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RESEARCH ARTICLE

INFLUENCE OF ABIOTIC FACTORS AND MACROPHYTE COVER ON ZOOPLANKTON DISTRIBUTION IN THE KETAR RIVER BACKWATERS

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ABSTRACT: The aim of this study was to assess the relative influence of abiotic parameters and macrophyte cover on the diversity and distribution of zooplankton along the backwaters of the Ketar River. Six sampling sites were selected along the river stretch and samples were collected from December 2017 to November 2018. Zooplankton samples were collected from stagnant backpools using 30 µm mesh size plankton net. A total of 36 species of zooplankton were identified. Rotifera was represented by 28 species while Copepoda had only 2 species. Significant difference in zooplankton taxa were observed between seasons and among the study sites. Downstream site 6 was the richest both in abundance and diversity, and the species richness was significantly higher in the dry season. *Mesocyclops aequatorialis* was a dominant species in all the study sites. Electrical conductivity and total phosphate were the main abiotic factors that positively influenced the distribution of zooplankton in the river (Redundancy analysis). Contrary to previous finding, significantly more diverse and abundant zooplankton communities were recorded in the sites with no macrophyte cover in the Ketar River. The study indicated that both spatial and temporal changes in abiotic factors were more important than macrophyte cover for zooplankton dynamics in this important influent river into Lake Ziway.

Key words/phrases: Diversity, Ketar River, Macrophyte cover, Water quality, Zooplankton.

INTRODUCTION

The literature on zooplankton dynamics is overwhelmingly replete with data from lentic systems (lakes, reservoirs and wetlands) compared to the few data for lotic systems such as rivers, largely because the fast current in rivers obviates the establishment and proliferation of planktonic organisms (Wetzel, 2001). However, many large rivers have extensive backwaters which could serve as suitable habitat for plankton development (Burdis and Hoxmeir, 2011; Burdis and Hirsch, 2017). Many of such backwaters are

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also covered with macrophytes which are preferred sites for zooplankton refuge and food source, even though strong interspecific competition can be critical in such crowded microhabitats (Brandl, 2005). Several ecologists who studied backwaters of large rivers such as the Mississippi have noted that water quality, physical habitat, presence of macrophytes and zooplankton sources are the main factors that influence zooplankton community structure (Burdis and Hoxmeir, 2011) including the water residence time of the habitats (Burdis and Hirsch, 2017).

Zooplankton dynamics is less understood in the slow-flowing parts of rivers which resemble lacustrine conditions, despite a vast literature on the ecology of zooplankton in lentic systems. Thus, it is interesting to examine whether the same abiotic factors that govern zooplankton dynamics in lakes are equally important in rivers. Although abiotic factors are important in regulating zooplankton dynamics in backwaters and large shallow lakes (e.g. Eshete Dejen *et al*., 2004 in Lake Tana), other biological interactions such as fish predation have been found to be of greater importance in other studies (Jack and Thorp, 2002). The important role of macrophytes in zooplankton ecology in backwaters has been well noted (Cazanelli *et al*., 2008) but their impact on zooplankton community structure has remained largely controversial. It is noted that aquatic macrophytes play an important role in structuring communities in aquatic environments by providing physical structure, increasing habitat complexity and heterogeneity and supporting various organisms including phyto- and zooplankton, macroinvertebrates and fishes. The physical structure and architectural complexity of macrophytes in aquatic habitats determine the communities that resides therein (Petry *et al*., 2003; Rennie and Jackson, 2005).

Macrophytes provide microhabitats for harboring diverse zooplankton taxa (Choi *et al*., 2014; Padovesi-Fonseca and Rezende, 2017). In ox bow lakes, for example, Joniak and Kuczynska-Kippen (2016) reported that habitat complexity of macrophytes increased zooplankton species richness while abiotic factors were more variable and unstable to account for changes in zooplankton densities. Meerhoff *et al*. (2007) confirmed, through their experimental study on phytoplankton, zooplankton and fish in sub-tropical lakes, that macrophytes are used as prey refuge and influence bottom-up and top-down mechanisms. Lehtiniemi (2005) and Okun and Mehner (2005) also contend that different predators such as invertebrates and young fish utilize aquatic macrophytes for survival. Predators' pressure in turn could affect the biomass, structure and average size of the zooplankton community (Brucet *et al*., 2010).

Aquatic macrophytes provide refuges for abundant and diverse zooplankton communities, even though different predators such as invertebrates and small fish are also attracted (Meerhoff *et al*., 2007; Mesfin Gebrehiwot *et al*., 2017). For instance, Cladocera and Copepod taxa prefer aquatic macrophytes to avoid predation due to their large size (Watkins *et al*., 1983). However, the smaller-sized, rotifers' preference to the non-vegetated area in aquatic ecosystem may be due to their ability to avoid predation (Hutchinson, 1967; Phan *et al*., 2021). Similarly, protozoa and meroplankton prefer the non-vegetated area, which could indicate allelopathic effect of macrophytes on their density (Abd El-Hady and Khalifa, 2015).

The abundance and diversity of zooplankton have positive relationship with macrophyte stands; since macrophytes provide them shelter and refuge (Padovesi-Fonseca and Rezende, 2017; Mimouni *et al*., 2018). Besides macrophytes, the taxonomic structure and the dynamics of zooplankton communities are also influenced by the physical and chemical parameters of the water where they live in (Nessimian *et al*., 2008). Factors such as temperature, pH, DO, transparency, electrical conductivity form part of abiotic components and nutrient status of the aquatic ecosystem directly affect the abundance of zooplankton (Imam and Balarabe, 2012). Semenchenko (2008) emphasized that the role of different factors associated with macrophytes such as allelopathy, competition between zooplankton taxa and predation interactions are largely unknown. Mesfin Gebrehiwot *et al*. (2017) on the other hand, concluded that zooplankton were more abundant in macrophyte-covered littoral sites in Lake Ziway. However, along the course of the Ketar River, macrophytes that could provide zooplankton shelter and refuge are being over-exploited by the local people. Therefore, this study aimed to investigate the spatio-temporal variations in zooplankton community structure among the sites with macrophyte stands and without macrophytes, and to test whether macrophytes in the influent River Ketar also harboured zooplankton or whether abiotic factors were more determinant.

