Research Article

The environmental quality and macroinvertebrate community structures of wetlands found in the Lake Tana Watershed, Ethiopia

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ABSTRACT

The present study was conducted to assess the environmental quality status and macroinvertebrate community structures of wetlands using macroinvertebrates as bioindicators. A multimetric biotic index approach was used for the study. The findings revealed 3,367 macroinvertebrates belonging to 37 families. The percentages of Ephemeroptera, Odonata, and Tricoptera (%EOT), percent Diptera, percent filterer-collectors, the ratio of Ephemeroptera, Plecoptera, and Trichoptera to Chironomid (EPT/C), the Biological Monitoring Working Party Score, and the Shannon–Wiener diversity index were all significantly related to human disturbance and could be used to assess water quality. Based on the macroinvertebrate index, human disturbance had a significant impact on Shesher wetland, a relatively lower impact on Avaji and Yitamot, and a moderate impact on Chimba, while Dena and Wonjeta had good habitat quality. Their water quality was very poor, poor, moderate, and very good, in that order. Farming, leather tanning, waste dumping, and effluent discharges were responsible for the poor habitat quality of impacted wetlands. Therefore, unless managed properly, human disturbance activities in the wetlands catchment were threatening macroinvertebrates and the wetlands ecosystem. Hence, implementation of catchment-based management together with continuous health status monitoring and a standalone wetland policy should be established.

Keywords: Human disturbance; Macroinvertebrate index; Water quality; Wetland

Résumé

La présente étude a été menée pour évaluer l'état de la qualité de l'environnement et les structures des communautés de macroinvertébrés des zones humides en utilisant les macroinvertébrés comme bioindicateurs. Une approche d'indice biotique multimétrique a été utilisée pour l'étude. Les résultats ont révélé 3 367 macroinvertébrés appartenant à 37 familles. Les pourcentages d'Éphéméroptères, d'Odonates et de Tricoptères (%EOT), le pourcentage de Diptères, le pourcentage de filtreurs-collecteurs, le rapport d'Éphéméroptères, de Plécoptères et de Trichoptères aux Chironomidés (EPT/C), le score du Groupe de travail sur la surveillance biologique et le Shannon– Les indices de diversité de Wiener étaient tous significativement liés aux perturbations humaines et pourraient être utilisés pour évaluer la qualité de l'eau. Sur la base de l'indice des macroinvertébrés, les perturbations humaines ont eu un impact significatif sur la zone humide de Shesher, un impact relativement plus faible sur Avaji et Yitamot et un impact modéré sur Chimba, tandis que Dena et Wonjeta avaient une bonne qualité d'habitat. La qualité de leur eau était très mauvaise, mauvaise, moyenne et très bonne, dans cet ordre. L'agriculture, le tannage du cuir, le déversement de déchets et les rejets d'effluents étaient responsables de la mauvaise qualité de l'habitat des zones humides touchées. Par conséquent, à moins d'être gérées correctement, les activités de perturbation humaine dans le bassin versant des zones humides menaçaient les macroinvertébrés et l'écosystème des zones humides. Par conséquent, la mise en œuvre d'une gestion basée sur les bassins versants ainsi qu'un suivi continu de l'état de santé et une politique autonome des zones humides devraient être établies.

1. INTRODUCTION

Aquatic ecosystems are an integral part of human existence on earth, and their importance is highlighted by the provision of several ecosystem services that underpin the livelihoods of billions of people (Aylward *et al.,* 2005). But despite their importance, they are one of the most altered ecosystems on earth (Carpenter *et al.,* 2011); they are increasingly threatened by anthropogenic activities (Mayers *et al.,* 2009). Depending on the region, 30–90% of the world's wetlands have been destroyed or strongly modified (Junk *et al.,* 2013). More than 50% of the original global wetland loss was primarily attributed to human activities (Van Dam *et al.,* 2014), and specifically in Ethiopia, 65% of wetland disturbances came from human origins (Dugan, 1990).

Anthropogenic activities related to agriculture and urbanization, like deposition of domestic and industrial effluents, increased nutrients due to misuse of pesticides and fertilizers, and silt load from the catchment, were some of the principal causes that changed water quality (Romshoo and Rashid, 2012). Changes in the physicochemical properties of water create variation in the abundance, distribution, and species composition of a given biotope (Ebenebe *et al.,* 2016).

Macroinvertebrates are among the most frequently applied groups in freshwater monitoring and assessment and have proven to be useful indicators in determining the health status of wetlands since differences in environmental requirements among taxa produce community characteristics that reflect ecological conditions (Gabriels *et al.,* 2010). Furthermore, macroinvertebrates are abundant inhabitants of wetlands that occupy all trophic levels (Culler *et al.,* 2014a); their patterns of community composition can reflect characteristics of the soil (Armitage and Fong, 2004), vegetation (Verberk *et al.,* 2010), and hydrology (Culler *et al.,* 2014b).

Additionally, macroinvertebrate taxa vary in habitat requirements and sensitivity to stressors, resulting in different assemblages based on the wetland condition (Batzer, 2013). Moreover, the assessment is less expensive and is used in studies conducted in a short period of time (Davies *et al.,* 2006).

