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A new diatom-based multimetric index (MMI-D) for ecological health monitoring in the Tropical Rift Valley Lake(Lake Hawassa, Ethiopia)

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Abstract

Multimetric assessment is one of the important tools for diagnosing, detecting and measuring the level of impairments of ecosystem function in lentic ecosystem. It also provides detection capability over a broader range and nature of stressors and gives a more complete picture of the ecological conditions than single metrics and biological indicators. A diatom-based multimetric index (MMI-D) was developed to evaluate the ecological-health of Lake Hawassa. Physicochemical and benthic diatom sampling was done at nine sites with different degrees of human disturbance along the lakeshore area from February to November 2015 and 2016. A priori classification of lake segments into minimally disturbed (three sites), moderately disturbed (three sites) and highly disturbed (three sites) was done by clustering sampling sites based on percentage disturbance score (PDS). From 24 diatom candidate-metrics, only 10 were chosen as core metrics for the development of MMI-D based on redundancy analysis, reaction to environmental conditions, percent discriminatory efficiency (%DE), and box-plots. The newly established MMI-D index clearly distinguished between reference and non-reference sites, as well as between the lake's three clusters. The MMI-D index's performance was validated using independent data sets from Lakes Hawassa and Ziway, and it demonstrated the best capability for discrimination between different disturbance levels. MMI-D TSLS regression analysis revealed an inverse but robust connection with PDS, indicating its responsiveness to Lake Hawassa habitat quality degradation (n=9, R^2=0.921, P=0.000). The MMI-D index revealed a high %DE (95.1%) and a negative but significant connection with nutrients, total suspended solids (TSS), and turbidity (R^2>0.6; P<0.05). Generally, it can be concluded that this index is a powerful tool that could assist end-users by providing a practical method for measuring the ecological quality of L. Hawassa.

Keywords: benthic diatoms, ecological quality, Lake Ziway, redundancy analysis, validation

Introduction

Lake Hawassa is one of the most threatened Rift Valley Lake because of human pressure related to adverse watershed land use, urban development, and expansion of industries. For example, around the 1980s, there were no observed pollution signs on adjacent sites of the lake to Hawassa City since there were few recreational activities and urban development (Kibret 1985). Nowadays, recessional farming, deforestation, urbanization, recreational activities and industrial expansion are among the stressors type that significantly contributes to the observed change of the lake water quality. As a result of the effect of these multiple stressors, the lake ecology has degraded in terms of its physical (like modified shoreline, less of riparian vegetation cover, lots of manmade structures in and around littoral zone), and chemical (like increasing concentration of nutrients) (Wondmagegn 2019) and high bioaccumulation load of trace metals (Nigussie et al. 2010)). In addition, there was also deterioration of biological quality (like dominancy of pollution tolerant macroinvertebrate assemblages (Aklilu 2011).

Lakes of sub-Saharan Africa including Lake Hawassa are utilized for a variety of purposes that are uncommon or unseen in developed temperate countries, like waste disposal, laundry washing, cattle watering, and personal hygiene (Wondmagegn and Mengistou 2023). According to Revenga et al. (2005) these activities have caused a decline in the overall ecological functioning, which has altered in species abundance and richness of biological communities (Strayer 2006). Such changes in benthic organisms in response to human pressures has been reported as effective tools to monitor the biological integrity East African waterbodies (Masese et al. 2013a). Besides, Odountan et al. (2019) recently suggested that benthic indices and metrics are advocated for the purpose of biomonitoring of lakes in West Africa and developing countries. Therefore, to have best management practices and to assure the sustainable function of the lake ecosystem, biological monitoring uses aquatic organisms is important to monitor changes in chemical and physical components of the aquatic environment. It can enhance the ability to identify the level of degradation as well as the actions to take (Masese et al. 2013b; Stribling and Dressing 2015a; Stribling and Dressing 2015b).

