudorancea and Taylor, 2002), while others are found elsewhere except in some low and dryland areas. Lakes, rivers, and wetlands support livelihoods by providing numerous ecosystem services (EWNHS, 2018). These services include potable water, sand and soda ash mining, fishing, flood attenuation, waste treatment, home for flora and fauna, irrigation, navigation, electric power generation, and other ecosystem services. Thus, utilizing freshwater ecosystems without compromising its ecological integrity determines future developmental needs and the societal well-being of the country (Nel *et al*., 2011).

The unwise use of water resources for various purposes has impacted aquatic ecosystems (Abebe Getahun and Stiassny, 1998; Zinabu G/Mariam *et al*., 2002). Water diversion from Lake Tana for irrigation and floriculture, for instance, damages the ecological integrity of the lake and its inhabitants, particularly the indigenous and endemic fish species (Ayalew Wondie, 2010; Wassie Anteneh *et al*., 2010). Lake Tana is designated as a Biosphere Reserve by UNESCO, which means that urgent action and proper management is needed. We lost Lake Haramaya decades ago, and Lake Abijata, which used to support a large number of Great White Pelicans and Lesser Flamingo, which left bird species on the verge of collapse due to soda ash extraction and other activities (Zinabu G/Mariam *et al*., 2002).

Wetlands in Ethiopia also face similar problems due to anthropogenic activities such as agricultural and domestic wastes that affect biodiversity and ecological services (Ayalew Wondie, 2010, 2018). Irrigation and hydropower development projects in the country rarely consider the hydrology and hydrogeology of water resources (Tenalem Ayenew, 2007; Tenalem Ayenew and Dagnachew Legesse, 2007). Freshwater ecosystems in Ethiopia, in general, are threatened by human activities, but by far the most severe damage occurs due to poor agricultural practices and industries (Seleshi Bekele *et al*., 2012). Agricultural practices damage the quality and quantity of nearby water bodies. Farmers utilize fertilizers and pesticides, the result of which is ultimately eutrophication and toxic Cyanobacteria (Tadesse Fetahi, 2019). Soil erosion fills aquatic ecosystems with sediment in many river basins of Ethiopia (Seleshi Bekele *et al*., 2012). It was estimated that 21 to 32 t ha^{-1} yr^{-1} of sediment is transported from the upper watershed and retained in the flood plains and Lake Tana (Fasikaw Atanaw *et al*., 2018). The main cause of this sedimentation is deforestation (Kloos and Worku Legesse, 2010), uncontrolled grazing, poor farming practices, and unsustainable land use land cover changes. Urban development and the construction of roads also add sediment to wetlands, lakes, and rivers (Kloos and

Worku Legesse, 2010; Graichen, 2011). According to Zinabu G/Mariam (1998), urbanization and human settlement near lakes in Ethiopia are the major factors affecting water quality and content. Many beautiful wetlands rich in papyrus reeds are drained for office and hotel construction in Bahir Dar (Pers. obs.). Water bodies near cities have shown signs of severe pollution because of recently emerging industries. Industrial and municipal wastes are directly released into wetlands, lakes, and rivers without prior treatment (Getachew Beneberu and Seyoum Mengistou, 2014). For instance, the Addis Ababa Environmental Protection Authority (EEPA) reported that more than 90% of the industries in Addis Ababa are operating without any wastewater treatment systems (EEPA, 2005). Zinabu G/Mariam and Elias Dadebo (1989) reported that the Rift Valley lakes and their feeder streams receive domestic and industrial organic wastes, and toxic chemicals from textile factories, distillers, and plywood factories, and agrochemicals. These contaminants harm the environment in many ways: species get replaced, toxins bioaccumulate and biomagnify toxic metals and pesticides in the food chain (Zinabu G/Mariam *et al*., 2002).

Therefore, the impact of these human activities on aquatic ecosystems need to be monitored using cost-effective monitoring tools. So far in Ethiopia, these anthropogenic impacts on freshwater ecosystems have been assessed mainly using the traditional approach of physico-chemical variables. However, these analyses cannot be done on-site and need expensive reagents and instruments that are not easily available in developing countries. Moreover, this approach does not allow establishing cause and effect relationships between inhabiting organisms and causative agents (Wolska *et al*., 2007). In East Africa, including Ethiopia, the use of biological organisms for the assessment and monitoring of freshwater ecosystem conditions is uncommon. In recent times, however, the management and conservation of freshwater resources in Africa have shifted to an improved understanding of species-environment relationships and development of new methodologies and frameworks to assess and monitor the health of aquatic ecosystems (Chutter, 1998; Kleynhans, 1999; Dickens and Graham, 2002). Biological monitoring is the use of biological responses to evaluate changes in the environment, mostly focusing on human impacts (Cairns *et al*., 1982). Biological monitoring provides a direct measure of ecological integrity by integrating various stressors. Biological indicators reinforce physico-chemical indicators and facilitate far better assessment and management of freshwater ecosystems (Bartram and Balance, 1996; Lobo *et al*., 2004). According to previous studies, biological indices derived from biological organisms are better indicators than the traditional method, as they indicate all kinds of anthropogenic disturbances and their cumulative impacts on aquatic ecosystems (Muralidharan *et al*., 2010). Biological monitoring programs are increasingly recognized around the world as they are fast, integrated, and cost-effective for assessing the consequences of environmental stressors on aquatic ecosystems. This paper is a review of current efforts done so far concerning the use of bioindicators and major challenges hindering their application in Ethiopia.

The concept of biomonitoring/bioassessment

Biological monitoring is one of the available instruments used to assess the status and degree of impairment of aquatic ecosystems (Birk *et al.*, 2012). Biotic component measurements in aquatic ecosystems provide information about environmental stress, which otherwise might be missed by periodic or continuous monitoring of physical and chemical factors (USEPA, 1987). Surveying and assessing the status of these aquatic communities and the quality of their habitats are the major principal tools for biomonitoring. Although the use of biomonitoring for pollution assessment goes back to 1909 (Kolkwitz and Marsson, 1909), its use for freshwater resource management in the tropics is not that progressive. The effect of environmental stress can be reflected by the organism's attributes such as presence/absence, abundance, or behavioral changes (Bonada *et al.*, 2006). The biota that frequently appeared in the most bioassessment programs includes macroinvertebrates, fish, and algae (Resh, 2008). The use of biota for biomonitoring has several advantages over the traditional monitoring approaches. The advantages include having diverse ecological requirements, cost, life cycles/strategies are different, and are unevenly distributed over space and time and thus can integrate the effects of pressure over space and time (Barbour *et al.*, 1999; De Pauw *et al.*, 2006). Assessing pollutants exhibiting temporal variation using traditional methods are very expensive, and the results may not be biologically dependable (Bonada *et al.*, 2006, Friberg *et al.*, 2011). Thus, biomonitoring is a vital tool for assessing the extent of anthropogenic impacts on freshwater ecosystems. However, the underlying cause of biotic index score deviation is unclear and the impacts cannot be attributed to a single pressure (Clews and Ormerod, 2009), which are considered as a weakness of biomonitoring tools. The applicability of these biological monitoring methods for developing countries, unless harmonized, is questionable (Everaert *et al.*, 2014). That is why many countries have developed their own biological indices according to local conditions.