The use of macroinvertebrates as bioindicators for freshwater quality has a lengthy history (De Pauw *et al.,* 2006). However, using a single index for water quality assessment encountered several constraints (Gabriels *et al.,* 2010). As such, a single index is frequently unable to reflect the general picture of aquatic ecosystems under a myriad of anthropogenic pressures. Therefore, a more integrated approach like the development of a multimetric index has received increased attention in recent years for its ability to include complementary information from a broad range of stressors (Vlek *et al.,* 2004).

Among Ethiopian freshwaters, Lake Tana is one of the largest lakes (Wondie and Mengistou, 2006). The lake is surrounded by large areas of wetlands and seasonally flooded plains that provide multiple services (Bijan and Shimelis, 2011). But despite the services, research indicates that due to erosion, sedimentation, pollution and pressure from an increasing population in the catchment, the sustainability of ecosystem services has been endangered (Goshu *et al.,* 2010). Untreated effluents were also released into the wetlands, leading to a reduction in water quality and biodiversity (Atnafu *et al.,* 2011). Consequently, a considerable number of wetlands are considered vulnerable, and some of the most exploited ones have lost their rejuvenating capacity (Tadesse, 2006).

Thus, to mitigate anthropogenic impacts or magnify the issue of wetlands, recent information was important, because understanding the health

status of wetlands is important for their sustainable management (Russi *et al.,* 2013). Therefore, this study was conducted to provide a recent report on the environmental quality status and macroinvertebrates community structures of wetlands in the Lake Tana Watershed.

2. MATERIALS AND METHODS
2.1. Description of the study area
Lake Tana is one of the largest lakes in Ethiopia, located in the northern part of the Ethiopian Highlands (Goshu and Aynalem, 2017), at an elevation of 1,840 meters with a latitude of 10°58`–12°47`N and a longitude of 36°45`–38°14`E (Admas *et al.,* 2017). The lake is surrounded by lagoons, wetlands and forty tributaries (Shimeles *et al.,* 2008). In the watershed, wetlands are distributed from the headwaters of Guna and Gishe-Abay to Fogera and Dembia, mainly around lake shores and along tributaries (Shimeles *et al.,* 2008). The total wetland area in the watershed was estimated to be 32,157 ha (Yitaferu, 2007). Wetlands included in the study were Shesher, Avaji, Yitamot, Dena, Wonjeta and Chimba (Fig. 1). They were selected based on their accessibility (U.S. EPA, 2002).
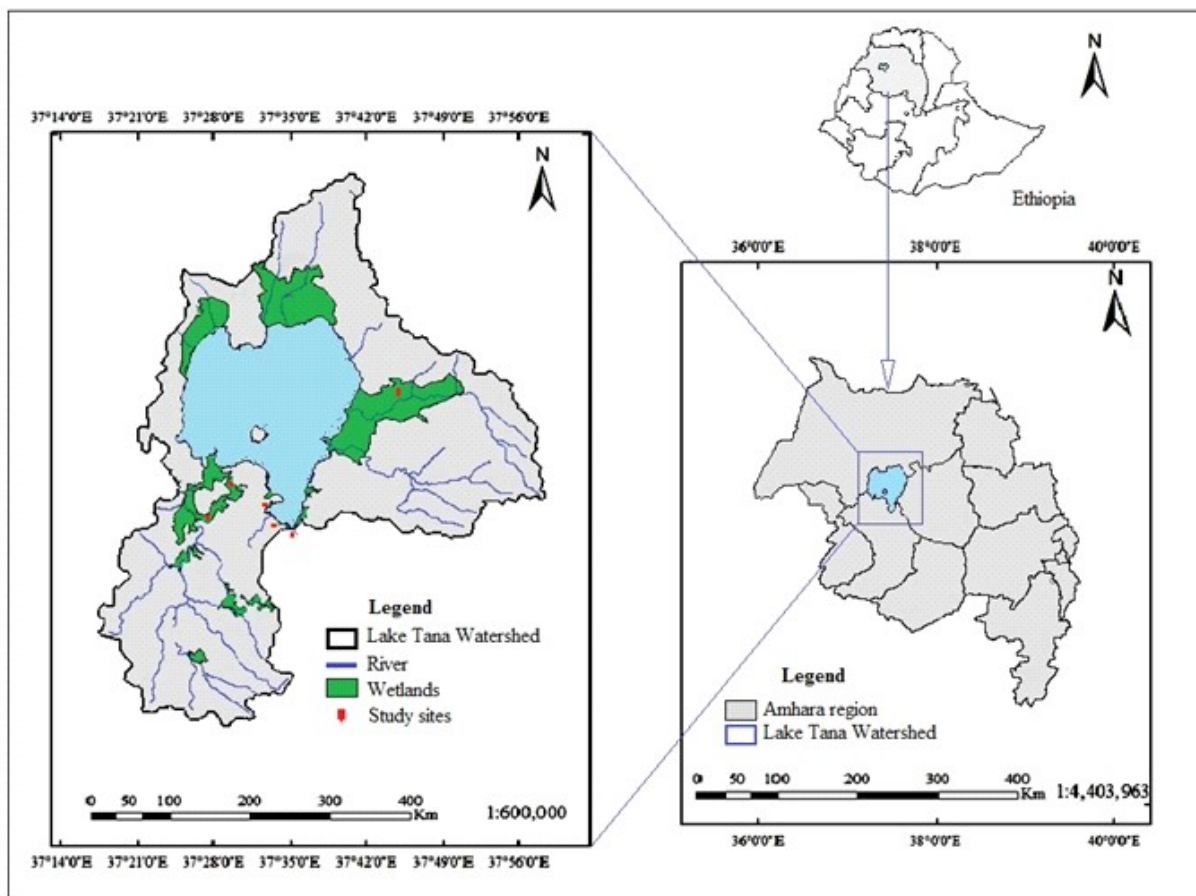

Fig. 1 Map showing location of study wetlands in the Lake Tana watershed

2.2. Methods of data collection

Measurements of water quality parameters and macroinvertebrates data were collected in October, November, February, and March; at each station, two replicates of the data were collected.