In earlier times, indicator organisms (metrics) were used for biomonitoring practice based on their response to human perturbation in their community structure. Later, ecologists developed single biotic index to get better discription on the human disturbance to aquatic ecology than the indicator organisms (Barbour et al. 1996). In recent years, using single biotic index is being replaced by multimetric biotic index sinces single biotic index can responds to limitted stressors which may affect the accuracy of the assessment (Wang et al. 2015). Thus, the multimetric approach is more robust water quality assessor and indicates ecosystem integrity, and provide opportunity to respond for different stressors type at a time (Schoolmaster et al. 2012; Wang et al. 2015). This method uses an aggregation of individual community metrics that comprise benthic biological elements for the development of a single composite multimetric index (De la Rey et al. 2004) which are recommended to use lakes suffered with multiples stress like that of Lake Hawassa (Wondmagegn and Mengistou 2020). This can potentially reflect multiple effects of human impact on the structure and function of aquatic ecosystem (Barbour et al. 1999; Menetrey et al. 2011) and is based on comparing the biological metrics form minimally disturbed to highly disturbed sites of the water body (Stoddard et al. 2006; Whittier et al. 2007).

The application of diatom based multimetric index in lake biomonitoring is quite recent and only few studies have been recorded from tropical regions (Phiri et al. 2007; Wang et al. 2015; Chen et al. 2017) but not Ethiopian lakes, including Lake Hawassa. Since the water quality of Lake Hawassa has been affected by a number of stressors, a multimetric approach is highly recommended (Wondmagegn et al. 2019) to obtain accurate results of the response diatoms to the potential stressors of the littoral regions of the lake. Therefore, the objective of this study was to develop a diatom base multimetric index of biotic integrity of L. Hawassa (MMI-D) and validate its capability of discriminating reference from non-reference sites of the lake.

Materials and Methods

Description of the study area

Lake Hawassa, lies 275 km south of Addis Ababa, in the Main Ethiopian Rift (MER), surface elevation 1,686 m asl (6°33' - 7°33' N and 38°22' - 38°29' E; **Figure 1)** (Welcome 1972). It has no visible outlet, however, a UN Geothermal Survey has suggested that there may be groundwater flow away from the lake on the south-west and north sides, which may account for a major loss of water. This outflow could moreover be used to explain the relatively low alkalinity of Hawassa compared with either saline Lake Shala or Lake Abiyata, both of which are also terminal lakes (Makin et al. 1975).

Tikur Wuha, the only perennial river feeding the lake drains the vast swamps of Wendo Genet area, which in itself drains the highlands on the east. The surface area of the lake is about 92 km² (Makin et al. 1975), 16 km long, up to 8 km wide, and it has an estimated volume of 1.3 billion m³. The maximum and mean depth of the lake is about 22 m and 11 m, respectively.

It is ecologically very important and is home to eight species of fish (Dadebo 2000; Tekle-Giorgis et al. 2017), Pelicans, Storks, Herons, Hammerkops, Sea Eagles and Kingfishers. There is a small-scale fish market on the shore at Amora Gedel. The lake also supports large mammals including hippopotamus (Wondmagegn et al. 2019).

Sampling site selection

The sampling sites were selected according to their exposure to anthropogenic activities by computing its habitat quality through percent disturbance score (PDS; **Table 1**) (Fig. 1). So, KW1, KW2 and WSH were categorized as reference groups whereas, the remaining sites (such as MK,TW1, TW2 of moderately disturbed sites and WR, RH1 and AG1 of Highly disturbed sites) were classified as non-reference groups (**Table 1)** according to Wondmagegn et al. (2019). All the physicochemical and the biological sampling was done on these categorized sites with three replications.

