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Seasonal And Spatial Dynamics of Zooplankton Community Structure In Ambala Lake, Ramtek (Nagpur), Maharashtra, India

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ABSTRACT

Zooplankton are integral components of freshwater ecosystems, contributing significantly to energy transfer within aquatic food webs while serving as reliable indicators of ecological condition and water quality. Their community composition and abundance are strongly influenced by seasonal environmental fluctuations and habitat-specific characteristics. The present investigation evaluated the seasonal and spatial dynamics of zooplankton communities in Ambala Lake, located in Ramtek, Nagpur district, Maharashtra, India. Monthly sampling was carried out from June 2024 to May 2025 at four strategically selected locations representing distinct ecological conditions within the lake. Zooplankton samples were collected using a standard plankton net, preserved immediately after collection, and identified through microscopic examination using established taxonomic references. The recorded organisms belonged predominantly to four taxonomic groups: Rotifera, Cladocera, Copepoda, and Ostracoda. Distinct seasonal variation was observed in community abundance, with maximum population densities occurring during the post-monsoon and winter seasons, whereas comparatively lower densities were recorded during the summer period. Rotifers constituted the dominant component of the zooplankton assemblage throughout the study, followed by cladocerans and copepods. Spatial assessment indicated comparatively greater zooplankton abundance at Site-2 and Site-3 than at Site-1 and Site-4. The findings demonstrate that seasonal climatic conditions together with local habitat characteristics strongly regulate zooplankton distribution within Ambala Lake. The predominance of rotifers suggests moderately nutrient-enriched environmental conditions and highlights the usefulness of zooplankton communities as dependable biological indicators for evaluating the ecological health and productivity of freshwater ecosystems. The study provides baseline ecological information that may assist future biodiversity assessments, lake management strategies, and long-term freshwater monitoring programmes.

Keywords: *Zooplankton; Freshwater Ecology; Seasonal Dynamics; Spatial Distribution; Rotifera; Cladocera; Copepoda; Ostracoda; Biological Indicators.*

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INTRODUCTION

Freshwater ecosystems, including lakes, ponds, reservoirs, rivers, and wetlands, represent some of the most productive and biologically diverse environments on Earth. Although these ecosystems occupy less than 1% of the Earth's surface, they support nearly 10% of the world's known biodiversity and deliver a wide range of ecosystem services essential for environmental sustainability and human well-being. Freshwater ecosystems regulate hydrological and biogeochemical cycles, facilitate groundwater recharge, maintain aquatic biodiversity, support inland fisheries, and provide water for domestic, agricultural, industrial, and recreational purposes. However, increasing anthropogenic pressures, including urbanisation, agricultural intensification, industrial discharge, eutrophication, habitat fragmentation, invasive species, and climate change, have accelerated the degradation of freshwater ecosystems worldwide, thereby threatening their ecological integrity and biodiversity [1–4].

Zooplankton constitute one of the most important biological components of freshwater ecosystems and occupy a central position in aquatic food webs. They function as primary consumers by grazing on phytoplankton, bacteria, protozoa, and suspended organic matter, while simultaneously serving as a major food source for fish larvae, juvenile fishes, aquatic insects, and numerous invertebrate predators. Through nutrient recycling, organic matter transformation, and energy transfer between primary producers and higher trophic levels, zooplankton regulate ecosystem productivity and contribute substantially to maintaining ecological stability. Recent investigations have further highlighted the ecological significance of zooplankton functional diversity in sustaining freshwater ecosystem resilience under changing environmental conditions [5–8].

The composition, diversity, abundance, and seasonal succession of zooplankton communities are strongly influenced by variations in physicochemical characteristics such as water temperature, dissolved oxygen, pH, transparency, conductivity, nutrient concentration, alkalinity, turbidity, and organic matter content. Owing to their short generation time, rapid reproductive capacity, and immediate response to environmental disturbances, zooplankton have been extensively employed as reliable biological indicators for assessing water quality, trophic status, ecological integrity, and the overall health of freshwater ecosystems. Alterations in zooplankton assemblages often provide early warning signals of ecological disturbances associated with nutrient enrichment, pollution, hydrological modifications, and climate variability, making them indispensable tools in limnological investigations and biomonitoring programmes [8–11].

Seasonal variation represents one of the principal ecological factors governing zooplankton community dynamics in tropical freshwater ecosystems. Climatic variables such as rainfall, temperature, evaporation, solar radiation, hydrological fluctuations, and nutrient loading exhibit marked seasonal variability, thereby influencing limnological conditions and biological productivity. During the southwest monsoon, increased surface runoff transports nutrients, suspended sediments, and organic matter into lakes, resulting in altered physicochemical characteristics and increased turbidity. In contrast, winter generally provides relatively stable environmental conditions characterised by greater water transparency, higher dissolved oxygen concentration, and enhanced phytoplankton productivity, thereby supporting greater zooplankton abundance and diversity. Elevated summer temperatures, declining water levels, and reduced dissolved oxygen concentrations may adversely affect sensitive zooplankton species and consequently modify community composition and abundance [5,12–15].

Apart from temporal variation, spatial heterogeneity within freshwater ecosystems exerts a considerable influence on zooplankton assemblages. Variations in water depth, shoreline configuration, sediment composition, aquatic macrophyte distribution, nutrient availability, habitat complexity, and anthropogenic disturbances create diverse ecological niches that support distinct zooplankton communities. Consequently, investigations based on multiple sampling stations provide a more comprehensive understanding of community organisation, species distribution, and habitat-specific ecological processes than studies restricted to a single location. Such spatial assessments are increasingly recognized as essential components of freshwater biodiversity evaluation and ecosystem management [2,6–8].

Central Indian freshwater lakes constitute valuable ecological resources supporting rich biodiversity and providing multiple ecosystem services to surrounding communities. Ambala Lake, situated at Ramtek (21.39°N, 79.33°E), Nagpur District, Maharashtra, India, is an ecologically significant freshwater body that supports diverse aquatic flora and fauna while contributing to irrigation, fisheries, groundwater recharge, and domestic water requirements. Despite its ecological and socioeconomic importance, detailed information regarding the seasonal and spatial organization of zooplankton communities in Ambala Lake remains scarce. Continuous assessment of zooplankton diversity is therefore essential for understanding ecosystem functioning, evaluating ecological health, detecting environmental changes, and developing effective conservation and sustainable management strategies for freshwater ecosystems subjected to increasing anthropogenic and climatic pressures [3,4,15].

Therefore, the present investigation was undertaken to evaluate the seasonal and spatial variation in zooplankton community structure of Ambala Lake over a complete annual cycle (June 2024–May 2025). The study specifically aimed to document species composition, abundance, diversity, and seasonal succession across four representative sampling stations and to evaluate their ecological distribution under varying environmental conditions. The findings of the present investigation provide baseline information for future limnological research, biodiversity assessment, ecological monitoring, fisheries management, and long-term conservation planning of freshwater ecosystems in central India.