2.2.1. Macroinvertebrate sampling and enumeration

For the macroinvertebrate collection, a D-frame dip net (500 μm mesh) was employed. Sweeps were made at each location, covering different microhabitats (including emergent vegetation and open-water areas) to incorporate habitat heterogeneity. After collection, macroinvertebrates were sorted in the field and preserved in labeled vials containing 80% ethanol and taken to the laboratory for identification. Identification was made using a stereomicroscope and a standard key of Bouchard (2012).

2.2.2. Measurement of physicochemical parameters

Wetlands were also sampled for water chemistry at locations where macroinvertebrate samples were collected. A number of *in situ* physicochemical measures were taken at each wetland, in which electrical conductivity (EC), total dissolved solids (TDS), and temperature were measured on sites using a portable digital multimeter (ECscan 30). Likewise, pH was measured on sites using a pH meter (pHep-pocket sized). For the measurement of total nitrogen (TN), nitrate (NO_3), phosphate (PO_4), total phosphorus (TP), and total suspended solids (TSS), water samples collected from representative locations were pooled and collected in acid washed bottles for analysis in the laboratory. Samples were analyzed following the standard methods of the American Public Health Association (1999).

2.2.3. Methods of selecting reference and impaired wetlands

To develop a macroinvertebrate index, it is necessary to analyze data obtained from the least disturbed (reference) wetlands to the most degraded (impaired) wetlands. The selected wetlands were then designated as reference and impaired following the human disturbance score (HDS) protocol of Gernes and Helgen (2002).

2.2.4. Determination of urban agricultural and reference wetlands

To determine the relative impact of urbanization and farming activity on macroinvertebrates' community structure and wetlands' ecological status, wetlands were grouped as less disturbed (reference), agricultural and urban influenced. Classification was carried out by considering human-induced pressures on wetlands (Silva *et al.,* 2017). Accordingly, those wetlands that were dominated by cultivation and grazing as a common activity were considered agriculturally impaired, whereas those wetlands that received storm and domestic wastewater from surrounding communities were considered urbanly impacted. Likewise, papyrus-dominated wetlands were regarded as references.

2.2.5. Macroinvertebrate metric selection and scoring

Candidate metrics were selected based on their relatedness to physicochemical indicators of water and habitat quality in past studies (Genet and Bourdaghs, 2006). Next, candidate metrics were tested for their stability, sensitivity, responsiveness to anthropogenic impact and redundancy (Couceiro *et al.,* 2012). Accordingly, in the first place, metrics were checked with the Shapiro-Wilk test for normality of data distribution (Ferreira *et al.,* 2011). This was followed by a sensitivity test, which was performed using the inter-quartile

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overlap of box and whisker plots (Baptista *et al.,* 2007).

A metric with a p-value < 0.05 in the stability test and with a discrimination efficiency higher than 50% in a box and whisker plot sensitivity test was selected for the subsequent step (Stribling *et al.,* 2000) and considered to be a strong discriminator between reference and impaired conditions (Baptista *et al.,* 2007). Those metrics that had extensive interquartile range overlap between the reference and impacted sites were rejected (Akalu, 2006).

Candidate metrics that satisfied Mann-Whitney and sensitivity tests were further examined for correlations. A correlation analysis was applied for the identification of redundancy among metrics. Metrics were considered redundant if the correlation coefficient was higher than 0.85 (Hering *et al.,* 2006). From the metrics considered redundant, the one with the highest correlation coefficient with environmental variables and the highest sensitivity score was selected. Then, prior to metrics integration, selected metrics were assigned a score from zero to 10. The scores were calculated using the upper and lower thresholds of their distribution in the reference and impaired wetlands following the protocol of Blocksom (2003) (equation 1).

$$Metric\ score = \frac{(observed - lower\ threshhold^a) \times 10}{upper^b - lower\ threshhold^a} \dots \dots Eq.\ 1)$$

Where, [a]Lower thresh hold = metrics that decrease (increase) with perturbation is 25th (75th) percentile of the impaired wetlands. [b]Upper = threshold for metrics that decrease (increase) with perturbation is 75th (25th) percentile of the reference wetlands.

Metrics with a value above the upper threshold for those decreasing with increased perturbation received a score of 10, whereas those below the lower threshold received a score of zero. For those metrics increasing with increased perturbation, values above the lower threshold (75th percentile of the impacted wetlands) received a score of zero, whereas those with metrics values below the upper threshold (25th percentile of the reference wetlands) received a score of 10. Then, after the values were linearly scaled along the range between zero and 10, they were summed up and the results were converted to a zero to 100 point scale for the narrative rating (Pond *et al.,* 2003). Finally, the final value was split into five quality classes: excellent, good, moderate, poor and bad conditions, following the indications of the Water Framework Directive (2003). The threshold between classes for each index was defined following a similar methodology of Barbour *et al.* (1999), Alba-Tercedor *et al.* (2002) and Munne and Prat (2009). First, the class boundary between excellent and good conditions was defined by taking the 25th percentile of the reference wetland value. Then, 61%, 36%, and 15% of the 25th percentile of the index value of reference wetlands were taken to determine the class boundaries between moderate and good, moderate and poor, and poor and bad, respectively.