Sampling of environmental parameters

A combined portable HQ40D multimeter was used to measure i*n situ* physicochemical parameters such as temperature (T), pH, conductivity (EC) and dissolved oxygen (DO). The turbidity was measured with an OAKTON turbidimeter (T-100). NO_2^-, NO_3^-, NH_4^+, soluble reactive phosphate (SRP) and total phosphorus (TP) were analysed spectrophotometrically in the Limnological Laboratory of Addis Ababa University. Nitrate was analysed with sodium salicylate method (Robarge et al. 1983), ammonium with indo-phenol blue (APHA 1995), and soluble reactive phosphate (SRP) with ascorbic acid method (APHA 1999). Nitrite concentration was determined by the reaction between sulfanilamide and N-naphthyl-(1)- ethylenediamine dihydrochloride (APHA 1995). Total phosphorus (TP) and silica (SiO2) were determined using persulfate digestion method and molybdosilicate method (APHA 1999), respectively.

The Chlorophyll *a* concentration was estimated according to the method of Talling and D. (1963). From each site, 200–500 ml of the lake water was filtered through Whatman GF/F filters. The filters were folded with aluminium foil, labeled and transported to the laboratory in an icebox and stored for not longer than one day. Pigments were ground and extracted in 90% acetone. After grinding, the algal material was centrifuged. Then, the extract was decanted into 5 ml cuvette and the absorbance of Chlorophyll *a* was measured spectrophotometrically at wavelengths of 665 nm and 750 nm, respectively. The total suspended solids (TSS) samples were filtered using Whatman GF/F filters and analyzed following Wetzel and Likens (2000)

Sampling of benthic diatoms

Diatoms were scraped from cobbles and macrophytes in the littoral areas of Lake Hawassa at the maximum of 1 m depth. Sampling was conducted by taking cobbles (five stones with upper surface areas of cobble ~25 cm^2) and macrophytes (five random stems of macrophytes with 5 cm length) from the lake shore (King et al. 2005; Martin and Fernandez 2012). Small amounts of lake water (approximately 50 ml) were poured into a tray the biofilm from the upper surface of each cobble and the macrophyte was removed by scrubbing vigorously with a toothbrush. The toothbrush was rinsed regularly with lake water. Finally, the suspension was poured into a labeled 150 ml plastic bottle. Before pouring, the suspension was swirled in the tray so that any settled particles were re-suspended. Then, the diatom samples were preserved with 70% ethanol.

A 5-10 ml aliquot of each sample was taken from the bottle and homogenized by shaking. Diatom samples were treated with concentrated sulfuric acid and potassium dichromate (Patrick and Reimer 1966). Then, a drop of cleaned diatom samples were taken and dropped onto a microscopic slide and placed on hot plate. After it had dried, a permanent slide was prepared by adding Naphrax® (refractive index of 1.73) to the coverslip and placing the latter into the dried slide. Diatom frustules were examined with Carl Zeiss Axioskop light microscope at 1000 x magnification, with oil immersion objective, using bright-field illumination with a green filter to increase the contrast in the laboratory of Environmental Centre of Lancaster University, UK.

Identification of diatom species was made by standard identification keys, manuals and publications of Van Meel (1954); Gasse (1986); Krammer and Lange-Bertalot (1986 and 1988 and 1991b and 1991a); Kelly (2000); Taylor et al. (2007a); Taylor et al. (2007b); (Taylor and

Cocquyt 2016). For each slide, 500 valves were counted and relative abundance, as percentage, was calculated for each species.

Diatom indices/ metric calculation

OMNIDIA software version 6.1 was employed to calculate the diatom indices/metrics listed in **Table 2** (Lecointe et al. 1993). Four diatoms (i.e. RAT, RRT, PRAT and PRRT; **Table 2**) reference based metrics were included as candidate metrics and calculated using Microsoft excel. The development of the MMI-D index was based on three a *priori* clustered sites, namely, C1-minimally disturbed sites (KW1, KW2 and WSH), C2- moderately disturbed sites (MK, TW1 and TW2) and C3-highly disturbed sites (WR, RH1 and AG1).

Selection and removal of redundant metrics

A total of 24 diatom candidate metrics (17 of them were published in Wondmagegn et al. (2019); **Table 2**) representing various aspects of the diatom communities related to family richness, taxonomic composition, tolerance measures, biotic indices and others (Kelly and Whitton 1995; Rott et al. 1999; Lecointe et al. 2003) were compiled.

