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Using zooplankton community to assess water quality and trophic condition of Lake Saheb Bandh, Purulia, West Bengal,India

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Abstract: The present contribution explores the usefulness of zooplankton as a tool for assessing the water quality and trophic status of a fresh water lake Saheb Bandh, situated between 23º29'42"N latitude and 86º21'37"E longitude of Purulia district, West Bengal, India. The lake water was sampled monthly and investigated for water limnology and zooplankton community structure using statistical measurement of diversity indices to characterize the zooplankton fauna for a period of one year (March 2014 to February 2015). Regarding zooplankton species composition, a total of 32 species belonging to 22 genera were recorded, out of which Rotifera was represented by 15 species, Cladocera by 10 species, Copepoda by 6 species and Ostracoda by 1 species. Rotifera was the predominant group (44.38%), followed by Cladocera (35.34%), Copepoda (19.37%) and Ostracoda (0.9%) in the following order of dominance: Rotifera > Copepoda > Cladocera > Ostracoda. There were strong correlations between the lake's limnological parameters and its zooplankton communities. From limnological analysis, it is evident that variables like lake surface temperature and dissolved oxygen are the most important factors influencing the seasonal pattern of zooplankton population. Alkaline pH and nutrients were the main environmental factors which affected zooplankton abundance in the lake. Monthly and seasonal variation of zooplankton species in respect of dominance, diversity, evenness and richness were calculated. Presence of certain species was considered to be a biological indicator for water quality status and trophic condition of the lake. Q Brachionus/Trichocerca ($Q_{B/T}$) index was used for the determination of trophic level of the lake and the lake is eutrophic. Overall, results showed that limnological parameters and zooplankton assemblages' have considerable effects on the water quality and trophic condition that can potentially affect the functioning of this ecosystem.

Keywords: Water quality, Trophic status, Zooplankton Diversity indexes, Limnological parameters, $Q_{B/T}$ ratio

1. INTRODUCTION

India is blessed with rich biodiversity due to its specific bio geographic location, vast climatic variations and diverse habitats [1]. Freshwater environments provide valuable ecosystem services such as fish production, energy production, transportation, water supply, and recreation or ecotourism [2]. Human society has over time used freshwater from rivers, lakes, groundwater and wetlands for many different rural, peri-urban and urban agricultural and industrial activities, but in doing so has overlooked its value in supporting ecosystems [3].

The inland freshwater ecosystems recognized for their ecological, economic and social importance [4], serves human population for ecosystem services such as drinking water, sources of aquatic products and venues for entertainment [5]. However, these natural environments are at risk and affected biodiversity in the past few decades, changes in natural flow regimes, over exploitation of natural water resources, contamination, habitat degradation induced by anthropogenic activities [5-6]. The increasing anthropogenic load leads to unfavourable changes (Toxicification, silting, eutrophication, etc.), which destroy the course of their natural cycles [7, 8].

The variables of water quality network, like pH, oxygen concentration, temperature etc., are linked and co-linked. Any changes in limnological variables can affect aquatic biota in a variety of ways. Limnological and biological parameters are mostly used to monitor the quality of water that should fall under set standards and guidelines. The occurrence of these parameters beyond the defined limit can be harmful for aquatic life as well as human health [8].

The diversity and abundance of Zooplankton organisms are ecologically important, as the integral biotic components of the food webs in any body of water, serve as an important factor in the formation of water quality, trophic levels as well as being the objects of bio indication and monitoring of the environmental conditions [8, 9, 10, 11,12].

Considerable investigations have been made on physico-chemical parameters, species composition and seasonal variations in zooplankton abundance in Indian fresh water bodies [10,13,14,15-19], but there have been no scientific investigations on trophic status and water quality of Saheb Bandh Lake (Purulia, West Bengal, India) in relation to limnological parameters and zooplankton assemblages. This lake area provides water and food to humans and is closely related to human survival: they are known as the “cradle of life” and “birds of paradise”. In recent years, a number of motors repairing shops, garages, nursing homes, private apartments, housing complexes, bathing ghats, amusement park etc. have cropped up surrounding Saheb Bandh. It is quite obvious that the lake water from these sources will change the limnological properties of the water and adversely affect the zooplankton community. Increase in human population and development of tourism cause harmful changes in this ecosystem. So, there is an urgent need to assess the water quality of this fresh water wetland to provide an early warning for ecological security and to aid management decisions.

The objective of the present study undertaken on Saheb Bandh Lake located in Purulia District, West Bengal, India, for one consecutive years during March 2014 – February 2015 was to provide detailed information on species composition and assessing the quantitative indices of zooplankton and cumulative influence of limnological factors on zooplankton assemblages and explore the usefulness of zooplankton as a resource for water quality monitoring. The explanation behind the present study was that zooplankton species would show, through analysis of qualitative and quantitative sample data, that the status of the environment is eutrophic. The species with constant frequency of occurrence in the system and showing low numerical abundance in response to the water’s nutrient level would be classified as bioindicators. The results will be beneficial for subsequent studies on the ecosystem ecological carrying capacity and long-term changes of zooplankton community.

2. METHODS

2.1. Study Area

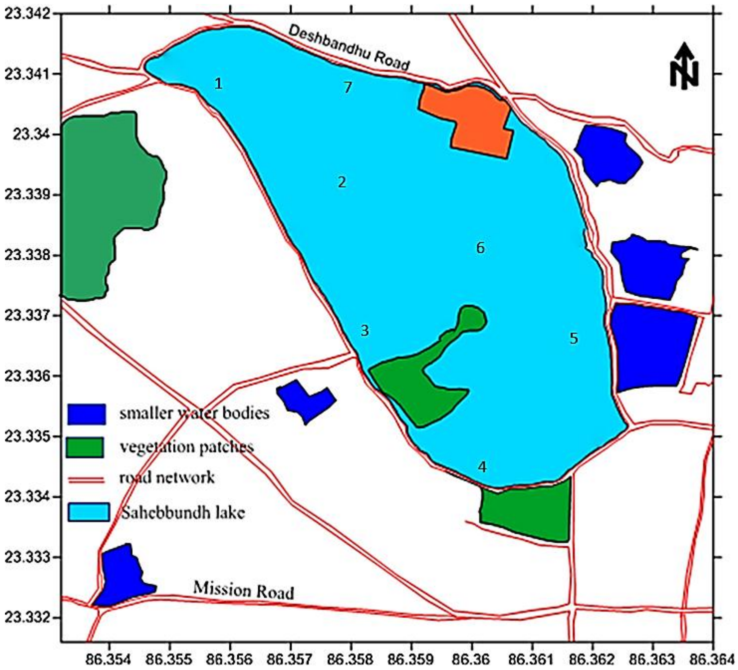
The Saheb Bandh Lake (Nibaran Sayar) of Purulia District, western part of state West Bengal, India is located at 23º29'42''N latitude and 86º21'37''E longitude (Figure 1), represents the biodiversity-rich freshwater wetland as well as an exclusive drinking water resource in drought-prone Purulia Town. The land and water area of lake covers an area of ~ 110 acres [20] with mean depth of 4.8 ± 2 m [21]. The water is mainly used for domestic as well as drinking purposes under the administrative control of Purulia Municipal Corporation (PMC), and also being used for fishing, sports, recreational and cultural purposes throughout the year. It is an important wetland ecosystem for its biological diversity, aesthetic beauty and multipurpose features like bathing, washing, fishing, boating etc. Apart from the water-spread area, its surrounding open landmass is also an integrated part of this lake ecosystem, which provides several cultural and recreational activities. Unfortunately, in spite of its environmental, recreational and aesthetic values it has received little attention in the past.