2.2.6. Metric index performance evaluation
The applicability of the index for assessing ecological quality was examined based on its performance in categorizing the sampling wetlands into the correct ecological quality status. For this, the reference and impaired wetlands were further examined using box and whisker plots and confirmed by U-test.

2.3. Methods of data analysis
The Shapiro-Wilk test was used to ensure that the data distribution was normal (p > 0.05). The non-parametric Mann–Whitney U test was used to compare the indices of impaired and reference wetlands. To investigate the relationship between

macroinvertebrate metrics and environmental variables, Spearman's correlation was used. The relationship between macroinvertebrate indexes and HDS was studied using linear regression analysis. To assess the response of metrics to physicochemical factors or human disturbance scores, the Kruskal-Walis and HD Tukey tests were used. All statistical analyses were performed using the PAST and Excel software statistical packages.

3. RESULTS

3.1. Patterns of abundance richness and diversity of benthic macroinvertebrates

The macroinvertebrate assemblage included 3,367 individuals that were divided into aquatic insects, mollusks, annelids, and arachnids. Of the total macroinvertebrates, insects comprised 93.2%, followed by mollusks. The proportion of annelids and arachnids was very low. The collected macroinvertebrates represented four classes, 10 orders, and 38 families. Insects remained the dominant group that contained 31 out of the 38 identified taxa. Relatively, the proportion of Hemiptera (27.89%) was highest, followed by Diptera (22.46%), whereas Plecoptera was the least abundant (0.15%) (Table 1).

In terms of diversity, the Hemiptera contained the most diverse order, with 8 families, followed by Diptera with 7 families, Coleoptera with 6 families, Odonata with 4 families,

Ephemeroptera with 3 families, Trichoptera with 2 families and Pelicoptera with one family. Libellulidae remained the most abundant family (354 individuals), followed by Chironomidae (349 individuals), Culicidae (254 individuals), Corixidae (230 individuals), Coenagrionidae (227 individuals), Belostomatidae (218 individuals) and Gyrinidae (196 individuals). Among non-insect taxa, a higher number of families was recorded in gastropod mollusks (Table 1).

3.2. Spatial variation of macroinvertebrates community

Spatially, the total number of individuals present at each wetland ranged from 816 (Chimba) to 469 (Shesher). Of the total orders, Diptera, Coleoptera, Odonata and Hempitera were dominant and found in almost all wetlands. In Dena wetland, the order Coleoptera was the most abundant taxon that contained 4.48% of the total abundance value, followed by Hemiptera (4.1%) and Ephemeroptera (2.1%). In Wonjeta, Coleoptera was the most abundant order (5.85%), followed by Hemiptera (3.83%) and Odonata (2.55%). In the same way, Chimba was dominated by Diptera (6.89%), whereas Yitamot, Avaji, and Shesher were dominated by Hemiptera. In all wetlands, macroinvertebrate relative abundance increased as sampling moved towards Chimba, where macroinvertebrate abundance was highest (24.23%), which was followed by Wonjeta (16.57%) and Avaji (16.22%) and it was lowest in Shesher (13.93%) (Table 2).

Table 1 Macroinvertebrate assemblage in wetlands of the Lake Tana Watershed

Taxa list	No. of Families	No. of Individuals	%
Insecta	31	3138	93.19
Arachnida	2	21	0.65
Gastropoda	4	180	5.34
Hirrudinea	1	28	0.83
Total	38	3367	100

Table 2 The spatial variation of macroinvertebrates in the six wetlands

Taxa list	Shesher		Yitamot		Dena		Avaji		Wonjeta		Chimba		Rel. abund.
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	%
Ephemerop.	3	0.08	5	0.14	72	2.13	0	0	69	2.04	30	0.89	5.31
Odonata	76	2.25	89	2.64	58	1.72	130	3.86	86	2.55	183	5.43	18.47
Hemiptera	171	5.07	141	4.18	139	4.12	167	4.95	129	3.83	192	5.70	27.89
Trichoptera	0	0	0	0	11	0.32	0	0	6	0.17	0	0	0.51
Coleoptera	40	1.18	92	2.73	151	4.48	69	2.04	197	5.85	71	2.10	18.41
Diptera	128	3.80	130	3.86	52	1.54	159	4.72	55	1.63	232	6.89	22.46
Plecoptera	0	0	3	0.08	0	0	2	0.05	0	0	0	0	0.15
Arachnida	6	0.17	2	0.05	2	0.05	5	0.14	3	0.08	3	0.08	0.62
Gastropoda	33	0.98	19	0.56	11	0.32	11	0.32	10	0.29	96	2.85	5.35
Hirudinea	12	0.35	0	0	1	0.02	3	0.08	3	0.08	9	0.26	0.83
Total	469		481		497		546		558		816		
Rel. abund.		13.9		14.28		14.76		16.21		16.57		24.2	100

Rel. abund. = relative abundance

Based on human-induced pressures on wetlands, the study wetlands were grouped into two less disturbed (reference) (Dena and Wonjeta), two agricultural (Chimba and Shesher), and two urban-influenced (Avaji and Yitamot) wetlands. From the agriculture-impaired wetlands, Hemiptera (28.25%) and Diptera (28.01%) were the dominant taxa, followed by Odonata (20.15%) and Gastropoda (10.04%). In urban-influenced wetlands, Hemiptera and Diptera were the dominant taxa, which accounted for 29.99% and 28.14% of total macroinvertebrate abundance, respectively, and similarly, in reference wetlands, Coleoptera was the dominant group (32.99%) (Table 3).