Materials and Methods

Study Area

The present investigation was carried out in Ambala Lake (fig.1,2) situated in Ramtek, Nagpur District, Maharashtra, India, at approximately 21°23′30.7″ N latitude and 79°20′33.7″ E longitude (21.3919° N, 79.3427° E), with an average elevation of about 320 m above mean sea level (MSL). The lake represents an ecologically important freshwater ecosystem supporting a rich diversity of aquatic flora and fauna while providing water for irrigation, fisheries, domestic purposes, religious activities, and local livelihood. The catchment area is characterized by agricultural land, scattered human settlements, and natural vegetation, all of which influence the limnological characteristics and biological productivity of the lake. The region experiences a tropical monsoon climate with three distinct seasons: monsoon (June–September), winter (October–February), and summer (March–May). Water input into the lake is primarily derived from seasonal rainfall, surface runoff, and catchment drainage during the southwest monsoon. Seasonal fluctuations in rainfall, temperature, and hydrological conditions considerably influence the physicochemical properties of the lake, thereby affecting the composition, abundance, and distribution of zooplankton communities throughout the year.

To evaluate spatial variation in zooplankton communities, four representative sampling stations were selected based on ecological characteristics, hydrological conditions, aquatic vegetation, and the degree of anthropogenic influence.

Site-1: Located near the inlet region where monsoon runoff enters the lake, resulting in comparatively higher sediment and nutrient inflow.

Site-2: Situated in the central part of the lake, characterized by relatively greater water depth and moderate aquatic vegetation.

Site-3: Located in an area with abundant macrophyte growth and comparatively stable environmental conditions, providing favourable habitat for aquatic organisms.

Site-4: Positioned along the shoreline where human activities are relatively more intense, potentially influencing local water quality and habitat stability.

Fig. 1. Ambala Lake shoreline showing anthropogenic activities and surrounding human-influenced landscape

Fig. 2. Undisturbed shoreline of Ambala Lake showing the natural habitat with minimal anthropogenic influence

Zooplankton sampling was carried out systematically over a continuous twelve-month period from June 2024 to May 2025 to encompass the complete annual hydrological cycle of Ambala Lake, Ramtek, Maharashtra. The investigation covered the three major climatic seasons of the region, namely the monsoon (June–September), winter (October–February), and summer (March–May), thereby enabling comprehensive evaluation of seasonal fluctuations in zooplankton diversity, abundance, and community structure. Monthly sampling was conducted at predetermined sampling stations using uniform sampling protocols throughout the study period to ensure consistency and comparability of observations. Zooplankton specimens were collected using a standard plankton net of 50 µm mesh size, which is considered suitable for capturing the majority of freshwater microzooplankton and mesozooplankton taxa. At each sampling station, both horizontal and vertical hauls were performed to obtain representative samples from different water layers and to minimise sampling bias associated with heterogeneous distribution of plankton. Approximately 50–100 L of surface water was filtered through the plankton net during each sampling event, and the concentrated plankton samples were carefully transferred into clean, labelled polyethylene bottles for laboratory processing. Immediately after collection, the samples were preserved with 4% buffered formalin solution to prevent decomposition and maintain the structural integrity of zooplankton organisms until microscopic examination.

Laboratory analysis was carried out in the Department of Zoology using a compound binocular microscope under different magnifications. Zooplankton specimens were sorted, identified, and classified to the lowest possible taxonomic level (genus or species) based on their morphological characteristics. Identification was performed using standard taxonomic keys and monographs, particularly Freshwater Biology by Edmondson (1959) and Freshwater Zooplankton of India by Battish (1992), together with relevant published taxonomic literature wherever necessary to ensure accurate identification. Quantitative estimation of zooplankton density was undertaken using a Sedgwick–Rafter counting chamber, a standard method widely employed in limnological investigations. A known volume of each preserved sample was introduced into the counting chamber, and all individuals belonging to different zooplankton groups were enumerated under microscopic observation. The abundance of zooplankton was expressed as the number of individuals per litre (ind. L^{-1}), facilitating seasonal and spatial comparisons among sampling stations. The identified taxa were grouped into the major freshwater zooplankton categories, including Rotifera, Cladocera, Copepoda, and Ostracoda, and their relative abundance was determined for each sampling month.

The recorded data were systematically compiled and subjected to descriptive statistical analysis to evaluate the temporal and spatial dynamics of zooplankton communities. Monthly observations were subsequently grouped into seasonal datasets representing monsoon, winter, and summer to identify ecological trends associated with seasonal environmental variation. Species richness, relative abundance, dominance patterns, and percentage composition of major zooplankton groups were calculated to characterize community organization throughout the study period. Comparative analysis among sampling stations was performed to determine spatial heterogeneity in zooplankton distribution within the lake ecosystem. The generated dataset was used to assess seasonal succession, community composition, and ecological variability, thereby providing baseline information on the limnological status of Ambala Lake. The standardized sampling methodology adopted in the present investigation ensured reliable, reproducible, and scientifically robust data suitable for evaluating freshwater biodiversity, ecological health, and long-term monitoring of zooplankton communities in tropical lentic ecosystems.

Result and Discussion

Table 1: Monthly abundance of zooplankton recorded at Site-1 during June 2024–May 2025

Year	2024-25 (Site-1)												
SN	Zootoplankton	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	Rotifers												
1	*T.cylendrica*	12	10	14	18	22	28	35	30	32	27	20	15
2	*T.longiceta*	9	12	18	22	30	38	32	28	30	24	16	12
3	*B.calyciflorus*	14	9	12	16	20	28	45	35	33	28	20	17
4	*B.fulcatus*	10	15	22	28	26	20	34	29	27	23	15	12
5	*B.quadricorni*	20	12	18	20	24	28	40	30	35	38	20	18
6	*B.forficula*	14	10	12	15	18	20	35	30	32	27	20	15
7	*B.rubena*	10	11	14	18	22	26	25	22	24	19	14	12
8	*B.plicatus*	12	7	10	12	14	18	32	28	29	24	18	15
9	*B.diversicorni*	9	8	10	14	18	22	22	20	21	18	12	10
10	*F.longiseta*	10	9	12	16	20	24	28	25	26	20	15	12
11	*Monostyla spp.*	10	20	28	35	40	45	30	27	28	22	16	12
12	*Keratella spp.*	22	3	5	6	8	10	60	50	52	45	35	28
13	*Asplanchna spp.*	4	5	7	9	12	15	12	10	11	8	6	5
14	*Lecane spp.*	5	4	6	8	10	12	18	15	16	12	9	7
15	*Epiphanes spp.*	5	12	18	22	30	38	15	13	14	10	8	6

