Distribution and Diversity of Macrophytes in Relation to Some Physico-Chemical Factors in the Ketar River, Ziway Catchment, Ethiopia

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Abstract

Distribution and diversity of macrophytes in relation to some physico-chemical factors in the Ketar River were studied from December, 2017 to November, 2018. Physico-chemical parameters and macrophytes were collected from three stations along the river for eight months. Onsite measurements and laboratory work of physico-chemical was analyzed as recommended by APHA [31]. Macrophytes were collected manually using belt transect method. Except for pH and surface water temperatures, all the physico-chemical parameters measured showed no significant difference spatially. During the study period, sixteen macrophyte species belonged to fourteen families were identified. Among the identified macrophyte, 11 of them were emergent, while 3 were rooted with floating leaves and 2 free-floating. Free-floating macrophytes were shared the highest abundance followed by emergent. This research observed that the site (site 3) that was exposed to minimal human impact was rich in diversity and abundance of macrophytes. All the sites were dominated by emergent macrophytes that attained the highest relative frequency followed by rooted emergent species. *Azolla nilotica* and *Pistia stratiotes* were shared the highest abundance and were the dominant macrophyte with the relative frequency of 7.24% and density of 40.91%, and 7.93% and 26.54%, respectively. Under a favorable environment, nutrient loading from nearby creates more favorable conditions for the infestation of the invasive species (*A. nilotica* and *P. stratiotes*) to flourish and out-compete the other species of macrophyte. Therefore, anthropogenic activities that enhance nutrient addition to the River should be regulated.

1 Introduction

The function of macrophytes in the ecosystems is related to their structural attributes like species composition, distribution, abundance, and diversity which in turn relies on various environmental factors such as light, water temperature, substrate composition, disturbance, competitive interactions, herbivory, epiphyte loading, water levels and water quality [1, 2, 3]. Sediment characteristics [4] and physical factors, such as slope, wind, or wave actions [1] are also important in determining aquatic vegetation patterns. In addition, competition between and within species have effect on the diversity and distribution of macrophytic species [5, 6]. The distribution of macrophytes in freshwater ecosystems also seems to be influenced by the nature of the geological formations and the degree and nature of the pressure exerted on these environments [7].

Aquatic macrophytes play an important role in the structure and function of aquatic ecosystems. However, many threats to freshwaters (e.g., climate change, eutrophication, alien species introductions) will also result in reduced macrophyte diversity and favor the establishment of exotic species, at the expense of native species [8]. In Ethiopia, the invasive *water hyacinth* (*Eichhornia crassipes*) is distributed in different water bodies of the country [9] and it has created serious problems for the use of the water as a resource and may affect the abundance and diversity of other macrophytes [10]. Similarly, water lettuce (*Pistia stratiotes*) is among the world's worst weeds [11] and it decreased the growth of aquatic macrophytes [12]. Therefore, because of the significant role played by macrophytes in freshwater ecosystems and the introduction and spread of numerous nonnative species, understanding and

quantifying their abundance, diversity and their relation to environmental factors is crucial for integrated management practices [13].

Macrophytes are an important component of many freshwater ecosystems that play different roles [13]. These include being primary producers [14], providing refuge for macro-invertebrates [15, 16], zooplankton [17], and habitat for the feeding, breeding, and refuge of littoral fish [16]. Moreover, macrophytes affect the cycling of nutrients and contaminants [14, 18], reducing shoreline erosion and sediment re-suspension. They can also be used as indicators of water quality [19, 6].

In Ethiopia, the ecological importance of macrophytes has been neglected and only a few studies have been conducted in some Lakes in this regard. These include Unbushe [20] on the ecology of the wetland vegetation around Abaya and Chamo in Southern and Fincha'a-Chomen and Dabus in Western Ethiopia, Tamire and Mengistou [21] on macrophytes of Lake Ziway, Pattnaik [22] and Lalisa Gemechu [23] on macrophytes composition of Lake Hawassa. Kassa *et al.* [24] have reported on wetlands of Lake Tana and their macrophyte composition and Dida [25] on the floristic composition of wetland in Wonchi District, South Western Shewa. Recently, Wosnie *et al.*, [26] and Getnet *et al.*, [27] reported on the macrophytes of Lake Koka and the Gilgel Abay catchment, respectively. Rivers have been less investigated than lakes with regard to macrophytes. The aquatic macrophyte in Ethiopian Rift Valley lakes was documented by Kassaye *et al.*, 2016 [28]. The Ketar River is one of the two important influents which accounts for 62.7% of the inflow into Lake Ziway [29]. Along its course, the river carries a lot of nutrients and sediments downstream and the role of macrophytes in regulating their dynamics has not been explained. Hence, this study was conducted to understand the species abundance, distribution, and diversity, and to identify key environmental factors that drive macrophyte in the Ketar River which will provide vital information that can be used for management purposes.