METHODOLOGY

Published articles on biological monitoring of Ethiopian freshwater ecosystem health were searched using academic databases and search engines (such as

Elsevier-Scopus, Web of Science, Science Direct, Google Scholar, and Mendeley) from 1988 to 2019. Besides, the grey literature of M.Sc. and Ph.D. thesis works were assessed from research institutions and universities. The search terms and phrases were combinations of keywords such as aquatic plants, algae, benthic macroinvertebrates, macrophytes, diatoms, fish, water quality, freshwater ecosystems, bioindicators, bioassessment, biomonitoring, organic pollution, physicochemical assessment, rivers/streams, wetlands, lake, and water resources management.

The following criteria were used for selecting articles: 1) studies conducted in Ethiopian aquatic ecosystems; 2) studies involving biological organisms to evaluate the health of aquatic environments; and 3) published and unpublished articles written in English. Furthermore, we have included some papers that, in the opinion of the authors, include information or theoretical concepts that are relevant to our narrative review work. The use of biological organisms for aquatic bioassessment in Ethiopia started in recent times, and thus all the available papers were considered in the review process. The number of research papers containing biological monitoring of freshwater environments in Ethiopia increased over the years, providing more efforts on the river and stream ecosystem (Figure 1a). Indeed, more than 95% of the studies were published from 2009 onwards. The majority of these studies have been published in peer-reviewed international journals and are available to international audiences (Figure 1). Only 2 articles were published in local journals (Figure 1c). Most of the studies have been conducted in localities where universities have opened Fisheries and Aquatic Science programs.

After selecting and assessing contents, the results and conclusions of 35 relevant papers were evaluated against the specific methods they applied, and compared among study results with similar ecological settings.

BIOMONITORING PRACTICES IN ETHIOPIA

Biomonitoring approaches using macroinvertebrates

Macroinvertebrates are a major constituent of freshwater biodiversity, often used as indicator organisms for assessing water quality.

Many countries have their own protocols on how to use macroinvertebrates to monitor the ecological status of river ecosystems. Bioassessments in the USA and Europe are a mandatory tool for water resources management and are thus supported by strong legislation of the Clean Water Act and Water Framework Directive, respectively (Birk *et al*., 2012; USEPA, 2013). In Africa, it's not applied satisfactorily except in South Africa, where a scoring system is developed (SASS) using local freshwater macroinvertebrates (Dickens and Graham, 2002).

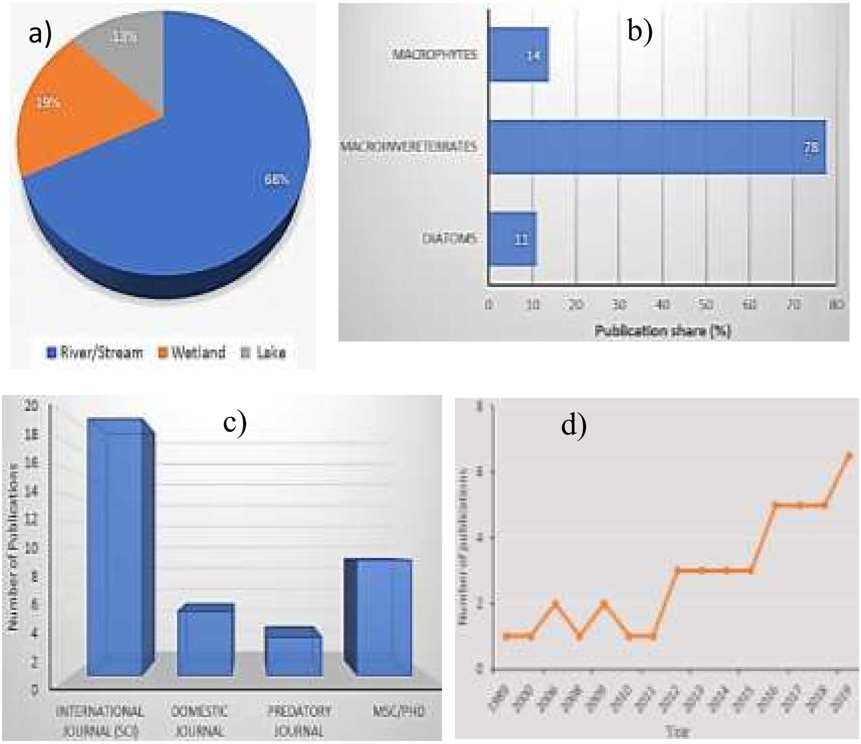

Figure 1. The overview of biological monitoring studies conducted in Ethiopian Freshwater Ecosystems; (a) Distribution of papers among aquatic ecosystem types; (b) distribution of published papers and reports based on indicator organisms; (c) distribution of published papers based on web search engines and academic databases; (d) publication trend over time.

South Africa's method has been modified and widely used in many other African countries such as Namibia (Palmer and Taylor, 2004), Zambia (Lowe *et al*., 2013), Ethiopia (Aschalew Lakew and Moog, 2015a) and Tanzania (Kaaya *et al*., 2015). In Ethiopia, although the importance of macroinvertebrates as bioindicators was recognized in the 1980s (Harrison and Hynes, 1988; Tesfaye Berhe *et al*., 1989), interest for use in bioassessment has increased in recent times (Figure 1d) (Baye Sitotaw, 2006; Abebe Beyene *et al*., 2009; Solomon Akalu *et al*., 2011; Getachew Beneberu *et al*., 2014; Aschalew Lakew and Moog, 2015a, b). However, the efforts are fragmentary and regionally restricted and there was no effort to develop a unified national bioassessment protocol. This is mainly because aquatic invertebrate research is neglected field in the country (Seyoum Mengistou, 2006). It is a marginalized sector and no institution specialized in aquatic invertebrate research. Some of the recent advances in research trying to develop biotic indices and multimetric indices based on benthic macroinvertebrate communities and other organisms are basically individual interests from some universities and research institutes (Seyoum Mengistou, 2006). These were used to assess water quality and the ecological status of freshwater ecosystems, mainly running waters. Because of lack of standardized protocols, the results are not reliable and cannot be used for comparison purposes with confidence. Among the bioassessment methods, single metric and multimetric approaches have been practiced in Ethiopia to detect ecological changes. Based on macroinvertebrates, the practices of these two approaches are discussed in the following sections.