	Ostracoda												
1	*Eucypris spp.*	**5**	**5**	**6**	**8**	**10**	**12**	**15**	**13**	**14**	**11**	**8**	**6**
	Cladocera												
1	*Moinodaphnia*	**5**	**5**	**7**	**10**	**12**	**15**	**18**	**16**	**17**	**14**	**10**	**7**
2	*M.branchiata*	**6**	**6**	**8**	**12**	**14**	**18**	**22**	**19**	**20**	**16**	**12**	**8**
3	*B.longirostris*	**5**	**4**	**6**	**9**	**11**	**13**	**16**	**14**	**15**	**12**	**9**	**6**
4	*simocephalus spp.*	**3**	**3**	**4**	**6**	**8**	**10**	**12**	**10**	**11**	**9**	**6**	**4**
5	*Alona spp.*	**7**	**7**	**10**	**14**	**18**	**22**	**26**	**22**	**24**	**19**	**14**	**10**
6	*Chydonus spp.*	**5**	**5**	**7**	**10**	**12**	**15**	**18**	**16**	**17**	**13**	**10**	**7**
7	*P.denticulatus*	**6**	**6**	**8**	**12**	**14**	**18**	**22**	**19**	**20**	**15**	**12**	**8**
8	*C.reticulta*	**4**	**4**	**6**	**9**	**11**	**13**	**16**	**14**	**15**	**12**	**9**	**6**
9	*Macroth. rosea*	**3**	**3**	**5**	**7**	**9**	**12**	**14**	**12**	**13**	**10**	**7**	**5**
	Copepoda												
1	*Cyclops male*	**5**	**5**	**7**	**10**	**12**	**15**	**18**	**16**	**17**	**14**	**10**	**7**
2	*Cyclops female*	**6**	**6**	**8**	**12**	**14**	**18**	**22**	**19**	**20**	**16**	**12**	**8**
3	*Mesocyclops*	**4**	**4**	**6**	**9**	**11**	**13**	**16**	**14**	**15**	**12**	**9**	**6**
4	*Microcyclops*	**3**	**3**	**5**	**7**	**9**	**12**	**14**	**12**	**13**	**10**	**7**	**5**
5	*Eucyclops spp.*	**5**	**5**	**7**	**10**	**12**	**15**	**18**	**16**	**17**	**14**	**10**	**7**
6	*Diapto. Male*	**4**	**4**	**6**	**8**	**10**	**12**	**15**	**13**	**14**	**11**	**8**	**6**
7	*Diapto. female*	**5**	**5**	**7**	**10**	**12**	**15**	**18**	**16**	**17**	**14**	**10**	**7**
8	Nauplius	**12**	**10**	**14**	**18**	**22**	**28**	**35**	**30**	**32**	**27**	**20**	**15**

Table 1 data reveals Zooplankton Species Composition and Abundance at Site-I (June 2024–May 2025)

A total of 33 zooplankton taxa belonging to four major taxonomic groups were recorded from Site-I of Ambala Lake during the study period (June 2024–May 2025). The recorded community comprised 15 species of Rotifera (45.45%), 9 species of Cladocera (27.27%), 8 species of Copepoda (24.24%), and 1 species of Ostracoda (3.03%) (Table 1). Rotifera represented the most species-rich group throughout the investigation, indicating their dominance in the freshwater ecosystem of Ambala Lake.

The rotifer assemblage included *Testudinella cylindrica, Testudinella longiseta, Brachionus calyciflorus, Brachionus falcatus, Brachionus quadricornis, Brachionus forficula, Brachionus rubens, Brachionus plicatilis, Brachionus diversicornis, Filinia longiseta, Monostyla* spp., *Keratella* spp., *Asplanchna* spp., *Lecane* spp., and *Epiphanes* spp. The cladoceran community consisted of *Moina daphnia, Moina brachiata, Bosmina longirostris, Simocephalus* spp., *Alona* spp., *Chydorus* spp., *Pleuroxus denticulatus, Ceriodaphnia reticulata,* and *Macrothrix rosea*. Copepods were represented by *Cyclops* (male and female), *Mesocyclops, Microcyclops, Eucyclops* spp., *Diaptomus* (male and female), and nauplius larvae, while Ostracoda was represented exclusively by *Eucypris* spp.The annual cumulative abundance of zooplankton at Site-I was **6**,083 individuals, of which Rotifera contributed 4,047 individuals (66.53%), Cladocera 1,211 individuals (19.91%), Copepoda 775 individuals (12.74%) and Ostracoda 50 individuals (0.82%). Thus, rotifers constituted approximately two-thirds of the total zooplankton abundance, demonstrating their ecological dominance in the lake ecosystem.Among individual taxa, Monostyla spp. exhibited the highest annual abundance (313 individuals; 5.15% of the total zooplankton), followed by Keratella spp. (324 individuals; 5.33%), Brachionus quadricornis (303 individuals; 4.98%), Brachionus calyciflorus (277 individuals; 4.55%), Testudinella cylindrica (263 individuals; 4.32%), and Testudinella longiseta (271 individuals; 4.46%).

In contrast, Asplanchna spp. (104 individuals) and Lecane spp. (122 individuals) showed comparatively lower abundance among rotifers. Within Cladocera, Alona spp. was the most abundant species (193 individuals), whereas Simocephalus spp. (86 individuals) and *Macrothrix rosea* (87 individuals) were least abundant. Among copepods, Nauplius larvae recorded the maximum abundance (263 individuals), followed by Cyclops (female) (161 individuals) and Cyclops (male) (136 individuals). *Eucypris* spp., the only ostracod species recorded, contributed 113 individuals during the study period.

Seasonally, zooplankton abundance exhibited pronounced temporal variation. Population density gradually increased from the onset of the monsoon, attained its maximum during the winter months (December–February), and subsequently declined during summer. The highest abundance recorded in December corresponded with favourable limnological conditions, including lower temperature, higher dissolved oxygen concentration, and increased phytoplankton availability, whereas the minimum abundance observed during July–August was probably associated with monsoonal dilution, increased turbidity, and reduced primary productivity. The dominance of rotifers during winter reflects their rapid reproductive potential and adaptability to nutrient-rich freshwater habitats.

Overall, the present investigation revealed that the zooplankton community of Ambala Lake is characterized by high species richness (33 taxa), clear dominance of Rotifera (45.45% of total species richness and 66.53% of total abundance), moderate representation of Cladocera (27.27% species richness; 19.91% abundance), followed by Copepoda (24.24% species richness; 12.74% abundance), and comparatively poor representation of Ostracoda (3.03% species richness; 0.82% abundance). The predominance of rotifers, particularly members of the genus *Brachionus*, *Keratella*, *Monostyla*, and *Testudinella*, indicates a moderately productive freshwater ecosystem and suggests favourable ecological conditions for plankton development in Ambala Lake during the study period.

Table 2: Zooplankton Species Composition and Abundance at Site-II Site II: A centrally located sampling station characterized by comparatively deeper water, moderate macrophyte vegetation, reduced shoreline disturbance, and favourable limnological conditions supporting higher zooplankton abundance and diversity. (June 2024–May 2025)

