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A review on freshwater biomonitoring with benthic invertebrates in Ethiopia

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Abstract: This paper reviews freshwater biomonitoring studies conducted in Ethiopia on benthic invertebrates. It encompasses the sampling tools, protocols, indices and taxonomic resolutions that have been used by researchers to assess the status of the freshwater bodies. Biomonitoring in Ethiopia is still, in its infant stage and ETHbios is the only biomonitoring program developed for assessing streams and rivers in the central and southwest parts of Ethiopia. Most benthic invertebrate studies use metrics and indices developed in temperate regions. The major problems for its development in Ethiopia, are poor taxonomic inventory, the absence of state-supported research, lack of infrastructures to access the water bodies and paucity of equipment for sampling and processing. For future advancement of biomonitoring in Ethiopia state supported research, biomonitoring training, invertebrate taxonomic inventory, adoption of indices with great care and development of ecoregion based indices are suggested.

Keywords: aquatic ecosystems, biomonitoring, benthic invertebrates, Ethiopia

Introduction

Physicochemical methods of aquatic ecosystems health assessment are found to be less appropriate in monitoring programmes as they cannot detect the biogeochemical changes happened in the ecosystem over a long period of time (Barbour *et al*, 2000). As a result, there was a concept of developing a more efficient, effective and lower-cost method of assessing water pollution using aquatic entities called biomonitoring (Elias *et al*, 2014). Biomonitoring is any activity in which inferences are made about the situation of the environment from structural or functional attributes of individuals, populations, communities or ecosystems (Hart, 1994). It is the systematic use of a living organism's responses to the effect of stressors on the receiving environment (Rosenberg, 1998). Biomonitoring is very important to detect the impact of pollution on aquatic ecosystems (Morse *et al*, 2007). The organisms used for biomonitoring are called bioindicators and these organisms provide better information on the impact of anthropogenic activities on the overall condition of ecosystems than physio-chemical variables, because they integrate the biogeochemical changes within the system (Barbour *et al*, 1999). Chemical sampling does not evaluate biological threats to ecosystem condition but bioindicators integrate stresses over a long period of time (Barbour *et al*, 1999; Beneberu *et al*, 2014; Lakew and Moog, 2015b). In addition, the response of bioindicators to stressors rages from a decrease in abundance and diversity to emergence of morphological deformity (Martinez *et al*, 2002), which really helps to signify the intensity of the impact.

A variety of bioindicators are used for bioassessment of aquatic ecosystems but benthic invertebrates are the most popular for water quality monitoring, because it is easy for sampling, need cheap sampling equipment, not mobile and show localized pollution, wide degree of tolerance and easy for identification to family level (Barbour *et al*, 1999; Barbour *et al*, 2000; Elias *et al*, 2014; Lakew and Moog, 2015). Different water quality assessment studies conducted in various freshwater bodies stated that benthic invertebrates are the best indicators yet available (Barbour *et al*, 1999; Tesfalem, 2010; Beneberu *et al*, 2014; Lakew and Moog, 2015b; Mezgebu *et al*, 2019a). The habit of benthic invertebrates staying in a specific location through most of their life cycles helps to show the intensity of localized pollution and they respond with respect to their degree of tolerance to different anthropogenic activities (Beneberu *et al*, 2014; Lakew and Moog, 2015a; Mezgebu *et al*, 2019b; Wosnie and Wondie, 2014). Besides, benthic invertebrates are easily identifiable at least to family level with cheap sampling equipment (Barbour *et al*, 1999; Lakew and Moog, 2015b; Mezgebu *et al*, 2019a).