From the total families, Chironomidae (95.41%), Libellulidae (88.41%), Coenagrionidae (64.76%), Corixidae (86.52%) and Culicidae (94.09%) were the most dominant pollution-tolerant taxa and largely found in urban and agriculturally influenced wetlands. Contrarily, Ephemeroptera, Plecoptera and Tricoptera orders were pollution-sensitive taxa and were commonly found in reference wetlands compared to other wetland types. On the other hand, Hirudinea and Gastropoda were found in all wetlands (Table 3).

Table 3 The relative abundance of macroinvertebrates in different impacted wetlands

Taxa list	Agricultural		Urban		Reference	
	No.	%	No.	%	No.	%
Ephemeroptera	33	2.57	5	0.48	141	14.36
Hemiptera	363	28.25	308	29.99	268	25.4
Trichoptera	0	0.0	0	0	17	1.61
Coleoptera	111	8.64	161	15.77	348	32.99
Diptera	360	28.01	289	28.14	107	10.14
Plecoptera	0	0.0	5	0.48	0	0
Araneae	9	0.70	7	0.68	5	0.47
Gastropoda	129	10.04	30	2.92	21	1.99
Hirudinea	21	1.63	3	0.29	4	0.37
Odonata	259	20.15	219	21.32	144	13.65
Total	1,285	38.16	1,027	30.50	1,055	31.33

3.3. Selection of reference and impaired wetlands

For the selection of reference and impaired wetlands, the HDS protocol of Gernes and Helgen (2002) was employed because it considered the physicochemical, biological, and hydrological variables (Factors one to six) to classify wetlands as reference or impaired. Accordingly, except for Dena and Wonjeta, the rest of the wetlands fall into the impaired category. Hence, Dena and Wonjeta wetlands were selected as references, whereas the remaining wetlands together were considered impaired (Table 4).

Table 4 The human disturbance score results obtained in the six wetlands

Wetland	Contributing factors						HDS	Status	Deci
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6			
Chimba	12	18	18	14	14	0	76	HI	imp
Shesher	18	18	18	21	14	0	89	HI	imp
Avaji	12	18	18	14	21	1	84	HI	imp
Yitamot	6	12	12	14	14	0	58	MI	imp
Dena	0	6	0	14	0	0	20	LI	ref
Wonjeta	0	6	0	14	6	0	26	LI	ref

LI stands for less impacted, MI=moderately-impacted, HI=highly impacted, HDS=human disturbance score, imp=impaired, ref=reference, Dec=decision

3.4. Benthic macroinvertebrate metric selection and testing

Twenty-eight potential metrics were nominated to represent four components of ecosystem quality, including tolerance, diversity, abundance and composition of macroinvertebrate assemblages (Lock *et al.,* 2011). Functional feeding groups were additionally included (Table 5).

Based on the Mann-Whitney U-test, out of the 28-candidate metrics, 18 possess significant power to separate reference from impaired wetlands (p < 0.05). The metrics were then subjected to the following test of metrics sensitivity: Accordingly, nine metrics were discarded because their 25th and 75th percentile ranges were not large enough to be used for metrics combinations (Klemm *et al.,* 2003) (Table 5). Moreover, based on redundancy

analysis, the Hilsenhoof biotic index, % Chironomidae, % EPT, % Ephemeroptera, % dominance, Margalef's diversity index, family richness, Simpsons diversity index, number of EPT, and the number of Trichoptera were redundant with a number of indices and rejected from the candidate. However, 15 metrics were retained.

Table 5 Candidate metrics for the development of a benthic macroinvertebrate index with their respective tests of stability and sensitivity

Metric category	Response to impairment	Mann-Whitney U-test (p-value)	Sensitivity (%)	Meets test criteria
Tolerance				
BMWP	Decrease	0.008*	74.19*	**
ASPT	Decrease	0.06*	43.47	−
Hilsenhof	Increase	0.008*	97.54*	**
Diversity				
Margalef	Decrease	0.008*	86.29*	**
Dominance_D	Decrease	0.01*	75*	**
Shannon_H index	Decrease	0.008*	86.11*	**
Evenness_e^H/S	Decrease	0.10	40	−
Simpson_1-D	Decrease	0.01*	75*	**
Abundance				
Family richness	Decrease	0.008*	71.42*	**
Family abundance	Increase	0.67	14.51	−
# Ephemeroptera	Decrease	0.79	5.88	−
# Plecoptera	Decrease	0.46	0.00	−
# Trichoptera	Decrease	0.001*	60*	**
# Odonata	Decrease	0.17	25.92	−
# EPT	Decrease	0.008*	88.88*	**
EPT/Chironomidae	Decrease	0.008*	80.85*	**
EOT/Chironomidae	Decrease	0.93	66.00*	−
Composition				
% Ephemeroptera	Decrease	0.008*	82.19*	**
% Plecoptera	Decrease	0.76	0.00	−
% Trichoptera	Decrease	0.008*	53.03*	**
% EPT taxa	Decrease	0.008*	91.39*	**
% Odonata	Decrease	0.05	66.80*	−
% EOT	Decrease	0.008*	69.81*	**
% Chironomidae	Increase	0.008*	93.27*	**
% Non-insect taxa	Increase	0.10	37.58655	−
% Diptera	Increase	0.008*	86.8*	**
Functional feeding				
% Filterer-collector	Decrease	0.005*	75*	**
% Shredder	Decrease	0.41	18.17	−