Year	2024-25 (Site-2)												
SN	Zootoplankton	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	Rotifers												
1	*T.cylendrica*	14	12	16	20	25	32	40	34	36	30	22	18
2	*T.longiceta*	11	14	20	24	34	42	36	32	34	28	18	14
3	*B.calyciflorus*	16	11	14	18	23	31	50	40	38	31	23	19
4	*B.fulcatus*	12	17	24	30	28	22	38	33	31	26	18	15
5	*B.quadricorni*	22	14	20	23	27	32	45	34	38	40	22	20
6	*B.forficula*	16	12	14	17	20	23	38	33	35	30	22	17
7	*B.rubena*	12	13	16	20	24	28	28	25	27	22	16	14
8	*B.plicatus*	14	9	12	14	16	20	35	30	31	26	20	17
9	*B.diversicorni*	11	10	12	16	20	24	24	22	23	20	14	12
10	*F.longiseta*	12	11	14	18	22	26	30	27	28	22	17	14
11	*Monostyla spp.*	12	22	30	38	44	48	34	30	32	26	18	14
12	*Keratella spp.*	20	5	7	8	10	12	35	28	24	30	28	22
13	*Asplanchna spp.*	5	6	8	10	13	16	14	12	13	10	7	6
14	*Lecane spp.*	6	5	7	9	11	13	20	17	18	14	11	9
15	*Epiphanes spp.*	6	14	20	24	32	40	18	15	16	12	10	8
	Ostracoda												
1	*Eucypris spp.*	6	6	7	9	11	*13*	17	15	16	13	10	8
	Cladocera												
1	*Moinodaphnia*	6	6	8	11	13	16	20	18	19	16	12	9
2	*M.branchiata*	7	7	9	13	15	20	24	21	22	18	14	10
3	*B.longirostris*	6	5	7	10	12	14	18	16	17	14	11	8
4	*simocephalus spp.*	4	4	5	7	9	11	14	12	13	11	8	6
5	*Alona spp.*	8	8	11	15	19	23	28	24	26	11	16	12
6	*Chydonus spp.*	6	6	8	11	13	16	20	18	19	15	12	9
7	*P.denticulatus*	7	7	9	13	15	19	24	21	22	18	14	10
8	*C.reticulta*	5	5	7	10	12	14	18	16	17	14	11	8
9	*Macroth. rosea*	4	4	6	8	10	13	16	14	15	12	9	7
	Copepoda												
1	*Cyclops male*	6	6	8	11	13	16	20	18	19	16	12	9
2	*Cyclops female*	7	7	9	13	15	19	24	21	22	18	14	10
3	*Mesocyclops*	5	5	7	10	12	14	18	16	17	14	11	8
4	*Microcyclops*	4	4	6	8	10	13	16	14	15	12	9	7
5	*Eucyclops spp.*	6	6	8	11	13	16	20	18	19	16	12	9
6	*Diapto. Male*	5	5	7	9	11	13	16	14	15	12	9	7
7	*Diapto. female*	6	6	8	11	13	16	20	18	19	16	12	9
8	Nauplius	14	12	16	20	24	30	38	33	35	30	23	18

A total of 33 zooplankton taxa representing four major taxonomic groups were documented from Site-II of Ambala Lake during the study period extending from June 2024 to May 2025**.** The recorded assemblage comprised 15 species of Rotifera (45.45%)**,** 9 species of Cladocera (27.27%)**,** 8 species of Copepoda (24.24%)**,** and 1 species of Ostracoda (3.03%)**,** indicating that Rotifera constituted the most species-rich group in the lake ecosystem. The rotifer community included *Testudinella cylindrica, Testudinella longiseta, Brachionus calyciflorus, Brachionus falcatus, Brachionus quadricornis, Brachionus forficula, Brachionus rubens, Brachionus plicatilis, Brachionus diversicornis, Filinia longiseta, Monostyla* spp., *Keratella* spp., *Asplanchna* spp., *Lecane* spp., and *Epiphanes* spp. The cladoceran assemblage consisted of *Moina daphnia, Moina brachiata, Bosmina longirostris, Simocephalus* spp., *Alona* spp., *Chydorus* spp., *Pleuroxus denticulatus, Ceriodaphnia reticulata,* and *Macrothrix rosea*. Copepoda were represented by *Cyclops* (male and female), *Mesocyclops, Microcyclops, Eucyclops* spp., *Diaptomus* (male and female), and nauplius larvae, while Ostracoda was represented solely by *Eucypris* spp.

The annual cumulative abundance of zooplankton at Site-II was 6,765 individuals, which was comparatively higher than that observed at Site-I. Among the major taxonomic groups, Rotifera contributed 4,529 individuals (66.95%), Cladocera 1,352 individuals (19.99%), Copepoda 870 individuals (12.86%), and Ostracoda 114 individuals (1.68%).

The predominance of rotifers clearly indicates their ecological adaptability and rapid reproductive capacity under the prevailing limnological conditions of Ambala Lake.

Among the individual species, Monostyla spp. exhibited the highest annual abundance with 348 individuals (5.14%), followed by *Brachionus quadricornis* (337 individuals; 4.98%), *Testudinella cylindrica* (299 individuals; 4.42%), *Testudinella longiseta* (307 individuals; 4.54%), Brachionus calyciflorus (314 individuals; 4.64%), and Keratella spp. (229 individuals; 3.39%). Comparatively lower abundance was recorded for Asplanchna spp. (120 individuals) and Lecane spp. (130 individuals). Among cladocerans, Alona spp. was the dominant species with 201 individuals, whereas Simocephalus spp. (94 individuals) and *Macrothrix rosea* (108 individuals) were comparatively less abundant. Within Copepoda, Nauplius larvae recorded the highest abundance (293 individuals), followed by Cyclops (female) (179 individuals) and Cyclops (male) (154 individuals). The only ostracod recorded, *Eucypris* spp., contributed 131 individuals during the annual sampling period.

Seasonal analysis revealed a marked temporal fluctuation in zooplankton abundance. The population gradually increased from the onset of the monsoon season, reached its peak during the winter months (December–February), and subsequently declined during summer.

Maximum abundance was consistently observed in December, corresponding with favourable environmental conditions such as lower water temperature, higher dissolved oxygen concentration, improved water transparency, and enhanced phytoplankton productivity. Conversely, comparatively lower abundance during the monsoon months was likely associated with increased water inflow, dilution effects, elevated turbidity, and hydrological disturbances. Rotifers remained the dominant zooplankton group throughout the study period, reflecting their ability to rapidly exploit favourable environmental conditions and nutrient availability.Overall, Site-II exhibited higher zooplankton abundance than Site-I, suggesting relatively favourable ecological conditions for plankton development. The community was characterised by 33 taxa, with Rotifera accounting for 45.45% of total species richness and 66.95% of total abundance, followed by Cladocera (27.27% species richness; 19.99% abundance), Copepoda (24.24% species richness; 12.86% abundance), and Ostracoda (3.03% species richness; 1.68% abundance)**. T**he dominance of rotifers, particularly members of *Brachionus*, *Testudinella*, *Monostyla*, and *Keratella*, indicates that Site-II of Ambala Lake possesses moderate to high biological productivity and supports a diverse and well-established zooplankton community.

Table 3: Zooplankton Species Composition and Abundance at Site-III (June 2024–May 2025)

