Natural Resources Conservation and Research 2024, 7(2), 9477.
https://doi.org/10.24294/nrcr9477

Article

Macrophyte species composition and abundance of hydrogeologically connected wetlands in upper Abbay river basin, Ethiopia

Getachew Fentaw[1,*], Getachew Beneberu[2], Ayalew Wondie[1,3], Belachew Getnet[4]

[1] Department of Fisheries and Aquatic Science, College of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 79, Bahir Dar 6000, Ethiopia
[2] Department of Biology, College of Science, Bahir Dar University, P. O. Box 79, Bahir Dar 6000, Ethiopia
[3] Lake Tana and other Water bodies Protection and Development Agency, Bahir Dar 6000, Ethiopia
[4] Faculty of Social Sciences, Bahir Dar University, P. O. Box 79, Bahir Dar 6000, Ethiopia
*** Corresponding author:** Getachew Fentaw, getachewfentaw2010@gmail.com

CITATION

Fentaw G, Beneberu G, Wondie A, Getnet B. Macrophyte species composition and abundance of hydrogeologically connected wetlands in upper Abbay river basin, Ethiopia. Natural Resources Conservation and Research. 2024; 7(2): 9477. https://doi.org/10.24294/nrcr9477

ARTICLE INFO

Received: 7 October 2024
Accepted: 13 November 2024
Available online: 27 November 2024

Abstract: Macrophytes are key components of aquatic ecosystems including wetlands that have considerable ecological importance. The role of macrophytes is closely linked to their structural attributes like species composition and abundance. Therefore, this study aimed to assess macrophyte species composition, abundance and diversity of six hydrogeologically connected wetlands in the upper Abbay River basin, Ethiopia. The studied wetlands (Gudera, Geray, Zindib, Kurt Bahir, Infranz and Wonjeta) are found in west Gojjam administrative zone, Amhara region, Ethiopia. Two cross-sectional surveys were conducted at the end of September 2021 and February 2022. Quadrat sampling technique was employed to collect macrophyte samples following protocols for sampling aquatic macrophytes in freshwater wetlands. A total of 41 species of macrophytes belonging to 16 families were identified across the wetlands. The wetlands were dominated by emergent macrophytes, with the Poaceae and Cyperaceae families being particularly abundant. The physicochemical water quality status, water level fluctuations and level of human interventions might be the reason for the variation in the macrophytes composition, abundance and diversity across the wetlands. The low macrophyte diversity index value and the presence of pollution-tolerant taxa such as *Pistia stratiotes* and *Azolla africana* indicate an overall ecological degradation of the wetlands. Therefore, this study highlights the potential role of macrophyte monitoring to identify anthropogenic pollution. Application of appropriate land use planning and the development of macrophyte based multimetric indices are recommended for their sustainable management.

Keywords: Abbay river basin; hydrogeology; macrophytes

1. Introduction

Macrophytes, often called hydrophytes are adapted morphologically, anatomically and physiologically to grow in aquatic habitats [1]. They comprise taxonomically diverse group of macroscopic plants including macro-algae (e.g., *Chara* and *Nitella*), liverworts, mosses, ferns (e.g., *Azolla*), and angiosperms i.e., both mono- and dicots [2,3]. They occupy different ecological niche in the aquatic environment [4] and grouped as freely floating and those attached to the substrate (floating-leaved, submerged and emergent) [3–7].

Macrophytes are continued to be cited as key components of fresh water ecosystems including wetlands [1–3,5,7–12]. These studies indicated their considerable ecological importance including sustaining oxygenation of water, enhancing water quality and nutrient cycling, and support and nurture the biodiversity. They play a vital role in supporting the structure and function of aquatic ecosystems [1,5,7,13–15]. Macrophytes are also sensitive to anthropogenic changes and can be used as an effective indicator that reflect the ecological health status of wetland ecosystems [1,3,8–10,15–21].

The role of macrophytes is closely related with their structural attributes like species composition and abundance [8,12,19,22]; which, in turn, depend on various climatic, hydrological, and land use variables [8,10,15–16,23–24]. In this regard, several studies have been conducted worldwide on macrophyte relationship with various environmental variables particularly water quality parameters [16, 23–31]. This is because water quality parameters are the major factors that are highly influencing the distribution and abundance of macrophytes [31].

Despite their importance, assessment and use of macrophytes as biological indicators of aquatic ecosystems in Ethiopia is very limited [32]. Macrophytes are used to assess the ecological status of only few Lakes [14,33], rivers [34,35], and wetlands [36,37], even though the country has vast wetland resources [38]. This indicates studies on species composition and abundance of macrophytes of aquatic ecosystems in general and wetlands in particular is highly demanded. Furthermore, none of these studies assessed the macrophytes of the six studied wetlands: Gudera, Geray, Zindib, Kurt Bahir, Infranze and Wonjeta. Therefore, this study aimed to assess the macrophyte species composition, abundance and diversity of hydrogeologically connected wetlands in the upper Abbay River basin, Ethiopia. The outcome of the study is important in providing baseline scientific information on the wetlands macrophytes composition that supports their management and sustainability.

2. Materials and methods

2.1. Description of the study area and studied wetlands

The studied wetlands (Gudera, Geray, Zindib, Kurt Bahir, Infranz and Wonjeta) are found in the upper Abbay River basin within west Gojjam administrative zone of Amhara region, Ethiopia (**Figure 1**). The region is known for its wetland potential including Lake Tana and its associated wetlands [39] and the wetland coverage is estimated to be around 1.4% [40]. Studies [41–43] suggested the hydrogeological connectivity among wetlands in the Lake Tana sub-basin. The studied wetlands share a similar landscape feature (rocky-bush land) and the locals also have indigenous knowledge on the hydrological connectivity between Gudera-and-Geray, and Kurt Bahir-and-Infranze wetlands (pers. communications). Geographically, they are situated within a range of 10°30′30″–11°59′04″ N latitude and 37°00′40″–37°28′45″ E longitude. The mean annual rainfall of the watersheds of the studied wetlands was from 1250 to 1800 mm and their mean annual temperature varied from 18 ℃ to 25 ℃. The water level of the wetlands fluctuate during the dry and wet season, in which a higher water level is observed during the wet season in the months of July, August and September.