MATERIALS AND METHODS

Description of the study area and sampling sites

The Ketar River originates from the ridges of Kaka, Galama and Chilalo mountains in the south-eastern side of the Ketar-Ziway watershed, named after Ketar River and Lake Ziway, and flows in the western direction and and finally empties into Lake Ziway. The watershed (area of 3,338 km^2) is located within the rift valley between 7.3°and 8.2º North latitude and 38.9º and 39.4º East longitude. The Ketar catchment shows variations in altitude ranging from around 1,646 m a.s.l. near Lake Ziway (at the inlet) to about 4,171 m a.s.l, on the high volcanic ridges along the eastern part of the watershed (Chilalo and Galama Mountains) (Damtew Tufa *et al*., 2015). The river shows striking variations in physical structure and nature and extent of human impacts. It is one of the two major influent rivers into Lake Ziway and contributes twice the annual discharge flow (ca. 11.10 m^3/sec) into the lake.

In Ketar River watershed, population growth and the consequent expansion of cultivated land have increased the mean rate of soil erosion, sediment yield and surface runoff in the last four decades (Damtew Tufa *et al*., 2015; Ajanaw Negese, 2021). A research conducted in Ketar River watershed by Damtew Tufa *et al*. (2015) indicate that agricultural land was increased by 27.7% between 1986 and 2010, with annual rate of 15.5 km^2/year. The same authors reported that wetlands in the watershed decreased by 15% between 1986 and 2010. Surface runoff has also increased from 40.6% to 45.0% due to anthropogenic activities carried out between 1986 and 2010 in Ketar River watershed (Damtew Tufa *et al*., 2015). A project called Ketar-Ziway Integrated Watershed Management Project Plan that was managed by Arsi University showed that Woodland decreased by 9%, montane forest decreased by 10% and forest decreased by 93% and grass land decreased by 35% due to the expansion rate of cultivated land within the 27 years (1989 to 2015 G.C.) (Unpublished).

Site sampling

Physico-chemical parameters and zooplankton were sampled from six selected backwater sites (Fig. 1) by purposely choosing sites with minimal water flow and macrophyte stands. Among the six sites, three were without macrophyte stands (sites 3, 5 and 6), while the other three were covered with macrophytes (sites 1, 2 and 4). The dominant macrophytes were *Azolla nilotica*, *Ipomoea aquatic*, *Nymphoides peltata*, *Echinochloa stagnina* and *Persicaria senegalensis*. The physical features of the sampling sites are summarized in Table 1.

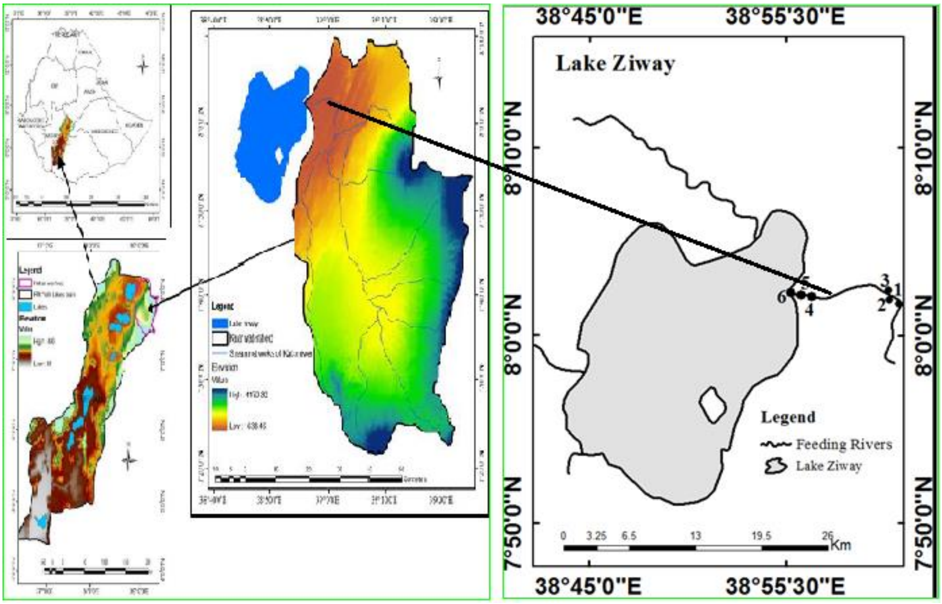

Fig. 1. Map of study area showing the river segment study sites.

Table 1. Description of sites along Ketar River used for the collection of samples employed for the analysis of the present studies.

Site	GPS location	Description
Site 1	8° 1′ 52.46″ N 39° 1′ 18.206″ E 1,678 m a.s.l	The site is exposed to different human activities including agricultural practice that causes high runoff and siltation. Dominant macrophytes at the site include *Azolla nilotica*, *Persicaria senegalensis* and *Echinochloa stagnina*.
Site 2	8° 1′ 55.33″ N 39° 1' 13.861″ E 1,678 m a.s.l	This site is influenced by agricultural inputs and the dominant macrophytes are *Azolla nilotica*, *Nymphoides peltata*, *Echinochloa stagnina* and *Ipomoea aquatic*.
Site 3	8° 1′.57.374″ N 39° 1′ 10.52″ E 1,677 m a.s.l	No macrophyte stands at this site but it is exposed to different stressors from the riparian.
Site 4	8° 2′ 7.976″ N 38° 56′ 15.648″ E 1,647 m a.s.l	This sampling site is minimally affected by human activities as compared to the other sites and is well covered with dominant macrophytes such as *Azolla nilotica*, *Pistia stratiotes*, *Ludwigia stolonifera* and *Nymphoides peltata*.
Site 5	8° 2′ 8.664″ N 38° 56′ 11.745″ E 1,647 m a.s.l	This downstream backwater site is minimally affected by humans and is not covered by macrophytes.
Site 6	8° 2′ 6.295″ N 38° 55′ 54.408″ E 1,646 m a.s.l.	This large backwater at the river mouth into Lake Ziway is minimally affected by human activities and with no macrophyte cover.

Water sampling and laboratory analyses

For the analysis of various physico-chemical parameters, routine water sample collections were carried out monthly for one year from December 2017 to November 2018 from six preselected sampling sites. The sampling months were grouped into two seasons (namely dry and wet seasons).

Dissolved oxygen (DO, mg L^{-1}), pH, electrical conductivity (EC, µS cm^{-1}) and water temperature (WT, °C) were measured *in situ* using a multi-parameter probe (HACH HD401, Loveland, USA) at each sampling site. Electrical conductivity values were converted to specific conductance at 25°C (K_{25}) using a temperature coefficient of 2.3% per degree Celsius (Talling and Talling, 1965). All samplings were done following the recommendations of APHA (2005).