2 Materials And Methods

2.1 Description of the study area and sampling sites

Ketar-Ziway watershed was named after Ketar River and Lake Ziway. Ketar River originates from the ridges of Kaka, Galama and Chilalo mountains along the South-eastern side of the watershed and flows in the western direction and forms part of Lake Ziway. The watershed is located within the Rift Valley basin between 7.3⁰ and 8.2⁰ North Latitude and 38.9⁰ and 39.4⁰ East Longitude. The Ketar catchment shows variations with altitude ranging from around 1638 m a.s.l. near Lake Ziway (at the inlet, present study) to about 4171 m a.s.l, on the high volcanic ridges along the eastern watershed (Chilalo and Galama Mountains) [30].

The river was studied at three sampling sites. The first two sites are located at the upstream of the river and exposed to different human activities carried out in the watershed. The last one is located at the downstream of the river and is relatively less exposed to different stressors. The physical features of the sampling sites are summarized in Table 1.

Table 1. Description of sites along Ketar River used for the collection of samples

Site	GPS location	Description
Site 1	08° 01' 903" N 039° 01' 247" E 1678 m a.s.l	The site is exposed to different human activities, predominantly bathing, livestock watering, water fetching and agriculture. In the proximity of site 1, there is agricultural practice that causes high runoff and siltation. Fertilizers and pesticides are regularly applied here to boost yield of horticultural crops. There is considerable coverage with macrophytes at the edge of the river. But, these macrophytes are affected by overgrazing and cut off by local people for cattle. The site is highly disturbed.
Site 2	08° 01' 904" N 038° 22' 237" E 1677 m a.s.l	This site is located between agricultural land and transport system (regarded as environmentally better than site 1). There is a high probability of organic pollution and inflow of other excess agricultural inputs from upstream into this site as well. However, along the course of the river, there is relatively good coverage of macrophytes and is less impaired by human activities.
Site 3	08° 02' 108" N 038° 56' 334" E 1647 m a.s.l	This sampling site is minimally affected by humans as compared to the other sites. At this site, there was fewer disturbances by livestock and humans. There was also no agricultural activity nearby and relatively low organic and domestic wastes loading. The site is well covered with different macrophytes and the river bank was covered with grass creating a sort of buffering system for the river. So, the site was minimally disturbed.

2.2. Onsite measurements, sampling and laboratory analyses

2.2.1. Onsite measurements

APHA (American Public Health Association) [31] recommends onsite measurements for parameters that change over time due to chemical reactions or biological changes. Thus, dissolved oxygen (DO, mg L⁻¹), pH, electrical conductivity (EC, $\mu\text{S cm}^{-1}$) and water temperature (WT, °C) were measured with a multi-parameter probe (HACH hd401, Loveland, USA) at each sampling site. Electrical conductivity values were corrected to specific conductance at 25 °C (K_{25}) using a temperature coefficient of 2.3% per degree Celsius [32].

2.2.2. Sampling and Laboratory analyses

Water samples were collected from the surface of the river using polyethylene bottles for chemical analysis. Water samples were transported in an ice-box to the limnology laboratory of Addis Ababa University and analyzed immediately. The samples were analyzed following the standard methods described in APHA [31]. SRP and TP (after digestion with persulfate) were measured by the ascorbic acid method. Nitrate ($\text{NO}_3\text{-N}$) was measured with the sodium salicylate method, while ammonia ($\text{NH}_3 + \text{NH}_4^+\text{-N}$) was determined by the phenate method. Nitrite ($\text{NO}_2\text{-N}$) was determined by diazotization with sulphanilamide and coupling to Naphthylethylene diamine di-HCl. The concentration of total suspended solids (TSS) was determined gravimetrically after filtration of a known volume of water sample.

2.3. Sampling design of macrophytes

Samples along the River were sampled eight times (From October to May). Macrophytes were collected manually from three sites. These sites were selected based on their distance from human settlements and anthropogenic effect and presence of macrophyte coverage and accessibility for quantitative study [21]. Sites 1 and 2 are close to human settlements. Site 1 is more exposed human impacts. Even though site 2 is close to human settlements, the site is less impaired by human activities than site 1. Site 3 is far from human settlements and is minimally disturbed. It is well covered with different macrophytes that could be creating a sort of buffering system for the river. The aim of such site selection was to encompass varying environmental conditions based on their exposure to anthropogenic activities in the assessment of distribution and abundance of macrophytes and to note the variation in macrophytes distribution and abundance along the course of the River.

After collection, the macrophyte samples were rinsed in situ, blotted, pressed and transported to the National Herbarium, Addis Ababa University, Ethiopia, for identification. Identification was made to the species level using Ethiopian floras such as mentioned in the study by Hedberg and Edward [33] and Edwards *et al.* [34], herbarium collections at Addis Ababa University and with the help of standard kinds of literatures [35, 36, 37] and finally authenticated by the staff of the Herbarium

The quantitative study was carried out in all study sites down the course of the Ketar River. To analyze the macrophyte community, a belt transect method was employed as recommended by IEP [38] and Dawson [39]. Each transect was taken from the shore bank perpendicularly towards the center of the River following Burlakoti and Karmacharya [40] and Dawson [39]. The number of transects at each site varied depending on vegetation cover and environmental heterogeneity [41]. The size of the quadrat used was 1 m^2 in all study sites, following the suggestion of Sutherland [42]. A total of 51 quadrates were laid during the study periods. The quadrates were laid along the transects at 50 m intervals following Dawson [39]. Macrophytes in each quadrat were counted by handpicking, and an independent morphological unit arising from rhizome was considered as an individual macrophyte as stated in the study by Pompeo and Moschini-Carlos [43].