Abbreviations: (%) relative abundance, EPT= ephemeroptera + plecoptera + trichoptera, EOT= ephemeroptera + odonata + trichoptera, BMWP= biological monitoring working party, ASPT= average score per taxon, (*) =rejected metrics, (**) =valid metrics

3.5. Relationship between physicochemical variables with selected metrics

The relationships between macroinvertebrate metrics and environmental features indicated that the responses of macroinvertebrate metrics were strong with respect to the physicochemical parameters of the studied wetlands. The Spearman rank order correlations analysis indicated that most of the environmental variables were significantly correlated with one or more of the core metrics ($p < 0.05$). Percent Diptera was positively correlated with TSS, pH, phosphate, nitrate, TP and conductivity, whereas it was negatively correlated with Shannon diversity index, BMWP, EPT/C, % EOT and % Trichopteran family. The BMWP was negatively related to phosphate, TP and conductivity. In the same way, percentage filterers were negatively correlated with TSS, phosphate, conductivity and pH.

3.6. Characterization of wetlands based on benthic macroinvertebrate index

All metrics that passed the screening process were considered for index development. Hence, six core metrics were selected for final macroinvertebrate index development, and their corresponding water quality was determined by following the protocol of the Water Framework Directive (2000). Accordingly, metric score < 9.18 = very poor, indicating highly impacted wetlands with severe disturbance, deteriorated habitat quality, and significant anthropogenic disturbances; 9.18 – 22.03 = poor, indicating slightly less than highly impacted wetlands; 22.03 – 37.33 = moderate, indicating moderately impacted wetlands; 37.33 – 61.2 = good, representing less disturbed wetlands; and > 61.2 = very good (reference), representing desirable biological integrity and fewer problems. Hence, Dena and Wonjeta (reference wetlands) with metric indexes of 84.56 and 81.65, respectively, were classified as very good, Chimba was categorized as moderately impaired, whereas Avaji and Yitamot fell into the poor category, and Shesher was placed in very poor water quality condition (Table 6).

Table 6 Multimetric index score of the core metrix and associated water quality

Metrics	Wetlands					
	Dena	Chimba	Avaji	Wonjeta	Shesher	Yitamot
BMWP	8.48	3.03	0.45	9.24	0.61	1.06
EPT/Chironomidae	8.81	0.09	0	7.1	0.02	0.08
Shannon diversity	8.75	6.25	1.25	6.25	0	6.25
% EOT	7.04	3.59	3.52	9.83	0	0.58
% Diptera	9.4	0.67	0.72	9.92	1.6	1.77
% Filterer-collector	8.26	3.33	1.6	6.65	0	1.6
Metric score (60%)	50.74	16.96	7.54	48.99	2.23	11.34
100%	84.56	28.26	12.56	81.65	3.71	18.9
Water class	Very good	Moderate	Poor	Very good	Very poor	Poor

4. DISCUSSION

Concerning the macroinvertebrate community structures, of the total macroinvertebrate assemblage, hemipterans contributed the highest relative abundance (27.89%). The highest abundance of hemipterans might be due to their considerable number of families and their broad range of habitats in a water body (Barman and Gupta, 2016). Furthermore, the survival of hemiptera might be attributed to their use of atmospheric oxygen at all life stages, which might contribute to survival in water of varying quality (Voshell, 2005). Their presence also describes the condition of wetlands as being fair or moderately polluted because they could tolerate fair degradation of water bodies.

Spatially, the total number of individuals present at each wetland ranged from 789 (Chimba) to 469 (Shesher). The higher relative abundance of individuals recorded at Chimba might be due to human influence by the community around the wetland, in which the area was dominated by pollution-tolerant species. The community used wetlands for various purposes (impaired by agriculture and grazing) that could influence macroinvertebrates (Mayers *et al.,* 2009). However, the low diversity and abundance of macroinvertebrates at Shesher could be due to the small vegetation cover, high TSS and degradation.

Basically, high levels of fine sediment input could significantly affect macroinvertebrate assemblages by altering substrate composition and changing suitability of the substrate for some taxa; increasing drift as a result of sediment deposition or substrate instability; resulting in low oxygen concentrations associated with fine sediment deposits; and affecting feeding activities by reducing the food value of periphyton and density of prey items (Wood and Armitage, 1997).