Water samples for chemical analysis were collected from the surface of the river using polyethylene bottles. The 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 (2005). Soluble reactive phosphate (SRP) and total phosphate (TP) (after digestion with persulfate) were measured by the ascorbic acid method. Nitrate (NO_3-N) was measured with the sodium salicylate method, while ammonia (NH_3-N) was determined by the phenate method. Nitrite (NO_2-N) was determined by diazotization with sulphanilamide and coupling with Naphthylethylenediamine di-HCl. The concentration of total suspended solids (TSS) was determined gravimetrically after filtration of a known volume of water sample.

Zooplankton sampling, identification and enumeration

Zooplankton samples were collected monthly from December 2017 to November 2018 from six preselected sampling sites. The sampling months were grouped into two seasons (namely dry and wet seasons). From each sites, triplicate zooplankton samples were collected. A 30 µm mesh size plankton net which was towed vertically over a distance of 1.5 to 2 m below the surface water and hauled out of the water both through the macrophyte stands and without macrophyte stands. Both horizontal and vertical sampling methods were used for the determination of distribution and abundance of zooplankton. Immediately after sampling, zooplankton samples were preserved with 4% neutral formaldehyde in 120 ml plastic bottles and transported to the laboratory for further analysis. Total counts were made and individual densities were expressed as numbers per litre.

In the laboratory, collected samples were thoroughly mixed and, a sub-sample was eventually poured into a gridded glass counting chamber containing 14 grids. Zooplankton were counted under dissecting microscope at a magnification of 40x. Identification of zooplankton species was done using standard methods and references, mainly, Koste *et al*. (1978) and Fernando (2002) and other supplementary sources from the web. Abundance of zooplankton was calculated following the modified equation used in Seyoum Mengistou and Fernando (1991).

$$V_{net}\ (m^3) = \pi\ r^2\ d$$

$$No.\ /m^3 = \frac{C \times TG \times F}{CG \times V_{net}}$$

Where, C = actual count of zooplankton, TG = total grid (14), F = factor of sub-sample, CG = counted grids, Vnet = filtered volume, r = radius of the net, d = the length of the course of the net through the water column (depth of sampling), and π = 3.14

Different aspects of the diversity indices were calculated including taxa richness simply a number of taxa (S), Pielou evenness index: which is expressed following the equation (1):

J = H'/H' max --- (1)

where H' is the number derived from the Shannon diversity index and H'max is the maximum value of H' and Shannon heterogeneity index calculated using equation (2):

H' = −Σpi ln pi -- (2)

where pi is the proportion of individuals found in the ith species

Statistical analysis

To assess the differences among study sites, with respect to levels of nutrients and other selected physico-chemical parameters, one way ANOVA was employed (SPSS version 21). PAST software was used to compute diversity indices. To examine the relationships between the abundance of taxa of zooplankton with environmental parameters, and identify environmental factors influencing zooplankton, Redundancy Analysis (RDA) was performed using Canoco 4.5 with automatic forward selection and 999 permutations. Detrended correspondence analysis (DCA) was used to determine the appropriate response model (linear or unimodal) for the zooplankton. Zooplankton taxa accounting for more than 1% of the total density were included in the analysis (Choi *et al*., 2014). The performed DCA gave a gradient length of < 3 standard deviations (SDs) in both cases, implying that taxa abundance exhibit linear response to environmental gradients (ter Braak and Smilauer, 2002). Prior to the ordination analysis, log (X+1) transformation was performed for the environmental variables, while Hellinger transformation (Legendre and Gallagher, 2001) was applied for the biological data to prevent extreme values (outliers) from unduly influencing the ordination (ter Braak and Smilauer, 2002).

RESULTS

Zooplankton distribution in backwaters

A total of 35 zooplankton species belonging to three groups were identified in this study, of which Rotifers showed the highest total species richness (28 species) followed by Cladocera (5 species). Copepoda was represented by only two cyclopoid species (Table 2).

Table 2. Composition of zooplankton identified in samples collected from Ketar River.

Rotifera		Cladocera	Copepoda (cyclopidae)
Anuraeopsis fissa	*Keratella tropica*	*Anola* sp.	*Mesocyclops aequatorialis*
A. navicula	*Lecane leontina*	*Bosmina* longirostris	*M. edax*
Asplanchna sp.	*L. stenroosi*	*Ceriodaphnia reticulata*	*Cyclopoid nauplii*
Brachionus calciflorus	*Lepadella similis*	*Daphnia barbata*	
B. patulus	*Platyias quadricornis*	*Moinamicrura*	
B. quadridentatus	*Polyarthra vulgaris*		
B. angularis	*Pompholyx sulcata*		
B. caudatus	*Scaridium longicaudum*		
B. longistrus	*Trichocerca elongata*		
B. plicatilis	*T. flagellata*		
Filina pejileri	*T. mus*		
F. pejileri grandis	*T. pussila*		
F. terminals	*T. tropis*		
Horaella brehmi	*T. similis*		

At all study sites, rotifers were numerically the most dominant, while cladocerans were the least abundant of the zooplankton species identified in this study (Fig. 2).

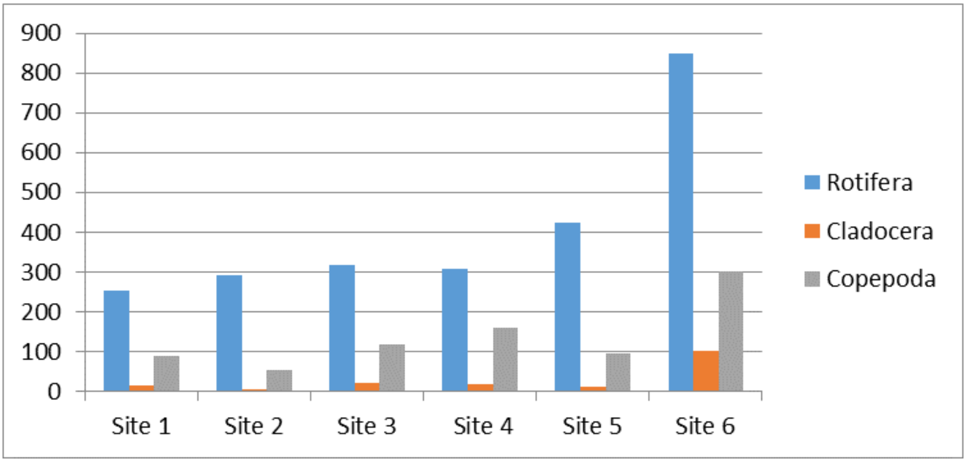

Fig. 2. Abundance and distribution of the three groups of zooplankton in the study sites.