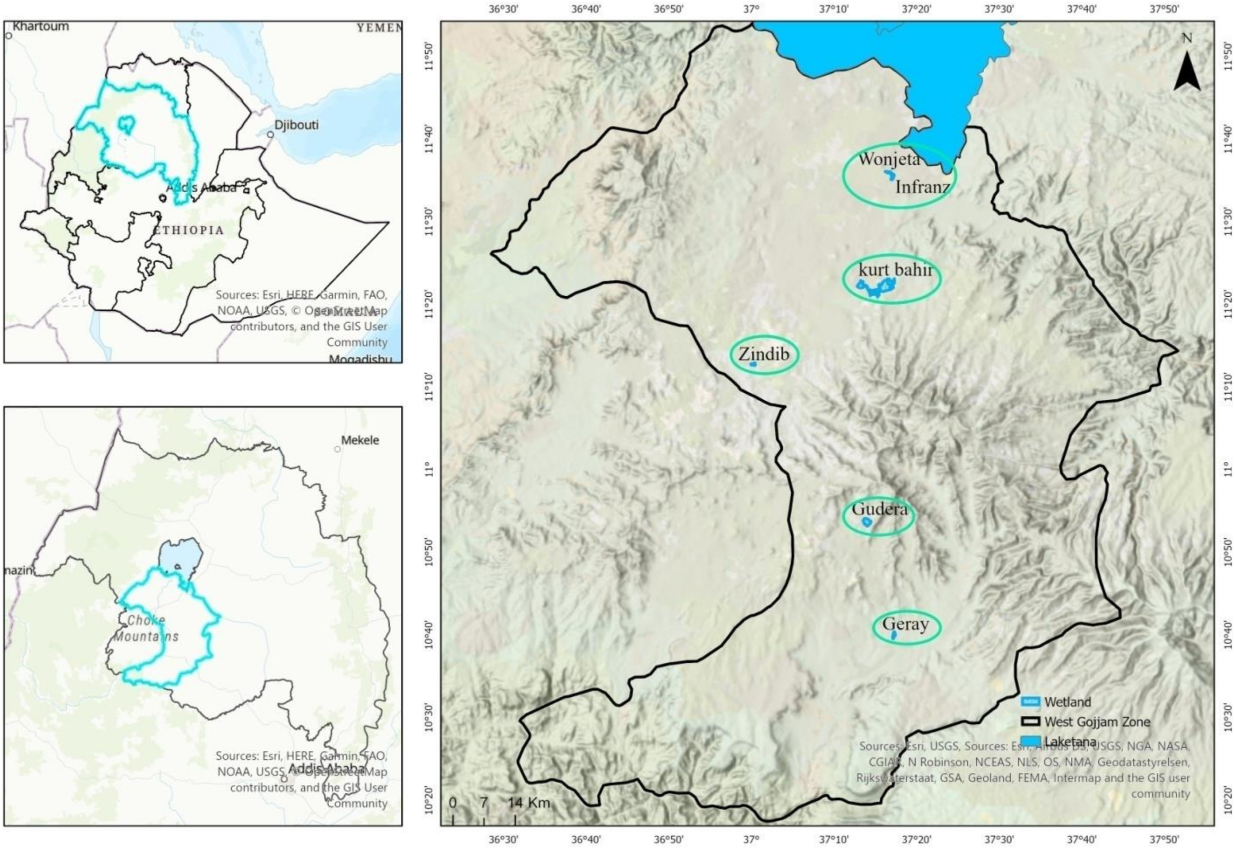

Figure 1. Location map of west Gojjam zone and the six studied wetlands.

Source: Reprinted from Fentaw et al. (2024) under CC BY license, with permission from ELSEVIER, original copyright 2024

2.1.1. Geray wetland

Geray is an artificial reservoir primarily used for irrigation. The wetland covers 10 ha with weir crest length of 105 m, height 4 m, 106 m^3 of water with a potential of irrigating 618 ha of arable land [44]. It is located near to (5 km) *Finote-Selam town* (the administrative city of west Gojjam zone). The *Arbaitu-Ensesa (Jabitehnan woreda)* and *Shembekuma-Yidafas (Finoteselam woreda)* are bordering *kebeles*. Geray flows into Lah River then Birr River and finally joins Gilgel Abay river.

2.1.2. Gudera wetland

Gudera is located about 17 km from *Gish-Abbay town, Sekela woreda*. It is located at a higher altitude (2344 m.a.s.l) with an estimated area of 140 ha with a shallow depth of about 2.5 m [45]. The study area is one of the tourist attraction sites; which has been associated with Gish Mountain (source of Gilgel Abay river) and Abune Zerea-Buruk church [46]. The Woreda is rich in big and annual rivers, including Lesser Abay; of which Zegez River overflows into the wetland during the rainy season. This is important for the locals in forming fertile farmland for recession agriculture; which is the main threat to the wetland.

2.1.3. Zindib wetland

Zindib is a palustrine type wetland located in *Dil-Betigil kebele* (north Mecha woreda) some 3 km from *Nada-Maryam* monastery adjacent to Gilgel Abay River.

Recently, a new bridge is under construction on Gilgel Abay river to connect the two *woredas* (north Mecha and Dangila woreda). The total surface area coverage of the wetland was estimated to be 28.55 ha and there is a small seasonal stream that flows to Gilgel Abay River during the rainy season.