In terms of species composition, the lower number of macroinvertebrate taxa in Avaji and Shesher could be attributed to excessive human activities above the wetlands. For instance, the wetlands were used for cattle grazing, leather tanning, domestic washing, and crop cultivation that had the potential to increase nutrient levels and sedimentation. Nutrient input through urine and fecal deposition and trampling of sediments by humans and livestock were frequent occurrences in these disturbed stations and could have had a direct impact on aquatic biota. Similar observations were obtained by Griffith *et al.* (2005). Aura *et al.* (2010) also reported the negative impacts of increased nutrient levels and sedimentation on macroinvertebrate abundance.

The highest taxon richness (34 genera) recorded in Dena could not be explained only by the availability of favorable microhabitats for macroinvertebrates' existence, but mainly by the absence of notable human activities that could cause disturbance to the area. This concurs with the study of Matthaei *et al.* (2000), who showed the distribution of benthic macroinvertebrates in aquatic systems is dynamic and strongly influenced by disturbance because diversity is a function of human disturbance and seasonal differences that influence the availability of organic matter (Mason, 2002). Taxonomic richness at Dena wetland could also be explained by the presence of vegetation cover, which provides shade that moderates nutrient levels as compared to open wetlands. Wetland vegetation actively takes up nutrients while its canopy shields direct sunlight (Wang and Lyons, 2003) and provides higher levels of dissolved oxygen (Findlay, 2006).

Regarding the characterization of the macroinvertebrate metric index, all calculated metrics might not gain similar importance; some metrics respond significantly to one type of

stressor and show no response to other stressors. Hence, the selection of potential metrics that enable us to differentiate between stressors is mandatory (Ofenboeck *et al.,* 2004). Accordingly, all of the selected core metrics possessed the potential to discriminate between reference and impaired wetlands, and the metrics' features were discussed as follows.

Diptera are important components of freshwater ecosystems and are abundantly found in disturbed wetlands. Tolerance metrics, such as % Diptera, were expected to respond positively across a gradient of declining wetland health caused by declining populations of all but the most tolerant taxa (Genet and Bourdaghs, 2006). As most Diptera were assumed to be tolerant of pollution and habitat degradation, their percentage contribution is important to identify the level of impact that each stressor causes. This means that the increasing abundance of Diptera indicates environmental disturbance and is attributed to organic pollution caused by enrichment and sedimentation caused by agricultural activities and animal use of the area (Masese *et al.,* 2009). In this study, the value of percent Dipterans was significantly reduced in reference wetlands, but in agricultural and urban wetlands the value was higher and did not vary significantly. Therefore, this index could be an effective tool to discriminate between disturbed and healthy wetlands.

The EOT assemblages were proven to be effective human disturbance indicators and the EOT metrics ranged from 16.82 at a severely impaired wetland (Shesher) to 32.13 (Wonjeta) and also, statistically, the spatial variation was significant (Mann-Whitney, p = 0.008). Therefore, this metric could be used to identify the level of degradation of wetlands or qualify as an indicator of good water quality. The higher the EOT index, the cleaner the water is (Perry, 2005). So, their

lower values at the disturbed wetland and higher values at the reference wetlands showed how seriously pollution affected these organisms. Abay (2007) reported a similar result in the absence of EOT at impacted wetlands. So, because of this discriminating power, it was included in the core metrics.

The Shannon diversity index (SDI) is among the most commonly used indices in ecological studies, and it accounts for abundance and evenness (Magurran, 2013). The index discriminated between the composition of taxa in reference and impaired wetlands. A high SDI indicates a good benthic habitat and non-impacted water quality (Damanik-Ambarita *et al.,* 2016). In the present study, the reference wetlands exhibited greater diversity than the impaired. This might be due to the elimination of sensitive taxa in the impaired wetlands. The results concur with Sponseller *et al.* (2001). Vinson (2006) also revealed that taxonomic diversity decreases with decreasing water quality.

The diversity index values for real communities ranged from 1.0 to 6.0, with a value of less than one indicating poor diversity, 1–3 indicating moderate diversity, and > 3 indicating high diversity (Staub *et al.*, 1970). As a result, reference wetlands were classified as having moderate diversity, whereas impaired wetlands were classified as having low diversity. Furthermore, according to Shannon, an index greater than three denoted clean water, 1–3 denoted moderate pollution, and a value of less than one indicated heavily polluted water (Wilhm and Dorris, 1968). Based on this criterion, reference wetlands were slightly impaired, whereas impaired wetlands were moderately polluted, so the low taxa diversity at impaired wetlands was attributed to the low water quality and the negative response of taxa diversity. As a result, this index could be a useful tool to

discriminate between polluted/disturbed and healthy wetlands.

The usefulness of assessing the relative abundance of different functional feeding guilds in benthic macroinvertebrates has been debated (Barbour *et al.,* 1999). But a study by Tomanova *et al.* (2006) mentioned that feeding strategies represent typical traits reflecting the adaptation of benthic communities into their trophic guilds. Tiku *et al*. (2013) also recommended the importance of employing percent filterer-collector for assessing the ecological quality of wetlands in Ethiopia. In this study, filterers like Culicidae were obviously higher in degraded and polluted wetlands. On the other hand, Hydropsychidae, Philopotamidae and Spaeridae decreased with anthropogenic disturbance. This was supported by the study of Kashian and Burton (2000), who described that filterers were sensitive indicators of water quality and that they were less abundant in disturbed wetland areas (Kashian and Burton 2000). Klemm *et al.* (2003) and Huang *et al.* (2015) also reported similar results. Therefore, the metric was included to assess the water quality status of wetlands.