The relative frequency and relative density of each species were calculated as in the study by Singh *et al.* [44] as follows:

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

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

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

Relative frequency = (frequency of species A / total frequency of all species) X 100

Relative density = (density of species A / total density of all species) X 100

Relative abundance = (abundance of species A / total abundance of all species) X 100

2.2.4. Data analysis

The macrophyte data were quantitatively analyzed for abundance, relative frequency and relative density as in the study by Singh *et al.* [44]. Then the data generated were statistically analyzed using SPSS version 21. Spatial variations in abundance and diversity of macrophytes and physicochemical parameters were tested using one-way ANOVA followed by Tukey-HSD. After determining the gradient length (<2) using DCA (Detrended Correspondence Analysis), RDA (Redundant Analysis) was employed to determine the relationship between macrophyte species composition and abundance and environmental parameters using CANOCO for windows 4.5 version Software [45]. To reduce the effect of a rarity on RDA analysis, families that comprised <1% of the organisms at sampling sites were excluded [46]. The macrophyte species diversity index in the River was computed using PAST software.

3 Results

3.1.1. Spatial variations in physico-chemical parameters

Water samples collected along the Ketar River for one year were tested for various physico-chemical water quality parameters (Table 2). The measured pH values showed significant differences among the study sites ($p < 0.05$), with the minimum and maximum mean pH values of 7.84 and 8.3 at sites 1 and 6, respectively (Table 2). The most important parameter related to the sustainability of aquatic life, dissolved oxygen (DO), did not significantly differ among the study sites ($p > 0.05$), with the maximum (6.3 mg/L) and minimum (5.25 mg/L) levels recorded at sites 5 and 6, respectively (Table 2).

The minimum and maximum average surface water temperatures were 20.4°C and 21.4°C recorded at sites 1 and 6, respectively (Table 2). Electrical conductivity (EC, $\mu\text{S}/\text{cm}$) was not significantly different

among the study sites ($p>0.05$) and varied from 202 to 239 (Table 2), with the maximum level occurring at site 6 where the river joins the Lake. TSS varied declining down the river, with the maximum (303.5) and minimum (231.1) levels occurring at sites 3 and 6, respectively.

Even though the concentrations of all nutrients (nitrite, nitrate, ammonia, TP and SRP) varied spatially, the differences among the study sites were not statistically significant ($p>0.05$). Mean values (mg L^{-1}) of nitrite, nitrate, ammonia, TP and SRP ranged from 0.11 to 0.18, 0.21 to 0.28, 0.64 to 0.7, 0.43 to 0.66, and 0.06 to 0.13, respectively (Table 2). Except for pH, and temperature, levels of all measured physico-chemical parameters were not significantly different across the study sites (Table 2).

Table 2. Spatial variations in mean $\pm$ standard deviation of physioc-chemical parameters

Sites	pH	Temp ($^{\circ}\text{C}$)	EC ($\mu\text{S}/\text{cm}$)	DO(mg/L)	TSS(mg/L)
	Mean $\pm$ SD ^a	Mean $\pm$ SD ^a	Mean $\pm$ SD ^a	Mean $\pm$ SD ^a	Mean $\pm$ SD ^a
1	7.84 $\pm$ 0.12 ^a	20.4 $\pm$ 1.1 ^a	202.7 $\pm$ 56 ^a	5.44 $\pm$ 0.66 ^a	298.7 $\pm$ 194.6 ^a
2	7.95 $\pm$ 0.16 ^b	20.6 $\pm$ 1.1 ^{ab}	202 $\pm$ 54 ^a	5.4 $\pm$ 0.67 ^a	286.1 $\pm$ 193.2 ^a
3	7.97 $\pm$ 0.2 ^{bc}	21.22 $\pm$ 1.3 ^{ab}	202 $\pm$ 55.4 ^a	5.25 $\pm$ 0.8 ^a	303.5 $\pm$ 182.5 ^a
4	8.11 $\pm$ 0.14 ^{cd}	20.9 $\pm$ 1.55 ^{ab}	213.4 $\pm$ 50 ^a	6.24 $\pm$ 0.7 ^a	232.3 $\pm$ 148.5 ^a
5	8.07 $\pm$ 0.13 ^d	21.3 $\pm$ 1.65 ^{ab}	217.3 $\pm$ 60.8 ^a	6.3 $\pm$ 0.67 ^a	238.4 $\pm$ 168.8 ^a
6	8.3 $\pm$ 0.14 ^e	21.4 $\pm$ 1.7 ^b	239 $\pm$ 55 ^a	6.1 $\pm$ 1.2 ^a	231.1 $\pm$ 155.8 ^a
Sites	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	TP (mg/L)	SRP (mg/L)
	Mean + SD ^a	Mean + SD ^a	Mean + SD ^a	Mean + SD ^a	Mean + SD ^a
1	0.11 $\pm$ 0.07 ^a	0.22 $\pm$ 0.05 ^a	0.7 $\pm$ 0.2 ^a	0.66 $\pm$ 0.6 ^a	0.13 $\pm$ 0.25 ^a
2	0.17 $\pm$ 0.3 ^a	0.28 $\pm$ 0.28 ^a	0.66 $\pm$ 0.18 ^a	0.55 $\pm$ 0.48 ^a	0.06 $\pm$ 0.1 ^a
3	0.12 $\pm$ 0.12 ^a	0.22 $\pm$ 0.06 ^a	0.65 $\pm$ 0.17 ^a	0.54 $\pm$ 0.43 ^a	0.07 $\pm$ 0.1 ^a
4	0.16 $\pm$ 0.26 ^a	0.22 $\pm$ 0.07 ^a	0.66 $\pm$ 0.2 ^a	0.43 $\pm$ 0.33 ^a	0.09 $\pm$ 0.1 ^a
5	0.18 $\pm$ 0.3 ^a	0.21 $\pm$ 0.05 ^a	0.64 $\pm$ 0.2 ^a	0.53 $\pm$ 0.46 ^a	0.08 $\pm$ 0.091 ^a
6	0.14 $\pm$ 0.19 ^a	0.21 $\pm$ 0.05 ^a	0.65 $\pm$ 0.23 ^a	0.56 $\pm$ 0.47 ^a	0.075 $\pm$ 0.08 ^a