Figure 1. Lake Saheb Bandh (Nibaran Sayar) in Purulia District, West Bengal, India (Courtesy Google Earth)

2.2. Collection of Sample

Samplings were carried out at monthly intervals from March 2014 to February 2015, from seven selected spots (Figure 2) during morning hours. The entire study period was classified into three seasons representing summer (March 2014 – June 2014), monsoon (July 2014 – October 2014) and winter (November 2014 – February 2015).

Figure 2. Map showing water sampling points of Saheb Bandh Lake



With the aim of determining the zooplankton fauna of lake Saheb Bandh, 50 litres of water were filtered from 0.5 m depth to the surface with a standard plankton net made up of bolting silk cloth of 45 μm mesh size. The collected samples from all stations were pooled and preserved in 5% formalin and concentrated samples were stored with 1ml of Lugol's solution, simultaneously in 100 ml vials at the site itself. The concentrated plankton sample was subjected to count using Sedgwick -Rafter Counter. The density of zooplankton was expressed as number of individual (Ind.L^{-1}) using formula by APHA [22].

2.3. Biological Identification

The zooplanktons were identified by referring the standard manuals, text books and monographs down to the lowest possible taxonomic level according to Dhanapathi [23] for Rotifera., Battish [24], Dussart and Defaye [25] for Copepoda., Sharma and Micheal [26] and Murugan et al. [27] for Cladocera and Altaff [28] for Ostracoda. The taxonomic identification was done under the stereoscopic microscope at a magnification of 40x to 100x.

2.4. Limnological Analyses

Selected limnological parameters of lake Saheb Bandh were monitored and water samples collected in cleaned acid washed plastic bottles and stored at 4°C. To avoid contamination, disposable gloves washed in 1 N HCl were worn during water sampling. At the time of sampling, surface water temperature (SWT), pH and electrical conductivity (EC) was recorded on the field by probe. Sampling bottles were kept in large, airtight plastic ice-cold containers at 4°C and were transported to laboratory within 6 hrs of their collection for further processing. Analyses of other variables like total alkalinity (TA), total hardness (TH), dissolved oxygen (DO), total phosphorus (TP) and total nitrate-nitrogen (TN) were conducted in the laboratory using standard procedures in APHA [22].

2.5. Diversity indices and Statistical analysis

The population of each group of zooplankton was expressed in average, number of individuals per litre ($Ind.L^{-1}$). The statistical analysis was done using software programmed for total zooplankton numbers of individual species, diversity indices namely, the species Dominance (D) index, Shannon-Wiener diversity index(H), Simpson diversity index(1-D), species richness in terms of Menhinick (R2) and Margalef (R1), and evenness(e^H/S) were calculated by using PAST software package (PAST; version = 3.07).

The Pearson correlation between selected limnological parameters and zooplankton groups were tested using Microsoft Excel. The value of correlation coefficient is symbolized by r. To interpret the strength of correlations, parameters were used, which consider perfect / high correlations to be where r = 1; strong correlations where r is between 0.7 and 0.9, moderate where r is between 0.4 to 0.6, and weak where r is less than 0.3.

2.6. $Q_{Brachionus/Trichocerca}$ ($Q_{B/T}$) Index analysis

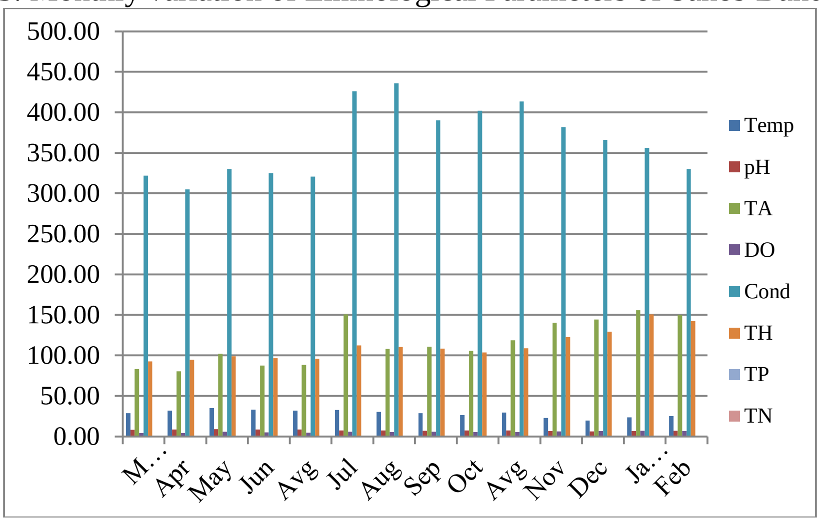
In order to determine the trophic level of the lake Saheb Bandh the $Q_{Brachionus/Trichocerca}$ index was applied [41-45/ 29-33]. The $Q_{B/T}$ index shows the rate of the number of *Brachionus* to the number of *Trichocerca*. The Q index is evaluated in three groups for the lake's trophic state, that Q=1 means oligotrophy, Q = 1.0-2.0 means mesotrophy, and Q>2 means eutrophy.

3. RESULTS

3.1. Limnological study

The monthly variation of eight different limnological parameters of surface water from Saheb Bandh Lake has been shown in Figure 3.