Most bioassessment techniques from the saprobic approach to molecular techniques have been

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developed and used well in the USA and European countries. Many of these countries incorporate biomonitoring as their legal and policy framework for aquatic ecosystem monitoring (Masese *et al*, 2013). The initiative to develop biomonitoring tools for aquatic ecosystem health assessment in tropical regions has largely based on in favour of modifying and adopting indices developed for non-tropical regions using a local freshwater taxa (Elias, 2014). Recently there has been a trend towards developing biomonitoring tools using a local freshwater macroinvertebrate families in some parts of Africa: the South African Scoring System (SASS) in South Africa (Chutter, 1998; Dickens and Grahm, 2002), the Namibia Scoring System (NASS) in Namibia (Palmer and Taylor, 2004), the Okavango Assessment System (OKAS) in Okavango (Dallas, 2009), the Zambia Invertebrate Scoring System (ZISS) in Zambia (Dallas *et al*, 2018) and The Ethiopian Biotic scoring system (ETHbios) in Ethiopia (Lakew and Moog, 2015a). Some of these biomonitoring tools are modified and adopted from indices developed in the temperate region. Also in the other parts of Africa, only fragmented studies on the use of benthic invertebrates for water quality assessment are available (Elias *et al*, 2014). As biomonitoring is a promising tool for developing countries to monitor their aquatic ecosystems, it is important to review the techniques used and challenges faced to improve future biomonitoring tasks. Therefore, this review is prepared to overview the status of biomonitoring in Ethiopia with discussions on sampling tools and protocols, indices and taxonomic resolution, major challenges and proposed solutions for future biomonitoring development in the country.

Aquatic biomonitoring in Ethiopia

In Ethiopia, biomonitoring is at its infant stage (Mengistou, 2006; Sitotaw, 2006; Lakew, 2012; Beneberu *et al*, 2014; Wosnie and Wondie, 2014; Lakew and Moog, 2015a). Most of the studies on Ethiopian water bodies were focusing on the nonbiological utilities of water for hydropower and irrigation. The biological resources such as fish, invertebrates, crocodiles, algae etc. were rarely mentioned (Mengistou, 2006). However, recently there is a tendency to study river invertebrates for assessment and monitoring of pollution and degradation of streams, rivers, wetlands and lakes in Ethiopia (Desta, 2006; Mengistou, 2006; Sitotaw, 2006; Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab).

Some studies have been conducted on the diversity of invertebrates and their potential use for biomonitoring. For example, Harrison and Hynes (1988) studied the benthic fauna of highland streams of Ethiopia and tried to establish reference taxa composition in the least impacted streams and rivers. They also pinpoint that soil erosion due to human population increase and human activities such as washing/bathing are the cause for the elimination of benthic fauna. Sitotaw (2006) assessed the ecological status of streams and rivers of Modjo, Kebena, Akaki, Chacha, Megecha, Wabe, Ghibe, Dabena and Sor, using community structures of benthic invertebrates and found that their community structure could show the intensity of human impact in the streams and rivers of Ethiopia. The degradation level and the relationship between physicochemical parameters and biological assessment of the Kebena River are also stated (Berhe 1988 and Worku *et al*, 2004). The degradation level of streams and rivers of Awash, Rift-Valley, Wabi-Shebele and Genale basins have been studied using benthic invertebrates as bioindicators (Lakew, 2012; Beneberu *et al*, 2014; Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab). Multimetric indexes were developed based on macroinvertebrate communities, to assess the ecological condition of the headwater streams in the Ethiopian highlands (Alemneh *et al*, 2019). Other similar studies in different rivers, streams and wetlands of Ethiopia showed that benthic macroinvertebrate structure and composition are effective tools to assess the degradation of the countries water bodies (Desta and Mengistou, 2009; Lakew, 2012; Wosnie and Wondie, 2014; Beneberu *et al*, 2014).

Recently, a macroinvertebrate based biotic score system (ETHbios) was developed for Ethiopia which is considered to be a rapid, inexpensive and scientifically sound monitoring method for assessing the ecological status of streams and rivers in the central highlands of the country (Lakew and Moog, 2015a). It has been established based on the principle of Biological Monitoring Working Party (BMWP) approach by excluding taxa that do not occur in Ethiopia and including some of the Ethiopian benthic fauna. A sensitivity score was assigned for 59 benthic macroinvertebrate taxa collected from 104 sites distributed in a total area of about 98,000 square kilometres in the upper Awash, Rift-Valley and Wabi-

Shebele and Genale basins.