Note: Mean values with different letters (a, b, c, d and e) within a column are significantly different, while those with the same letter are not significantly different ($p<0.05$).

3.2. Species composition, abundance and distribution of macrophytes

Sixteen macrophyte species belonged to fourteen families were identified, and their relative frequency and density are listed below in Table 1. Relatively, Cyperaceae and Poaceae were dominant families both represented by 2 species each, while other families were represented by a single species. Among the identified macrophyte, 11 of them were emergent, while 3 were rooted with floating leaves (*Nymphoides peltata* and *Nymphaea lotus*) and 2 free floating (*Pistia stratiotes* and *Azolla nilotica*). Free floating macrophytes were shared the highest abundance followed by emergent. All the sites were dominated by emergent macrophytes that attained the highest relative frequency followed by the rooted emergent species, while free floating macrophyte species shared highest relative density followed by emergent species. The largest percentage compositions of macrophytes was comprised by the emergent group (66.58%), followed by rooted emergent (18.27%). The lowest percentage (15.17%) was contributed by free-floating species (Fig. 1). *Azolla nilotica* and *Pistia stratiotes* were shared the highest abundance and were the dominant macrophyte with the relative frequency of 7.24% and density of 40.91%, and 7.93% and 26.54%, respectively. *Azolla nilotica* was occurred at all the sites, while *Pistia stratiotes* has occurred at site 3 only. *Ludwigia stolonifera*, *Nymphoides peltata* and *Echinochloa stagnina* followed in their dominance with the relative frequency of 10%, 9.66% and 12.07%, and relative density of 9.13%, 7.03% and 4.93%, respectively. Even though *Persicaria senegalensis* did not dominant abundantly, it had high relative frequency (12.76%) and density (3.94%) (Table 3).

Table 3. Macrophyte diversity, life form and abundance in Ketar River

Macrophyte		Life forms	Abundance (m ⁻²)	%RF	%RD
Family	Species				
Acanthaceae	<i>Asteracantha longifolia</i> (L.) Nees	Emergent	2.56	3.1	0.81
Alismataceae	<i>Limnocharis flava</i> (L.) Buchenau	Emergent	2.3	3.45	0.18
Amaranthaceae	<i>Antheranthera sessilis</i>	Emergent	7.92	4.48	0.8
Araceae	<i>Pistia stratiotes</i> L. (Khudipana)	Free floating	148.48	7.93	27
Azollaceae	<i>Azolla nilotica</i>	Free floating	250.62	7.24	41.62
Commelinaceae	<i>Commelina latifolia</i>	Emergent	13.23	4.48	1.36
Convolvulaceae	<i>Ipomoea aquatic</i> forssk	Rooted Emergent	12.74	6.55	1.91
Cyperaceae	<i>Cyperus dives</i>	Emergent	5.82	7.58	1
	<i>Cyperus papyrus</i> L	Emergent	4.09	3.79	0.356
Menyanthaceae	<i>Nymphoides peltata</i>	Rooted Emergent	31.75	9.66	7.03
Nymphaeaceae	<i>Nymphaea lotus</i> L.	Rooted Emergent	5.17	2.07	0.25
Onagraceae	<i>Ludwigia stolonifera</i> (Guill.&Perr.) P.H.Raven	Emergent	39.79	10	9.13
Poaceae	<i>Echinochloa stagnina</i> (Retz.) P.Beauv	Emergent	17.83	12.07	4.93
	<i>Phragmites australis</i>	Emergent	3	1.03	0.07
Polygonaceae	<i>Persicaria senegalensis</i> (Meisn.) Sojak	Emergent	13.46	12.76	3.94
Thyphaceae	<i>Typha latifolia</i>	Emergent	2.45	3.79	0.21