Rotifera contributed the highest percentage (71.30%) of the total abundance of zooplankton, while Copepoda and Cladocera accounted for 23.80% and 4.90%, respectively (Fig. 3).

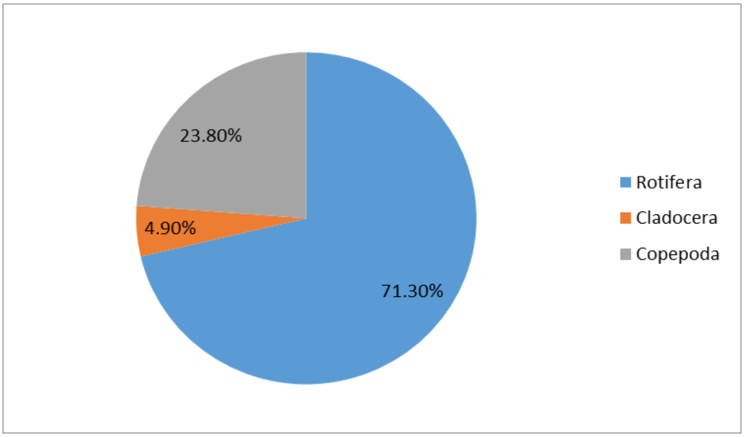

Fig. 3. The percentage composition in group of zooplankton identified in Ketar River.

Mean density of zooplankton varied significantly between the sites with macrophyte cover and the open water ($p<0.05$). The mean of all the three taxa of zooplankton density was higher in the sites where there were no macrophyte stands (open water) (Fig. 4).

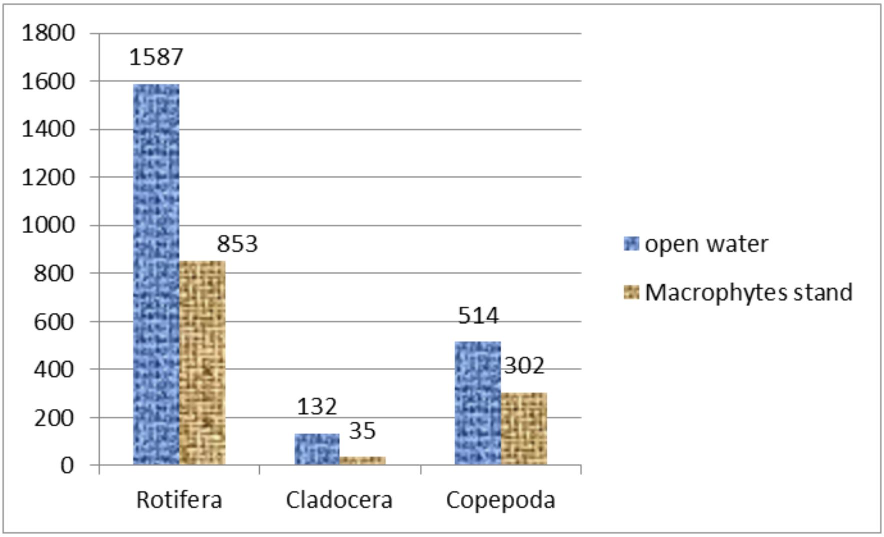

Fig. 4. Abundance of zooplankton taxa across the macrophyte stands and without macrophyte stands.

All zooplankton species encountered in this study and accounting for greater than 1% of the total zooplankton abundance are listed in Table 3. *Mesocyclops aequatorialis* made the highest percentage contribution (11.35%) followed by *Anuraeopsis navicula* whose contribution was 8.01%.

Table 3. The abundance and percentage contribution of identified zooplankton (shared >1%) of the six sites along the Ketar River.

Species	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Contribution**
M. aequatorialis	46.2	30.8	63.14	87.78	55.44	203.28	11.35%
A. navicula	49.28	35.42	41.58	103.18	56.98	56.98	8.01%
C. Nauplii	38.5	23.1	53.9	64.68	41.58	86.24	7.19%
Asplanchna sp	47.74	49.28	4.62	18.48	38.5	129.36	6.72%
P. vulgaris	7.7	15.4	64.68	6.16	36.96	149.38	6.54%
H. brehmi	16.94	12.32	58.52	21.56	30.8	35.42	4.10%
L. leontina	30.8	24.64	23.1	18.48	13.86	43.12	3.59%
A. fissa	12.32	46.2	23.1	20.02	29.26	1.54	3.09%
B. angularis	30.8	18.48	1.54	23.1	16.94	26.18	2.73%
F. pedjeri	0	0	6.16	0	7.7	103.18	2.73%
K. tropica	6.16	13.86	12.32	7.7	20.02	46.2	2.48%
T. mus	4.62	3.1	0	16.94	21.56	55.44	2.37%
B. caudatus	3.08	3.08	4.62	0	27.72	61.6	2.34%
L. stenroosi	7.7	15.4	13.86	20.02	18.48	10.78	2.01%
T. pussila	0	9.24	23.1	0	15.4	38.5	2.01%
B. longirostris	10.78	0	6.16	0	0	40.04	1.33%
L. similis	6.16	9.24	0	7.7	15.4	18.48	1.33%
D. barbata	0	0	4.62	7.7	12.32	24.64	1.15%
B. longistrus	0	0	0	0	0	46.2	1.08%

The highest number of species (29) was recorded at site 6, while the lowest (19) was observed at site 2 (Table 4). The highest and lowest total abundance of zooplankton were recorded at sites 6 (1281) and 2 (338), respectively (Table 4).

The means of the Shannon diversity index (SDI) values of the entire zooplankton community in this study showed no significant difference among the sites 1 to 3. However, at sites 5 and 6 where there were high number of taxa and abundance, and the Shannon diversity index were significantly different from the other sites (Table 4). High mean SDI values of 2.97 and 2.9, recorded for sites 5 and 6, respectively, were considerably different from other sites. The lowest (2.58) and highest (2.97) SDI values were recorded at sites 4 and 5, respectively (Table 4).

Table 4. Diversity, abundance and Shannon diversity index values of zooplankton groups at six sampling sites along Ketar River.

		Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**
All groups of zooplankton	Taxa_S	22	19	22	22	25	29
	Individuals	344	338	432	459	507	1251
	Shannon_H	2.65ab	2.7a	2.6ab	2.58b	2.97c	2.9c

Note: Different letters (a, b and c) within a row indicate the mean SDI values of zooplankton groups are significantly different among sites, while SDI means (within column) associated with the same letter are not significantly different (p>0.05).