Single metric

Single metric is commonly used to monitor the integrity of aquatic ecosystems based on a single biological attribute. Qualitative sampling and family level identification are sufficient without taking into account abundances per taxon (De Pauw *et al*, 2006). This single metric biotic approach has been widely used around the world and has been successfully adopted for monitoring rivers in Ethiopia as well. For instance, the study of Harrison and Hynes (1988) in Ethiopian mountain streams showed that anthropogenic pressures were the major threatening factors contributing to the eradication of numerous groups of invertebrates in highland streams. Some taxa (e.g. Gerridae and Veliidae) have become rare in the studied streams and rivers due to the intensive use of detergents for washing purposes (Harrison and Hynes, 1988). The order Plecopteran (Perlidae) has almost disappeared from Ethiopian water bodies as it requires well-oxygenated water with a rocky bottom substrate (Getachew Beneberu, 2013). Macroinvertebrate assemblages and composition with physico-chemical parameters were also used to assess the ecological status of Ethiopian rivers (Tesfaye Berhe, 1988; Worku Legesse, 2000). Along the Akaki river, for instance, visible changes in macroinvertebrate species composition and density, as well as physical and chemical changes were recorded, and the result was that the river was found seriously degraded due to anthropogenic disturbance (Tesfaye Berhe, 1988). Ayenew Gezie *et al*. (2017), on the other hand, used five metrics of macroinvertebrates in the wetlands of Lake Tana region, which helped successfully identify the gradients of human disturbances. With increased human disturbance, the richness of Ephemeroptera and Odonata (EO), Biological Monitoring Working Party (BMWP) score, family richness, and Shannon diversity index responded negatively, while the Family Biotic Index (FBI) score was increased. Single metrics were also used (Solomon Akalu *et al*., 2011; Solomon Akalu, 2017) to assess the impacts of human activities on the Greater and Little Akaki rivers. Eleven metrics representing richness, composition, and tolerance/intolerance measures were included in their study. Macroinvertebrate community structures in upstream and downstream were different: the upstream had higher taxa while the middle and downstream sites were dominated by fewer tolerant taxa. The observed change was attributed to nutrient enrichment and oxygen depletion due to the release of untreated industrial and domestic wastes from the city. Community changes along downstream direction were due to the natural phenomenon as explained by the river continuum concept (Vannote *et al.,* 1980). However, this may not be the case all the time as changes in community structure along the Greater Akaki river could not be explained in terms of nature (Solomon Akalu *et al*., 2011). The Average Score Per Taxon (ASPT) index was employed with success in some streams of Ethiopia (e.g. Aschalew Lakew and Moog, 2015a; Sololom Akalu, 2017). Although sampling sites (3 stations) were considered to be very small, Habiba Gashaw and Seyoum Mengistou (2012) reported that Lake Hora showed symptoms of severe organic pollution and very poor water quality based on Hilsenhoff Family Biotic Index (H-FBI). The high H-FBI value for Lake Hora was because of the abundance of pollution tolerant taxa such as *Chironomids* with higher tolerance values. Stressor specific problems (siltation, agricultural activities, and paper mill wastes) were identified in the central highland streams of Ethiopia (Aschalew Lakew and Moog, 2015a). Accordingly, five metrics were found to be very helpful in distinguishing the origin of the stressor impacting stream sites. The metrics included taxa richness, % EPT, % Oligochaeta and Chironomidae, % EPT-BCH (EPT with no Baetidae, Caenidae, and Hydropsychidea, and ASPT. Of these, % EPT-BCH was found to be more successful in discriminating against the impacts of siltation from agriculture and reference sites (Alemayehu Negassa, 2016). Some other macroinvertebrate-based indices (EPT richness, % EPT, EPT-Chironomidae ratio, FBI, ETHbios, % gathering collectors, and % scrapers) also showed deterioration in the water quality of the Huluka river at downstream sites. This river received a huge amount of untreated sewage discharges from various sources in Ambo town, including agricultural activities of the watershed (Alemayehu Negassa, 2016). Other similar studies have demonstrated Shannon diversity index and richness have been effectively used to identify the degree of anthropogenic disturbance in wetland and stream ecosystems (Argaw Ambelu *et al*., 2010; Abebe Beyene *et al*. 2012; Melaku Getachew *et al*., 2012; Assefa Wosnie and Ayalew Wondie, 2014; Temesgen Alemneh *et al*. 2017; Abrehet Kahsay *et al*., 2015; Gurmessa Tesfahun and Agumassie Tessema, 2018; Selamawit Nagassa *et al*., 2018a, b; Sisay Misganaw, 2018).

The metrics derived from macroinvertebrates in our country largely depended on the family-level resolution. In contrast, Getachew Beneberu *et al.* (2014) worked on a specific group of Chironomids identified to lower taxonomic levels. Chironomid taxa were able to separate the degree of pollution between moderately polluted and heavily polluted sites (Getachew Beneberu *et al*., 2014). Moreover, the head capsule deformities among *Chironomus* species were utilized as an indicator of environmental stress in the Sebeta river (Ethiopia). Moderate level of deformities of the species was associated with a worse ecological status of the river (Getachew Beneberu and Seyoum Mengistou, 2014). A study by Mekedes Hone (2016) at the head of the Blue Nile river impacted by tannery wastes showed a high number of *Chironomus* species (Mekedes Hone, 2016). This is an indication that the genus is tolerant of inorganic and organic pollutants and thus can indicate water quality degradation (Oliveira *et al*., 2010). A similar study revealed that stream sites receiving wastes directly from the brewery and textile industries were rich in pollution tolerant Chironomid species, namely, *Chironomus alluaudi* and *Chironomus imicola* (Amare Mezegebu *et al*., 2019), which indicate the incidence of poor ecological status. Moderately polluted sites comprised high numbers of *Polypedilum wittei*, *P. bipustulatem,* and *Dicrotendipus septemmaculatus.* On the other hand, the genus *Conchapelopia* including *Chironomus cliptres* were common in reference sites (Amare Mezegebu *et al*., 2019). Therefore, identifying Chironomids to lower taxa (genera and species) could serve as better indicators of water quality for streams and river ecosystems. However, heavily polluted sites on the Sebeta river were characterized by low number of *Chironomus,* and especially sites with DO levels <2 mg/l were devoid of this genus, indicating that extreme pollution may even challenge the survival of this genus (Getachew Beneberu, 2013).

Indices such as BMWP and H-FBI that are developed for temperate regions have also provided satisfactory results in tropical streams (Resh, 2007).

Table 1. Taxa and sensitivity scores of benthic macroinvertebrates for ETHbios calculations (Aschalew Lakew and Moog, 2015a).

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

This is because most benthic macroinvertebrate families are cosmopolitan, which may grant a comparable general tolerance value of each family in different regions or continents. This provides a good opportunity to adopt the biotic indices by making minor adjustments based on the occurrence of local fauna in relation to water quality parameters (Thorne and Williams, 1997). A single metric approach based on a single parameter from an indicator group has been used in Ethiopia, mainly for riverine ecosystems. The most widely used metrics include % EPT (Ephemeroptera, Plecoptera, and Trichoptera), FBI, BMWP, and taxa richness (TR). These metrics are easy to apply and best reflect the ecological water quality (Resh, 2007). The only such metrics developed for Ethiopian water bodies is that of Aschalew Lakew and Moog (2015a), which is a modification of the Biological Monitoring Working Party Principles (BMWP) and the South African Scoring system (SASS) (Table 1). ETHbios categorizes five water quality grades (High, Good, Moderate, Poor, and Bad) for highland streams.

Multimetric

Karr (1981) introduced the concept of a multimetric index approach for the first time to evaluate anthropogenic pressure on freshwater ecosystems using fish communities as bioindicators. Subsequently, this approach was implemented in macroinvertebrates (Plafkin *et al*., 1989; Barbour *et al*., 1992; Kerans and Karr, 1994; Karr and Chu, 2000) and wetland vegetation (Gernes and Helgen, 1999; Nichols *et al*., 2000; Mack, 2001; Gernes and Helgen, 2002; Ferreira *et al*., 2005; Miller *et al*., 2006). Multimetric index (MMI) addresses overall multiple impacts and is composed of individual metrics into a unitless index that can be used to judge the ecological conditions of a site. The MMI combines metrics such as taxa richness, diversity measures, the proportion of sensitive and tolerant species, and trophic structure, which are reflecting various dimensions of the environmental conditions and characteristics of the community (Karr and Chu, 2000). Thus, a multi-metric approach is considered a more dependable monitoring tool than assessment methods based on single metrics (Moog *et al*., 2018). The typical benefit of MMI is its flexibility, which could be easily adapted to other regions for use according to the local conditions (Gabriels *et al*., 2010; Nguyen *et al*., 2014). The development of a multi-metric index follows the procedures and steps shown in Figure 2.