Figure 3. Monthly variation of Limnological Parameters of Saheb Bundh Lake



In any aquatic environments surface water temperature (SWT) is an important limnological factor affecting biological processes, in this study surface water temperature varied from 19.5°C to 34.8°C. The maximum water temperature (34.8°C) was noticed during

May 2014 while the minimum was registered as 15.6°C during December 2014. Seasonally, the maximum water temperature was recorded during summer and minimum in winter. The observed pH values ranged between 6.32 and 8.87. The maximum pH (8.87) was noticed during May 2014, while the minimum (6.32) was observed in December 2014. Seasonally, the maximum water pH was recorded during summer and the minimum during winter. Total Alkalinity (TA) as $CaCO_3$ was variable throughout the study period, ranged from 80.32 ppm to 155.53 ppm. The maximum TA (155.53 ppm) was observed in January 2015 and the minimum (80.32 ppm) during April 2014. Seasonally, the maximum TA was recorded during winter while the minimum in summer season. The dissolved oxygen (DO) concentration varied between 4.16 ppm and 6.75 ppm with the highest peak registered during January 2015 and the minimum during April 2014. Seasonally the value of DO was recorded maximum during winter season and the minimum during summer season. The electrical conductivity (EC) was significantly different throughout the study period, varied from 305 µs.cm-1 to 436 $\mu s.cm^{-1}$. The maximum EC (436 $\mu s.cm^{-1}$) was noticed during August-2014, while the minimum (305 $\mu s.cm^{-1}$) was observed in April 2014. Seasonally, the maximum EC was recorded during monsoon and minimum in summer season. The total hardness (TH) was ranged between 92.6 ppm. and 150.5 ppm. Highest value was observed during January 2015 (150.5 ppm.) and minimum during March 2014 (92.6 ppm.). Seasonally, the maximum TH was recorded during winter and minimum during summer season. Total phosphorus (TP) was maximum (0.78 ppm) during May 2014 and the minimum concentration 0.42 ppm was noticed during November 2014. Seasonally, the maximum concentration was recorded during summer and minimum during winter season. The level of total Nitrate (TN) throughout the study period was ranged between 0.34 ppm. and 0.88 ppm. Both the maximum (0.88 ppm) and the minimum (0.34 ppm) TN concentration was registered during May 2014 and December 2014 respectively. Seasonally, maximum TN was recorded during monsoon and the minimum during winter season.

3.2. Zooplankton Assemblages

Altogether, 8188 zooplankton assemblages were composed of 32 species belonging to four taxonomic groups, namely Rotifera (15 species), Cladocera (10 species), Copepoda (6 species) and Ostracoda (1 species) in Saheb Bandh Lake. Zooplankton production was maximum during May-2014 and minimum during October-2014. Seasonally the number was highest during summer (4184 $Ind.L^{-1}$) followed by winter (2034 $Ind.L^{-1}$) and the lowest during monsoon (1970 $Ind.L^{-1}$) season. The monthly and seasonal variations of zooplankton assemblages were illustrated in Table 1. In the present investigation, rotifera holds the top rank in percentage composition in Saheb Bandh Lake. The rotifera were found to be predominant with 44.382% followed by cladocera with 35.34%, copepoda with 19.37% and ostracoda with 0.904% in the lake. The monthly species composition of various groups was shown in the Table 1 and Figure 4.

Table 1. Percentage composition of zooplankton from study area

CLASS	SPECIES	Ind.L^{-1}	Species % in class	Species % in total zooplankton	Class % in total zooplankton
Rotifera	1. *Brachionus fulcatus*	544	14.97	6.64	44.382
	2. *B.forficula*	270	7.43	3.30	
	3. *B.diversicornis*	224	6.16	2.74	
	4. *B. caudatus*	258	7.10	3.15	
	5. *B. quadridentatus*	234	6.44	2.86	
	6. *B. rubens*	228	6.27	2.78	
	7. *Asplanchna* sp.	156	4.29	1.91	
	8. *Lecane* sp.	140	3.85	1.71	
	9. *Monostyla* sp.	170	4.68	2.08	
	10. *Filinia terminalis*	162	4.46	1.98	
	11. *Filinia opoliensis*	170	4.68	2.08	
	12. *Keratella tropica*	262	7.21	3.20	
	13. *Platylus quadricornis*	140	3.85	1.71	
	14. *Trichocerca cylindrica*	316	8.70	3.86	
	15. *Trichocerca elongata*	360	9.91	4.40	
	TOTAL ROTIFERA	3634			
Cladocera	1. *Daphnia carinata*	302	10.44	3.69	35.344
	2. *Diphanosoma sarsi*	292	10.09	3.57	
	3. *Ceriodaphnia* sp.	308	10.64	3.76	
	4. *Chydorus ciliatus*	304	10.50	3.71	
	5. *C.parvus parvus*	260	8.98	3.18	
	6. *Moina brachiata*	382	13.20	4.67	
	7. *Moinodaphnia macleayi*	318	10.99	3.88	
	8. *Leydigia ciliata*	286	9.88	3.49	
	9. *Pleuroxus trogonellus*	252	8.71	3.08	
	10. *Daphnia similis*	190	6.57	2.32	
	TOTAL CADOCERA	2894			
Copepoda	1. *Cyclops nauplius*	316	19.92	3.86	19.370
	2. *Paradiaptomus* sp.	280	17.65	3.42	
	3. *Neodiaptomus* sp.	204	12.86	2.49	
	4. *Mesocyclops hyalinus*	312	19.67	3.81	
	5. *Mesocyclops leuckarti*	256	16.14	3.13	
	6. *Phyllodiaptomus blanci*	218	13.75	2.66	
	TOTAL COPEPODA	1586			
Ostracoda	1. *Cypris* sp.	74	100	0.90	0.904
	TOTAL OSTRACODA	74			
	GRAND TOTAL	8188			100

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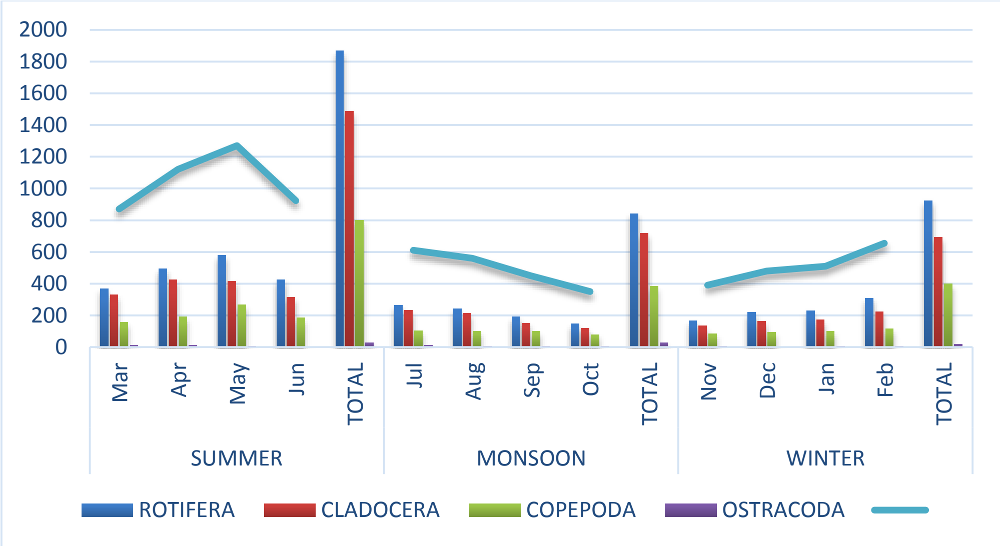
Figure 4. Monthly and Seasonal abundance of Zooplankton population (Ind.L^{-1}) of Saheb Bandh Lake, Purulia, West Bengal.