The listed candidate metrics/indices were used for the selection of the potential/core metric which were incorporated in the development of multimetric index of biotic integrity of Lake Hawassa (MMI-D). The procedure for selecting the potential metric was done according to Barbour et al. (1999), with some modification. The selection was done based on the metrics response to physicochemical parameters and with the relationship between themselves and their ability to characterize the reference and non-reference sites. Metrics which significantly correlated with physicochemical variables were selected for the next analysis. Redundancy analysis was employed to identify the pair of metrics with a significant correlation (i.e., correlation coefficient ≥ 0.7) (Ofenböck et al. 2004; Hering et al. 2006). From the redundant metrics, the one which strongly correlated with the physicochemical variables was considered for further analysis and the others were rejected.

Percent discriminatory efficiency (%DE) of each metric was calculated to identify the most suitable metrics having high % DE (usually greater than or equal to 50%) as was used in

Wondmagegn et al. (2019) and Wondmagegn and Mengistou (2023) . Besides this, for diatom indices selection, percent inclusion of the diatom species in index calculation was also considered as an important criterion in which <50% inclusion was excluded for further analysis (Wondmagegn et al. 2019). The distribution of each metrics between the reference and non-reference sites was visualized using Box and Whisker plots. The sensitivity of the metrics was examined based on their interquartile overlap degree according to the method outlined in Barbour et al. (1996).

Scoring of metrics

Using the discrete type of scoring system, calculated metric values were converted (normalized) to metric scores of 5, 3 or 1 depending on their proximity to the optimal values as used in Wondmagegn and Mengistou (2023). Metrics whose values decreased with the increase of disturbance (positive metric) 5, 3 and 1 scoring was used, and the reverse scoring for negative metrics. For instance, positive metrics values above 75th percentiles were scored as 5. Metric values between and including the 75th and 25th percentiles were scored as 3, and all metric values below the 25th percentile were scored as 1 (Barbour et al. 1996; Wang et al. 2005).

Development of multimetric index of biotic integrity for Lake Hawassa (MMI-D)

The scored values of each potential metric value were combined into a multimetric diatom index (MMI-D) by summing up the score of each individual metric. The possible maximum and minimum MMI-D index values were calculated (maximum value= total number of selected metric multiplied by 5, and minimum value= total number of selected metric multiplied by 1) and divided into quartile rages to have four quality classes. Thus, the highest score classified as very good quality and the lowest score as poor quality. Box and Whisker plots were also used to visualize MMI-D index's distribution between the reference and non-reference sites and to test its potential to discriminate the minimally disturbed sites from the moderately and highly disturbed sites of Lake Hawassa.

Ecological quality ratio (EQR)

The ecological quality ratio (EQR) of each sampling station was used for the purpose of classification of ecological status (Wondmagegn and Mengistou 2023). EQR was calculated by dividing MMI-D values of each site with the median MMI-D values of reference sites. The ratio is expressed as a numerical value usually between zero and one. Then the 90th percentile of the reference site of the EQR values was used to classify into five ecological classes. Generally, as the value of EQR becomes close to one, it is considered as high ecological status and as its values approaches to zero, it is considered as bad ecological status (EQR 2007; Delgado et al. 2010).

Validation of the MMI-D

The validation of MMI-D index was conducted using independent data sets which were not incorporated in the MMI-D index development of L. Hawassa. One of the independent data set was taken from the reference and non-reference sites of Lake Hawassa. In addition, it was also validated using the independent data set from L. Ziway with box and whisker plot of Sigma Software version 10.0. The independent data set of Lake Ziway was taken form unpublished data of Abnet Woldesenbet. Two-stage Least Squares (TSLS) regression analysis was also employed to test the relationship between the MMI-D index and percent disturbance score (PDS) in the SPSS package version 20. Principal component analysis (PCA) was also used to visualize the capability of MMI-D index's distribution between the reference and non-reference sites of Lake Hawassa.