In Ethiopia, few studies have been tried to adopt MMI for bioassessment of aquatic ecosystems. In this regard, Baye Sitotaw (2006) was the pioneer providing a comprehensive set of data describing macroinvertebrate communities in 8 streams located in Awash, Blue Nile, Omo-Ghibe, and Baro-Akobo basins to develop the Index of Biological Integrity (B-IBI). Among the 17-candidate metrics, only 14 metrics were included in the final index development (Table 2). The index effectively discriminated sampling sites into different impairment levels: severe, slight, moderate, less, and very little. B-IBI and its metric components had significant relationships with many physicochemical and habitat quality parameters. But habitat metrics, organic pollution, and water colour showed a strong correlation with B-IBI. Thus, the discriminating power of the index is commendable, which was able to separate urban and agricultural sites from reference sites irrespective of the different geographical locations of the sites. Urban sites supported a very low number of EPT taxa, indicating that these groups of invertebrates are sensitive to excessive nutrient and organic loading (Baye Sitotaw, 2006).

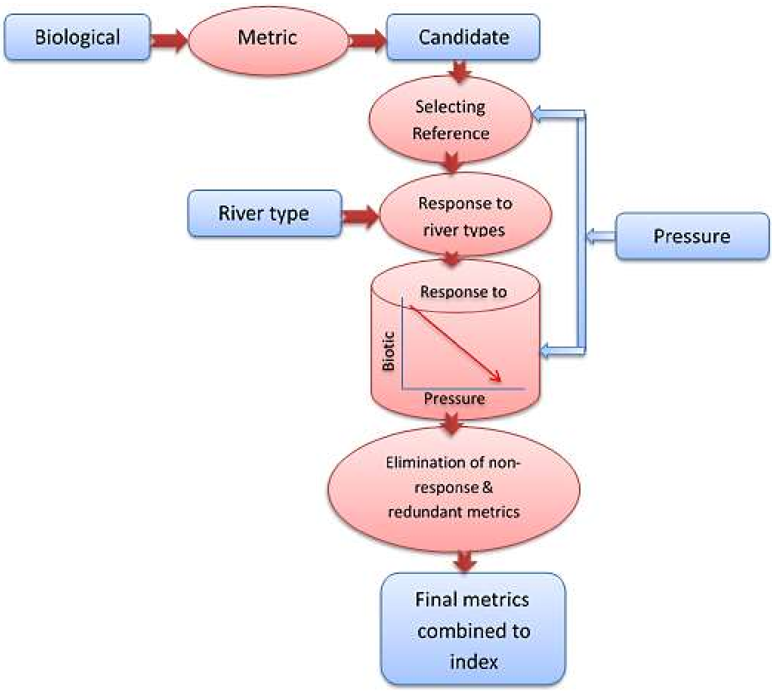

Figure 2. Key steps in developing multi-metric indices (adopted from Moog *et al*., 2018).

A multimetric index based on benthic macroinvertebrates for assessing the ecological status of streams and rivers was developed for some selected rivers in Ethiopia (Getachew Beneberu, 2013; Amelework Zewudu, 2017), Central and Southeast Highlands of Ethiopia (Aschalew Lakew and Moog, 2015b; Temesgen Alemneh *et al*, 2019), and northwestern Ethiopia (Lake Tana basin). The multi-metric index (MMI) developed by Aschalew Lakew and Moog (2015b) is composed of a set of 9 core metrics chosen from an initial list of 75 potential metrics (Table 2). The core metrics were recruited based on their ability to reflect the level of water quality degradation, land-use changes, habitat variability, hydrological conditions, and pollution. The responses of the core metrics in this study were well correlated with anthropogenic impacts than with habitat variability. The developed index categorized sites into five river quality classes with different colors: high (blue), good (green), moderate (yellow), poor (orange), and bad (red). Its response to seasonal hydrological conditions remained constant in reference and impaired sites (agriculture, siltation, and paper mill wastes), indicating that the model was stable and could be applied to other regions of the country (Aschalew Lakew and Moog, 2015b). Similarly, Amelework Zewudu (2017) developed Lake Tana sub-basin multi-metric index (LTSBMI) (Table 2). Five core metrics were selected among 30 candidate metrics for their ability to discriminate between reference sites and sites influenced by domestic sewage from households, industries, sand mines, intensive irrigation, and riparian habitat degradation. LTSBMI was used to classify sites into five water quality classes with cutting threshold scores: very good (>72), good (65.9-72), fair (32.6-65.9), poor (16.3-32.6), and very poor (0-16.3).

As for rivers, IBI was also developed for wetlands found in Jimma zone using 10 metrics. IBI score categorized wetland sites into moderate and poor ecological conditions. FBI (Family level biotic index), one component of this index, was able to discriminate wetland sites that were significantly affected by organic pollution (Hayal Desta and Seyoum Mengistou, 2009). Macroinvertebrate-based multi-metric index (M-MMI) was also developed for natural wetlands found in Jimma that combined three core metrics (all family richness; the family richness of Ephemeroptera, Odonata, and Trichoptera (EOT); and % filterer–collectors). These metrics were selected among 58 candidate metrics using the procedures and steps indicated in Figure 2. The 58 metrics were chosen from the literature and calculated using a data set of 222 samples collected from 63 sites at eight different wetlands in Jimma area (Seid Tiku *et al*., 2013). Redundancy analysis (RD) indicated that only three metrics were indirectly related to anthropogenic disturbance (land use, habitat alteration, hydrological modification) and water quality parameters (COD, Chl-a) and positively related to vegetation cover (Seid Tiku *et al*., 2013). According to Barbour *et al*. (1996), high richness implied the presence of physical habitat diversity, good water quality, and high availability of food resources. The developed MMI scores varied from 3 to 15, and helped categorize the wetland sites into five water quality classes: very good (14-15), good (12-13), moderate (9-11), bad (6-8), and very bad (3-5). This suggested that the M-MMI was good in discriminating impaired wetland sites from the reference sites (Seid Tiku *et al*., 2013). Besides, the index was negatively linked to both disturbance score and water quality index.

Its value decreased as the disturbance score increased and water quality (despite a weak correlation) deteriorated, suggesting that this index could be suitable for detecting environmental degradation in natural wetlands (Figure 3) (Seid Tiku *et al*., 2013). Development of macroinvertebrate-based MMI required including appropriate and representative of several biological aspects of macroinvertebrate assemblages (Karr and Chu, 1998).

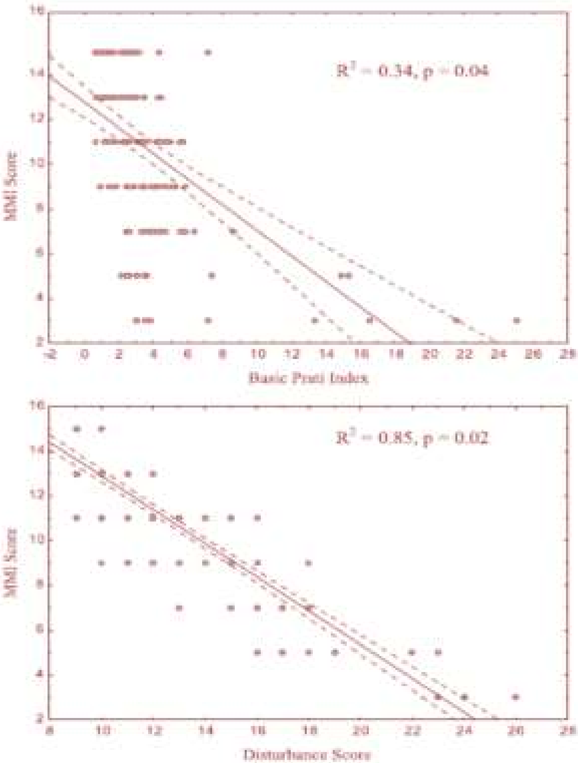

Figure 3. Correlation of multi-metric macroinvertebrates (MMI) with water and habitat quality developed using the Basic Prati index and habitat disturbance score (Seid Tiku *et al*., 2013).