ETHbios considers the sensitivity of benthic invertebrates to organic pollution, siltation and some hydro-morphological degradation. Taxa with low scores indicate high tolerance to stressors and high scores indicate low tolerance to stressors. The procedure for assigning scores was based on calculation of a 'guide score' according to Ofenboeck et al (2010) and by experts' judgement. The 'guide score' is calculated on the basis of the distribution and frequency of benthic macroinvertebrate taxa among the five river quality classes based on Ethiopian multimetric index (Lakew and Moog, 2015b). The final values were assigned on the basis of experts' consensus, numerical proportioning applied to taxon occurrences and abundances, reference scores of taxon obtained from SASS and HKHbios score and using autecological knowledge of benthic invertebrate taxon. Then after ETHbios was calculated as the sum of sensitivity score of each taxon present in a sample and the Average Score Per Taxon (ASPT) was calculated as ETHbios divided by the total number of taxa considered in the calculation (Lakew and Moog, 2015a). In all studies mentioned above biomonitoring using benthic invertebrates is assured as an effective tool in assessing the impact of different human activities on the ecological health of Ethiopian water bodies.

Sampling tools and protocol used

Most biomonitoring studies in Ethiopia use a rapid bioassessment protocol of Barbour et al (1999). They use 80m-200m reach length for a sampling of benthic invertebrates (Abay, 2007; Wosnie and Wondie, 2014; Beneberu, *et al* 2014: Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab). Most of these studies consider pool and riffle habitats within the reach length (Abay, 2007; Mehari *et al*, 2014; Wosnie and Wondie, 2014; Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab). Multi habitat sampling scheme which includes different substrate types (megalithal, macrolithal, mesolithal and microlithal) was also implemented with at least 5% share of each habitat type within a reach length (Lakew, 2012; Lakew and Moog, 2015ab: Mezgebu *et al*, 2019ab). Different sampling effort and sampling season (dry season or both) were also practised by some of the studies (Abay, 2007; Mehari *et al*, 2014; Wosnie and Wondie, 2014; Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab).

Sampling protocols like quantitative (Mehari *et al*, 2014; Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab), semi-quantitative (Abay, 2007) and qualitative (Wosnie and Wondie, 2014) have been used. Sampling tools such as Surber sampler (Akalu *et al*, 2011; Beneberu *et al*, 2014), D-frame net (Mehari *et al*, 2014; Wosnie and Wondie, 2014), scoop net (Abay, 2007; Akalu *et al*, 2011) and square net (Lakew and Moog, 2015ab; Mezgebu *et al*, 2019ab) have been used to collect benthic macroinvertebrate samples. The use of different sampling protocols and tools may produce data that is difficult for comparison of the results (Buss *et al*, 2015). Data collected using different techniques and tools may provide strange and inconsistent interpretations, even at the same ecoregions and the biomonitoring tool develop using this data may be a doughty in precision (Elias *et al*, 2014; Buss *et al*, 2015). Clarke and Hering (2006) also stated that the application of different sampling tools and protocols produce errors and uncertainty to data collected even in the same climatic ecoregions or biotopes. Everall *et al* (2017) compared macroinvertebrate biomonitoring indices of river health derived from semi-quantitative and quantitative methodologies and found that quantitative sampling best determine the density of the community (individual m^{-2}) than semi-quantitative methodology. It has been recommended to use standardized sampling protocol, tools and taxonomic knowledge to easily differentiate site conditions (Dickens and Graham, 2002; Elias *et al*, 2014; Buss *et al*, 2015).

Indices and metrics used

Almost all biomonitoring studies in Ethiopia use keys, metrics and indices of benthic invertebrates developed in the temperate region. Some of the identification keys used were Naidu (1965), Scott (1983), Harrison (1992), Merritt and Cummins (1996), Nesemann and Neubert (1999) and Epler (2001). Even if the study of benthic fauna in Ethiopia started some 80 years ago (Mengistou 2006), only the taxonomy of some group of invertebrates were studied and that was the reason of using benthic invertebrate keys developed from temperate regions (Mengistou 2006; Beneberu *et al*, 2014). Formerly developed benthic invertebrate keys in Ethiopia were for taxa collected from individual rather than systematic inventory and attention was given to invertebrates of medical, agricultural, ecological or anthropological importance (Mengistou, 2006). Use of metrics developed elsewhere may not have a problem on the results found as it is based on the proportion of collected taxa. However, use of tolerance/intolerance indices and index of biotic integrity ranges may not provide real information as the distributions of benthic invertebrates are affected by geology and hydrology of the area under investigation (Elias *et al*, 2014; Lakew and Moog, 2015ab).