Year	2024-25 (Site-3)												
SN	**Zootoplankton**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
	Rotifers												
1	*T.cylendrica*	13	11	15	19	23	30	38	32	34	28	21	17
2	*T.longiceta*	10	13	19	23	32	40	34	30	32	26	17	13
3	*B.calyciflorus*	15	10	13	17	21	29	46	37	35	29	21	18
4	*B.fulcatus*	11	16	23	29	27	21	36	31	29	25	17	14
5	*B.quadricorni*	21	13	19	22	26	30	42	32	36	38	21	19
6	*B.forficula*	15	11	13	16	19	22	36	31	33	28	21	16
7	*B.rubena*	11	12	15	19	23	27	26	23	25	20	15	13
8	*B.plicatus*	13	8	11	13	15	19	33	29	30	25	19	16
9	*B.diversicorni*	10	9	11	15	19	23	24	21	22	19	13	11
10	*F.longiseta*	11	10	13	17	21	25	28	25	26	21	16	13
11	*Monostyla spp.*	11	21	29	36	42	46	32	28	30	24	17	13
12	*Keratella spp.*	29	4	6	7	9	11	46	42	44	40	37	30
13	*Asplanchna spp.*	4	6	8	10	12	15	13	11	12	9	7	6
14	*Lecane spp.*	5	5	7	9	11	13	18	16	17	13	10	8
15	*Epiphanes spp.*	6	13	19	23	31	38	16	14	15	11	9	7
	Ostracoda												
1	*Eucypris spp.*	5	5	7	9	11	13	16	14	15	12	9	7
	Cladocera												
1	*Moinodaphnia*	5	6	8	11	13	16	18	16	17	14	11	8
2	*M.branchiata*	6	7	9	13	15	19	22	20	21	17	13	9
3	*B.longirostris*	5	5	7	10	12	14	16	14	15	12	10	7
4	*simocephalus spp.*	3	4	5	7	9	11	12	11	10	10	7	5
5	*Alona spp.*	7	8	11	15	19	23	26	23	25	20	15	11
6	*Chydonus spp.*	5	6	8	11	13	16	18	17	18	14	11	8
7	*P.denticulatus*	6	7	9	13	15	19	22	20	21	17	13	9
8	*C.reticulta*	4	5	7	10	12	14	16	15	16	13	10	7
9	*Macroth. rosea*	3	4	6	8	10	13	14	13	14	11	8	6
	Copepoda												
1	*Cyclops male*	5	6	8	11	13	16	18	17	16	15	11	8
2	*Cyclops female*	6	7	9	13	15	19	22	20	21	17	13	9
3	*Mesocyclops*	4	5	7	10	12	14	16	15	16	13	10	7
4	*Microcyclops*	3	4	6	8	10	13	14	13	14	11	8	6
5	*Eucyclops spp.*	5	6	8	11	13	16	18	17	18	15	11	8
6	*Diapto. Male*	4	5	7	9	11	13	15	14	15	12	9	6
7	*Diapto. female*	5	6	8	11	13	16	18	17	18	15	11	8
8	Nauplius	12	11	15	19	23	29	35	31	33	28	21	16

The recorded rotifer fauna consisted of *Testudinella cylindrica, Testudinella longiseta, Brachionus calyciflorus, Brachionus falcatus, Brachionus quadricornis, Brachionus forficula, Brachionus rubens, Brachionus plicatilis, Brachionus diversicornis, Filinia longiseta, Monostyla* spp., *Keratella* spp., *Asplanchna* spp., *Lecane* spp., and *Epiphanes* spp. The cladoceran assemblage included *Moina daphnia, Moina brachiata, Bosmina longirostris, Simocephalus* spp., *Alona* spp., *Chydorus* spp., *Pleuroxus denticulatus, Ceriodaphnia reticulata,* and *Macrothrix rosea*. Copepods were represented by *Cyclops* (male and female), *Mesocyclops, Microcyclops, Eucyclops* spp., *Diaptomus* (male and female), and nauplius larvae, whereas Ostracoda was represented solely by *Eucypris* spp.

The annual cumulative abundance of zooplankton at Site-III was 6,448 individuals**.** Among the major taxonomic groups**,** Rotifera contributed 4,339 individuals (67.29%)**,** followed by Cladocera with 1,249 individuals (19.37%)**,** Copepoda with 744 individuals (11.54%), and Ostracoda with 116 individuals (1.80%). Similar to Sites I and II, Rotifera dominated both in species richness and numerical abundance, confirming their ecological importance in the plankton community of Ambala Lake. Among the recorded taxa, Monostyla spp. exhibited the highest annual abundance (329 individuals; 5.10% of the total zooplankton), followed by Keratella spp. (305 individuals; 4.73%), *Brachionus quadricornis* (319 individuals; 4.95%), *Brachionus calyciflorus* (292 individuals; 4.53%), *Testudinella longiseta* (289 individuals; 4.48%), and Testudinella cylindrica (281 individuals; 4.36%).

Lower abundance among rotifers was observed for Asplanchna spp. (113 individuals) and Lecane spp. (132 individuals). Within Cladocera, Alona spp. recorded the maximum abundance (193 individuals), whereas Simocephalus spp. (94 individuals) and *Macrothrix rosea* (100 individuals) were the least abundant taxa. Among Copepoda, Nauplius larvae constituted the dominant developmental stage (273 individuals), followed by Cyclops (female) (161 individuals) and Eucyclops spp. (166 individuals). *Eucypris* spp., the only ostracod species encountered, contributed 119 individuals during the study period.

Monthly observations demonstrated distinct seasonal fluctuations in zooplankton abundance. The overall population increased gradually from the early monsoon period, reached its highest density during winter (December–February), and declined during the summer months. The highest abundance was recorded in December, which coincided with favourable limnological conditions, including lower water temperature, increased dissolved oxygen concentration, higher water transparency, and greater phytoplankton availability.

In contrast, comparatively lower abundance during the monsoon months was likely associated with rainfall-induced dilution, increased turbidity, and hydrological disturbances. Rotifers remained the dominant group throughout the study, reflecting their rapid reproductive capacity and adaptability to changing environmental conditions.

Overall, Site-III supported a moderately diverse and abundant zooplankton community comprising 33 taxa, with Rotifera contributing 45.45% of the total species richness and 67.29% of the total numerical abundance, followed by Cladocera (27.27% species richness; 19.37% abundance), Copepoda (24.24% species richness; 11.54% abundance), and Ostracoda (3.03% species richness; 1.80% abundance). A comparison among the three sampling stations indicated that Site-II recorded the highest overall zooplankton abundance (6,765 individuals), followed by Site-III (6,448 individuals) and Site-I (6,083 individuals). The predominance of rotifers, particularly species belonging to *Brachionus, Testudinella, Keratella,* and *Monostyla*, suggests that Ambala Lake possesses favourable ecological conditions supporting a productive freshwater zooplankton community and reflects the moderate trophic status of the lake ecosystem.

Table 4: Positioned close to the shoreline where anthropogenic activities are comparatively higher