2.1.4. Kurt Bahir wetland

Kurt Bahir is a depressional and palustrine type of wetland [39,47]. It is located about 3 to 5 km to the north-east direction of Merawi town (north Mecha woreda) and 30 km south-west of Bahir Dar city. It is bordered by the *Kurt-Bahir, Midre-Genet, Tatek-Geberie* and *Enashenifalen* villages (*kebeles*). The total area coverage of the wetland was estimated to be 764 ha [48]. Surface water (during rainy season) and groundwater are the main water sources for the wetland and there is a small seasonal stream, which flows to Koga dam on the downstream side of the wetland.

2.1.5. Infranz wetland

Infranz wetland is located in the southern-most tip of Lake Tana; which is internationally recognized as an Important Bird Area (IBA) [49]. The total area of the wetland is estimated to be 25,750 ha [50]. The wetland comprises a series of relatively high-discharge springs. These springs sustain the Infranz river (which drains into Lake Tana), the downstream wetlands, and serve as a significant source of water for Bahir Dar city and nearby villages [42,50].

2.1.6. Wonjeta wetland

Wonjeta wetland is located 19 km northwest of Bahir Dar (the capital city of Amhara regional state). It is a papyrus dominated palusterine type wetland that receives water from springs. The area of this wetland is estimated to be 300 ha [39].

2.2. Study design

Two cross-sectional surveys were conducted at the end of September 2021 when most of the vascular plants flourish and February 2022 during which they were fully grown and flowered [51,52].

2.3. Macrophyte sampling, collection and identification

Macrophyte samples were collected following protocols for sampling aquatic macrophytes in freshwater wetlands [53]. Quadrat sampling technique was employed [17]; in which a quadrat size of 1 m^2 [52] were placed randomly [26] within the purposively selected sampling stations. Two sampling stations were selected based on the preliminary evaluation of plant community variations within the wetlands [52] and easy accessibility for sampling [14,34]. To have representative samples of each life forms; floating, submerged and emergent [4,5,7], quadrats were laid at the open water and littoral zones in each sampling stations as Ekpo et al. [19] employed. Thus, the total sampling sites from all the studied wetlands were 24 quadrats. The macrophytes within each quadrat were counted manually by hand picking [6]. Identification (and inventory of floating, submerged and emergent) of macrophytes was done using pictorial identification guides [54–58] and the ‘plants of the world online’ database (https://powo.science.kew.org).

2.4. Data analysis

Taxonomic composition of the macrophytes was recorded and grouped according to their life forms into floating, submerged, and/or emergent [4–5,7]. Ecological indices were computed which provide quantitative information on the richness, evenness and diversity of macrophytes using PAleontological Statistics (PAST4.13) software.

The relative frequency, relative abundance and relative density of each species were calculated as used in the studies [33,34,59] following the following formula:

$$\text{Frequency (\%)} = \frac{\text{No. of quadrats in which the species occurs}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Density/quadrant} = \frac{\text{Total number of indiviuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Abundance/quadrant} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species ocuurs}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of species A}}{\text{Total frequency of all species}} \times 100$$

$$\text{Relative density} = \frac{\text{Density of species A}}{\text{Total density of all species}} \times 100$$

$$\text{Relative abundance} = \frac{\text{Abundance of species A}}{\text{Total abundance of all species}} \times 100$$

3. Results

Macrophyte composition, abundance and diversity

A total of 41 species of macrophytes belonging to 16 families were identified across all the six studied wetlands. They are classified as floating, submerged and emergent based on their life forms (**Table 1**).

Table 1. Relative score of macrophyte species richness across the wetlands following the procedure of Agbogidi et al. [60]: +++ (more abundance), ++ (sparse abundance) and + (rare abundance or just present).

Taxa		**Wetlands**					
Family name	***Species name***	**Geray**	**Gudera**	**Zindib**	**Kurt_Bahir**	**Infranz**	**Wonjeta**
Floating							
Nymphaeaceae	*Nymphaea lotus* L.	+++			++	+++	
Azollaceae	*Azolla africana* Desv.	+++				++	+++
Araliaceae	*Hydrocotyle ranunculoides* L.f.	+++					
Araceae	*Pistia stratiotes* L.		+++				
Submerged							
Ceratophyllaceae	*Ceratophyllum demersum* L.	+++	++		++	+	
Potamogetonaceae	*Potamogeton alpinus* Balb.			+++		+++	
Characeae	*Chara* sp. (L.)	++			++		

Table 1. (*Continued*).

Taxa		**Wetlands**					
Family name	***Species name***	**Geray**	**Gudera**	**Zindib**	**Kurt_Bahir**	**Infranz**	**Wonjeta**
Floating							
Emergent							
Commelinaceae	*Murdannia bracteata*(C.B.Clarke) J.K.Morton ex D.Y.Hong	++					+
	Floscopa glomerata (Willd. ex Schult. & Schult.f.) Hassk.			+++	+++		
Typhaceae	*Typha latifolia* L.	++			++	+	
Marsileaceae	*Marsilea minuta* L.			++			
Cyperaceae	*Cyperus papyrus* L.	+	++		+	+++	+++
	Cyperus digitatus Roxb.		+	+			+++
	Cyperus alopecuroides Rottb.			+++		+++	+++
	Cyperus longus L.		+	++	+++		
	Cyperus rotundus L.		+		++		
	Cyperus esculentus L.				+++	+++	+++
	Cyperus flavescens L.		+++	+		++	+++
	Cypreus macrostachyos Lam.					+	++
	Cypreus elegantulus Steud.		+	+	++		
	Scirpus sp. (L.)		+	++	+		
	Schoenoplectus sp. (Rchb.) Palla	+	++	+	++	++	+
Poaceae	*Leymus cinereus* (Scribn. & Merr.)Á. Löve		+	+	+++	+++	+
	Pennisetum longistylum Hochst. Ex A. Rich.			+	++	++	
	Sporobolus africanus (Poir.) Robyns & Tournay				++		
	Cynodon aethiopicus Clayton & J.R.Harlan			+	++		
	Cynodon dactylon (L.) Pers.						
	Hyparrhenia rufa(Nees) Stapf			+	++		
	Sacciolepis africana C.E.Hubb. & Snowden				+++	+++	+++
	Leersia hexandra Sw.				+		
	Echinochloa sp. (P. Beauv.)	+					
	Eleusine indica (L.) Gaertn.				+		
	Phalaris arundinacea L.					+	
Polygonaceae	*Polygonum glabrum* Willd.	+++	+++	++	+++	+++	+++
Acanthaceae	*Hygrophila auriculata*(Schumach.) Heine			+++	++	++	+++
Leguminosae	*Trifolium rueppellianum*Fresen.			+	+++		
Asteraceae	*Bidens laevis* L.				+++		
	Ageratum conyzoides L.			+			
	Galinsoga quadriradiata Ruiz & Pav.			+			
	Xanthium spinosum L.			+			
Thelypteridaceae	*Cyclosorus interruptus* (Willd.) H.Itô			+	+		