During the dry season, all zooplankton groups had higher abundances (Fig. 5). Total zooplankton abundance varied significantly between the dry and wet seasons (Table 5). Unlike those of cladocerans, mean Shannon diversity index values of rotifers and copepods showed significant difference between the seasons (Table 5).

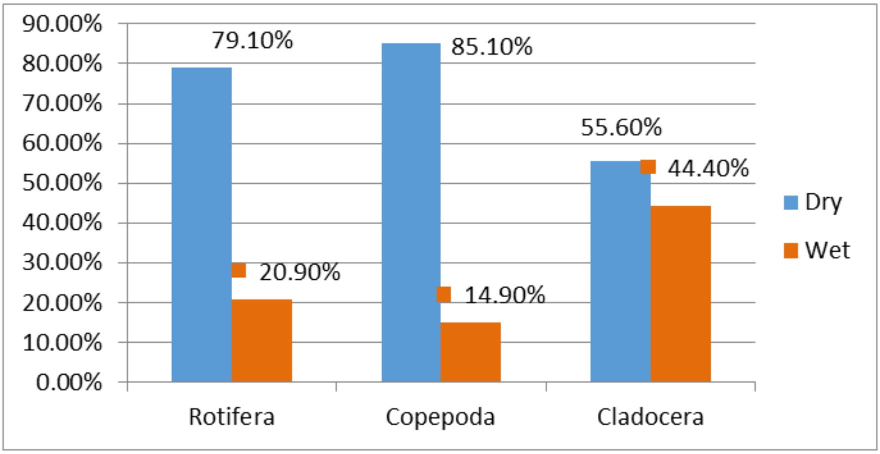

Fig. 5. Percentage contribution of the three group of zooplankton during the dry and wet seasons.

Table 5. Variation of diversity indices of different groups of zooplankton in Ketar River between seasons.

Group	Dry season		Wet season	
	SDI	Evenness	SDI	Evenness
Sum of values of all group of zooplankton	3.02[a]	0.57[a]	2.81[b]	0.76[b]

Note: Different letters (a and b) within a row associated with SDI and evenness values indicate significant differences between dry and wet seasons, while the same letters denote differences, which are not statistically significant ($p<0.05$).

Spatio-temporal variation in physico-chemical parameters along Ketar River

Table 6 gives the result of physico-chemical water quality parameters that were determined in the six backwater sites for one year. The 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). DO was not significantly different among the study sites ($p<0.05$), with the maximum (6.3 mg/L) and minimum (5.25 mg/L) levels occurring at sites 5 and 6, respectively (Table 6).

Table 6. Spatial variations (mean ± standard deviation) of physico-chemical parameters.

Sites	pH	Temp (°C)	EC (µS/cm)	DO (mg/L)	TSS (mg/L)
1	7.84 ± 0.12[a]	20.4 ± 1.1[a]	202.7 ± 56[a]	5.44 ± 0.66[a]	298.7 ± 194.6[a]
2	7.95 ± 0.16[b]	20.6 ± 1.1[ab]	202 ± 54[a]	5.4 ± 0.67[a]	286.1 ± 193.2[a]
3	7.97 ± 0.2b[c]	21.22 ± 1.3[ab]	202 ± 55.4[a]	5.25 ± 0.8[a]	303.5 ± 182.5[a]
4	8.11 ± 0.14[cd]	20.9 ± 1.55[ab]	213.4 ± 50[a]	6.24 ± 0.7[a]	232.3 ± 148.5[a]
5	8.07 ± 0.13[d]	21.3 ± 1.65[ab]	217.3 ± 60.8[a]	6.3 ± 0.67[a]	238.4 ± 168.8[a]
6	8.3 ± 0.14[e]	21.4 ± 1.7[b]	239 ± 55[a]	6.1 ± 1.2[a]	231.1 ± 155.8[a]
Sites	**NO_2 (mg/L)**	**NO_3 (mg/L)**	**NH_3 (mg/L)**	**TP (mg/L)**	**SRP (mg/L)**
1	0.11 ± 0.07[a]	0.22 ± 0.05[a]	0.7 ± 0.2 [a]	0.66 ± 0.6[a]	0.13 ± 0.25[a]
2	0.17 ± 0.3[a]	0.28 ± 0.28 [a]	0.66 ± 0.18[a]	0.55 ± 0.48[a]	0.06 ± 0.1[a]
3	0.12 ± 0.12 [a]	0.22 ± 0.06 [a]	0.65 ± 0.17[a]	0.54 ± 0.43[a]	0.07 ± 0.1[a]
4	0.16 ± 0.26[a]	0.22 ± 0.07[a]	0.66 ± 0.2 [a]	0.43 ± 0. 33[a]	0.09 ± 0.1[a]
5	0.18 ± 0.3[a]	0.21 ± 0.05 [a]	0.64 ± 0.2[a]	0.53 ± 0.46[a]	0.08 ± 0.091[a]
6	0.14 ± 0.19[a]	0.21 ± 0.05 [a]	0.65 ± 0.23[a]	0.56 ± 0.47[a]	0.075 ± 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 ($p<0.05$).

The minimum recorded mean surface water temperature was 20.4°C and the maximum was 21.4ºC (Table 6). The mean electrical conductivity (EC, µS/cm) varied from 202 to 239 and was not significantly different among the study sites ($p<0.05$) (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 levels recorded at site 3 (303.5) and minimum recorded at site 6 (231.1).

Except for pH and temperature, values of all measured physico-chemical parameters were not significantly different across the study sites. Although the concentrations of all nutrients (nitrite, nitrate, ammonia, TP and SRP) varied spatially, the differences were not significant ($p>0.05$) among the study sites (Table 6).

The mean levels of all physico-chemical parameters recorded during the one-year period differed significantly between seasons (namely; dry and wet seasons) ($p<0.05$, Table 7), with higher levels of all, except temperature (Temp) and electrical conductivity (EC), occurring during the wet season.

Table 7. Variations of (means ± standard deviations) physico-chemical parameters between seasons.