Abbreviations: RF = Relative Frequency, RD = Relative Density

3.3. Site Specific Diversity Measures

In macrophyte assemblage terms, *Azolla nilotica*, *Ipomoea aquatic*, *Nymphoides peltata*, *Echinochloa stagnina* and *Persicaria senegalensis* were shared by all the sites and *Azolla nilotica* was dominant throughout the study period. *Pistia stratiotes*, *Cyperus papyrus*, *Phragmites australis* and *Typha*

latifolia were present at site 3 only; the former species shared highest relative abundance next to *Azolla nilotica*, while the latter 3 species contributed the least to the relative abundance of macrophytes (Table 3). During the study period, site 3 shared the highest species richness (12), while site 1 and 2 shared 10 species at each site. *Azolla nilotica* was dominant throughout the sampling periods, while *Pistia stratiotes* was dominant throughout the sampling periods at site 3 only (Personal observation).

Table 4. Occurrence and relative abundance (in %) of macrophyte species among the study sites

Species	Sites		
	Site 1	Site 2	Site 3
<i>Antheranthera sessilis</i>	3.31	0.81	0
<i>Asteracantha longifolia</i> (L.) Nees	0.96	0.67	0
<i>Azolla nilotica</i>	68.39	73.56	51.96
<i>Commelina latifolia</i>	5.92	0	2.1
<i>Cyperus dives</i>	0	1.86	0.76
<i>Cyperus papyrus</i> L	0	0	0.69
<i>Echinochloa stagnina</i> (Retz.) P.Beauv	5.92	5.32	2.6
<i>Ipomoea aquatic</i> forssk	0.83	4.43	0.34
<i>Limnocharis flava</i> (L.) Buchenau	1.05	0.4	0
<i>Ludwigia stolonifera</i> (Guill.&Perr.) P.H.Raven	0	3.88	7.31
<i>Nymphaea lotus</i> L.	1.91	0	0
<i>Nymphoides peltata</i>	4.44	5.78	6.47
<i>Persicaria senegalensis</i> (Meisn.) Sojak	7.25	3.28	1.53
<i>Phragmites australis</i>	0	0	0.51
<i>Pistia stratiotes</i> L. (Khudipana)	0	0	25.1
<i>Typha latifolia</i>	0	0	0.7
Total Species	10	10	12

Among the studied sites, site 3 shared the highest species richness (12), while sites 1 and 2 shared 10 species each. Down the course, the abundance of the macrophytes was increased and the highest abundance was recorded at site 3. Key community parameters (Shannon Diversity Index and evenness) generated for each site showed significant site-specific variation (ANOVA, $p < 0.05$). The overall macrophyte diversity index of site 3 was high ($H' = 1.44$) and; the site had a value significantly higher than sites 1 and 2. Evenness also varied significantly among the sampling sites ($p < 0.05$); site 3 (0.36)

had value significantly higher than the site 1 and 2. Generally, site 3 had the highest species richness, abundance, Shannon diversity and evenness value.

Table 5. Spatial variation in macrophyte taxa, abundance and diversity indices (mean $\pm$ SD)

	Site 1	Site 2	Site 3
Taxa_S	10	10	12
Individuals	264	363	587
Shannon_H	1.23 $\pm$ 0.02 ^a	1.07 $\pm$ 0.02 ^b	1.44 $\pm$ 0.03 ^c
Evenness_e^H/S	0.34 $\pm$ 0.005 ^a	0.29 $\pm$ 0.005 ^b	0.35 $\pm$ 0.01 ^c

Note: Different letters (a, b and c) within a row associated with SDI and evenness values indicate significant differences among sites.

3.4. Relationships between Macrophytes and Environmental Variables

Results of RDA showed that all of the environmental factors were the main determining factors that governed the distribution of macrophytes in Ketar River. The first two axes explained 96.6% of the species-environment relation, while axis 1 only explained 81.1%. pH, temperature, conductivity and dissolved oxygen had significant positive with axis 1 and determined the distribution of *Azolla nilotica*, *Nymphoide speltata* and *Ludwigia stolonifera* and *Pistia stratiotes* while ammonium, total phosphorous and total suspended solid had a significant negative correlation with axis 1 and determined the distribution of most of the macrophytes. Axis II had significant positive correlation with nitrate and nitrite and predicted the distribution of *Azollanilotica*, *Echinochloa stagnina*, *Ipomoea aquatic*, *Ludwigia stolonifera* and *Nymphoides peltata* and ammonium had a significant negative correlation and predicted the distribution of most macrophytes. RDA supports the result obtained with ANOVA and the physicochemical parameters pH, temperature, conductivity and dissolved oxygen characterize at site3 (**Table 6 and Fig. 2**).