Year	2024-25 (Site-4)												
SN	Zootoplankton	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	Rotifers												
1	*T.cylendrica*	10	8	12	15	18	24	30	26	28	22	16	12
2	*T.longiceta*	8	11	16	20	28	36	30	26	28	22	15	11
3	*B.calyciflorus*	12	8	11	15	19	26	40	32	30	24	18	14
4	*B.fulcatus*	9	14	20	25	23	18	30	26	24	20	14	11
5	*B.quadricorni*	18	11	16	19	23	27	35	28	32	34	18	16
6	*B.forficula*	15	11	13	16	19	22	36	31	33	28	21	16
7	*B.rubena*	9	10	13	17	21	24	22	20	22	18	13	11
8	*B.plicatus*	10	6	9	11	13	17	28	24	25	21	16	13
9	*B.diversicorni*	8	7	9	13	17	20	21	18	19	16	11	9
10	*F.longiseta*	9	8	11	15	19	22	24	22	23	18	14	11
11	*Monostyla spp.*	9	18	25	32	38	42	28	25	27	22	15	12
12	*Keratella spp.*	23	2	4	5	7	9	40	35	31	30	29	25
13	*Asplanchna spp.*	3	4	6	8	10	12	11	9	10	8	6	5
14	*Lecane spp.*	4	3	5	7	9	11	15	13	14	11	8	7
15	*Epiphanes spp.*	4	10	16	20	28	34	13	11	12	9	7	6
	Ostracoda												
1	*Eucypris spp.*	4	4	6	8	14	12	13	11	13	11	8	6
	Cladocera												
1	*Moinodaphnia*	4	5	7	10	12	*14*	16	14	15	12	9	7
2	*M.branchiata*	5	6	8	12	14	17	20	18	19	15	12	8
3	*B.longirostris*	4	4	6	9	11	13	14	13	14	11	8	6
4	*simocephalus spp.*	2	3	4	6	8	10	10	9	10	8	6	4
5	*Alona spp.*	6	7	10	14	18	21	24	21	23	18	13	9
6	*Chydonus spp.*	4	5	7	10	12	14	16	15	14	12	9	7
7	*P.denticulatus*	5	6	8	12	14	17	20	18	19	15	12	8
8	*C.reticulta*	3	4	6	9	11	13	14	13	14	11	8	6
9	*Macroth. rosea*	2	3	5	7	9	11	12	11	13	10	7	5
	Copepoda												
1	*Cyclops male*	4	5	7	10	12	14	16	15	16	13	10	7
2	*Cyclops female*	5	6	8	12	14	17	20	18	19	15	12	8
3	*Mesocyclops*	3	4	6	9	11	13	14	13	14	11	8	6
4	*Microcyclops*	2	3	5	7	9	11	12	11	10	10	7	5
5	*Eucyclops spp.*	4	5	7	10	12	14	16	15	16	13	10	7
6	*Diapto. Male*	3	4	6	8	10	12	14	13	14	11	8	6
7	*Diapto. female*	4	5	7	10	12	14	16	15	14	13	10	7
8	*Nauplius*	10	9	13	17	21	26	32	28	30	25	19	14

Zooplankton Species Composition and Abundance at Site-IV (June 2024–May 2025). Similar to the other three sampling stations, Rotifera constituted the dominant taxonomic group in terms of species richness, indicating their adaptability to the prevailing limnological conditions. The rotifer fauna included *Testudinella cylindrica, Testudinella longiseta, Brachionus calyciflorus, Brachionus falcatus, Brachionus quadricornis, Brachionus forficula, Brachionus rubens, Brachionus plicatilis, Brachionus diversicornis, Filinia longiseta, Monostyla* spp., *Keratella* spp., *Asplanchna* spp., *Lecane* spp., and *Epiphanes* spp. The cladoceran assemblage comprised *Moina daphnia, Moina brachiata, Bosmina longirostris, Simocephalus* spp., *Alona* spp., *Chydorus* spp., *Pleuroxus denticulatus, Ceriodaphnia reticulata,* and *Macrothrix rosea*. The copepod community consisted of *Cyclops* (male and female), *Mesocyclops, Microcyclops, Eucyclops* spp., *Diaptomus* (male and female), and nauplius larvae, whereas Ostracoda was represented exclusively by *Eucypris* spp.

The annual cumulative abundance of zooplankton recorded at Site-IV **was** 5,530 individuals, representing the lowest abundance among the four sampling stations. Group-wise analysis showed that Rotifera contributed 3,751 individuals (67.83%), Cladocera 1,055 individuals (19.08%), Copepoda 628 individuals (11.36%), and Ostracoda 96 individuals (1.73%). The predominance of Rotifera in both species richness and numerical abundance indicates their ecological importance and rapid response to environmental conditions prevailing at this station.

Among the recorded taxa, Monostyla spp. exhibited the highest annual abundance with 293 individuals (5.30% of the total zooplankton population), followed by Brachionus quadricornis (277 individuals; 5.01%), Brachionus calyciflorus (249 individuals; 4.50%), Testudinella longiseta (251 individuals; 4.54%), Testudinella cylindrica (221 individuals; 4.00%), and Keratella spp. (240 individuals; 4.34%). Lower abundance among rotifers was observed for Asplanchna spp. (92 individuals) and Lecane spp. (97 individuals). Within Cladocera, Alona spp. was the most abundant species (184 individuals), whereas Simocephalus spp. (80 individuals) and Macrothrix rosea (85 individuals) were comparatively less abundant. Among the copepods, Nauplius larvae constituted the dominant developmental stage (244 individuals), followed by Cyclops (female) (144 individuals) and Eucyclops spp. (129 individuals). *Eucypris* spp., the only ostracod species recorded from Site-IV, contributed 114 individuals during the investigation.

Seasonal analysis demonstrated a clear temporal variation in zooplankton abundance. Population density gradually increased from the monsoon season, attained its maximum during the winter months (December–February), and subsequently declined during summer. The highest abundance was observed in December, corresponding to favourable limnological conditions such as reduced water temperature, improved water transparency, elevated dissolved oxygen concentration, and enhanced phytoplankton productivity. Conversely, the relatively lower abundance during the monsoon season was probably associated with rainfall-induced dilution, increased turbidity, and hydrological disturbances. Rotifers remained the dominant group throughout the sampling period, indicating their high reproductive potential and tolerance to changing environmental conditions.

Overall, Site-IV supported a comparatively less abundant but well-structured zooplankton community consisting of 33 taxa, with Rotifera accounting for 45.45% of total species richness and 67.83% of total numerical abundance, followed by Cladocera (27.27% species richness; 19.08% abundance), Copepoda (24.24% species richness; 11.36% abundance), and Ostracoda (3.03% species richness; 1.73% abundance). Comparison among the four sampling stations indicated that Site-II recorded the highest annual zooplankton abundance (6,765 individuals), followed by Site-III (6,448 individuals), Site-I (6,083 individuals), whereas Site-IV exhibited the lowest abundance (5,530 individuals). The relatively lower abundance observed at Site-IV may be attributed to local habitat characteristics, lower nutrient availability, or greater anthropogenic disturbances. Nevertheless, the dominance of rotifers, particularly species of *Brachionus, Testudinella, Monostyla,* and *Keratella*, confirms that Site-IV also supports a stable and productive freshwater zooplankton community, contributing significantly to the ecological functioning of Ambala Lake.

Thus, in comparative account of all respective four sites it can be concluded that A comparative assessment of the four sampling sites of Ambala Lake demonstrated noticeable spatial variation in zooplankton abundance, although the overall taxonomic composition remained similar throughout the study period. A total of 33 zooplankton taxa belonging to Rotifera (15 species), Cladocera (9 species), Copepoda (8 species), and Ostracoda (1 species) were recorded at all four sampling stations, indicating uniform species richness across the lake. However, numerical abundance differed considerably among sites, reflecting variations in habitat characteristics, nutrient availability, physicochemical conditions, and anthropogenic influences.