Barbour *et al*. (1999) recommended core metrics should comprise at least one metric in each of the four metric categories, namely, (1) richness measures for diversity or variety of the assemblage; (2) composition measures for identity and dominance; (3) tolerance measures representative of the sensitivity to perturbation; and (4) trophic or habit measures for information on feeding strategies and guilds. Among the reviewed articles, only 33% of them were met the standard criteria or protocol regarding core metrics selection in the development of a multi-metric index (Table 2). The remaining research papers (67%) failed to include one or more representative metrics from each of the four major metric categories. The missing components of macroinvertebrate assemblage metrics were composition (Seid Tiku *et al*., 2013), tolerance (Seid Tiku *et al*., 2013, Amelework Zewudu, 2017) and feeding guild (Baye Sitotaw, 2006; Hayal Desta and Seyoum Mengistou, 2009).

Table 2. Metrics for macroinvertebrates that have been considered and evaluated for the development of an index of biotic integrity for selected streams and wetland ecosystems in Ethiopia and their predicted responses to increased levels of perturbation.

SN	Metric	Metric definition	Predicted response to increased perturbation
1.	Taxa richness[1,3,5]	Total number of individual taxa	Decrease
2.	% Ephemeroptera[1,2]	Percentage composition of mayfly	Decrease
3.	% Plecoptera[1]	Percentage composition stonefly	Decrease
4.	% Trichoptera[1]	Percentage composition of caddisfly	Decrease
5.	% Baetidae[1]	Percentage composition of mayfly family nymphs	Decrease
6.	% EPT individuals[1,2]	Percentage composition of mayfly, stonefly and caddisfly larvae	Decrease
7.	% Odonata[1]	Percentage composition of damson flies and dragonflies	Decrease
8.	Shannon diversity index[1]	A general measure of sample diversity that incorporates richness and evenness	Decrease
9.	% Red chironomids[1,4]	Percentage composition of blood-red midge larvae	Increase
10.	% Diptera[1]	Percentage composition of "true" fly larvae	Increase
11.	% Oligochaeta[1]	Percentage composition of aquatic worms	Increase
12.	% Non-insect[1]	Percentage composition of non-insect BMIs	Increase
13.	% Dominant taxon[1]	Percentage composition of the single most abundant taxon	Increase
14.	H-FBI[1,4]	Hilsenhoff Family Level Biotic Index	Increase

15.	# Ephemeroptera taxa[2]	Number of mayfly taxa	Decrease
16.	% Shredders[2,4,5]	Percent of individuals in the shredder functional feeding groups	Decrease
17.	% Filters feeders[2]	Percent of individuals in the filterer Functional feeding group	Increase
18.	Taxa richness of EOT[3,5]	Family richness of Ephemeroptera, Odonata, and Trichoptera together	Decrease
19.	% Filterer–collectors[3]	Percent of filterer- collectors	Decrease
20.	Total taxa #[4]	Total number of taxa	Decrease
21.	EPT-BH>1sp.[4]	Total number of EPT (Ephemeroptera, Plecoptera, and Trichoptera taxa) where Baetidae and Hydropsychidae taxa are considered if they consist more than one taxon	Decrease
22.	COPTE[4]	Total number of Coleoptera, Odonata, Plecoptera, Trichoptera, and Ephemeroptera	Decrease
23.	% EPT-BCH[4]	Percentage composition of EPT taxa without Baetidae, Caenidae, and Hydropsychidae	Decrease
24.	ASPT-SASS[4]	Average South African Scoring System Per Taxa	Decrease
25.	% Collector gathering[4]	Percentage composition of gathering collector individuals	Increase
26.	Simpson index[5]	A measure of diversity including both taxa richness and an evenness component	Decrease

NB: 1= Baye Sitotaw, 2006; 2=Ameleworku Zewudu, 2017; 3= Seid Tiku *et al.*, 2013, 4= Aschalew Lakew and Moog, 2015b; 5= Temesgen Alemneh, 2019.

The discrepancy in the core metrics selection for the aggregated MMI could be attributed to geographical differences, the intensity of anthropogenic impacts, and protocols used for the development of the MMI (Dedieu *et al.*, 2016; Silva *et al.*, 2017). The use of different taxonomic resolutions could also affect the development of MMI. For instance, Aschalew and Moog (2015b) went to deeper taxonomic resolutions during the development of the MMI, which may contribute to the observed differences. In fact, using refined taxonomic resolution (genera or species) can allow the detection of multiple stressors and have better discriminating differences in biological conditions (Aschalew Lakew and Moog, 2015b). Extensive overlap of interquartile ranges, missing functional feeding groups, the difference in sampling gear, and having a zero value were some of the contributing factors to missing one or more representative metrics during MMI development.

Biomonitoring using aquatic plants/macrophytes

Aquatic plants are also used as sensitive tools for predicting and recognizing environmental stresses. The use of macrophytes for monitoring the status of aquatic environments (rivers, streams, lakes, and wetlands), therefore, is increasingly recognized around the world. Accordingly, plant-based monitoring and assessment indices have been developed in response to the legislative requirement around the world, mainly for the assessment of stream ecology status. Wetland ecosystem health and quality has also been monitored in the USA for a long-time using wetland vegetation as an indicator (USEPA, 2002). They are also used as a basis for comparing the reference and restored or mitigated states (Matthews *et al*., 2009), and as one of the three indicators of jurisdictional wetlands (Environmental Laboratory, 1987). Macrophytes are sensitive indicators due to their links to other trophic levels, which influence the delivery of ecosystem goods and services of aquatic ecosystems (Fennessy *et al*., 2015). Many advantages cited for using aquatic macrophyte communities for biomonitoring include susceptibility to multitude kinds of human pressure (Seo *et al*., 2014; Alahuhta and Aroviita, 2016), reduction of species richness in response to water level regulation and extraction (Gallardo *et al*., 2016).

Furthermore, macrophytes are widespread, abundant, immobile and easy to identify (Bornette and Puijaalon, 2011). Despite these advantages, ecological assessment of aquatic ecosystem health is rarely used in Ethiopia as well as in other African countries (Kennedy *et al*., 2016). A few attempts were reported only recently. In Kenya, for example, Achieng *et al*. (2014) assessed the ecological health of a small palustrine/riverine King'wal wetland, within Lake Victoria basin using the plant index of biotic integrity (PIBI). They concluded that the vegetation metrics used could effectively delineate different levels of anthropogenic disturbances affecting the wetland area. Kennedy *et al*. (2016) also developed a new biomonitoring protocol called the Zambian macrophyte trophic ranking scheme (ZMTR) to assess the trophic status of tropical southern African rivers. ZMTR was able to accurately indicate the trophic status of 83.1% of the study sites of rivers in Zambia and Botswana. In Ethiopia, only a single study tried to develop a plant-based index of biotic integrity (PIBI) as an alternative management tool in Jimma highlands (Admasu Moges *et al*., 2016). The results showed that macrophytes are dependable and sensitive indicators for bioassessment purposes, which discriminated reference and impacted sites in the study area. The development of a multi-metric index involves considering as numerous as possible potential metrics searching from the literature. Admasu Moges *et al*. (2016) chose a total of 35 potential plant community indicators. Of these, 13 relevant metrics were incorporated based on their responsiveness to anthropogenic perturbations. After avoiding redundant metrics using the Spearman correlation coefficient, they selected only 4 core metrics for developing the final index (PIBI). The core metrics included a % cover of native species, sensitive species richness, tolerant species richness, and % of shrub species richness. They reported that among the four metrics, sensitive species richness was able to discriminate impaired sites from the reference sites better than any other metrics. A strong correlation was thus reported between the core metrics and environmental variables (Table 3). A negative but significant correlation was also observed between PIBI and the majority of physico-chemical variables (Admasu Moges *et al*., 2016).