Table 6. Results of redundancy analysis (RDA) of the relationships between macrophytes communities and environmental parameters (strong correlations are marked in boldface figures).

	Axis 1	Axis 2
Eigenvalues:	0.817	0.149
Cumulative percentage variance of species-environment relation:	81.7	96.6
pH	0.9468	0.3217
Temperature	0.9499	0.3124
Conductivity	0.9887	-0.1499
Dissolved oxygen (DO)	0.9903	-0.1391
Nitrite (NO ₂ -N)	0.4697	0.8828
Nitrate (NO ₃ -N)	-0.4163	0.9092
Ammonium (NH ₄)	-0.5793	-0.8151
Total Phosphorous (TP)	-0.9415	-0.3369
Total suspended solid (TSS)	-0.9978	-0.0667

Table 7. Spatial variation in macrophyte taxa, abundance and diversity indices

	Site 1	Site 2	Site 3
Taxa_S	10	10	12
Individuals	264	363	597
Dominance_D	0.4904	0.5632	0.3367
Simpson_1-D	0.5096	0.4368	0.6633
Shannon_H	1.229	1.072	1.462
Evenness_e^H/S	0.3419	0.2921	0.3596
Brillouin	1.079	0.9427	1.391
Menhinick	0.6106	0.5212	0.4899
Margalef	1.614	1.527	1.721
Equitability_J	0.5339	0.4655	0.5884
Fisher_alpha	2.048	1.896	2.125
Berger-Parker	0.686	0.7416	0.5116
Chao-1	10	10	12

Table 8. Physicochemical parameters (mean) along the study sites

	Site 1	Site 2	Site 3
pH	7.84	7.95	8.11
Temp	20.4	20.6	20.9
EC	202.7	202	213.4
DO	5.44	5.4	6.24
NO ₂	0.11	0.17	0.16
NO ₃	0.22	0.28	0.22
NH ₄	0.7	0.66	0.66
TP	0.66	0.55	0.43
TSS	298.7	286.1	232.3

4 Discussion

4.1. Physico-chemical parameters

The pH of Ketar River varied from 7.84 - 8.11 indicating the alkaline nature of the river water, The pH values of the present study are within the range of desirable levels of pH (6.5-8.5) set by WHO [47] for optimal growth of aquatic organisms. The slight increase in pH observed along the river course (Table 2) may be associated with the deposition of sediment, which is known to contribute to an increase in pH values [48].

Temperature is a factor of great importance for an aquatic ecosystem, as it affects the organisms, as well as the physical and chemical characteristics of water [49]. The present surface water temperatures are cooler than those reported by Degefu *et al.* [50] (23.53 - 25.65 °C) for Awash River. The lower level of surface water temperature of the present study might be due to the shading effect of macrophytes found along the banks of Ketar River, a condition, which was shown to impact river water temperature by, Lin and Herold [51] and Willis *et al.* [52]. The recorded mean levels of EC (202 to 239 µS/cm), which is a function of the amount of total dissolved salts [53], are lower than the permissible limit set by WHO [47] for drinking water. Koning and Roos [54] reported that the average EC value of typical, unpolluted rivers is approximately 350 mS/cm. Thus, the present result, which is less than 350 mS/cm indicates that the river water is suitable for direct domestic use. Compared to the levels of EC reported by Degefu *et al.* [50] for Awash River (327.67 - 492.87 µS/cm), the present results for Ketar River indicate its much lower level of EC. This suggests that the river receives a low amount of dissolved inorganic substances in ionized form from its surface watershed [55].

The TSS content of water depends on the number of suspended particles, soil and silt, which are directly related to the turbidity of water. The present average values of TSS (231.1 - 303.5 mg/L) are much higher than the permissible limit (150 mg/L) set by WHO [47] for drinking water. These high TSS values could be attributed to surface runoff and disposal of domestic sewage. Although the recorded TSS levels showed no significant differences among the study sites, the slightly higher values recorded at site 3 seem to have resulted from surface runoff from nearby agricultural lands. According to Akan *et al.* [56], river water with TSS values greater than 100 mg/L but less than 220 mg/L is classified as medium wastewater. Thus, the overall mean TSS value for Ketar River is 267.3 mg/L, which warrants its classification as high wastewater.

Dissolved Oxygen is the most important parameter related to the sustainability of aquatic life. The lowest level of the range of concentrations of DO recorded in this study (5.25 – 6.3 mg/L) occurred at sites 2 and 3, which receive agricultural runoff and animal wastes from nearby livestock holding operations. The high mean concentrations of DO recorded at the lower sites (sites 4 – 6) could be due to the self purification of the water along the course of the river. The absence of statistically significant difference in the DO levels among sites at 95% confidence level (Table 2) might be that the river flowing down its course creates turbulence, which favors the dissolution of atmospheric oxygen [57]. The mean values of the present study varied within a narrower range compared with those reported previously by Degefu *et al.* [50] and Eliku and Leta [58] for Awash River (3.62 – 7.58 mg/L). At all sites, the concentrations of DO were above the minimum required (4mg/L) for the survival of the biological components of aquatic ecosystems [59]. According to USEPA [60], the values of DO within the range of 5–14.6 mg/L indicate a healthy water body. Furthermore, the measured values of DO of all sampling sites are within the range of desirable levels (>5 mg/L) recommended by WHO [47] for the survival of aquatic life.