The studied wetlands were dominated by emergent macrophytes (34 species) with the highest relative density of 82.93%, followed by floating (n = 4; 9.76%) and submerged (*n* = 3; 7.32%) macrophytes. The Poaceae and Cyperaceae families had the highest number of species (*n* = 11; 26.19%) and were found to be particularly abundant, followed by Asteraceae with four species (9.52%). Comparatively, the most frequent species was *Polygonum glabrum,* occurring in all the studied wetlands except Zindib. It was more abundant, more frequent and covered most of the area of the studied wetlands.

Nymphaea lotus, Azolla africana, Pistia stratiotesand Hydrocotyle ranunculoides are floating macrophytes identified in the present study (**Table 1**). The relative abundance of *Nymphaea lotus* was 1.28%, 1.27% and 1.23% (at Geray, Infranz and Kurt Bahir, respectively) (Annex 1). Similarly, the relative abundance of *Azolla africana* was 34.0%, 44.35%, 44.69% and 59.65% at Gudera, Geray, Infranz and Wonjeta, respectively. *Hydrocotyle ranunculoides* 17.91% (at Geray) and *Pistia stratiotes*17.2% (at Gudera) were the other floating macrophytes identified. *Ceratophyllum demersum* (from Geray, Gudera, and Kurt Bahir wetlands), *Potamogeton alpines* (from Zindib and Infranz wetlands) and *Chara spp.* (from Geray and Kurt Bahir wetlands) are submerged macrophytes identified in the present study.

The studied wetlands vary in macrophytes species abundance, diversity and evenness (**Table 2**). In comparison, highest number of species (24 species) was recorded at Kurt Bahir wetland with higher Shannon-Weiner index value (*H*' = 2.8). However, high macrophyte abundance was recorded from Wonjeta wetland (*n* = 804) but with the lowest Shannon-Weiner index value (*H*' = 1.5). The Shannon diversity index (*H*') of macrophytes of the wetlands followed the order as: Kurt Bahir (2.8) > Zindib (2.2) > Gudera (2.1) > Infranz (2.0) > Geray (1.6) > Wonjeta (1.5). Likewise, the evenness index revealed higher at Kurt Bahir (*E* = 0.9) and lower at Wonjeta (*E* = 0.6).

Table 2. Spatial variation in macrophyte taxa, abundance and diversity indices in the six studied wetlands.

Biotic indices	**Geray**	**Gudera**	**Zindib**	**K Bahir**	**Infranz**	**Wonjeta**
Species diversity	12	15	17	24	16	13
Abundance	588	378	176	347	399	804
Shannon-Weiner index (*H*')	1.6	2.1	2.2	2.8	2	1.5
Evenness (*E*)	0.6	0.8	0.8	0.9	0.7	0.6

4. Discussion

Our results revealed that the studied wetlands were highly dominated by emergent macrophytes, which could be due to their high tolerance for water-level fluctuation [4,14,26,61–63]. It is also an indication of water-level decline [8,64] as well as the encroachment of littoral vegetation [6,64]. Because of excessive abstraction of water mainly for small-scale irrigation, the water level of the studied wetlands has been declining (per. obs.). There is also high seasonal variation in water level in the wetlands, which is attributed to seasonal rainfall. An increasing trend in anthropogenic activities like intensive agriculture (recession and irrigation) and siltation in the wetlands could also further aggravate the condition. According to

Ghosh and Biswas [6], accumulation of silt from the catchment promotes the encroachment of littoral vegetation by reducing the core area of the aquatic ecosystem. Previous studies in the country have also shown that the littoral zone of Lake Ziway [14], Ketar river in Ziway catchment [34], Infranz wetland [50] in the Lake Tana area, south-western littoral zone of Lake Tana [33], and selected wetlands in Lake Tana [65] were dominated by emergent macrophytes.

The Poaceae and Cyperaceae families had the highest number of species and were found to be particularly abundant, followed by Asteraceae (**Table 1**). The dominance of these families suggests that the environmental characteristic favors these species. These emergent macrophytes are highly resistance to harsh environmental conditions like water-level fluctuations, high trophic conditions, high rainfall and temperature, and poor lighting conditions [4,12] which might accounted for their dominance in our studied wetlands. The dominance of these macrophytes in varying degree is also reported from other wetlands of Ethiopia including wetlands in: Jimma highlands [52], Kafa Zone [51], Lake Tana area [33,50,65]and from Ketar river in Ziway catchment [34] and Cheleleka wetland in central Rift valley of Ethiopia [37].