Data analysis

OMNIDIA software version 6.1 was employed to calculate the diatom indices/metric. Spearman rank correlation was used to check relationships of candidate metrics with themselves and with environmental parameters, in order to select the core metrics. Two-stage least squares (TSLS) regression analysis was also employed to test relationship between the MMI-D index and percent disturbance score (PDS). The above analyses were done with Statistical Package for Social Science Students (SPSS Inc., software version 20.0). Box and Whisker plot and Principal components analysis (PCA) were employed to show the discriminatory potential of the multimetric index (MMI-D) among the reference and test sites of Lake Hawassa using Sigma-plot version 15.0 and PAST 3.15 software programmes, respectively. The validation of the potential of MMI-D index with independent data set of L. Ziway was checked with Box and Whisker figures using Sigma-plot version 10.0.

Result

Metric Selection

Metric selection was done based on percent inclusion of the diatom species in index calculation (the more species are included in index calculation; the more efficient index is to explain the ecology). In addition, their discrimination efficiency, correlation, and response to environmental parameter were checked **(Table 2&3)**. Therefore, IDAP, P.SI, WAT, DES, LOBO, PDI, and P.TI indices were excluded from selection due to <50% inclusion of the diatom species in the index calculation using OMNIDIA software. These indices did not also exhibit a significant correlation with ecologically important physicochemical variables such as TP, SRP and Nitrate (**Table 3**). IBD, IPS, and CEE were not also included in metrics selection because of having a high correlation with SHE, IDG and TDI.

Thus, indices those which had greater than 50% discrimination efficiencies, ≥ 50% species inclusion, lack redundancy and showed a significant correlation with most of physicochemical variables (EPID, SHE, SLA, IDG, TDI, ROTT, TDIL and LDTI2) were included in metrics selection (**Table 3)**. From the four reference taxa-based metrics, RATD and PRATD were selected due to their high discriminatory efficiency for the multimetric index (MMI-D) development **(Table 2& 3)**. These metrics did not exhibit a complete overlap on their interquartile and had potential to characterize the reference sites and non-reference sites as illustrated on **Fig. 2**.

Developments of multi-metric index of L. Hawassa (MMI-D)

From the list of 24 diatom candidate metrics, 10 diatom metrics were selected, based on their response to the different level of disturbances, discriminatory power between the reference and test sites, and correlation with physicochemical parameters. The selected metrics were used for the development of multimetric index of biotic integrity of L. Hawassa (MMI-D; **Table 4**). The MMI-D used a 5, 3 or 1 discrete type scoring system to normalize the metric value for positive metric using 75th and 25th percentiles of the metric values and the reverse for negative metrics. For positive metrics, metric values above 75th percentiles were scored as 5. Metric values between and including the 25th and 75th percentiles were scored as 3, and all metric values below the 25th percentile were scored as 1(**Table 5**). The sum of the total score of each site was considered as the MMI-D values. The maximum and minimum possible ranges of the MMI-D values were 50 and

10, respectively. These MMI-D values were divided into quartile ranges. So, the MMI-D range values 41-50, 31-40, 21-30, and 10-20 were classified as very good, good, fair and poor quality, respectively.

Therefore, the current study showed that the multimetric index (MMI-D) had a potential to discriminate clearly the reference site and the non-reference and between the three-disturbance level (minimal, moderate and high disturbance level) of the clustered sampling stations of the lake (**Fig. 3**). It put the minimally disturbed sites (C1) into very good to good categories (KW1, KW2, and WSH), moderately disturbed sites (C2) into fair (MK, TW1 and TW2) and highly disturbed sites (C3) into poor categories **(Table 6)**.

The discrimination capacity of the MMI-D index between reference and non-reference sites was tested by Box and Whisker plots within the comparison of the previously classification of sampling stations of L. Hawassa**.** Thus, the MMI-D clearly discriminated the reference sites from the non-reference (test) sites **(Fig. 3a)**. It also showed a demarcation potential between the three clusters such as C1 (minimally disturbed), C2 (moderately disturbed) and C3 (highly disturbed sites) of the lake **(Fig. 3b)**.