Biomonitoring indices are developed for specific regions by local biotic assemblages that show regional variation based on the organism's sensitivity or tolerance. Applying these indices to other regions might affect its capability, functioning and reliability (Elias *et al*, 2014). Therefore, indices developed in the temperate region should be calibrated before use in tropical regions including Ethiopia. This is due to the fact that some macroinvertebrate taxa might occur abundantly in the temperate region but not in Ethiopia climatic regions and vice versa. Even if the organisms in the temperate region occur in Ethiopia, attention should be given as it may differ in diversity. For example, there is a low diversity of Plecoptera in the tropics but, high diversity in temperate and Mediterranean regions (Elias *et al*, 2014). Such variation in both diversity and abundance of invertebrates might affect the capability, functioning and reliability of the existing non-tropical biomonitoring indices when applied in Ethiopian water bodies. But, to use modified indices developed in the temperate region to tropical regions is usually hindered by incomplete taxonomical resolution and the scarcely known sensitivity levels of many tropical taxa (Jacobsen, 2008). Therefore, tropical regions including Ethiopia should develop their own dependable regional biomonitoring index than adopting non-tropical indices.

Taxonomic resolution

With regard to taxonomic resolution, most of the studies conducted in Ethiopia used family level identification of the benthic invertebrates (Sitotaw, 2006; Akalu *et al*, 2011; Wosnie and Wondie, 2014; Lakew and Moog, 2015ab). Some researchers identified some of the macroinvertebrate taxa up to sub-family, genus and species level (Beneberu *et al*, 2014; Lakew and Moog, 2015a; Mezgebu *et al*, 2019a). In biomonitoring, a taxonomic resolution is based on a cost-benefit analysis. The cost saved in identifying invertebrates to develop family level indices may not be sound if precision cannot be achieved by such taxonomic level. Likewise, the cost spent to obtain species-level indices may also not be sound if cheaper family level indices can evaluate accurately the status of aquatic ecosystems (Elias *et al*, 2014). But, from a large set of data and developed indices, it has been described that lower taxonomic resolutions best reflect the intensity of degradation and overall ecological status of the aquatic ecosystem (Verdonschot, 2000). For example genus/species of Chironomidae best reflect the status of the aquatic ecosystem health than the family level (Beneberu and Mengstou 2010; Beneberu *et al*, 2014; Mezgebu *et al*, 2019a). It has also been recommended that for the sake of data accuracy and precision, an index developed in the tropical region should be in lower taxonomic level resolution (Elias *et al*, 2014).

For future development of biomonitoring, it is important to develop tools standardized across regions, to allow global comparisons and able to measure change over multiple time points (Jackson, 2016). A universally consistent data is important for global issues such as climate change and appropriate sampling and processing effort and standardized indicators to resolve dissimilarities among biomonitoring methods is vital (Buss *et al*, 2015; Jackson, 2016). This is through the use of key technological and logistical advances including remote sensing, molecular tools, and local-to-global citizen science networks (Jackson, 2016).

Challenges of biomonitoring in Ethiopia

The diverse physical and chemical setting of Ethiopian aquatic systems in its 20 natural lakes and 12 river basins leads to a high diversity of aquatic fauna, but the major utilized living resource is only fish (Mengistou, 2006). There are major problems for the under-development of biomonitoring systems in aquatic ecosystems of Ethiopia and in fact it shares the problems of other African countries. In Ethiopia, there is no biomonitoring supportive decision-making process and there is no state support research. The Environmental Policy of Ethiopia (EPE) serves as a benchmark and reference for all national development programs. The National Policy on Biodiversity and Research (1998) approved for conservation, development and sustainable utilization of bio-diversity. The Ethiopian Water Resources Management Policy works on the management of all water resources of the country. Fisheries