Based on Cavalcanti and Larrazabal apud [66], Shannon-Wiener diversity index considered as high when the calculated value is ≥3.0, medium when it is between 2.0 and 3.0, low between 1.0 and 2.0 and very low when it is less than 1.0. The diversity values of Shannon-Wiener's diversity index (range: H' = 2.8−1.5) varied from medium to low. The low diversity values of Geray and Wonjeta (**Table 2**) indicate the communities with lower species richness and evenness. It also implied the studied wetlands to be degraded [16] and had high anthropogenic activities [6], mainly associated with farming and overgrazing. The relatively low evenness value (0.6) and highest abundance (n = 804) of macrophytes of Wonjeta wetland indicated the wetland was dominated by few species. It was dominated by *Azolla africana* and *Polygonum glabrum* with a relative abundance of 59.7 % and 10.5 %, respectively. Similarly, Geray wetland was dominated by *Azolla africana* and *Hydrocotyle ranunculoides.* Anthropogenic activities like drainage, overgrazing, cultivation and pollution affect wetland-dependent species [51]. These wetland disturbances can reduce species diversity by removing disturbance-sensitive species and/or the dominance by few strong competitors [39,52]. Wetlands of the present study are also highly impacted by mainly agriculture (irrigation and recession) and grazing. Studies [39,51,52] also indicated the species richness was reported as low in agriculture impacted rural wetlands.

In comparison, a better diversity value (medium value: H' = 2.0−3.0) was obtained from Infranz, Gudera, Zindib and Kurt Bahir wetlands. However, they are highly disturbed due to the high external loading of sediments from their degraded catchments in addition to the intensive agricultural activities (irrigation and recession) and grazing pressure. Disturbance might increases species diversity by creating microhabitats suitable for other colonizer species [67]; until disturbance becomes so severe that only a few species are able to adapt to the adverse conditions [16]. Similar result was reported by Moges et al. [52] in that the mean diversity of agriculture impacted wetlands was higher than urban impacted and forested wetland types. Disturbed (mainly cultivated) wetlands have more macrophyte diversity compared to the undisturbed (uncultivated) natural wetlands [39, 52, 68–70].

Free floating macrophytes were shared the second highest abundance in which *Nymphaea lotus*, *Azolla africana*, *Hydrocotyle ranunculoides* and *Pistia stratiotes* were identified in most of the studied wetlands. They are usually dominant when nutrient levels in the water are sufficiently high; and thus used as an indicator of organic pollution [6,10,29]. Therefore, they are regarded as pollution tolerant species and used as a biological indicator for eutrophication. The main source of pollution is due to runoff from agricultural fields in the rainy season carrying inorganic fertilizers, toxic pesticides and other chemicals enter in to these wetlands. Eutrophication causes native species of macrophytes to decline and gets replaced by invasive and stress-tolerant species [29]. The major impact of invasive species includes the replacement of native species that can lead potential extinction, changing food webs, and modifying the system biogeochemistry [3]. The occurrence of *Pistia stratiotes* and *Azolla africana* alone were a clear indication of organic pollution and invasion of alien species [3,71]. According to Holmes and Whittonapud Chibsa et al. [34], they are considered as among the most problematic invasive floating species. They are also well known for invading new habitats within a short period of time under high nutrient loading [14]. The abundance of free floating macrophytes (mainly *Azolla nilotica* and *Pistia stratiotes*) was also reported by Chibsa et al. [34] from Ketar River in Ziway catchment.

Submerged aquatic vegetations are indicators of water quality and nutrient level of the water, and it exists where there is a better water quality condition [21]. According to Dar et al. [8], low water level and the turbidity of water have a greater impact on the extent of colonization of submerged aquatic plants. The absence of open water due to dense mats of floating macrophytes (*Azolla africana*) in Wonjeta wetland; and the higher turbidity and fluctuation in water level (mainly due to recession agriculture) in Gudera wetland are among the limiting factors of the diversity and abundance of submerged macrophytes. The restricted distribution of submerged macrophytes with the absence of open water due to dense mats of floating macrophytes is also reported by Saluja and Garg [16] from Lake Bhindawas. According to Ademola et al. [72] the abundance and species composition of macrophytes are greatly influenced by eutrophication. Relatively, the higher abundance in other wetlands could be the excess nutrients, which can leads to eutrophication and results in bloom of submerged macrophyte [60].

5. Conclusion and recommendations

The study describes macrophyte composition, abundance and diversity across six hydrogeologically connected wetlands found in the upper Abbay River basin, Ethiopia. The studied wetlands were dominated by emergent macrophytes indicating water level fluctuation and reduction as well as the encroachment of littoral zone. In addition, the observed differences in diversity and abundance of macrophytes could also be attributed to the nutrient status of the wetlands and level of human activities such as farming. The low and medium macrophyte diversity value indicates an overall ecological degradation, which might be due to the poor water quality status of the wetlands. The ecological degradation in the wetlands is also evidenced by the presence of pollution-tolerant taxa such as *Pistia stratiotes* and *Azolla africana*. Therefore, this study highlights the potential role of macrophyte monitoring to identify anthropogenic pollution. Management interventions like the establishment of buffer zone, application of ecohydrological principles and appropriate land use planning are recommended for protecting and rehabilitating the studied wetlands. The authors also recommend the development of macrophyte based multimetric indices, which are important tools for freshwater monitoring and management.

Authorcontributions: Conceptualization GF, GB, AW and BG; methodology, GF, GB, AW and BG; formal analysis, GF; investigation, GF; data curation, GF; writing—original draft preparation, GF; writing—review and editing GB, AW and BG; supervision, AW. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: We would like to acknowledge the local agricultural development agents, natural resource and environmental experts (especially Migbaru, Gashaye, Zelalem and Mastie) for their unreserved support in data collection. We also thank Masresha Birara (BDU, School of Fisheries and Wildlife) for his assistance in macrophyte identification.