In the present study, rotifera was the most species-rich group, represented by 15 species belonging to 8 genera (Table 1) during the study period. The recorded population density of rotifer ranged between 148 and 580 Ind.L^{-1} with minimum population density during the month of October 2014(148 Ind.L^{-1}) and maximum in May 2014(580 Ind.L^{-1}). Seasonally, the maximum density was recorded during summer (1868 Ind.L^{-1}) and minimum during monsoon (842 Ind.L^{-1}). The density of rotifer species started to increase from the monsoon season and reached its maximum in the summer season.

Cladocera was represented by 8 genera and 10 species (Table 1). The maximum population density (426 Ind.L^{-1}) of cladocera was noticed in the month of April 2014 and minimum (120 Ind.L^{-1}) in October 2014 (Table 1). Seasonally, the maximum density was recorded during summer (1486 Ind.L^{-1}) while the minimum during winter (692 Ind.L^{-1}) and monsoon (Ind.L^{-1}) season. The density of cladocera species was reached its maximum during summer season.

Copepoda was represented by 5 genera and 6 species (Table 1). The copepod density was observed maximum (268 Ind.L^{-1}) in the month of May 2014 and minimum (78 Ind.L^{-1}) in the month of October 2014 (Table 1). Seasonally, the maximum density was recorded during summer (802 Ind.L^{-1}) and minimum during monsoon (384 Ind.L^{-1}) and winter (400 Ind.L^{-1}) season. The density of copepod species started to increase from the monsoon season and reached its maximum in the summer season.

Only, one species of ostracoda was recorded in this study. The population density of 12 Ind.L^{-1}was recorded during the month of March 2014 and July 2014 whereas no such organism was noticed during June 2014(Table 1). Higher population size was observed during summer months. The rich and diverse composition of various zooplankton communities at Saheb Bandh Lake accurately revealed a better and appropriate biological heterogeneity at all station.

3.3. Zooplankton species diversity indices

The results of various zooplankton diversity indices are presented in Table 2. The species dominance (D) of rotifera were high (0.121) in January - 2015 and low (0.069) in November

- 2014. The Shannon diversity index (H) was found to be the maximum (2.689) in November 2014 and the minimum (2.37) in January 2015. Simpson's diversity index was maximum (0.931) in November 2014 and minimum (0.879) in January 2015, the species evenness(e^H/S) was higher (0.981) in November 2014 and lower (0.713) in January 2015, the species richness as Menhinick(R2) index value was found to be maximum (1.233) during October 2014 and minimum (0.623) during May 2014, the Margalef(R1) species richness was recorded to be maximum (2.802) in October 2014, while minimum (2.20) was noticed during May 2014 (see Table 2A and 2B)

The species dominance (D) of cladocera was high (0.114) in January -February 2015 and low (0.102) in April 2014. The Shannon diversity index(H) was found to be maximum (2.294) in April 2014 and minimum (2.223) in May 2014, Simpson's diversity index(1-D) was found to be maximum (0.898) in April 2014 and minimum (0.886) in January-February 2015,the species evenness(e^H/S) was higher (0.991) in April 2014 and lower (0.923) in May 2014, the species richness as Menhinick index(R2) value was found to be maximum (0.913) in October 2014 and minimum (0.485) in April 2014,the Margalef index(R1) species richness was maximum (1.880) in October 2014 and minimum (1.487) in April 2014 (see Table 2A and 2B).

The species dominance (D) of copepoda was high (0.114) in January -February 2015 and low (0.102) in April 2014. Shannon diversity index(H) was found to be maximum (1.787) in May 2014 and minimum (1.674) in August 2014, Simpson's diversity index(1-D) was maximum (0.832) in May 2014 and minimum (0.792) in August 2014, the species evenness(e^H/S) was higher (0.996) in May 2014 and lower (0.889) in August 2014, Menhinick index(R2) was recorded in the range between 0.367 and 0.679, the species richness of Margalef index(R1) was minimum (0.894) in May 2014 and maximum (1.148) in October 2014 (see Table 2A and 2B)

The species dominance (D) of ostracoda was 1 throughout the year except in the month of June 2014, where the value is 0. The species evenness(e^H/S) and Margalef index(R1) were recorded same throughout the study period except June 2014, Shannon diversity index(H) and Simpson's diversity index(1-D) were found to be 0 throughout the study period, Menhinick index(R2) was recorded in the range between 0 and 0.4082(see Table 2A and 2B).

Table.2A. Annual variations of zooplankton diversity indices of Saheb Bandh Lake

Class	Diversity Indices	Mar 14	Apr	May	Jun	Jul	Aug
Rotifera	Density (Ind.L^{-1})	370	492	580	426	262	240
	Dominance_D	0.084	0.078	0.079	0.082	0.091	0.092
	Shannon_H	2.600	2.631	2.629	2.596	2.527	2.526
	Simpson_1-D	0.916	0.922	0.921	0.918	0.910	0.908
	Evenness_e^H/S	0.898	0.926	0.924	0.894	0.834	0.833
	Menhinick (R2)	0.780	0.676	0.623	0.727	0.927	0.968
	Margalef (R1)	2.367	2.259	2.200	2.312	2.514	2.554
Cladocera	Density (Ind.L^{-1})	330	426	416	314	232	212
	Dominance_D	0.103	0.102	0.112	0.107	0.104	0.107
	Shannon_H	2.288	2.294	2.223	2.267	2.285	2.270