The mean concentrations (mg L^{-1}) of nitrite (0.11 - 0.18), nitrate (0.21 - 0.28) and ammonia (0.64 - 0.7) varied within narrow ranges (Table 2). The values of nitrate are less than those reported by Degefu *et al.* [50] for Awash River, while those of ammonia are much higher than the levels documented by Degefu *et al.* [50]. In the present study, the concentration of both nitrate and ammonia were much lower than the maximum permissible limit set by the Ethiopian EPA [61]. Agricultural practices within the catchment taking place in the vicinity of the river seem to have resulted in the high concentrations of nitrate-nitrogen [62]. The increasing trend of ammonia levels (0.64 - 0.7 mg/L) from upstream to downstream of the river may have been associated with the differences in the level of application of fertilizers.

Means of the concentrations (mg L^{-1}) of TP (0.43 - 0.66) and SRP (0.06 - 0.13) measured in Ketar River, which did not show significant differences among sampling sites, were noticeably low despite the occurrence of agricultural practices that involve the application of fertilizers within the basin. The maximum concentrations of TP and SRP recorded at site 1 could be associated with the application of phosphate-containing fertilizers in agricultural activities carried out in the vicinity of Ketar River [62].

SRP values recorded for the river water are agreed with the value reported for Elala River (0.03 ± 0.001 to 0.14 ± 0.008 mg/L) by Gebreyohannes *et al.* [63] while, much lower than the value reported for the Awash River (49 – 56 mg/L) by Degefu *et al.* [50]. In contrast, Awash River originates from the central highland

area of Ethiopia and receives effluents from different sources while crossing extensive areas of agricultural farms as well as various industries [58]. Thus, the lower levels of such physico-chemical parameters as SRP and TP in Ketar River relative to those of Awash River are not surprising.

4.2. Diversity and distribution of macrophytes

In this study, 16 species of macrophytes belonging to 14 families were identified. From the identified species of macrophytes, Cyperaceae and Poaceae shared 2 species each, while other families were represented by a single species. A comparable result with the present study, fourteen macrophyte species belonged to nine families were reported in Lake Ziway (which feed by Ketar River) by Tamire and Mengistou [21]. The present study was higher than the result reported in other Rivers, Viz., 9 species in the main channel of the Upper Paraná River reported by Souza *et al.* [64] and 13 species in the Lepenci River by Bytyqi *et al.*, [65], while was much lower than 31 species reported in mid cross River by Uneke & Ekuma [66]. The difference in limnology and water level fluctuations of the Rivers water could be the reason for the variation in the macrophytes assemblages between these rivers [67]. In addition, the sampling effort and frequency might be a reason for the variation. However, no submerged macrophytes were recorded in Ketar River. Nurminen [68] noted that water transparency or turbidity, a fluctuation in water level and dominance of free floating macrophytes are among limiting factors of the diversity and abundance of submerged macrophytes.

Among the identified macrophyte species, 11 of them were emergent, while 3 were rooted with floating leaves (*Nymphoides peltata* and *Nymphaea lotus*) and 2 free floating (*Pistia stratiotes* and *Azolla nilotica*). Ketar River is highly dominated by emergent macrophytes in terms of species diversity (compared with floating and submerged macrophytes), which could be due to their high tolerance of water-level fluctuation [5] and water current [69]. Among the emergent species *Ludwigia stolonifera*, *Echinochloa stagnina* and *Persicaria senegalensis* were dominant and shared a relative frequency of 10%, 12.07% and 12.76%, relative density of 9.13%, 4.93% and 3.94%, respectively. However, emergent species did not show dominance in abundance compared with free floating species.

On the contrary, free floating macrophytes shared the highest abundance. The free floating species of macrophytes identified in this study; *A. nilotica* (at all sites) and *Pistia stratiotes* (at site 3) shared highest abundance and were the dominant macrophytes throughout the sampling periods with the relative frequency of 7.24% and density of 40.91%, and 7.93% and 26.54%, respectively. *A. nilotica* was presented at all the study sites, while *Pistia stratiotes* presented at site 3 only. In contrast to the other macrophytes, *A. nilotica* has the ability to fix nitrogen from the air [70] which could create favorable condition for it to compete with other macrophytes. *P. stratiotes* was also the dominant in abundance next to *A. nilotica* in the River. Temperature is one of the most important factors determining growth rates of free floating macrophytes and *P. stratiotes* can grow very quickly in tropical conditions [71]. The optimum temperature growth of *Azolla* ranges from 18 and 28°C [72]. Thus, in addition to a nutrient concentration in Ketar River, the temperature might be created favorable conditions for these dominant species (*A. nilotica* and *P.*

stratiotes) to flourish and out-compete the other species. As Sadeghi *et al.* [73, 74] reported, the presence of macrophytes communities also provides a good opportunity for the flourish of free floating macrophytes by breaking wind speed and water velocity.