Conflict of interest: The authors declare no conflict of interest.

References

1. Chaurasia S. Role of Macrophytes: A Review. Advances in Zoology and Botany. 2022; 10(4): 75-81. doi: 10.13189/azb.2022.100401
2. Chambers PA, Lacoul P, Murphy KJ, et al. Global diversity of aquatic macrophytes in freshwater. Hydrobiologia. 2007; 595(1): 9-26. doi: 10.1007/s10750-007-9154-6
3. Rejmankova E. The role of macrophytes in wetland ecosystems. Journal of Ecology and Environment. 2011; 34(4): 333-345. doi: 10.5141/jefb.2011.044
4. Oyedeji AA, Abowei JFN. The Classification, Distribution, Control and Economic Importance of Aquatic Plants. Biology, Economics, Environmental Science; 2012.
5. Deshmukh UB, Shende MB, Rathor OS. Aquatic macrophytes biodiversity assessment from Asolamendha reservoir of Chandrapur district, Maharashtra State (India). International journal of applied research. 2016.
6. Ghosh D and Biswas JK. Biomonitoring Macrophytes Diversity and Abundance for Rating Aquatic Health of an Oxbow Lake ecosystem in Ganga River Basin. American Journal of Phytomedicine and Clinical Therapeutics. 2015.
7. Lesiv MS, Polishchuk AI, Antonyak HL. Aquatic macrophytes: ecological features and functions. Studia Biologica. 2020; 14(2): 79-94. doi: 10.30970/sbi.1402.619
8. Dar NA, Pandit AK, Ganai BA. Factors affecting the distribution patterns of aquatic macrophytes. Limnological Review. 2014; 14(2): 75-81. doi: 10.2478/limre-2014-0008
9. Dienye H. Species Diversity of Macrophytes of the New Calabar River, Niger Delta, Nigeria. International Journal of Fisheries and Aquatic Studies. 2015.
10. Manjunath S, Manjunath S, Narayana J, and Kiran BR. Diversity and distribution of Aquatic Macrophytes in Gudavi Wetland, Sorab Taluk, Karnataka, India. International Journal of Basic and Applied Sciences. 2016.
11. Meena T and Rout J. Macrophytes and their ecosystem services from natural ponds in Cachar district, Assam, India. Environmental Science; 2016.
12. Pirini C, Karagiannakidou V, Charitonidis S. Abundance, diversity and distribution of macrophyte communities in neighboring lakes of different trophic states and morphology in north-central Greece. Arhiv za bioloske nauke. 2011; 63(3): 763-774. doi: 10.2298/abs1103763p

13. Deshmukh UB, Reddy ES, and Rathor OS. Survey of Aquatic Macrophyte Diversity of Mohabala Lake From Bhadrawati Tahsil of Chandrapur District, State Maharashtra (India). International Journal of Current Science and Technology. 2017.
14. Tamire G, Mengistou S. Macrophyte species composition, distribution and diversity in relation to some physicochemical factors in the littoral zone of Lake Ziway, Ethiopia. African Journal of Ecology. 2012; 51(1): 66-77. doi: 10.1111/aje.12007
15. Wijeyaratne D, Bellanthudawa A. Macrophytes as indicators of the ecological status of a tropical rehabilitated wetland ecosystem: Application of multivariate statistics and ecological state macrophyte index (esmi). International Journal of Aquatic Biology. 2020.
16. Saluja R, Garg JK. Macrophyte species composition and structure along littoral region in relation to limnological variables of a tropical wetland ecosystem. Chemistry and Ecology. 2017; 33(6): 499-515. doi: 10.1080/02757540.2017.1328502
17. USEPA. Methods for evaluating wetland condition: Using vegetation to assess environmental conditions in wetlands. United States Environmental Protection Agency. 2002.
18. Bytyqi P, Czikkely M, Shala-Abazi A, et al. Macrophytes as biological indicators of organic pollution in the Lepenci River Basin in Kosovo. Journal of Freshwater Ecology. 2020; 35(1): 105-121. doi: 10.1080/02705060.2020.1745913
19. Ekpo IE, Ekpenyong UR, Management AE. Abundance, distribution and biotic indices of aquatic macrophyte community of a riparian stream in Odot, Niger Delta, Nigeria. FUTA Journal of Research in Sciences. 2016.
20. Mallappa P, Takrya PN. Diversity of Aquatic Macrophytes of Four Lakes of Holalkere, Chitradurga District, Karnataka, India. Research Square. 2022.
21. Rameshkumar S, Radhakrishnan K, Aanand S, et al. Influence of physicochemical water quality on aquatic macrophyte diversity in seasonal wetlands. Applied Water Science. 2019; 9(1). doi: 10.1007/s13201-018-0888-2
22. Labat F, Thiébaut G, Piscart C. Principal Determinants of Aquatic Macrophyte Communities in Least-Impacted Small Shallow Lakes in France. Water. 2021; 13(5): 609. doi: 10.3390/w13050609
23. Lahon D, Sahariah D. Physico-chemical Properties of Water and Its Impactson the Species Diversity of Aquatic Plants at Disangmukh Wetland of Assam, India. Ecology, Environment and Conservation. 2022; 203-207. doi: 10.53550/eec.2022.v28i01.026
24. Zelnik I, Potisek M, and Gaberščik A. Environmental conditions and macrophytes of karst ponds. Polish Journal of Environmental Studies. 2012.
25. Akwuma OD, Ezra AG, Nayaya AJ. Assessment Of Emergent And Floating Macrophytes In Relation To Some Physicochemical Parameters Of Waya Pond, Bauchi, Nigeria. Open Journal of Bioscience Research. 2021; 2(2): 66-73. doi: 10.52417/ojbr.v2i2.287
26. Badra R, Panda J, Sahoo S. A Study on Water Quality and Macrophyte Diversity in Three Wetlands of Sambalpur District, Odisha from Ecosystem Management Perspective. Ecology, Environment and Conservation. 2022; 1395-1403. doi: 10.53550/eec.2022.v28i03.042
27. Bubíková K, Hrivnák R. Relationships of macrophyte species richness and environment in different water body types in the Central European region. Annales de Limnologie-International Journal of Limnology. 2018; 54: 35. doi: 10.1051/limn/2018027
28. Germ M, Janež V, Gaberščik A, et al. Diversity of Macrophytes and Environmental Assessment of the Ljubljanica River (Slovenia). Diversity. 2021; 13(6): 278. doi: 10.3390/d13060278
29. Gupta P, Tamot S, and Shrivastava VK. Effect of physico-Chemical properties of water on macrophyte diversity with special reference to Bhoj Wetland. Indian Journal of Ecology. 2020.
30. Ondiba R, Omondi R, Nyakeya K, et al. Environmental constraints on macrophyte distribution and diversity in a tropical endorheic freshwater lake. International Journal of Fisheries and Aquatic Studies. 2018.
31. Rameshkumar S, Radhakrishnan K, Aanand S, et al. Influence of physicochemical water quality on aquatic macrophyte diversity in seasonal wetlands. Applied Water Science. 2019; 9(1). doi: 10.1007/s13201-018-0888-2
32. Fentaw G, Mezgebu A, Wondie A, et al. Ecological health assessment of Ethiopian wetlands: Review and synthesis. Environmental and Sustainability Indicators. 2022; 15: 100194. doi: 10.1016/j.indic.2022.100194
33. Kassa Y, Mengistu S, Wondie A, et al. Distribution of macrophytes in relation to physico-chemical characters in the south western littoral zone of Lake Tana, Ethiopia. Aquatic Botany. 2021; 170: 103351. doi: 10.1016/j.aquabot.2020.103351
34. Chibsa Y, Mengistou S, Kifle D. Distribution and Diversity of Macrophytes in Relation to Some Physico-Chemical Factors in the Ketar River, Ziway Catchment, Ethiopia. Environmental Science; 2021.
35. Derso TT. Macrophyte species diversity, composition and distribution in relation to some environmental factors in Upper