	Simpson_1-D	0.897	0.898	0.888	0.893	0.896	0.893
	Evenness_e^H/S	0.985	0.991	0.923	0.965	0.982	0.968
	Menhinick (R2)	0.551	0.485	0.490	0.564	0.657	0.687
	Margalef (R1)	1.552	1.487	1.492	1.565	1.652	1.680
Copepoda	Density (Ind.L^{-1})	158	192	268	184	104	102
	Dominance_D	0.182	0.175	0.168	0.174	0.175	0.208
	Shannon_H	1.746	1.765	1.787	1.769	1.766	1.674
	Simpson_1-D	0.818	0.825	0.832	0.826	0.825	0.792
	Evenness_e^H/S	0.955	0.973	0.996	0.978	0.975	0.889
	Menhinick (R2)	0.477	0.433	0.367	0.442	0.588	0.594
	Margalef (R1)	0.988	0.951	0.894	0.959	1.077	1.081
Ostracoda	Density (Ind.L^{-1})	12	10	6	0	12	6
	Dominance_D	1	1	1	0	1	1
	Shannon_H	0	0	0	0	0	0
	Simpson_1-D	0	0	0	0	0	0
	Evenness_e^H/S	1	1	1	0	1	1
	Menhinick (R2)	0.289	0.316	0.408	0	0.289	0.408
	Margalef (R1)	0	0	0	0	0	0

Table.2B. Annual variations of zooplankton diversity indices of Saheb Bandh Lake

	Diversity Indices	Sep	Oct	Nov	Dec	Jan 15	Feb
Rotifera	Density (Ind.L^{-1})	192	148	166	220	230	308
	Dominance_D	0.073	0.071	0.069	0.075	0.121	0.097
	Shannon_H	2.656	2.676	2.689	2.655	2.370	2.536
	Simpson_1-D	0.927	0.929	0.931	0.925	0.879	0.903
	Evenness_e^H/S	0.949	0.969	0.981	0.949	0.713	0.842
	Menhinick (R2)	1.083	1.233	1.164	1.011	0.989	0.855
	Margalef (R1)	2.663	2.802	2.739	2.596	2.574	2.443
Cladocera	Density (Ind.L^{-1})	152	120	134	162	172	224
	Dominance_D	0.105	0.104	0.105	0.108	0.114	0.114
	Shannon_H	2.278	2.280	2.281	2.264	2.231	2.231
	Simpson_1-D	0.895	0.896	0.896	0.892	0.886	0.886
	Evenness_e^H/S	0.976	0.977	0.979	0.962	0.931	0.931
	Menhinick (R2)	0.811	0.913	0.864	0.786	0.763	0.668
	Margalef (R1)	1.791	1.880	1.838	1.769	1.748	1.663
Copepoda	Density (Ind.L^{-1})	100	78	86	96	102	116

	Dominance_D	0.172	0.191	0.200	0.181	0.192	0.178
	Shannon_H	1.776	1.714	1.706	1.752	1.712	1.755
	Simpson_1-D	0.828	0.809	0.800	0.819	0.808	0.822
	Evenness_e^H/S	0.984	0.926	0.918	0.961	0.923	0.964
	Menhinick (R2)	0.600	0.679	0.647	0.612	0.594	0.557
	Margalef (R1)	1.086	1.148	1.122	1.095	1.081	1.052
Ostracoda	Density (Ind.L^{-1})	6	4	4	2	6	6
	Dominance_D	1	1	1	1	1	1
	Shannon_H	0	0	0	0	0	0
	Simpson_1-D	0	0	0	0	0	0
	Evenness_e^H/S	1	1	1	1	1	1
	Menhinick (R2)	0.408	0.5	0.5	0.707	0.408	0.408
	Margalef (R1)	0	0	0	0	0	0

3.4. The Q $_{Brachionus/Trichocerca}$ (Q $_{B/T}$) Index

For lake Saheb Bandh the $Q_{B/T}$ index was highlighted in the Table 3. In this study, it was found that 6 species belonged to the *Brachionus* genus and 2 species belonged to the *Trichocerca* genus. The range of $Q_{B/T}$ index was in between 2.15 and 3.10. The average $Q_{B/T}$ index was 2.62 (Table 3).

Table 3. The Q $_{Brachionus/Trichocerca}$ (Q $_{B/T}$) Index of Saheb Bandh Lake in various months

	Summer	Monsoon	Winter	
Zooplankton Component				Average
1.*Brachionus fulcatus*	284	106	154	
2.*B.forficula*	150	70	50	
3.B.diversicornis	110	58	56	
4.B. caudatus	124	72	62	
5.B. quadridentatus	126	62	46	
6.B. rubens	110	74	44	2.60
Total Brachionus spp.	904	442	412	
14. Trichocerca cylindrica	168	68	80	
15. Trichocerca elongata	178	96	86	
Total Trichocerca spp.	346	164	166	
$Q_{B/T}$ Ratio	2.61	2.70	2.48	

Values of $Q_{B/T}$, less than 1.0 means Oligotrophy
Values of $Q_{B/T}$, between 1.0 - 2.0 means Mesotrophy
Values of $Q_{B/T}$, greater than 2.0 means Eutrophy

3.5. Correlation between limnological parameters and zooplankton abundance

Correlation analysis is a valuable tool to establish the relationship between water quality constraints and the zooplankton assemblages in the freshwater ecosystems. The correlations ‘r’(Pearson) between densities of the major zooplankton groups and selected limnological parameters in summer(S), monsoon(M) and winter(W) season showed that only some resulting values were high enough and of statistical significance (Table 4). A significant positive and strong correlation was established between the densities of Rotifera with SWT (r = 0.863), pH (r = 0.760), TA (r = 0.726), DO (r = 0.715), TH (r = 0.810), TP (r = 0.996), TN(r=0.768) and weak correlation with EC (r = 0.121) during summer season whereas during monsoon all the limnological parameters showed positive and strong correlation (Table 4) but TN (r = -0.956) showed negative correlation. During winter season pH and DO showed positive and strong correlation whereas SWT, TA, TH, TP, TN showed moderate but EC (r = -0.993) showed negative correlation with Rotifera densities (Table 4). The abundance of Cladocera was found to be positively correlated with all the limnological parameters but negatively with EC (r = -0.993) during summer season whereas during monsoon all the limnological parameters showed positivity. EC (r = -0.996) showed negativity result whereas all other limnological parameters showed positive and strong correlation during winter season (Table 4). A significant positive and strong correlation was established between the densities of copepods with all selected limnological parameters (Table 4) during summer, monsoon and winter season except conductivity (r = -0.999), which shows negatively result during winter season. The abundance of Cladocera was found to be positively correlated with selected limnological parameters during monsoon and winter season, except conductivity in winter but there was negative correlation during summer season (Table 4). The correlation results show perfect or high correlations among the zooplankton density and selected limnological parameters of the Saheb Bandh Lake.