Site 3, the site where faced minimal human impact was contributed the higher species diversity (12) and Shannon Diversity Index (1.44) than other sites. During the study period, the site was dominantly covered with *P. stratiotes* and *A. nilotica*. However, in addition to the higher taxa richness at site 3, the site exhibited a higher evenness value than sites 1 and 2. Research conducted by Larbi *et al.* [75] concurred that the site away from human impact is rich in diversity. So, species richness at site 3 might be related to the minimal human impact at the site. However, species richness among sites did not show significant differences among each other which might be related to the homogeneity among the sites [76], which also agreed with the recorded physicochemical parameters of the present study.

4.3. Environmental drivers of Macrophyte Abundance

Redundancy analysis (RDA) indicated that all the environmental parameters studied in this study had strong correlations and were important predictors of macrophyte species distribution in Ketar River. A number of reports indicate that the distribution, abundance and diversity of macrophytes have an association with various environmental factors such as temperature [4, 71], water turbidity [67], nutrient enrichment [77, 78, 13], pH and DO [79] and conductivity [80] which is also shared with the present study. In this study, macrophytes including *A. nilotica*, *N. peltata* and *L. stolonifera* and *P. stratiotes* were strongly associated with pH, temperature, conductivity, dissolved oxygen, total phosphorous and total suspended solids. Ammonium, total phosphorous and nitrate were determined the distribution of most macrophytes such as *A. nilotica*, *E. stagnina*, *I. aquatic*, *L. stolonifera* and *N. peltata*. Frankouich *et al.* [81] also confirmed the association of the distribution and growth of aquatic macrophytes with nutrient rich.

A. nilotica and *P. stratiotes* are the worst invasive floating macrophytes and have the ability to invade new habitats within a short period of time under a favorable environment. I observed that at the late dry season (before set on the wet season) the river was loaded with nutrients that could be encouraging the infestations of these macrophytes. In contrast to *P. stratiotes*, *A. nilotica* can exist even under low nutrient conditions by fixing nitrogen from the air. The occurrence of *A. nilotica* in the River seems not to be affected by differences in the nutrient condition among sites, and its ability to colonize these varied sites indicates its potential to adapt to diverse trophic conditions. Additionally, the presence of an emergent macrophyte provides a good opportunity for Azolla to grow widely by breaking wind speed and water current.

Ketar River is the main tributary of Lake Ziway. Research conducted by and Tamire and Mengistou [21] indicates that Lake Ziway is dominated by emergent macrophytes. But, the littoral area of the Lake has been affected by anthropogenic activities; such as irrigation developments and abstraction of water for floriculture, and as result the water level of Lake Ziway has been declining [82, 83]. The above authors [82, 83] also reported that due to high evaporation, the lake showed a net loss of 74 million m³ volume of

water annually. The emergence of some invasive species of macrophyte such as *P. stratiotes* and *A. nilotica* including *water hyacinth (Eichhornia crassipes)* in Lake Ziway further makes worse the condition which calls for serious intervention in the catchment.

5 Conclusion

In general, the site (site 3) that was exposed to minimal human impact was rich in diversity and abundance of macrophytes. In this study, the emergent macrophytes were dominant in terms of species diversity, while free floating macrophytes (*P. stratiotes* and *A. nilotica*) were dominant in abundance. Biotic and abiotic factors lead to significant variations in distribution, diversity and abundance of aquatic macrophytes. In addition to good physical condition and presence of macrophyte stand that provides a conducive environment, increases in nutrient loading from nearby create favorable conditions for the infestation of the invasive species (*A. nilotica* and *P. stratiotes*) to flourish and out-compete the other species of macrophyte. Therefore, anthropogenic activities that enhance nutrient addition to the River should be regulated.

Abbreviations

ANOVA	Analysis of Variance
APHA	American Public Health Association
m.a.s.l.	Meter above sea level
PAST	PAleontological STatistics
SD	Standard Deviation
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

Declarations

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Availability of data and material

It's prepared on separated part (on Microsoft excel sheet). Or, if anybody request for the additional material/s, the corresponding author ready to afford accordingly.

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Competing interests

The authors declare no competing of interest.

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Figures

Figure 1

Percentage coverage of species of macrophyte life-form to the total macrophyte counts in the Ketar River

Figure 2

Redundancy analysis (RDA) tri-plot of macrophyte in relation to selected physicochemical parameters and sites (Sites abbreviation: 1 – site 1. 2- site 2 and 3 – site 3; Species abbreviation: Antheran- Antheranthera sessilis, Azol- Azolla nilotica, C.lati – Commelina latifolia, E.stag – Echinochloa stagnina, I.aquat- Ipomoea aquatic, Luwd – Ludwigia stolonifera, N.pelt- Nymphoides peltata, Persi- Persicaria senegalensis and Pistia- Pistia stratiotes)

Supplementary Files

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- [BMCEcologyandevolution.xlsx](#)