Awash River, Ethiopia. Addis Ababa University; 2020.
36. Getnet H, Mengistou S, Warkineh B. Diversity of macrophytes in relation to environmental conditions in wetlands along the lower part of the Gilgel Abay River catchment in Ethiopia. African Journal of Aquatic Science. 2021; 46(2): 173-184. doi: 10.2989/16085914.2020.1842721
37. Tesfaye H, Warkineh B. Macrophyte species diversity and distribution in relation to water quality of the Cheleleka Wetland in Ethiopia. African Journal of Aquatic Science. 2021; 47(1): 36-46. doi: 10.2989/16085914.2021.1940823
38. Abunie L. The distribution and status of Ethiopian wetlands. In Proceedings of a Seminar on the Resource Sratus of Ethiopia's Wetlands, Addis Ababa: International Union of Conservation of Natural Resources (IUCN); 2003.
39. Wondie A. Ecological conditions and ecosystem services of wetlands in the Lake Tana Area, Ethiopia. Ecohydrology & Hydrobiology. 2018; 18(2): 231-244. doi: 10.1016/j.ecohyd.2018.02.002
40. Tecklie A, Yosef B. Assessment of Major Wetlands' Current Situation and Their Contribution To Livelihood Improvement, South Wollo, Ethiopia. International Journal of Ecology. 2022; 2022: 1-10. doi: 10.1155/2022/9697899
41. Mamo S, Ayenew T, Berehanu B, and Kebede S. Hydrology of the Lake Tana Basin, Ethiopia: Implication to Groundwater-Surface Waters Interaction. Journal of Environment and Earth Science. 2016.
42. Nigate F, Van Camp M, Yenehun A, et al. Recharge–Discharge Relations of Groundwater in Volcanic Terrain of Semi-Humid Tropical Highlands of Ethiopia: The Case of Infranz Springs, in the Upper Blue Nile. Water. 2020; 12(3): 853. doi: 10.3390/w12030853
43. Tigabu TB, Wagner PD, Hörmann G, et al. Modeling the spatio-temporal flow dynamics of groundwater-surface water interactions of the Lake Tana Basin, Upper Blue Nile, Ethiopia. Hydrology Research. 2020; 51(6): 1537-1559. doi: 10.2166/nh.2020.046
44. Checkol G, and Alamirew T. Technical and institutional evaluation of Geray Irrigation Scheme in West Gojjam Zone, Amhara Region. Available online: https://api.semanticscholar.org/CorpusID:114014352 (accessed on 2 May 2024).
45. Endalew M, Goshu G, Zelalem W. A preliminary survey of the ecohydrological management challenges faced by Lake Gudera, Sekela woreda, West Gojjam, Ethiopia. Ecohydrology & Hydrobiology. 2010; 10(2-4): 325-331. doi: 10.2478/v10104-011-0024-5
46. Asmare E, Bekele K, Fentaw S. Households' willingness to pay for the rehabilitation of wetlands: evidence from Gudera Wetland, Northwest Ethiopia. Heliyon. 2022; 8(1): e08813. doi: 10.1016/j.heliyon.2022.e08813
47. Gezie A, Anteneh W, Dejen E, et al. Effects of human-induced environmental changes on benthic macroinvertebrate assemblages of wetlands in Lake Tana Watershed, Northwest Ethiopia. Environmental Monitoring and Assessment. 2017; 189(4). doi: 10.1007/s10661-017-5853-2
48. Gebremedhin S, Getahun A, Anteneh W, et al. A Drivers-Pressure-State-Impact-Responses Framework to Support the Sustainability of Fish and Fisheries in Lake Tana, Ethiopia. Sustainability. 2018; 10(8): 2957. doi: 10.3390/su10082957
49. Aynalem S, and Bekele A. Species composition, relative abundance and distribution of bird fauna of riverine and wetland habitats of Infranz and Yiganda at southern tip of Lake Tana, Ethiopia. Tropical Ecology; 2008.
50. Eneyew BG, Assefa WW. Anthropogenic effect on wetland biodiversity in Lake Tana Region: A case of Infranz Wetland, Northwestern Ethiopia. Environmental and Sustainability Indicators. 2021; 12: 100158. doi: 10.1016/j.indic.2021.100158
51. Woldemariam W, Mekonnen T, Morrison K, et al. Assessment of wetland flora and avifauna species diversity in Kafa Zone, Southwestern Ethiopia. Journal of Asia-Pacific Biodiversity. 2018; 11(4): 494-502. doi: 10.1016/j.japb.2018.08.003
52. Moges A, Beyene A, Ambelu A, et al. Plant species composition and diversity in wetlands under forest, agriculture and urban land uses. Aquatic Botany. 2017; 138: 9-15. doi: 10.1016/j.aquabot.2016.12.001
53. DiFranco JL. Standard operating procedures: Protocols for sampling aquatic macrophytes in freshwater wetlands. Maine Department of Environmental Protectio; 2019.
54. Burland GR. An Identification guide to Alberta aquatic plants. Alberta Environment Pesticide Management Branch; 1989.
55. Chapman D. Water Quality Assessments—A Guide to Use of Biota, Sediments and Water in Environmental Monitoring, 2nd ed. London: CRC Press; 1996.
56. Gerber A, Cilliers CJ, van Ginkel C, and Glen R. Easy Identification of Aquatic Plants: A guide for the identification of water plants in and around South African impoundments. Department of Water Affairs All rights reserved; 2004.
57. Kennedy M, and Murphy K. A picture guide to aquatic plants of Zambian rivers. SAFRASS, Southern African Freshwarer Research Assessment. Available online: http://www.kew.org/science-research-data/directory/projects/FloraZambesiaca.htm (accessed on 2 May 2024).