Table 4. Pearson Correlation(r) between Limnological Parameters and Zoolankton Density of Saheb Bandh Lake in various seasons

Limnological Factor	ROTIFERA			CLADOCERA		
	S	M	W	S	M	W
SWT(C°)	0.863	0.983	0.520	0.454	0.971	0.580
pH	0.760	0.662	0.764	0.274	0.714	0.796
TA(ppm_CaCo3)	0.726	0.708	0.604	0.272	0.703	0.596
DO(ppm)	0.715	0.627	0.751	0.211	0.560	0.732
EC(μs/cm)	0.121	0.761	-0.993	-0.396	0.822	-0.996
TH(ppm_CaCo3)	0.810	0.977	0.641	0.328	0.948	0.635
TP(ppm)	0.996	0.730	0.619	0.835	0.655	0.599
TN-nitrogen(ppm)	0.768	-0.956	0.387	0.255	0.791	0.978

Perfect / high correlations to be where r = 1;
Strong correlations where r is between 0.7 and 0.9,
Moderate where r is between 0.4 to 0.6, and
Weak where r is less than 0.3.
S= Summer
M= Monsoon

W= Winter

4. DISCUSSION

Limnological factors in aquatic environments are very important for growth and dispersal of zooplankton for their existence [34]. The surface water temperature (SWT) of an aquatic ecosystem is a significant environmental parameter to regulate various abiotic and biotic activities of aquatic organisms [35-37], which manages chemical and biological activity [38-39]. In freshwater ecosystem, zooplankton communities are influenced by water temperature, competition and predation [40-41] whereas the increasing temperature speeds up the chemical and biochemical reactions [42] and reduces the solubility of gases [40**]**. The average highest value of SWT in Saheb Bandh lake was recorded in summer(31.98 ºC,), while lowest in winter (22.8 ºC) could be attributed to increased day length and high solar radiation during summer, whereas decrease in temperature may be because of reduced illumination, shorter day length and strong breeze [43-44].

The average pH value of Saheb Bandh Lake is 7.4, which is within the range of 6.5 to 8.5 established by WHO [45], reflecting a neutral to slightly alkaline environment. The majority of surface waters have a pH that ranges between 6.5 and 9, due to the buffer system developed by carbonates and bicarbonates [40,46]. Seanonally, Saheb Bandh Lake water pH showed an alteration between 8.52 in summer and 6.58 in winter on average. The pH value of Shahu Lake was higher than 7.0, and its water was at a certain degree of eutrophication [47]. Present results on pH of water are in close conformity with earlier finding [48].

Total Alkalinity (TA) as $CaCO_3$ was variable throughout the study period, ranged from 80.32 ppm to 155.53 ppm. The maximum TA (155.53 ppm) was observed in January 2015 and the minimum (80.32 ppm) during April 2014. Alkalinity (TA) is used as a measure of productivity of water [49]. Seasonally, the maximum TA was recorded during winter while the minimum in summer season. During winter Increasing trend of TA is due to the reduced photosynthetic activities resulted in decreased uptake of HCO_3^- as a source of carbon in photosynthesis [50] whereas in summer aquatic biota directly utilizes bicarbonates by lowering of HCO_3- which lead to resulting in low value of TA [51]. The degradation of plants, other organism and organic wastes might also be one of the reasons for the increase in carbonate and bicarbonate and thereby the alkalinity [49,52].

In the present study, average DO concentration was recorded as 6.59 ppm. within the range of 4.16 ppm. and 6.75 ppm. well settled by WHO [45] which is of (5–8 mg/L). In present investigation, low levels of DO during summer months were possibly due to the lower oxygen holding capacity of water at high temperature and increase in its assimilation for biodegradable organic matter by microorganism [44] indicate a state of eutrophication-driven deoxygenation in the environment [46], which can be attributed to an increase of algal activities [53], high phosphate and ammonia concentrations [54], or high loads of untreated wastewater discharges [55]. The solubility of oxygen increases with decrease in temperature and low DO during summer may be another issue of high temperature as its solubility decreases at higher temperature [56]. Agitation of water due to heavy rainfall caused an increase in DO during monsoons [57] whereas higher DO during winters may be because of increased oxygen solubility at low temperature [58]. So, DO fluctuations occur due to its utilization for decomposition of organic matter and respiration of organisms [59].

EC of the present study recorded an average value of 364.16 $\mu S.cm^{-1}$, is <1500 $\mu S.cm^{-1}$ [45],which is a function of temperature and proportional to the mineralization [46]. There is seasonal variation of EC in Lake Saheb Bandh mainly due to fluctuations in the ionic precipitation and the dilution effects of the rains [59].

The value of Total Hardness (TH) fluctuation ranged from 92.60 to 150.50 ppm. The high value of TH was recorded during rainy and winter season whereas low during summer season (92.60 ppm). Hardness of Saheb Bandh Lake is moderate [60] which favours to zooplankton production [61].

Nitrate is an essential nutrient depending on different factors including season and origin of the water, oscillating between 1-15 mg. L^{-1} and a concentration of 2 or 3 mg. L^{-1}can be considered as normal [46,62]. In the present study, nitrate values ranged between 14.66 ppm. and 38.72 ppm. with increased nitrate content was recorded in monsoon season might be because of surface runoff from lands and rain-water run-off during early rains [63-64]. The increase in the magnitude of nitrate in aquatic ecosystems can be directly correlated with accelerated rates of anthropogenic activities [65]. In view of the health status of the water body nitrates are not dangerous but become toxic by the fact that they turn into nitrites and participate in the important eutrophication phenomenon of stagnant water [46].

Phosphates are essential nutrient for the growth of organisms that limits primary productivity of a wetland [64]. In the lake water, recommended threshold limit of phosphate content is 5 mg. L^{-1} [45,62] but in the present study average value (6 ppm) exceeding the recommended concentration. Its natural presence in the water is related to the decomposition of organic matter [46,66] and proliferation of algae and phytoplankton lead to the eutrophication of lakes and streams, which is threatened to aquatic life [67-68]. The decrease in water level of the lake helps to increase nutrients during the summer season [58] is also related with release of nutrient during decomposition with increasing temperature [61]. The declining concentration during winters might be due to its utilization by algal and its co-precipitation with carbonates at high pH [69].

In freshwater ecosystem zooplankton faunal structure varies among regions and aquatic environment due to trophic status of water, regional temperature, age of aquatic environment and ecological factors of existed species [70]. Zooplanktons are important indicators for aquatic habitat, since most of them are used to determine the water quality, the trophic level and evaluating the degree of eutrophication [53,71]. A total zooplankton of 32 genera were identified from lake Saheb Bandh and diversity of species are also reported by the researcher from the lakes of India [10,14, 53,72-79].

In the present investigation higher density of zooplankton was observed during summer season compared to the other season coincide with finding of other researchers [14,34,53,76-78,80-82]. The maximum population is probably due to the high photosynthetic activity [83] that provides the food for zooplankton, as well as to favourable environmental conditions, leads to high zooplankton density during the summer season [34]. Increasing temperature during summer enhances the rate of evaporation and decomposition due to which the water becomes nutrient rich [84] and availability of food corresponding to the water clarity, decaying vegetation, increased levels of organic matter in the sediment and higher abundance of bacteria to enhance increasing trends of zooplankton population in the wetland during this time [85-86].