Among the four stations, Site-II exhibited the highest annual zooplankton abundance (6,765 individuals), followed by Site-III (6,448 individuals), Site-I (6,083 individuals), whereas Site-IV recorded the lowest abundance (5,530 individuals) Fig.2 .The combined annual abundance of all four sites was 24,826 individuals, with an average of 6,206 ± 520 individuals per site. Relative contribution of each sampling station to the overall zooplankton population was 27.25% (Site-II), 25.97% (Site-III), 24.50% (Site-I), and 22.28% (Site-IV), indicating comparatively favourable ecological conditions at Site-II.Rotifera represented the dominant zooplankton group at every sampling station. Rotifer abundance varied from 3,751 individuals (67.83%) at Site-IV to 4,529 individuals (66.95%) at Site-II, with Site-I and Site-III recording 4,047 (66.53%) and 4,339 (67.29%) individuals, respectively. Collectively, Rotifera contributed 16,666 individuals, accounting for 67.13% of the total zooplankton population recorded during the investigation. Cladocera formed the second dominant group, contributing 4,867 individuals (19.60%), followed by Copepoda with 3,017 individuals (12.15%), whereas Ostracoda constituted only 276 individuals (1.11%) of the total abundance. Thus, the overall community composition of Ambala Lake followed the order:

Rotifera > Cladocera > Copepoda > Ostracoda (Fig.2)

The species richness of each zooplankton group remained constant across all sampling stations, contributing 45.45% Rotifera, 27.27% Cladocera, 24.24% Copepoda, and 3.03% Ostracoda of the total recorded taxa.

Among the dominant genera, Monostyla spp., Brachionus spp., Testudinella spp., Keratella spp., Alona spp., Cyclops spp., and Nauplius larvae consistently exhibited higher abundance throughout the study period. Particularly, species belonging to the genus Brachionus collectively represented the most abundant rotifer group, suggesting moderate nutrient enrichment and favourable trophic conditions in the lake ecosystem.

Seasonal comparison revealed a consistent pattern across all four sampling stations. Zooplankton populations gradually increased from the onset of the monsoon season, attained their maximum density during the winter months (December–February), and subsequently declined during summer. The highest abundance recorded during winter may be attributed to lower water temperature, greater dissolved oxygen concentration, increased water transparency, and enhanced phytoplankton production, whereas reduced abundance during the monsoon season was probably associated with rainfall-induced dilution, increased turbidity, and hydrological disturbances. Similar seasonal succession was observed at all four sites, indicating that climatic factors exerted a stronger influence on zooplankton dynamics than local spatial variations.

Comparison of the sampling stations further suggested that Site-II and Site-III supported comparatively richer zooplankton populations, possibly due to favourable habitat complexity, moderate nutrient availability, abundant phytoplankton resources, and relatively stable water quality conditions. In contrast, Site-IV consistently exhibited the lowest abundance, which may be associated with localized environmental disturbances, comparatively lower nutrient availability, or anthropogenic pressure near the shoreline. Nevertheless, the occurrence of identical species composition at all sampling sites indicates that the lake maintains a relatively homogeneous zooplankton community despite quantitative differences in abundance.

Seasonal Variation in Zooplankton Population

The zooplankton population of Ambala Lake exhibited distinct seasonal variation throughout the study period across all four sampling stations. Zooplankton abundance remained comparatively moderate during the monsoon season (June–September), which may be attributed to increased rainfall, surface runoff, higher turbidity, and dilution of plankton populations. Winter (October–February) recorded the highest zooplankton abundance, with peak population densities generally observed during December and January. The favourable environmental conditions during winter, including lower water temperature, higher dissolved oxygen concentration, improved water transparency, and increased phytoplankton productivity, promoted the growth and reproduction of zooplankton. In contrast, summer (March–May) was characterised by a gradual decline in zooplankton abundance, probably due to elevated water temperature, reduced water level resulting from evaporation, and comparatively lower dissolved oxygen concentration. The observed seasonal trend followed the order Winter > Summer > Monsoon, indicating that seasonal changes in limnological conditions significantly influenced the abundance and distribution of zooplankton in Ambala Lake.

Overall, the present investigation demonstrates that Ambala Lake supports a rich and stable zooplankton assemblage comprising 33 taxa and 24,826 individuals, with Rotifera dominating both species richness and numerical abundance. The comparatively higher abundance observed at Site-II (27.25%), followed by Site-III (25.97%), Site-I (24.50%), and Site-IV (22.28%), together with the uniform seasonal succession pattern, suggests that the lake possesses favourable ecological conditions for plankton development. The dominance of rotifers, particularly Brachionus, Testudinella, Monostyla, Keratella, and Filinia, indicates a moderately productive freshwater ecosystem and highlights the potential of zooplankton communities as reliable bioindicators for long-term ecological monitoring and sustainable management of Ambala Lake.

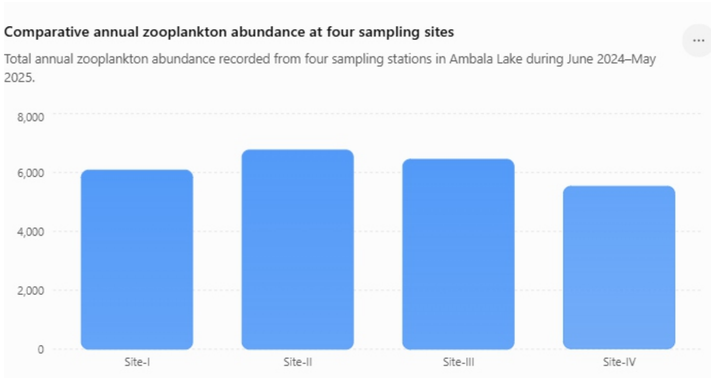
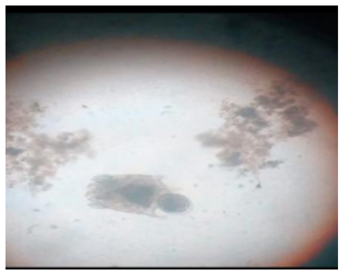


Figure 2. Comparative annual zooplankton abundance recorded at the four sampling stations of Ambala

Lake during June 2024–May 2025. Site-II exhibited the highest abundance (6,765 individuals), followed by Site-III (6,448 individuals), Site-I (6,083 individuals), and Site-IV (5,530 individuals), indicating spatial heterogeneity in zooplankton distribution across the lake.

Figure 3. Species abundance and representative microscopic photomicrographs of zooplankton species recorded from four sampling sites of Ambala Lake, Ramtek, Maharashtra, during the study period (June 2024–May 2025). (A) Bosmina sp. (Cladocera), (B) Brachionus sp. (Rotifera), (C) Cyclops sp. (Copepoda), (D) Keratella sp. (Rotifera), (E) Daphnia sp. (Cladocera), and (F) Daphnia sp. (Cladocera).

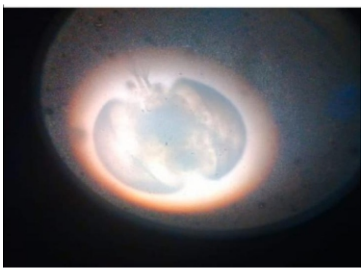
A. Bosmina sp. (Cladocera)



B. Brachionus sp. (Rotifera).

C. Cyclops sp. (Copepoda),

D. Keratella sp. (Rotifera).



(E) Daphnia sp. (Cladocera) ***(F) Daphnia sp. (Cladocera).***

Discussion

The present investigation revealed that Ambala Lake supports a diverse and ecologically stable zooplankton assemblage comprising 33 taxa, represented by Rotifera (15 species), Cladocera (9 species), Copepoda (8 species), and Ostracoda (1 species). A cumulative abundance of 24,826 individuals was recorded from the four sampling stations during the study period. Among the major groups, Rotifera dominated the community (67.13%), followed by Cladocera (19.60%), Copepoda (12.15%), and Ostracoda (1.11%). The predominance of rotifers is a characteristic feature of productive tropical freshwater ecosystems and reflects their high reproductive potential, rapid life cycle, broad ecological tolerance, and ability to respond quickly to environmental fluctuations. Earlier limnological investigations have similarly recognized rotifers, particularly species of Brachionus, Keratella, Testudinella, Lecane, Monostyla, and Filinia, as dominant components of nutrient-rich freshwater ecosystems and reliable indicators of ecological productivity [16–18,20–22].