Table 3. Spearman's rank order correlations between core metrics and mean water quality parameters (Admasu Moges *et al*., 2016).

	Physico-chemical parameters				
Core metrics (of species)	**Water temperature**	**Electrical conductivity**	**Nitrates /NO_3^-**	**Chlorine / Cl^-**	**Total suspended solids/TSS**
Natives (%)	-0.20	-0.34*	-0.25	-0.46*	0.39*
Sensitive†	-0.68*	-0.36*	-0.20	-0.44*	-0.18
Tolerant†	-0.43*	-0.06	-0.40*	-0.13*	-0.28*
Shrubs (%)†	-0.05	0.44	-0.28	0.02	0.01

*Significant difference at $p < 0.05$; † stands for richness.

Yetneberk Kassaye *et al*. (2016) also investigated the concentration of trace elements in aquatic macrophytes in Ethiopian Rift Valley lakes aiming to evaluate the pollution levels of these lakes. They found macrophyte species *Aeschynomene elaphroxylon* (1.6×10^3 mg kg^{-1}dw, Lake Ziway) and *Eichhornia crassipes* (1.2×10^3mg kg^{-1}dw, Lake Koka) accumulated high concentrations of Mn as compared to the lakes' water and sediment. Similarly, Girma Tilahun and Tigist Ashagre (2012) reported that *Typha latifolia* accumulated higher heavy metals (Pb, Cd, Hg) concentration than *Schoenoplectus corymbosus*. Zn and Cr were also found in high concentrations in both macrophyte species compared to other heavy metals. Yezbie Kassa (2016) reported that Yitamot wetland (in the upper Blue Nile basin) had removed 99% of the nutrients (nitrate and total nitrogen) and metals (such as Mn) from wastes contaminated by Bahir Dar city municipality and Bahir Dar University (Peda campus). This is mainly attributed to the uptake by dominant macrophytes (*C. papyrus, C. digitatus, P. karka, Spaeranthus suaveolens, Hydrocotyle ranunculoides,* and *Echinochloa stagnina*) inhabiting the wetlands (Yezbie Kassa, 2016). Macrophytes accumulate more trace elements gradually in their leaves during the growing season (Schierup and Larsen, 1981). A study on tissue nutrient (TN and TP) contents of some macrophyte species (*T. latifolia, C. papyrus,* and *P. karka*) in Lake Tana confirmed that their nutrient composition differed among plant species and their body parts (Yezbie Kassa, 2016). The leaves of the three species had higher total nitrogen content than their stems. This may be attributed to the metabolic activity of the tissues. Leaves are the place where photosynthesis takes place and thus are more active, whereas roots and stems are usually involved in storage, transporting water, and nutrients (Yu *et al*., 2014). The change in the nutrient content of water among places may also contribute to the variability of plant tissue nutrient levels in both plant species and seasons. These results suggest that macrophytes are important in guarding aquatic ecosystems against pollution by improving water quality through removing heavy metals and nutrients, and therefore, they could serve as potential indicators of pollution and phytoremediation. Apart from ecosystem degradation, trace element accumulation, however, has a grave consequence on the health of human and animal populations that are involved along the food chain of the lakes. Herbivorous animals may bioaccumulate trace elements in their body through eating these macrophyte plants accumulating trace elements, which may perhaps biomagnify at higher trophic levels in the food chain. For instance, *A. elaphroxylon* is a multipurpose wetland shrub around Lake Ziway and its wilted leaves have been used as feed for small ruminants (Kaitho *et al*., 1996). The concentration of Mn in *A. elaphroxylon* from Lake Ziway exceeded the maximum tolerable level of Mn for animal feed (Ammerman *et al*., 1980).

Biomonitoring using diatoms

The diversity of diatoms is substantially higher in freshwater ecosystems compared to other algal groups (Stoermer and Smol, 1999). They are important primary producers of aquatic systems and playing major roles in food webs and biogeochemical cycles (Stevenson *et al*., 2010). The change in diatom biomass and community composition can be used to infer the level of water quality degradation and environmental changes, which could ultimately be used to assess the physical, chemical, and biological integrity of aquatic ecosystems. They provide a quick response to environmental disturbances (Figure 4) such as pH, conductivity and nutrients (Bennion and Smith, 2000; Potapova and Charles, 2003), eutrophication (Kitner and Poulícková, 2003), global warming problems (Leelahakriengkrai and Peerapornpisal, 2010) and physical habitat alterations (Stevenson, 2014). Using diatoms for Ecotoxicology is also advantageous because it allows us to investigate the influence of contaminants at various levels of ecological organization ranging from the individual cell to community levels

(Debenest *et al*., 2013). Furthermore, they are easy for sampling, preserving, observing live frustules, and identifying using acid-cleaned frustules (Pandey and Bergey, 2016; Pandey *et al*., 2018).

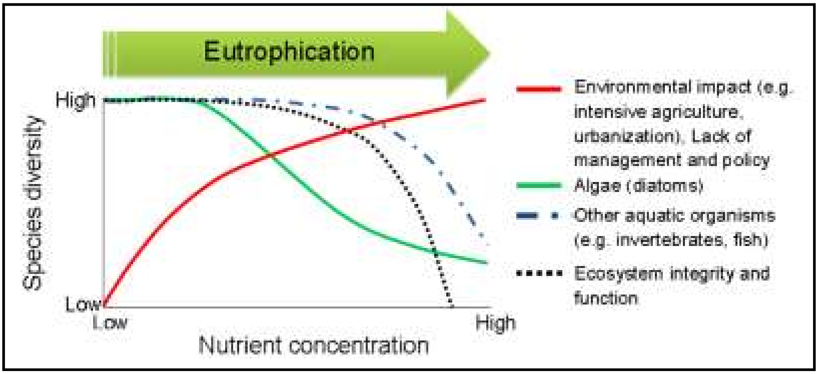

Figure 4. Anthropogenic impacts on aquatic biodiversity, ecological integrity, and functioning of aquatic ecosystems as the changes can be monitored using diatoms (Dalu and Froneman, 2016).

As a result, many potential biotic indices of diatoms have been developed around the world: trophic diatom indices (TDI), pollution sensitivity indices (IPS), generic diatom indices (GDI), and trophic diatom indices (TDIL) for lakes (Taylor *et al*., 2007a; Blanco *et al*., 2004). Owing to its ubiquity, diatom assemblages and pollution indices are also an integral part of many stream assessment programs worldwide (Simkhada *et al*., 2006). They are even used in paleolimnology to infer past and future conditions of aquatic ecosystems (Rühland, 2003; Levy, 2017).

Bioassessments of short- and long-term environmental quality changes using diatoms are growing in Africa (De La Rey *et al*., 2004; Taylor *et al*., 2007b; De La Rey *et al*., 2008; Abebe Beyene *et al*., 2009; Bere and Tundisi, 2010; Lang *et al*., 2012; Bere and Mangadze, 2014). However, the diatoms biomonitoring of water resources in East Africa, including Ethiopia, is very limited. A few studies exist based on benthic diatoms were performed in Kenyan rivers for assessing their health conditions (Ndiritu *et al*., 2003; Ndiritu *et al*., 2006; Triest *et al*., 2012), and researchers were able to demonstrate that appropriate watershed management tools can be successfully developed using diatom communities within aquatic ecosystems.