Seasons	**pH** Mean ±SD[a]	**Temp (°C)** Mean ±SD[a]	**EC (µS/cm)** Mean ±SD[a]	**DO (mg/L)** Mean ±SD[a]	**TSS (mg/L)** Mean ±SD[a]
Dry season	8.01 ± 0.22[a]	21.15 ± 1.7[a]	245.4 ± 34.2[a]	5.51 ± .88[a]	197 ± 136.5[a]
Wet season	8.1 ± 0.2[b]	20.7 ± 0.8[b]	146.8 ± 25[b]	6.33 ± .75[b]	400.9 ± 165.6[b]
Seasons	**NO_2 (mg/L)**	**NO_3 (mg/L)**	**NH_3 (mg/L)**	**TP (mg/L)**	**SRP (mg/L)**
Dry season	0.14 ± 0.12[a]	0.2 ± 0.03[a]	0.62 ± 0.18[a]	0.4 ± 0.3[a]	0.11 ± 0.2[a]
Wet season	0.18 ± 0.03[b]	0.24± 0.15[b]	0.73 ± 0.21[b]	0.87 ± 0.5[b]	0.21 ± 0.031[b]

Note: Mean values with different letters (a and b) within a column are significantly different and those followed by the same letter are not significantly different ($p<0.05$).

Relationships between zooplankton and environmental variables

Results of Redundancy Analysis (RDA) indicated that the first two axes explained 84.8% of the cumulative percentage of variance in species - environmental relationship (Table 8). The first axis, which explained 71.3% of the variance, was positively correlated with TP, EC and pH, while the second axis was correlated positively with TSS, TP and temperature. Axis I was negatively but strongly associated with EC, TP and TSS, while axis II was also negatively but strongly correlated with EC, DO and NH_3 (Table 8 and Fig. 6).

Table 8. Results of redundancy analysis (RDA) of the relationships between zooplankton communities and physico-chemical parameters (strong correlations are marked in boldface figures).

Environmental Variables	**Axis 1**	**Axis 2**
Eigen values:	0.713	0.135
Cumulative percentage variance of species-environment relation	71.3	84.8
pH	0.4087	-0.1322
Temperature	-0.3279	0.2723
EC	**0.5493**	**-0.6957**
DO	-0.0796	**-0.6128**
NO_3	-0.0854	-0.3594
NH_3	-0.3571	**-0.6861**
SiO_2	-0.2563	-0.3052
TP	**0.6454**	0.3775
TSS	**-0.7677**	0.4328

Among the physico-chemical parameters determined in the present study on Ketar River, TP, EC and TSS influenced the distribution of *M. aequatorialis*, *T. mus*, *F. pedjeri*, *Naupili*, *P. vulgaris*, *Asplanchna* sp., *B. caudatus* and *B. longirostris*. Ammonium, DO and EC were, however, strongly but negatively correlated with axis II, and influenced the distribution of most zooplankton species (Fig. 6).

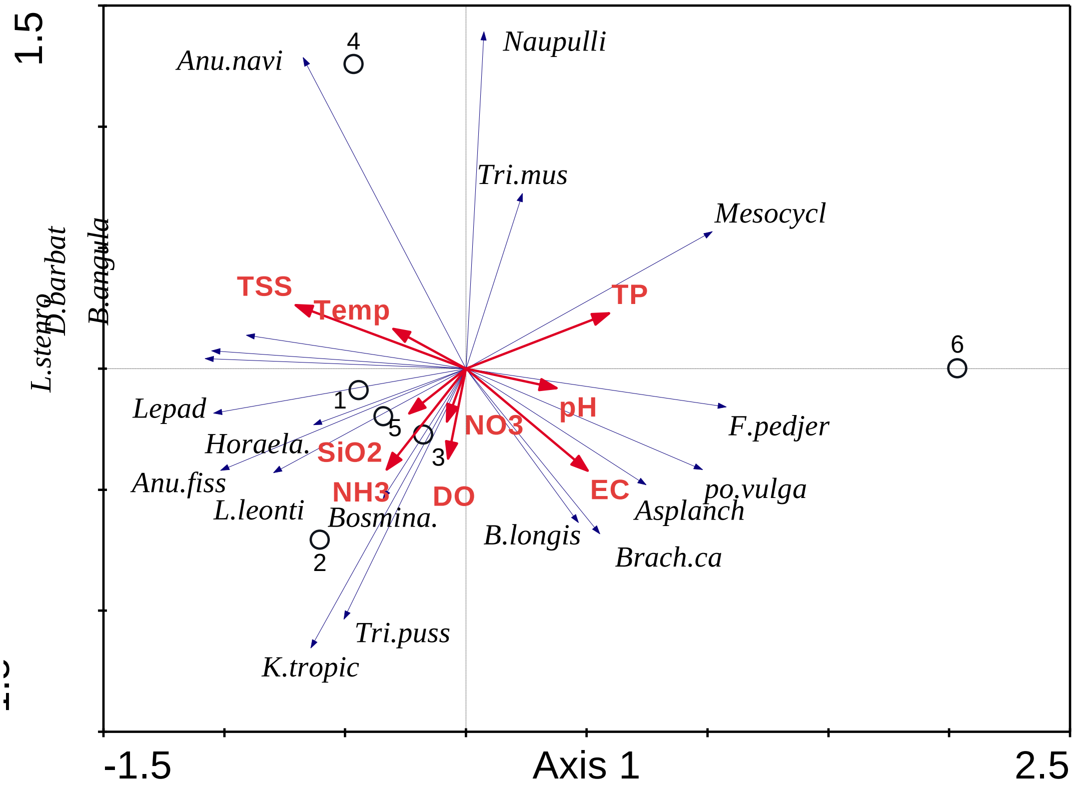

Fig. 6. Redundancy analysis (RDA) tri-plot of dominant Zooplankton (>1%) in relation to selected physic-chemical parameters and sites. (sites abbreviation: 1 – site 1. 2- site 2, 3 – site 3, 4- site 4, 5 – site 5 and 6 – site 6; Species abbreviation: Anu. fiss– *Anuraeopsis fissa*, Anu.navi– *Anuraeopsis navicula*, Asplanchn – *Asplanchna* sp, B.angula– *Brachionus angularis*, Bosmina.–*Bosmina longirostris* , Brach.ca– *Brachionus caudatus*, B.longis– *Brachionus longistrus*, D. barbat - *Daphnia barbata*, F.pedjer– *Filina pejileri*, Horaela.– *Horaella brehmi*, K. tropic– *Keratella tropica*, L.leonti– *Lecane leontina*, L.stenro– *Lecane stenroosi*, Lepad– *Lepadella similis*, Mesocycl– *Mesocyclops aequatorialis*, Naupuli- *Cyclopoid nauplii*, Po.vulga - *Polyarthra vulgaris*, Tri.mus–*Trichocercas mus* and Tri.puss– *Trichocerca pussila*).