Ecological quality ratio (EQR)

The ecological quality ratio (EQR) was calculated and its range was between one and zero, but there were values greater than one which were considered as one. The 90th percentile of the reference site of the EQR values was 1. The sampling sites ecological status was classified based on the EQR values with its range (**Table 7).**

The Ecological Quality Ratio potentially discriminated the reference and non-reference sites. It characterized the minimally disturbed (C1) sites into high and good quality or reference condition (KW1, KW2, and WSH), moderately disturbed sites into moderate quality and highly disturbed sites into poor quality sites (**Table 8**). The Box and Whisker plots also showed that the EQR had the efficiency to discriminate between reference and non-reference sites and the three clustered sites (C1, C2 and C3; **Fig. 4**).

Validation of the multi-metric index

The efficiency of the MMI-D index to discriminate between reference and non-reference sites, and between *a priori* classification of the sampling station (i.e. minimal, moderate and high disturbance levels) were tested by Box and Whisker plots in previous section. Furthermore, to confirm the suitability and robustness of this newly developed index (MMI-D index) it requires validation. The validation of the MMI-D index was performed using independent data sets where the MMI-D index was not based. Thus, the performance of the MMI-D index was tested in the new data sets of Lake Hawassa and Lake Ziway. Three sites were taken from Lake Hawassa and subjected to validation using the MMI-D index. Thus, the MMI-D classified one site as very good (MMI-D value= 34), and the other two sites as fair (MMI-D value= 28 and 28) which coincided with prior classification of these sites.

The developed MMI-D also discriminated L. Ziway's reference and test sites as shown in **Fig. 5**. It showed good potential of characterizing the L. Ziway clustered sites. For example, all the three reference sites (C1) were classified as very good quality; from three moderately disturbed sites (C2) all of the sites were characterized as fair. The three highly disturbed sites (C3) of the lake were also classified as fair to poor category. The principal component analysis (PCA) also clearly explained 96.85% of the variation between the reference site and non-reference/test site of Lake Hawassa with both the first and the second axis (**Fig. 6**). This confirms the potential of the MMI-D index to discriminate between reference and non-reference sites of Lake Hawassa.

The two-stage least squares (TSLS) regression analysis of MMI-D showed an inverse but strong relationship with percent disturbance score (PDS) which demonstrates the MMI-D index responsiveness to the habitat quality degradation of Lake Hawassa (n=9, R^2=0.921, P=0.000; **Fig. 7**). The MMI-D index also showed significant positive response to DO, and negative but significant correlation with temperature, nutrients, TSS and turbidity and had high percent discriminatory efficiency (%DE= 95.1; **Table 9**).

Discussion

Lake Hawassa has been affected by multi-type stressors which come from different sources (more often from non-point sources), the need of multimetric index development is a mandatory practice to quantify the ecological status of the sampling stations that have suffered from human induced level of disturbances. The multimetric index of biotic integrity of L. Hawassa (MMI-D) was developed in order to harvest these benefits.

The multimetric index of biotic integrity of L. Hawassa (MMI-D) showed a clear demarcation between the reference and non-reference/ test sites (**Table 6; Fig. 3**). It also placed the minimally disturbed sites (C1) as very good to good categories (KW1, KW2 and WSH), moderately disturbed (MK, TW1 and TW2) sites into fair and highly disturbed (WR, RH1 and AG1) sites into poor quality (**Table 6**). Hence, the MMI-D index showed a robust result able to discriminate the three clusters of the sampling stations of the lake as previously classified. Besides, the ecological quality ratio (EQR) explained the status of the sampling sites in-terms of their ecological condition (**Table 8**) as it is believed that EQR is an ecological expression of the MMI-D index (Lepistö et al. 2004; Wells et al. 2007; Gabriels et al. 2010).