Abebe Beyene *et al.* (2009) was the first who attempted to apply diatoms as indicators of severe water pollution in Kebena and Akaki rivers in Addis Ababa, Ethiopia. They used 9 diatom metrics namely; Abundance, Richness, Evenness, Diversity, Simpson diversity, Alpha diversity, IPS (specific pollution-sensitive index), IBD (diatom biological index), and % PT (percent pollution-tolerant taxa). Their results showed that species diversity was higher at the upstream sites than downstream sites. Both IPS and IBD revealed a similar pattern that upstream sites had better ecological quality than their corresponding downstream sites. Biochemical oxygen demand (measured up to a level of 1250 mg/l) and nutrients (phosphate and nitrogen) were found significantly higher in the downstream river sites (Abebe Beyene *et al*., 2009), which corroborated the results of the diatom biomonitoring. The diatom species *Achnantidium minutissima* (low nutrient indicator) was most abundant at the upstream sites. Its abundance was strongly correlated with the gradient of primary habitat quality. They measured habitat quality using the qualitative habitat evaluation index (QHEI) based on Rankin's (2006) classes. The index indicated that most sites were categorized into poor quality classes, reflecting high habitat degradation and loss in the local rivers. The RDA ordination of diatom species and environmental variables classified the sampling sites in ascending order of pollution level from the relatively clean upstream sites to the progressively more polluted downstream sites (Abebe Beyene *et al*., 2009). Alemayehu Negassa (2016) also reported that diatom species richness declined within the downstream sites in response to increased conductivity, nutrient loads, organic pollution, and contaminations with heavy metals mainly cadmium. Moreover, diversity indices, evenness, dominance, Trophic diatom index (TDI), Saprobic index (SI), and community lost index (CLI) indicated an increased water quality deterioration at downstream sites. Taffere Addis (2008) also reported the same result for the same river. A similar result was also reported from Beijing, China (Chen *et al*., 2016). They used a range of diatom structural metrics, including species richness, Shannon diversity, species evenness, and Simpson diversity. These metrics were able to discriminate urban downstream from reference and urban upstream sites. All study sites had different diatom species composition. However, *Achnanthidium minutissima, Staurosira construens* and *Pseudostaurosira brevistriata,* and *Nitzschia palea* species were dominant at the reference, urban upstream, and urban downstream sites, respectively. The relative abundance of these species was positively correlated with some environmental variables (potassium ion, electrical conductivity, total nitrogen, chloride ion, and pH) in urban downstream samples; whereas water temperature and fluorine ion were correlated with reference and urban stream diatom composition. Thus, the researchers were able to demonstrate that diatom species composition was more sensitive to urbanization than the water's physico-chemical parameters, and implying diatom assemblage structure metrics have more accurately assessed water quality.

Diatoms appeared to be better indicators of urban stream conditions (Taffere Addis, 2008; Abebe Beyene *et al*., 2009; Chen *et al*., 2016) compared to macroinvertebrates. A comparative study of diatoms and macroinvertebrates as indicators of severe water pollution in Ethiopian urban rivers by Abebe Beyene *et al*. (2009) showed that macroinvertebrate species composition was more affected by the stream physical habitat quality and water chemistry than diatoms. Consequently, macroinvertebrates were completely absent in the majority of the polluted sites, especially when the dissolved oxygen concentration was very low. At these stream sites, diatoms were more accurately identified gradient of pollution than the corresponding macroinvertebrates.

CHALLENGES IN THE USE OF BIOLOGICAL MONITORING IN ETHIOPIA

The commitment of the Ethiopian government with regard to water resources and freshwater ecosystem conservation is promising as reflected from a wide range of policies, legislations, and laws. However, their implementation and enforcement by the authorities at different levels for safeguarding aquatic ecosystems against physical degradation and chemical pollution is very low. Regulatory authorities involved in environmental management rarely apply biological data for monitoring purposes. The country doesn't, therefore, recognize the importance of biological organisms for better management and conservation of freshwater ecosystems. The concept of bioassessment is not yet an integral part of the Ethiopian water resource management policy. Lack of legislation and standard protocols for sampling and analysis of macroinvertebrates further complicated its implementation. Thus, neither biotic indices (multi-metric methods) nor multivariate approaches have been used so far by government environmental monitoring organizations. As a result, researchers are using non-standardized protocols and different methodologies for sampling and processing of macroinvertebrate samples (Table 4), which is difficult to reach at a conclusive result. For instance, net mesh size used is not uniform (which varies from 250 to 000 μm). According to Buss *et al*. (2015), the smallest size of macroinvertebrates caught is determined by the size of the mesh. Consequently, the calculation of biotic metrics will be affected if abundance is used as input data because a sampler with a very small size mesh can collect more organisms.

Table 4. Comparison of methodologies for the collection and processing of benthic macroinvertebrates as indicator organisms for developing biotic indices in Ethiopia.

Author	**Sampling sites (%)**	**Sampling protocol, net type, and net mesh size**	**Location**	**Metric scoring methods**
Baye Sitotaw (2006)	15	Surber sampler (sampler (mesh size = 500 µm, sampling area = 0.9 m^2); D-frame net with no mesh size, Scoop net, multihabitat approach within 200 m reach	Abay, Baro, Omo-Ghibe, and Awash basins	Continuous
Solomon Akalu *et al*. (2011)	8	Surber sampler (mesh size = 500 µm, sampling area = 0.9 m^2); Scoop net sampled during dry season in riffles & pools	Greater Akaki river, Addis Ababa	Continuous
Solomon Akalu (2017)	12	Surber sampler (area = 0.09 m^2, mesh size = 500 µm); Scoop net, brush for attached organisms.; wet & dry season in riffles& pools of 100 m reach	Greater and Little Akaki rivers	SASS 5 and ETHbios
Hayal Desta and Seyoum Mengistou (2009)	3	D-frame dip nets with 1000 µm mesh size; samples were taken during the dry season and at high rainfall & vegetation growth months (April, May)	Jimma town wetlands	Hilsenhoff Family Level Biotic Index (FBI)
Mekedes Hone (2016)	4	D-frame net with mesh size 500 µm	Blue Nile river head	==
Amelework Zewudu (2017)	20	Surber sampler (30 × 30 cm); net mesh size 1000 µm-riffle sampling D-frame net-pool sampling	Streams and rivers in Lake Tana sub-basin	Continuous scoring
Aschalew Lakew and Moog (2015b)	104	Standard hand net with 25×25 cm and mesh size 500 µm, multi-habitat approach	Streams in Awash, Wabe-Shebelle, Genale, and Rift Valley basins	Continuous scoring

Seid Tiku *et al.* (2013)	63	Rectangular frame net 20×30 cm with 300 µm	Five riverine wetlands and three floodplain wetlands, Gilgel Ghibe watershed	Continuous scoring
Amare Mezgebu *et al*. (2019)	9	Square frame hand net with 25×25 cm and mesh size of 500 µm, multihabitat sampling scheme in 100 m reach; sampling units consider substrate types	Four streams around Sebeta town exposed to various anthropogenic activities	SASS 5 and ETHbios
Mesfin G/Hiwot *et al*. (2017)	34	Rectangular frame kick net with 50×33 cm frame, mesh size 250 µm	Gilgel Ghibe watershed	==
Temesgen Alemneh *et al*. (2017; 2019)	36	D-frame net with a mesh size of 300 µm; sampling taken during dry and wet seasons in 10 m stretch micro- and meso-habitats	Choke mountain, Chemoga river	==