DISCUSSION

Macrophytes and zooplankton community in Ketar River

Rotifers showed the highest number of species richness (28) compared to copepods and cladocerans. The dominance of rotifers in species richness in Ketar River is also reflected by their high diversity in tropical fresh waters (Seyoum Mengistou and Fernando, 1991; Adamneh Dagne *et al*., 2008). The major species of rotifers, which were responsible for the dominance of the group included *Anuraeopsis* (*A. navicula* and *A. fissa*), *Asplanchna* sp., *Brachionus* spp. (*B. angularis*, *B. caudatus*, and *B. longistrus*), *Filina pejileri*, *Horaella brehmi*, *Keratella tropica*, *Lecane* (*L. leontina*, *L. stenroosi* and *L. similis*) and *Trichocerca* spp. (*T. mus* and *T. pussila*). The high diversity of rotifers might be associated with the availability of edible phytoplankton (diatoms and green algae) and the low predation pressure due to their smaller size that enable them to avoid predation (Lürling, 2020).

Rotifers were in general more abundant and diverse than other zooplankton in all the sites along the backwaters. Among the recorded Rotifer species; *Anuraeopsis fissa*, *Anuraeopsis navicula*, *Asplanchna* sp., *Brachionus angularis*, *Horaella brehmi*, *Keratella tropica*, *Lecane leontina*, *Lecane stenroosi*, *Lepadella similis* and *Polyarthra vulgaris* were observed in all the study sites, while all identified Rotifera except *Brachionus patulus*, *Brachionus quadrimentatus*, *Filina terminals*, *Platia squadricornis* and *Scaridium longicaudum* were present at site 6. The mean abundance of rotifers at sites not covered with macrophytes was significantly different from that of sites covered with macrophytes. Thus, the present results are not consistent with the generalization that the presence of macrophyte stands may be important in creating comfort zone and providing zooplankton a refuge against predators (Mimouni *et al*., 2018). However, the results of the present study concur with the work of Hutchinson (1967), who reported that rotifers prefer non-vegetated area in aquatic ecosystems owing to their ability to avoid predation.

Copepoda was the second dominant zooplankton taxon and contributed 23.80% of the total abundance. The peak abundance of copepods was observed during the dry season, which might be related to the presence of peak abundance of diatoms and green algae during this season (Okogwu and Ugwumba, 2013). In the present study, the large-sized *Mesocyclops aequatorialis* had the highest abundance of all zooplankton species, accounting for 11.35% of the total abundance of recorded zooplankton species along the Ketar River. As Sampaio *et al*. (2002)

suggested, larger size zooplankton species are highly affected by predation mortality rate. In contrast to this hypothesis, the results of the present study seem to suggest that the dominance of *M. aequatorialis* could be related to its low adult mortality and high fecundity (Ayalew Wondie and Seyoum Mengistou, 2006; Tadesse Fetahi *et al*., 2011).

Cladocerans had the least abundance in all the sites, with mean Shannon diversity index value of 0.73 and accounting for only 4.90% to the total abundance of zooplankton taxa. In this study, all species of identified cladocerans (*Bosmina longirostris, Ceriodaphnia reticulate*, *Daphnia barbata* and *Moina micrura*) were present at site 6. *Bosmina longirostris* and *Daphnia barbata* were more abundant than other species recorded in this study, accounting for 1% of the total abundance of zooplankton. Grazing pressure seems to be the reason for the low abundance of cladocerans since food resources (diatoms and green algae) were also abundant.

Along the course of the river (sites 1 to 6), the abundance and species richness of zooplankton increased. Shannon diversity index (SDI) values were higher at the lower sites (sites 5 and 6), and also abundance as indicated by high evenness. The relationship between zooplankton diversity and richness and macrophytes abundance is expected to be strong and positive (Padovesi-Fonseca and Rezende, 2017; Mimouni *et al*., 2018) because macrophytes enable zooplankton species to get ecological gradients of food availability and low predator visibility (Mimouni *et al*., 2018). Also, macrophytes can reduce water velocity by their stems (Sand-Jensen and Mebus, 1996). Research conducted by Mesfin Gebrehiwot *et al*. (2017) in the littoral zone of Lake Ziway also confirmed the more abundance of zooplankton at sites which were covered with macrophytes. In contrast, in this study, higher abundance and diversity of zooplankton were recorded at sites with no macrophyte cover, which is agreeable with the work of Czerniawski and Pilecka-Rapacz (2011). Abundance of phytoplankton were high in macrophyte-uncovered sites, which could be one reason for the high abundance of zooplankton at these sites (personal observation).

Mesocyclops aequatorialis dominated the total zooplankton abundance throughout the sampling period. Larger crustaceans like *M. aequatorialis* take refuge among macrophytes to avoid predation (Meerhoff *et al*., 2007). However, the dominance of *M. aequatorialis* over other zooplankton species was recorded at a sites where there was no macrophyte cover. Previous studies in Ethiopian lakes have also recorded the dominance of *Mesocyslops* *aequatorialis* in the zooplankton (Seyoum Mengistou and Fernando, 1991; Ayalew Wondie and Seyoum Mengistou, 2006; Tadesse Fetahi *et al*., 2011) and suggested possible reasons such as its high escape ability, low adult mortality and high fecundity.

In the present study, there were considerable temporal variations in the distribution pattern of zooplankton and their relative abundance, a finding, which is consistent with the observations of Umi *et al*. (2018) who reported high seasonal variations of zooplankton communities. All the three zooplankton groups had highest abundance during the dry season probably due to the high phytoplankton biomass. This marked temporal variation was probably due to some proximal causes such as changes in weather (seasonal variation in water temperature, precipitation, etc), and predation pressure as well as environmental conditions (Manickam *et al*., 2018). The high turbidity during wet season could also affect the zooplankton groups as it interferes with filter feeding and leads to low abundance (Eshete Dejen *et al*., 2004).

Physico-chemical parameters along the Ketar River

The pH of Ketar River varied from 7.84 to 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 (2008) for optimal growth of aquatic organisms. The slight increase in pH observed along the river course may be associated with sediment deposition, which is known to contribute to an increase in pH values (Salmiati and Salim, 2017).