Generally, the MMI-D index and the EQR showed robust results that clearly discriminate sampling stations into their ecological quality level as very good, fair and poor quality. Hence, conservation of very good quality sites and rehabilitation of the fair and poor-quality sites are important recommendations that can be drawn from the current result.

The suitability and robustness of a newly developed multimetric index (MMI-D) requires validation which is an effective method for evaluating the lake condition to recommend future use of the MMI-D, effective restoration and conservation methods and research gaps (Jun et al. 2012). Validation of MMI-D using independent data sets is an appreciable method that indicates how well the multimetric index would be expected to work with sampling sites and gives good insight to scale up and use for other lakes in the ecoregion (Lunde and Resh 2012; Villamarín et al. 2013). The potential use of MMI-D was confirmed by the discrimination efficiency of the independent data set taken from Lake Hawassa and L. Ziway, which coincided with prior classification of these sites. Thus, the validation of the MMI-D index showed its potential to be used in the biomonitoring of the initial lake and lakes which are situated in the same ecoregion of Lake Hawassa, namely Northern Eastern Rift (Thieme et al. 2005).

Furthermore, the MMI-D was further validated using physicochemical parameters, PCA, and its relationship with disturbance score (PDS) that showed the responsiveness of the MMI-D with different levels of degradation which were already observed on the reference and non-reference sites. Thus, the significant inverse relationship between MMI-D and PDS represents a strong responsiveness of the MMI-D index to the lake habitat quality levels (PDS: $n=9$, $R^2=0.921$, $P<0.01$, **Fig. 7**). Similar phenomenon was observed on the study of multimetric index of Lake Kariba of Africa (Phiri et al. 2007), lakes of USA (Stevenson et al. 2013) and Lake Dongting (Wang et al. 2015). Since the MMI-D index is considered as a positive metric, its value decreased against the habitat disturbance (**Fig. 7**) as was observed on wetlands of California (Lunde and Resh 2012). This wetland report showed that a higher multimetric index scores was considered as signal of a less disturbed environment, while lower multimetric index scores indicated highly disturbed habitat. MMI-D index showed a better potential than that of the single metrics of diatoms tested in Wondmagegn et al. (2019). Similar potential was also observed on the multimetric developments of Alaska’s biomonitoring practice with high precision and high discrimination efficiency (Bouchard et al. 2004).

In addition, the MMI-D index also showed significant positive response to DO, and negative but significant correlation with temperature, nutrients, TSS and turbidity (**Table 9**). Similar response of the MMI index to nutrient concentration was observed in lakes of USA (Stevenson et al. 2013), Lithuanian lakes (Šidagytė et al. 2013) and lakes in Flanders, Belgium (Gabriels et al. 2010). The negative response of the MMI-D index to nutrients, TSS and turbidity corresponds with what can be expected for stress-related variables (Gabriels et al. 2010). This indicates that the MMI-D index was suitable for ecological quality assessment of Lake Hawassa.

The overall finding of the current research indicated that such multimetric approach has significant advantage when the water body is exposed to multiple stressor types not usually counted (Everard et al. 2011). The index can also reduce the independent metric prediction problem and maximize the efficiency to express the not-visualized and unmeasured disturbance of segments of the lake ecosystem. As noted by Schoolmaster et al. (2012), when there is a problem of understanding the exact cause of degradation of water quality, the multimetric approach is most effective. The discrimination power of the MMI-D index between different levels of human disturbance showed the effectiveness of multimetric approach.

In addition, the benefit of such MMI-D development to specific lake would also increase the performance of the multimetric index by reducing natural variability (like in geology, soils, landscapes, climate, and water chemistry) among sites since it is difficult to distinguish the effect of natural variability form human induced variability if it is applied across large spatial scale (Stevenson et al. 2013). Furthermore, the MMI-D index clearly discriminated the reference and non-reference sites of Lake Hawassa and showed similar performance on Lake Ziway (within the same ecoregion); thus, it can be recommended for application to biomonitoring activity in other lakes of the same ecoregion.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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