Habitat evaluation, sampling procedures/protocols, including metric scoring methods were some of the variants observed among the researchers. Lack of identification keys is another serious problem as the majority of the researchers used identification keys developed for temperate regions. It is well documented that Ethiopia is rich in invertebrate diversity and above all with a high degree of endemism (Seyoum Mengistou, 2006). The majority of the studies conducted in Ethiopia identified macroinvertebrates to the family level, though few studies have tried to combine both genus and species levels (e.g., Getachew Beneberu, 2013; Aschalew Lakew and Moog, 2015b). Despite exercising taxonomic resolutions at a lower resolution is expensive and time-consuming, the degree of pollution and aquatic environmental conditions are reflected very well at the genera and species levels. It is recommended that the index to be developed in the tropics should depend on identification to lower taxonomic level resolution that can provide accurate and precise data (Elias *et al*., 2014). The number of sampling sites also varied and ranged from 3 to 104 (Table 5). How many sample sizes and areas are sufficient for representing invertebrate communities in a given ecosystem considered for a study are important questions. For example, the value of taxon richness is extremely influenced by many interacting factors such as the size of the sample area, the diversity of habitats visited, antecedent flow as well as the number of individuals identified and the taxonomic level of identification

(Wagenhoff *et al*., 2016). The biological data and their corresponding habitat, physical, and chemical parameters generated through inconsistent methods and protocols will compromise the reliability and quality of the information synthesized. Hence, consistency in the collection and processing of data is crucial for comparison across sites or years.

Apart from the laws and protocols, the absence of identification keys and expertise hampered the development of biomonitoring tools in the country. Almost all the papers examined in the present review use guides and keys for macroinvertebrate identification that have been applied in the United States of America (USA), Europe, Australia, and South Africa, which may limit the credibility of the assessments. In fact, Ochieng *et al*. (2019) reported that East African researchers are facing taxonomic challenges while monitoring freshwater bodies using macroinvertebrates. They recommended the urgent development of identification guides that are based on local species to ensure the development of biotic metrics important for intended purposes. In other countries, the development of bioassessment tools is legislation driven by supporting researcher funds, capacity building, field and lab equipment, and creating a conducive working environment. Unavailability of these kinds of support via legislation in our country certainly discourages researchers from developing monitoring tools and advancing the system to a higher level. Moreover, even in the few studies, the approaches utilized for bioassessment are very traditional, but others are usually complemented using molecular approaches. In the current situation, obtaining a reference condition for a basin in Ethiopia is very challenging as most areas are easily accessible to humans. Such problems can be solved using historical data/baseline information or else from paleolimnology, which is rarely available in Ethiopia. Lack of this information would be a major deterrent to the development of metrics for assessing water resources in the country.

Generally, people have been doing researches related to biomonitoring based solely on individual interest facing all the above grand constraints. The efforts are appreciated, however, the bioassessments conducted in the country may not be comparable in terms of results across seasons, sites, and ecoregions. These pitfalls will limit the anticipated information from the studies. According to Clarke and Hering (2006), the utilization of inconsistent sampling tools and protocols might introduce erroneous and uncertainty during data collection even in the same climatic regions, resulting in undependable biomonitoring results. The application of a standardized protocol is, therefore, a prerequisite to obtaining quality data for the development of biological indices to monitor water resources. In line with this, De Pauw *et al*. (2006) underlined that sampling equipment, field sampling technique, processing of organisms, level of taxonomic resolution with taxonomic references, and index calculation should be defined and standardized.

CONCLUSION AND FUTURE DIRECTIONS

The progress of developing biomonitoring tools in Ethiopia is promising as reflected by several attempts in different water bodies initiated by interested individuals. However, these efforts have been hindered by the unavailability of standardized methods, protocols, and identification keys; absence of biological monitoring experts; lack of logistics and equipment as well as very low attention by the government. Furthermore, most studies are skewed towards the indicator values of macroinvertebrates, focusing more on stream and river ecosystems. Macrophytes, fish, and to a lesser extent algae/diatom seem to be neglected biological entities in Ethiopia in particular and the whole of Africa in general. This may be related to the availability of resources, and difficulty in sampling and identification. In Africa, for instance, diatom-based indices are not commonly used owing to the absence of capacity and training in diatom taxonomy, which resulted from limited funding and job opportunities (Bere, 2016). The facilities and expertise required to process and analyze diatoms in most African institutions are completely absent (Dalu and Froneman, 2016). Although bioassessments conducted in the country are limited, few studies were able to successfully indicate the intensity of degradation and aquatic ecosystem health including the sources of the stressors. The major stressors include agricultural activities, catchment degradation, untreated domestic and industrial wastes, siltation, habitat quality deterioration, water abstraction, flow impairment, etc. We, therefore, encourage the use of biological indicators as they are reliable, cost-effective, and provide an integrated assessment of ecosystem health status compared to the traditional approach (physico-chemical analyses).

Environmental and water management efforts should concentrate on the specific nature of the damage, along with enforcement of existing wastewater discharge standards, restoration of degraded habitats, and mitigation of further degradation, based on accurate assessment and interpretation of component metrics and an apprehension of the amounts and types of human interference. Thus, policies governing the environment and water should also consider aquatic ecosystem protection and conservation as key components in water resources and ecosystem management (Masese *et al*., 2013; Mangadze *et al*., 2019).

RECOMMENDATIONS

Biotic indices could be developed with less cost and effort, but they are efficient tools to assess the health of aquatic environments. They are very appropriate for developing countries such as Ethiopia, where the allocation of budget and materials are inadequate for collecting continuous time series physicochemical data. To advance the use of biomonitoring in our country the policy issues, financial and technical challenges should be resolved, and the following recommendations are forwarded:

(1) Government agencies who work related to water and aquatic ecosystems should recognize the importance of biomonitoring and encourage its utilization, support it by ratifying relevant laws, legislations, and standard protocols including finance and materials. Aquatic ecologists and environmentalists who are work in the area of biomonitoring should increase the awareness of policy and decision-makers, and the public at large regarding the importance of biological indices for better management of water resources preparing symposiums, policy briefs, and leaflets in vernacular languages. Moreover, we need to keep on promoting the Regional and Federal Governments to include the bioassessment program in Water Resources Management Policy and Proclamation;

(2) The inventory and description of native floras and faunas, including their ecology, should be worked out accompanied by identification keys and guides that can allow easy taxonomic identification. Until the flora and fauna are better known, biomonitoring will remain unutilized;

3) Tolerance values for biological organisms (macroinvertebrates, diatoms, macrophytes) and their corresponding indices should be developed based on different ecoregions of the country, possibly using qualitative toxicological tests or by direct gradient-analysis to identify the various environmental optima for various taxa;

(4) Ecoregion-based key biological metrics from families containing high diversity should be identified for developing a new biomonitoring index;

(5) Universities and research institutes should be encouraged for the development of appropriate monitoring tools using biological organisms (Macroinvertebrates, Diatoms, and Macrophytes) to assess water quality changes and habitat degradation;

(5) Technical manpower that is good at identifying and understanding the ecology of organisms (floristic and fauna) should be trained through short- and long-term training programs and their number should be increased in government agencies and

(6) Biomonitoring should be included as a separate course that should be given at least at the postgraduate level.

ACKNOWLEDGMENTS

We wish to thank the editors and two anonymous reviewers for the helpful comments on the earlier version of this manuscript. We also appreciate the internet service provided by Bahir Dar University for searching the literature.

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