Regarding EPT/C, pollution-tolerant families including Chironomidae were more common in urban and agricultural impaired wetlands compared to reference wetlands. The percentage of Chironomidae tends to increase with a decrease in water quality because Chironomids tend to be very tolerant of nutrient enrichment or pollution conditions (Burgmer *et al.,* 2007). Contrarily, Ephemereptera was a pollution-sensitive taxon and was commonly found in reference wetlands. Likewise, pollution-sensitive Plecoptera and Tricoptera orders were mainly found in reference wetlands compared to the other wetland types (Table 3). As a result, the higher percentages of Chironomidae in impaired wetlands and lower percentages in reference wetlands indicated a

negative relationship with ecosystem integrity. Higher scores of percentage-tolerant organisms at impaired wetlands in turn testify to higher ecological impairment since percent-tolerant organisms tend to increase with perturbation (Gallardo *et al.,* 2006). So, because of this discriminating power, it was included in the core metrics.

Concerning the Biological Monitoring Working Party Score (BMWP), the result provided single values at the family level, which are representative of the organisms' tolerance to pollution. The index was higher in less impaired wetlands compared with disturbed wetlands; the higher the BMWP score, the clearer the water. In support of the argument, Varnosfaderany *et al.* (2010) concluded that the index showed a greater correlation with water quality parameters than that of the richness and diversity indices. Furthermore, because of its ease of usage and reasonable cost, the BMWP index has been used in many other countries in Africa, Asia, Oceania and Latin America (Chang *et al.,* 2014). Therefore, because of its power to separate impaired from reference wetlands, the metric was included to assess the water quality status of wetlands.

Regarding the water quality status of wetlands, based on the integrity classes, Chimba was placed under moderate quality; Avaji and Yitamot wetlands were grouped in the fourth class and poor category, whereas Shesher was categorized under the very poor habitat quality class.

The poor water and habitat quality of Avaji and Yitamot might be partly attributed to the intense human activities like waste disposal, leather tanning (in Avaji), open grazing, agricultural activities, waste discharging from Bahir Dar University (in Yitamot), and domestic and municipal wastes from Bahir Dar town. In Dena and Wonjeta, despite the use of water for irrigation

and livestock drinking, the areas were relatively less affected by human activities. Additionally, the presence of vegetation to some extent buffers any runoff into the wetland water or filters out sediments, taking up nutrients and chemicals from the water column and sediments into their tissues, thereby improving water quality.

In Chimba, although the wetland was degraded by agriculture and open grazing, the impact was relatively less severe. Unlike in Avaji and Yitamot, there was no leather tanning, municipal and domestic waste discharges, or pollution from detergent use while washing clothes. This might be the reason for the wetland's moderate water quality. The reason for categorizing Shesher as a very poor quality class might be due to agricultural activities up to the wetland margin (watery area), disturbing the wetland area by hand pushing the water into the canal for irrigation purposes, sediment accumulation, a lack of vegetation, and, in general, it was strongly affected by agriculture-related human activities.

The overall reason for the poor water and habitat quality of impaired wetlands might be directly or indirectly associated with agriculture and urbanization-related human activities. The values of physicochemical parameters of impaired wetlands increased as nutrient concentrations due to non-point source runoff, agriculture and urbanization, leading to elevated conductivity, suspension solid, total dissolved solid and TSS, causing extensive sediment deposition and water quality deterioration of the disturbed sites (Nguyen *et al.,* 2014).

Cattle grazing, on the other hand, could have a significant impact on wetlands by increasing nutrient inputs through urine and fecal deposition or trampling of sediments, which in turn affects organisms that rely on this habitat (Steinman *et al.*, 2003). Agricultural activities also increase

sedimentation load associated with tillage practices, increased pesticide runoff, and altered hydrological regimes, all of which can affect the overall structure and function of a wetland (Steinman and Rosen, 2000). Agriculture and urban land practices, in particular, have a negative impact on macroinvertebrates (Gleason *et al.*, 2003).

5. CONCLUSION

In conclusion, aquatic environments are being modified by anthropogenic activities in terms of their biological, physical and chemical conditions. The response of macroinvertebrates to disturbance made it possible to develop an index for monitoring wetlands. Metrics composed of sensitive groups and pollution-tolerant taxa enable investigators to differentiate between references from agricultural and urban-influenced wetlands and detect organic pollution and stressors originating from various sources. Metrics like %EOT, %Diptera, %Filterer-collectors, EPT/C, BMWP score, and Shannon diversity index were significantly related to human disturbances and physicochemical factors and could be used to assess the environmental quality status of wetlands. Based on the developed macroinvertebrate index, human disturbance had a significant impact on Shesher wetland, a relatively lower impact on Avaji and Yitamot, and a moderate impact on Chimba, while Dena and Wonjeta had good habitat quality. The respective water quality of these wetlands was very poor, poor, moderate, and very good, respectively. Human activities related to agriculture and urbanization, such as farming, leather tanning, solid waste dumping, and effluent discharges, might be responsible for the poor water quality of impacted wetlands. Therefore, unless managed properly, human disturbance activities in the wetlands catchment were threatening macroinvertebrates and the wetlands ecosystem. Hence, implementation of catchment-based

management (like settlement, waste removal, leather tanning, and farming around wetlands) together with continuous health status monitoring and a standalone wetland policy should be established.

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