Zooplankton population density decline during monsoon season as noticed in the present findings could be due to sudden fall of temperature and dilution in concentration of minerals and salts in the lake water [34,44] whereas earlier researchers have also been reported high turbidity, low light intensity, cloudy sky besides high rain fall also responsible for low density [14-16,34,87-88]. However, lower monsoon abundance also reported from other studies [88-89].

The population density raised during winter season is as most favourable period for the growth and multiplication of zooplankton species due to the availability of abundant food in the form of bacteria, nanoplankton and suspended detritus [34]. This pattern is common in freshwater lakes, ponds, reservoirs and rivers [73-75,81,91].

Rotifera constitute the dominant group with the highest species richness and population density among zooplankton community in tropical freshwater environments [78,92-97] followed by Cladocera, copepoda, and Ostracoda [53,93,98-100] with high seasonal variation was also observed by other researchers [34,101-103]. Various ecological factors like nutrients load and pollution status in a particular water body is controlled by zooplankton species composition and dominance [88]. In the present study Rotifers (44.38%) share the maximum in zooplankton composition and their dominancy is the indicator of eutrophication [104-105] indicating that the lake water became polluted in nature [106,107] and the abundance may be attributed to its dependence on phytoplankton and retrial matter as food [108]. Summer peak of rotifer diversity and density may be due to optimal nutrient [11] and temperature conditions, and dissolve oxygen contents in this season [109-110]. Low rotifer density, diversity and richness during the rainy season can be attributed to turbulence generated by the excess flow of water and reflection of environmental stress during this season [111]. An increasing trend in winter season with peak during summer month and minimum population during rainy season also coincide with the result of other studies [112]. Among rotifers Brachionidae indicate eutrophication [113], abundance of *Brachionus calyciflorus*, *B.forficula* are the pollutant tolerant species indicates organic pollution [114-115] and *B.calyciflorus*, *B.quadridentatus* indicates eutrophication [11,15,42,61,70,116-117] whereas, *Keratella tropica*, *T.cylindrica* are the pollutant tolerant species and indicate organic pollution [118]. Accordingly from several studies it was reported that thriving of *B. caudates*, *B. diversicornis* and *Filina longiseta* in the present lake has been considered as an indicator of eutrophication [30, 32-34,42,44-47,56,78,119-122]. The presence of these entire pollution indicator species suggests that the lake Saheb Bandh was organically polluted [42].

Cladocera comprised 35.34% in lake Saheb Bandh and has been reported various species of Cladocera in India [13,15,16,42]. The density and abundance of Cladocera depends on food supply of the water body (44,123). The cladoceran population densities in the present study were higher in summer followed by monsoon and lowest in winter season, has also been reported by other researchers [47,124-125,128]. Summer maxima of cladocera is attributed to favourable temperature and availability of food [81] in the form of bacteria, nanoplankton and suspended detritus while in monsoon the factors like water temperature, dissolve oxygen, turbidity and transparency play an important role in controlling the density and diversity of cladocera [126-129]. Predominant species may have more functional importance than total species numbers in the plankton community. In lake Saheb Bandh presence of *Diaphanosoma*, *Daphnia*, *Ceriodaphnia* and *Moina* indicating eutrophic lakes has also been recorded throughout the world [44,130-133] whereas *Daphnia* spp. *Moina* sp. indicating that the lake is towards organically polluted [81,134] and the lake is in highly degraded condition. *Chydorus* are notable Cladoceran species in this study and quantitative importance of the chyrodidae concurred with the result of Sharma [135], and Sharma [136].

Presence of Copepod indicates the abundance of diatoms and blue green algae which are more important food sources for all the developmental stages of cyclopoid Copepods [44]. also feeds up on Rotifers and Cladocerans [137-139]. In the present study, most abundant

species of Copepods are *Cyclops nauplius*, *Mesocyclops hyalinus*, *Mesocyclops leuckarti*, *Paradiaptomus* sp, *Neodiaptomus* sp, and *Phyllodiaptomus blanci*. Abundance of Copepods maxima during summer and minimum during monsoon and winter season corroborate with the trends of seasonal fluctuation of other studies [70,93,115]. Better development in warmer months as noticed in the present study is in accordance with the result of Gupta et al. [140], Dar and Dar [141]. The presence of rotifers which may serve as prey species for them might also be responsible for their maxima in summers [50] whereas lesser abundance of copepods during monsoon had also been reported by Majagi and Vijaykumar [142]. The high-water currents, increased water flow and other adverse conditions during monsoons might be responsible for their minima in monsoon season [143]. It is reported that calanoid Copepods best adapt to oligotrophic lakes, and cyclopoid Copepods best adapt to eutrophic lakes [144]. The cyclopoids (*Mesocyclops* spp.) mainly influenced by abundance of this group throughout the study period, showed an active continuous reproductive phase and concurred with the reports of Sharma [135], and Sharma and Sharma [145]. The copepods are also the indicator of influence of pollutants as well as domestic sewage discharges [127].
The population density of ostracoda was higher in summer season and less in monsoon in the present investigation concour with the result of Pawar[146] and Mahor [147]. According to Jadav et al. [148], the temperature of water and availability of food affect the population of Ostracods. The occurrence of lower population density and species diversity of Ostracoda among the all four groups have been reported from other studies [13,16,117]. In the present study, the presence of *Cypris* suggests [42] that the Lake was eutrophicated.
Diversity indices reflect how rich and productive a water body is in terms of zooplankton species [93]. Shannon-Weiner Index (SWI), combines species richness (SR) and species evenness (e^H/S) components are overall index of diversity. Zooplankton species diversity index (ZSDI) values were higher throughout the study period. The higher value of Shannon's index (0-2.689) indicated greater species diversity and hence increases the stability of the community [149]. The SWI values under 1.0 indicate the low quality of water and not supporting the survival of the zooplankton [150]. In the Saheb Bandh lake, SWI ranged from 0 (Ostracoda) to 2.689 (Rotifera), indicates conditions of intermittent surface distribution where, certain zooplankton species have better environmental conditions to reach higher individual numbers. In Rotifer the SWI index value were between 2.37 and 2.689 indicate greater species diversity. Cook [151] after examining diversity in a range of polluted and unpolluted streams concluded that the values of SWI greater than 3 indicate clean water, values in the range of 1-3 were characterized by moderate pollution and values less than 1 characterized heavily polluted condition. Meshram et al. [152] found moderate to good values of Shannon–Wiener diversity index (SWI) in Dal–Nigeen lake of Srinagar (India) indicating a slight impact of contamination. The maximum values of SWI were also calculated by other researchers [44,153,154].
Simpson's diversity index (1- D) of zooplankton varied from 0-1, gives the probability that two individuals drawn at randomly from a population belonged to the same species, simply stated, if the probability was high both individuals belong to the same species, then the diversity of the community sample was low [155]. With this Simpson's index, 0 represents infinite diversity and 1.0, no diversity. This is the greater the value of D, the greater the sample diversity. Analysis of data revealed that Simpson's index were found in lake 0(0stracoda) to 0.931 (rotifer). Higher values of these indices indicate greater species diversity and thus, less diversity from lower values; hence it showed higher species diversity at Lake Saheb Bandh is different from the study [44,156]. Evenness Index (e^H/S) value is