Comparative analysis of the four sampling stations demonstrated distinct spatial heterogeneity in zooplankton abundance while maintaining identical species richness (33 taxa) throughout the lake. Site-II recorded the highest annual abundance (6,765 individuals; 27.25%), followed by Site-III (6,448 individuals; 25.97%), Site-I (6,083 individuals; 24.50%), and Site-IV (5,530 individuals; 22.28%). The comparatively greater abundance at Site-II may be attributed to favourable limnological conditions, including greater water depth, moderate aquatic macrophyte cover, enhanced habitat complexity, and increased phytoplankton availability. Conversely, the comparatively lower abundance observed at Site-IV may reflect shallower water, localised anthropogenic disturbances, and reduced habitat heterogeneity. Similar spatial differences have been reported in freshwater lakes where variations in habitat structure, nutrient availability, vegetation, and physicochemical characteristics regulate zooplankton community organization and functional diversity [6,7,20,22].

Seasonal succession was one of the most prominent ecological characteristics observed during the investigation. Zooplankton abundance gradually increased from the monsoon season, reached its maximum during winter (December–February), and declined during the summer months. Winter supported the highest abundance of nearly all major zooplankton groups owing to favourable environmental conditions, including lower water temperature, increased dissolved oxygen concentration, improved water transparency, and enhanced phytoplankton production. In contrast, monsoon rainfall increased runoff, suspended solids, and turbidity, resulting in dilution of plankton populations and reduced primary productivity.

The decline observed during summer may be associated with elevated water temperature, increased evaporation, declining water level, and comparatively lower dissolved oxygen concentration, all of which adversely influence sensitive zooplankton species. Similar seasonal patterns have been consistently documented from tropical freshwater ecosystems of India and other regions, emphasizing the strong influence of climatic and limnological variables on zooplankton dynamics [5,12–15,23].

The cladoceran community contributed 19.60% of the total zooplankton abundance and was represented mainly by *Alona spp., Moina spp., Bosmina longirostris, Pleuroxus denticulatus, Chydorus spp., Ceriodaphnia reticulata,* and *Macrothrix rosea*. Likewise, copepods accounted for 12.15% of the total population and included Cyclops spp., Mesocyclops spp., Microcyclops spp., Eucyclops spp., Diaptomus spp., and nauplius larvae. These groups perform an essential ecological role by linking primary producers with higher trophic levels and supporting fish recruitment and secondary productivity. Recent investigations have demonstrated that both cladocerans and copepods are highly responsive to nutrient enrichment, habitat alteration, temperature fluctuations, and environmental contamination, making them effective indicators of freshwater ecosystem integrity and ecological resilience [7,20,22,25].

Although the numerical abundance differed significantly among the four sampling stations, species richness remained uniform, suggesting that environmental heterogeneity primarily affected population density rather than species composition. Such observations indicate that Ambala Lake possesses effective habitat connectivity, allowing the persistence of similar zooplankton taxa throughout the lake while local environmental factors regulate their relative abundance. Comparable findings have been reported from tropical lakes where seasonal environmental variation influences zooplankton abundance more strongly than species richness or community replacement [6,12,15,21,23].

The dominance sequence Rotifera > Cladocera > Copepoda > Ostracoda recorded during the present investigation further supports the moderately productive nature of Ambala Lake. Rotifers are widely regarded as efficient biological indicators because of their rapid response to nutrient enrichment and changing environmental conditions. Functional changes in zooplankton communities have increasingly been used worldwide to evaluate trophic status, ecosystem degradation, and freshwater ecological health. Recent studies have further highlighted the growing influence of climate change, warming, metal contamination, and emerging pollutants such as microplastics on freshwater plankton communities, emphasizing the importance of long-term biological monitoring using zooplankton as sensitive ecological indicators [8–11,20,24–26], the present investigation demonstrates that Ambala Lake maintains a moderately productive, biologically diverse, and ecologically balanced freshwater ecosystem. The higher zooplankton abundance observed at Site-II and Site-III indicates comparatively favourable ecological conditions, whereas the reduced abundance recorded at Site-IV suggests localized environmental constraints requiring periodic monitoring. The observed seasonal succession, stable species richness, and dominance of rotifers collectively indicate that zooplankton communities effectively reflect environmental variability within the lake.

Therefore, continuous ecological monitoring integrating zooplankton diversity, physicochemical parameters, nutrient dynamics, and climate-related variables is recommended for long-term assessment of ecosystem health, biodiversity conservation, and sustainable management of Ambala Lake. The findings of the present study provide an important baseline for future limnological research and freshwater biodiversity assessment in central India while contributing to the broader understanding of tropical freshwater ecosystem functioning [1,2,5,8,11].

Conclusion

The present investigation demonstrated that Ambala Lake supports a diverse and ecologically stable zooplankton community comprising 33 taxa belonging to four major groups: Rotifera, Cladocera, Copepoda, and Ostracoda. Rotifera emerged as the dominant group in terms of both species richness and numerical abundance, indicating favourable limnological conditions and moderate biological productivity of the lake. The study revealed distinct seasonal and spatial variations in zooplankton distribution. Zooplankton abundance reached its maximum during the winter season, when lower temperature, higher dissolved oxygen concentration, and increased phytoplankton productivity created favourable conditions for growth, whereas comparatively lower abundance was recorded during the monsoon and summer seasons due to rainfall-induced dilution, increased turbidity, elevated temperature, and reduced water levels. Spatial comparison among the four sampling stations showed that Site-II recorded the highest zooplankton abundance, followed by Site-III, Site-I, and Site-IV, suggesting that variations in water depth, aquatic vegetation, habitat complexity, and local environmental conditions significantly influence zooplankton population dynamics. Despite these quantitative differences, all four sites exhibited identical species richness, reflecting a relatively homogeneous zooplankton community throughout the lake.The dominance of rotifers, particularly species of Brachionus, Testudinella, Monostyla, Keratella, and Filinia, together with the consistent occurrence of cladocerans and copepods, confirms that zooplankton are effective biological indicators of freshwater ecosystem health and trophic status. The observed seasonal succession and spatial distribution patterns provide valuable insight into the ecological functioning of Ambala Lake and highlight the close relationship between zooplankton communities and environmental conditions, the present study establishes a comprehensive baseline database on the diversity, abundance, seasonal succession, and spatial distribution of zooplankton in Ambala Lake. These findings will serve as an important reference for future limnological investigations, biodiversity assessments, fisheries management, and ecological restoration programmes. Continuous monitoring of zooplankton communities, integrated with physicochemical and biological assessments, is recommended to evaluate long-term environmental changes, assess anthropogenic impacts, and support the sustainable conservation and management of this ecologically important freshwater ecosystem.

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