The present surface water temperatures are cooler than those reported by Fasil Degefu *et al*. (2013; 23.53–25.65ºC) 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 Ketar River, a condition, which was shown to impact river water temperature by Lin and Herold (2016). Koning and Roos (1999) reported that the average EC of typical, unpolluted rivers is approximately 350 mS/cm. Compared to the levels of EC reported by Fasil Degefu *et al*. (2013) for Awash River (327.67–492.87 μS/cm), the present results for Ketar River indicates its much lower level of EC. This suggests that the river receives low amount of dissolved inorganic substances in ionized form from its surface watershed (Payne, 1986). The lower EC recorded during the wet season might be due to the dilution of the river as a result of high rainfall, which in agrees with the work of Kalkidan Asnake *et al*. (2021) who also reported lower EC during the wet season for Kebena River, in Ethiopia.

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*. (2008), river water with TSS values between 100 mg/L and 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. Significantly higher TSS was observed during the wet season, which might be attributed to the increased input of particulate materials through runoff from the watershed of the river (Kidu Mezgebe *et al*., 2015).

The lowest level 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 and an increase in the algal biomass that is expected in the lower reach of rivers. The absence of statistically significant difference in the DO levels among sites (Table 6) might be that the river flowing down its course creates turbulence, which favours dissolution of atmospheric oxygen (Bevelhimer and Coutant, 2006). The mean values of the present study varied within a narrower range compared with those reported previously by Fasil Degefu *et al*. (2013) and Temesgen Eliku and Seyoum Leta (2018) for Awash River (3.62–7.58 mg/L). At all sites, the concentrations of DO were above the minimum required (4 mg/L) for the survival of organisms of aquatic ecosystems (Begum, 2008). Furthermore, the measured values of DO of all sampling sites are within the range of desirable levels (>5 mg/L) recommended by WHO (2008) for the survival of aquatic life.

Means concentrations of DO recorded in this study (5.51–6.33 mg/L) varied significantly across seasons, with lower levels occurring during the dry season. The high concentrations of DO during the wet season might be related to the rainfall event (Ling *et al*., 2017). The occurrence of higher DO level during the wet season is consistent with the results of Temesgen Eliku and Seyoum Leta (2018) who reported that low concentration of DO (6.25 mg/L) was recorded during the dry season, while high concentration (6.48 mg/L) was observed during the wet season along the Awash River.

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 6). The values of nitrate are less than those reported by Fasil Degefu *et al*. (2013) for Awash River, while those of ammonia are much higher than the levels documented by Fasil Degefu *et al*. (2013). Agricultural practices within the catchment taking place in the vicinity of the river seem to have resulted in the high concentrations of ammonia (Withers *et al*., 2014). Ammonia levels increased only slightly from upstream to downstream of the river (0.64–0.7 mg/L) which may have been associated with the differences in the level of application of fertilizers.

The 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 high and could be due to the occurrence of agricultural practices that involve application of fertilizers within the catchment. Compared to other standards, e.g., 0.005 to 0.020 mg/L PO_4-P (Chapman, 1996), the present study's result indicated the existence of pollution. 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 (Withers *et al*., 2014).

Relationship between zooplankton and environmental variables

In the present study, the RDA plot indicated that the abundance of *Mesocyclops aequatorialis* was positively correlated with TP suggesting that TP was a controlling factor for the dominant Copepod species. *Mesocyclops aequatorialis* was strongly but negatively correlated with TSS. *Mesocyclops* is a predator (Rao and Kumar, 2002) and may find it difficult to prey in the turbid water. Total suspended solids (TSS) cause a reduction in light penetration, which in turns interferes with the ability of visual predators to pursue and capture their prey (Fanela *et al*., 2019). Thus, the negative association of TSS and *Mesocyclops aequatorialis* suggests that water turbidity in the backwaters affected this raptorial cyclopoid from feeding on its preys easily.

In rivers, various environmental factors, such as physical, chemical and biological factors can influence the composition and quantitative structure of zooplankton communities. As Song *et al*. (2016) stated, when multiple factors work together on plankton, some environmental factors play a leading role. In aquatic ecosystem, physico-chemical variables and biotic factors such as predation and interspecific competition for resources, shape the structure of zooplankton (Seminara *et al*., 2008). Zooplankton requires dissolved oxygen for energy generation through metabolism. Their sensitivity to low oxygen concentration differs between species, among various life stages (eggs, larvae and adults), and with different life processes including feeding, growth and reproduction (Imam and Balarabe, 2012). This is evident in the highly significant association of DO with zooplankton species (*Anuraeopsis fissa*, *Asplanchna* sp., *Bosmina longirostris*, *Brachionus caudatus*, *Brachionus longistrus*, *Horaella brehmi*, *Keratella tropica*, *Lecane leontina*, *Lepadella similis*, *Polyarthra vulgaris* and *Trichocerca pussila*). Abolude *et al*. (2012) argue that DO has strong associations with zooplankton such as copepods and rotifers. Levels of dissolved oxygen, which indicates water health, were within the optimum range required to support aquatic life (Begum, 2008; WHO, 2008).

Zooplankton play a critical role as indicators of the condition of their habitats, and can respond quickly to changes of their immediate habitats of the aquatic ecosystem (Basu *et al*., 2010). Their response to their habitats can provide important information about current and past processes of changes in biological relationships and in the physical and chemical properties of water (Perbiche-Neves *et al*., 2019). Dominance of zooplankton groups among sites and between seasons might be associated with their ability to tolerate the unfavorable influences (Sharma and Saini, 2016), and turbid nature of the river; which food availability could be the key factor in turbid systems. This study largely determined that abiotic factors more influenced the distribution of zooplankton in backwaters of the Ketar River.

CONCLUSION AND RECOMMENDATIONS

This study revealed spatial and high temporal variations in zooplankton composition and diversity in Ketar River that could be indicating a gradual change in water quality of the river. Zooplankton were less abundant and diverse within the sites of macrophyte stands. Except pH and water temperature, abiotic factors were more or less similar among the study sites, while all the measured parameters were significantly different across seasons. Rotifers were more abundant and diverse, while Cladocerans had the lowest abundance in all the study sites and seasons. *Mesocyclops aequatorialis* was dominant indiscriminately in all the study sites (in the sites of both macrophytes stands and without macrophyte stands). Since the macrophytes provide food and refuge for zooplankton, the interaction between macrophytes and zooplankton is expected to be positive. However, the result of the present study indicated the reverse with abundant zooplankton communities recorded in sites where there was no macrophyte cover along the River. Further study is recommended to replicate similar study in Meki and Bulbula rivers, and Lake Ziway littoral areas, to determine more conclusively about the interactions between abiotic factors, macrophytes and zooplankton.

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