in between 0 – 1. When the value is getting closer to 1, it means that the individuals are distributed equally. In this study value of the above index was noted to be always more than 0.50 which signifying a greater equitability in the apportionment of individuals among the species in Saheb Bandh. The components of the communities share the resources and there is niche overlap to a greater extent, which supports more species and vice-versa. Evenness indices determine whether all species in a sample are equally abundant or not [44,157]. This means that species evenness decreased with increasing size of the zooplankton population. High evenness of zooplankton observed in this result affirmed equitable abundance of various species and it is endorsed by lower dominance [135,145].

Though Margalef index still remains a widely used index of diversity emphasizing species richness also studied by Sangakkara and Wijeyaratne [158] and depends on nutrient status. The present observed value was 0-2.802, which is also at the lower to moderate limit of the scale. Margalef's diversity index (R1) commonly varies between 1 and 5, larger the index value a healthier body of water. When it tends towards 1, pollution is thought to increase and damage is suspected. Moderate high values of this index in Saheb Bandh Lake reflect the suitability of habitat for the organisms and a relatively stable community. The value of R1 is strongly dependent on sampling and highlighted genera/species richness of 2 to 3 genera/species [44,153,154].

The Menhninick's Index is used for comparison of samples of different sizes (Pandit) Menhinick index (R2) closer to 1 indicates nearly satisfactory diversity status of the Saheb Bundh Lake. These diversity indices indicated that the lake under study have a well-balanced zooplankton community [159] that enjoyed an even representation of several species indicating the dynamic nature of this aquatic ecosystem. Earlier, it has been reported this index from 0.870 to 0.942 at Ramesar wetand [44]. The mean values of H' > 2 and D' > 0.9 indicates the healthy diversity of the ecosystem [49]. Therefore, present work indicates some unhealthy diversity of zooplankton in this water body.

In the present investigation the trophic status was prepared by calculation of $Q_{B/T}$ quotient (Table 3). Sladecek [29] has suggested an index Q for the determination of the trophic level of a given lake. He reported that if the ratio of Q = 1.0 the lake is oligotrophic, if Q = 1.0 to 2.0 the lake is mesotrophic, and if Q = above 2.0 the lake is eutrophic. The $Q_{B/T}$ results in Saheb Bandh Lake showed highly eutrophic condition of the water. Zooplankton community compositions are affected by eutrophication, and these communities have potential value as indicators of changing trophic condition [29,160-161]. The trophic values, reported in Table 3, in Lake Saheb Bandh varied from 2.15 to 3.10 with an average value of 2.62 during the study period affirmed its 'eutrophic' nature following Sladecek's classification. That situation should be a direct consequence of eventual high content of nutrients, mainly total phosphate. Edmondson [162] indicated that eutrophication has been, and will perhaps continue to be, the most widespread type of environmental pollution in freshwater systems. The relationship between the composition and abundance of zooplankton and the trophic state of lakes has been studied in both temperate (29,163] and tropical ecosystems [164].

In the present study Rotifers and Copepods are positively co-related with SWT, pH, TA, DO, TH, TP and TN (see Table 4) during summer but negatively correlated with conductivity favoured the production of zooplankton [165]. Cladocerans and Ostracods are positively co-related with SWT, pH, TA, DO, TH, TP, TN and EC [Table 4] during monsoon but negatively correlated with EC during winter. Statistically the density of Rotifera, Cladocera, Copepod and Ostracoda have shown significant correlation with SWT, TA, TH, pH, DO, TP, TN, EC. However various limnological parameters show either significant positive or negative correlation with density of different zooplankton groups or their seasonal abundance [78].

5. CONCLUSION

This result provides the first glimpse of Saheb Bandh Lake water quality and trophic status in relation to zooplankton community assemblages and limnological assessment. In this lake decaying organic matter is abundantly available. It contains high organic enrichment which favours positive establishment of macrophytes and associated animal communities shows the diverse fluctuation among zooplankton throughout the year. Zooplanktons are one of the major primary consumers in most of the aquatic ecosystem and are the best indicator of water quality. Any undesirable changes in the limnological and biological properties of the water lead to the changes in zooplankton diversity and abundance. The species composition and distribution were strongly influenced by the limnological factors of surface waters. Temperature, DO, pH, TH, availability of the food, and nutrients were found as major factors that could influence the growth, composition and distribution of zooplankton. So that regular monitoring of zooplankton gives information about the proper management of aquatic ecosystem. Normally polluted water contains very low count of zooplankton, some species of zooplankton especially species of Rotifers show dominance in organically polluted water. The results of the water quality clearly show that the greatest number of parameters was higher than the desirable limit. This investigation confirms that Saheb Bandh Lake is organically polluted, eutrophicated and a various population of pollution indicator zooplanktons. It was observed that domestic animals used to drink and bath, rain water enter from the surroundings into the lake. Surrounding the lake is covered by local people who are engaged in washing clothes and discharge soap water into the lake, local people immerse worship material in lake water, discharge their waste and domestic sewage directly into its water increase the organic load of the lake water. This leads to detrimental effects like eutrophication, algal bloom, depletion of dissolved oxygen etc. The high concentration of Total Phosphorous and Total Nitrogen is mainly responsible for eutrophication and having significant impacts on lake water quality. By perusing the results of the Trophic level status ($Q_{B/T}$), it can be concluded that the lake is highly eutrophic lentic ecosystem. Fluctuations in population density and species composition of Zooplankton become prominent in the lake depending on the existing ecological conditions. This aquatic ecosystem is undergoing many changes due to the impact of human activities. Hence, the status of water quality of Saheb Bandh Lake should be protected and enhanced by raising the awareness of the local people and by reducing anthropogenic activities. Protection of water quality and prevention of urban pollution in the lake will enhance the water quality and species composition and distribution of zooplankton population.

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