Development and Utilization Proclamation No. 315/2003 deals with all water bodies found within the boundary of Ethiopia where fishes are found. The Environmental Impact Assessment Proclamation (EIAP, 2002) aims at bringing about sustainable development by predicting and mitigating adverse environmental impacts. All these institutions do not use and incorporate biomonitoring based information to monitor the aquatic environments. Mengstou (2006) described that institutions concerned about invertebrate resources like Environmental Policy (April 1997), Biodiversity Conservation and Research Policy (April, 1998) and the Water Resources Management Policy (1999) do not mention and have no any provision for the utilization, conservation and management of aquatic invertebrate resources of the country.

There are also other bottlenecks for the under-development of biomonitoring like lacking infrastructures for accessing the water body and absence of equipment for sampling and processing, lack of trained manpower. It has also been described that technical, financial and logistical constraints have hindered biomonitoring programs to be implemented in Tropical African region (Elias *et al*, 2014). Absences of invertebrate curators in many African museums have hindered aquatic invertebrate collection in Africa and these lack of taxonomic inventory and knowledge on benthic invertebrates hinder their use as biomonitoring tool (Mengistou, 2006).

Proposed solutions for the future development of biomonitoring in Ethiopia

Biomonitoring training: As biomonitoring is a cheap, easy and promising tool towards reflecting the influence of anthropogenic activities on water bodies, training of professionals has paramount importance. This can be achieved through formal education at colleges and universities and informally to the local community and school children using simple biomonitoring tools.

Taxonomic inventory and development of identification keys: For biomonitoring to be in use, taxonomic inventory at least at the family level is mandatory. Taxonomic inventory has an advantage in one hand to know the aquatic resources of the country and on the other hand, make biomonitoring easy. In this regard huge inventory studies and collection of invertebrate samples throughout the country is vital.

State support: Since biomonitoring is a cheap, easy and robust method of water quality assessment, the government sectors should incorporate this method as a legal policy framework. This is by establishing a National and Aquatic Ecological Program (NAEP), which can be funded by Forest Climate and Environment Commission with a task of assessing the health of freshwater ecosystems of the country using biological indices, establish reference streams/rivers and collect baseline invertebrate taxonomic data.

Extrapolation of ETHbios: As ETHbios is developed for monitoring the central and south-east highland streams and rivers of Ethiopia updating it to use for other parts of the country is important through incorporating and awarding ETHbios score value for benthic invertebrates found in other regions of the country.

Adoption and development of ecoregion-based indices: Before using indices developed elsewhere to Ethiopia, calibration with great care is important, as it is affected by regional geology and climate characteristics. Even if the same organisms are present, diversity will matter and adoption should take this into consideration. If possible, the development of ecoregion based indices is highly recommended as it can clearly show the status of ecosystem health in that ecoregion. The distribution and abundance of invertebrates are affected by ecoregion characteristics and therefore, there is a need to develop indices that are reliable in a specific ecoregion.

Standardization of methods and reference conditions: Sampling tools and protocols should be standardized for a better comparison of data collected from different water quality classes. The sampling tool, mesh size, time of collection, range of habitat type sampled should be fixed to avoid bias and better interpretation of results.

Conclusions and the way forward

Biomonitoring is an easy and robust aquatic ecosystem health assessment method. It is a very promising tool for assessing aquatic ecosystem health of developing countries, as it requires cheap equipment for sampling and processing. But, in Ethiopia utilization of biomonitoring is at an early stage. Studies conducted in the country use different protocols, sampling tools and indices developed at the temperate region which may produce data difficult for comparison. The major challenges for the under-development of freshwater biomonitoring are basically on logistics, financial and technical issues. For biomonitoring to be developed theoretically and practically, professional training, taxonomic inventory, state support, extrapolation of ETHbios and development of ecoregion-based indices are recommended. For future development of bio-monitoring, it is important to develop tools standardized across regions, through the use of key technological and logistical advances including remote sensing, molecular tools, and local-to-global citizen science networks.

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