58. NPMS. National Plant Monitoring Scheme, Species Identification Guide. Centre for Ecology and Hydrology, Botanical Society of Britain and Ireland, Plantlife and the Joint Nature Conservation Committee; 2015.
59. Singh KK, Sharma BM, and Usha K. Inventory of the Aquatic Macrophytes in Lake Kharungpat, India. Journal of Energy Technologies and Policy. 2013.
60. Agbogidi OM, Nwabueze AA, Onochie P, et al. Species Diversity of Macrophytes and Physicochemical Parameters of Ponds of Abraka Inland, Delta State, Nigeria. European Journal of Botany. 2022; 1(1): 1-5. doi: 10.24018/ejbotany.2022.1.1.6
61. Akomolafe G, and Nkwocha O. Assessment of the distribution of aquatic macrophytes in Lafia and Doma Metropolis, Nasarawa state, Nigeria. Journal of Research in Forestry, Wildlife & Environment. 2017.
62. Nurminen L. Macrophyte spices composition reflecting water quality changes in adjacent water bodies of lakes Hiidenvesi, SW-Finland. Ann. Bot. Fennici; 2003.
63. Sultana T, Islam MdT, Hasan MdM, et al. Survey on aquatic macrophytes and physico-chemical quality of water from Satla Beel of Barishal district, Bangladesh. International Journal of Fisheries and Aquatic Studies. 2021; 9(5): 01-05. doi: 10.22271/fish.2021.v9.i5a.2555
64. Burlakoti C, Karmacharya SB. Quantitative analysis of macrophytes of Beeshazar Tal, Chitwan, Nepal. Himalayan Journal of Sciences. 1970; 2(3): 37-41. doi: 10.3126/hjs.v2i3.229
65. Kahsay A, Stiers I, Wondie A, et al. The effect of human disturbance on the community composition and diversity of aquatic plants in the tropical wetlands of Lake Tana, Ethiopia. Research Square; 2022.
66. Atsbha T, Desta AB, Zewdu T. Woody species diversity, population structure, and regeneration status in the Gra-Kahsu natural vegetation, southern Tigray of Ethiopia. Heliyon. 2019; 5(1): e01120. doi: 10.1016/j.heliyon.2019.e01120
67. Handa C, et al. Opportunistic vascular plant introductions in agricultural wetlands of East Africa. International Journal of AgriScience. 2012.
68. Alvarez M, Becker M, Böhme B, et al. Floristic classification of the vegetation in small wetlands of Kenya and Tanzania. Biodiversity & Ecology. 2012; 4: 63-76. doi: 10.7809/b-e.00060
69. Kassahun M, Debela H, Endalkachew K. Socio-economic impacts of wetland cultivation in South-Bench, Southwest Ethiopia. African Journal of Agricultural Research. 2015; 10(8): 840-848. doi: 10.5897/ajar2013.7992
70. Ruto W, Kinyamario J, Ng’etich N, et al. Plant Species Diversity and Composition of Two Wetlands in the Nairobi National Park, Kenya. Journal of Wetlands Ecology. 2012; 6: 7-15. doi: 10.3126/jowe.v6i0.5909
71. Maybelstarlin N. Macrophyte Diversity of Paakootukulam, a rural Freshwater Pond in Kulasekaram Panchayat, Kanniyakumari District, Tamilnadu, India. International Journal of Innovative Research In Technology. 2022.
72. Ademola BT, Mahuta SI, Argungu LA. Macrophytes abundance in relation to eutrophication status of peri-urban impoundments in Katsina metropolis, Nigeria. Bayero Journal of Pure and Applied Sciences. 2022.