

Zooplankton Assemblages as Bioindicators of Freshwater Ecosystem Health under Environmental Changes

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ABSTRACT

Freshwater lakes are dynamic and ecologically significant ecosystems that play a vital role in sustaining aquatic biodiversity and maintaining ecosystem stability, particularly in semi-arid regions experiencing increasing environmental variability. Zooplankton communities, due to their short life cycles, rapid response to environmental fluctuations, and central role in aquatic food webs, are widely recognized as reliable bioindicators of freshwater ecosystem health. The present study assesses seasonal variation and group-wise composition of zooplankton in relation to physico-chemical characteristics of Bommakal Freshwater Lake, Karimnagar District, Telangana State, India, with the objective of evaluating ecosystem condition under changing environmental influences. Seasonal sampling was conducted during monsoon, post-monsoon, and pre-monsoon periods. Zooplankton samples were collected using standard plankton net filtration techniques, preserved, identified, and quantitatively analyzed following established limnological protocols. Simultaneously, key physico-chemical parameters including water temperature, pH, dissolved oxygen, transparency, and nutrient concentrations were analyzed to understand their influence on zooplankton assemblages. A total of 1450 zooplankton individuals were recorded during the study period. Seasonal distribution showed maximum abundance during the post-monsoon season (52.55%), followed by monsoon (24.28%) and pre-monsoon (23.17%). Group-wise composition revealed the dominance of Rotifera (41.93%), followed by Cladocera (28%), Copepoda (19.72%), and Ostracoda (10.34%), indicating a well-structured zooplankton community. Higher post-monsoon abundance can be attributed to favorable temperature conditions, improved water quality, enhanced nutrient availability, and hydrological stability, while reduced abundance during the pre-monsoon period reflects elevated temperature, reduced water volume, and increased environmental stress. The observed seasonal shifts in zooplankton assemblages clearly demonstrate their sensitivity to changes in physico-chemical parameters and environmental conditions. Overall, the study indicates that Bommakal Freshwater Lake maintains good ecological integrity and supports a productive and balanced aquatic ecosystem. The baseline data generated provide valuable insights for long-term ecological monitoring, bioindicator-based assessment, and sustainable management of freshwater resources in semi-arid regions.

Keywords: Zooplankton assemblages; Bioindicators; Seasonal variation; Physico-chemical parameters; Freshwater ecosystem health; Environmental changes; Bommakal Freshwater Lake

INTRODUCTION

Freshwater ecosystems represent less than 1% of the Earth's surface, yet they support nearly 10% of all known species and approximately one-third of vertebrate diversity. Lakes, reservoirs, and wetlands play a pivotal role in maintaining ecological balance by regulating hydrological cycles, sustaining biodiversity, and providing essential ecosystem services such as drinking water, irrigation, fisheries, and recreation. However, these ecosystems are increasingly threatened by rapid urbanization, agricultural intensification, nutrient enrichment, industrial effluents, and climate-driven environmental changes, resulting in habitat degradation, biodiversity loss, and declining water quality at a global scale (Reid et al., 2019; Dudgeon, 2020).

Among the various biological components of freshwater systems, zooplankton occupy a central position in aquatic food webs, acting as a critical link between primary producers (phytoplankton) and higher trophic levels such as fish and macroinvertebrates. Zooplankton communities comprise diverse taxonomic groups including *Rotifera*, *Cladocera*, *Copepoda*, and *Ostracoda*, each exhibiting distinct ecological preferences and sensitivities to environmental conditions. Due to their short life cycles, high reproductive rates, and rapid response to changes in water chemistry and trophic status, zooplankton assemblages are widely regarded as reliable bioindicators of freshwater ecosystem health (Jeppesen et al., 2020; Basińska et al., 2021).

Environmental parameters such as water temperature, pH, dissolved oxygen, conductivity, and nutrient concentrations (nitrates and phosphates) exert strong control over the composition, abundance, and seasonal succession of zooplankton populations. Alterations in these parameters—particularly under conditions of pollution and eutrophication—often lead to pronounced shifts in community structure, favoring pollution-tolerant and eutrophic indicator taxa such as *Brachionus*, *Filinia*, and *Moina*, while reducing sensitive cladocerans and

calanoid copepods. Consequently, changes in zooplankton diversity and dominance patterns serve as early warning signals of ecological stress and deteriorating water quality (Nandini & Sarma, 2022; Akbar et al., 2023).

In India, freshwater lakes and reservoirs are under mounting pressure due to unregulated anthropogenic activities, including agricultural runoff, domestic sewage discharge, and land-use changes. Several studies across different regions of the country have demonstrated the effectiveness of zooplankton-based assessments in evaluating trophic status and ecological integrity of inland waters (Goswami et al., 2021; Sharma et al., 2023). Despite this growing recognition, systematic and region-specific studies remain limited in semi-arid landscapes, particularly in Telangana State, where seasonal rainfall variability and increasing nutrient inputs significantly influence freshwater ecosystems.

Karimnagar District, located in the semi-arid region of northern Telangana, contains numerous small to medium-sized freshwater lakes that are vital for local water supply, agriculture, and fisheries. These lakes are increasingly subjected to anthropogenic stressors such as agricultural runoff, sedimentation, and nutrient enrichment. However, comprehensive ecological assessments using biological indicators are scarce. Bommakal Freshwater Lake, situated in Saidapur Mandal, represents a typical inland lake of this region and provides an ideal natural system for evaluating zooplankton assemblages in relation to environmental changes.

The present study focuses on seasonal and spatial variations in zooplankton assemblages of Bommakal Lake and examines their relationships with key physico-chemical parameters to assess ecosystem health. By identifying dominant and indicator taxa and evaluating the impacts of pollution and eutrophication on community structure, this study aims to generate baseline ecological data essential for long-term monitoring and sustainable management of freshwater resources in Karimnagar District and similar semi-arid regions of India.

MATERIALS AND METHODS

Study Area

Bommakal Freshwater Lake (18.377°N, 79.155°E) is located in Saidapur Mandal of Karimnagar District, Telangana State, India. The lake lies in a semi-arid climatic region characterized by hot summers, moderate monsoonal rainfall, and mild winters. It is a seasonal freshwater body of ecological and socio-economic importance, supporting fisheries, agriculture, aquatic biodiversity, and local water requirements. The lake covers approximately 15 hectares, with a maximum depth ranging between 2.5 and 4.0 m during the post-monsoon period. Water levels decline considerably during the summer season due to evaporation and reduced inflow. These seasonal hydrological fluctuations influence water chemistry, nutrient dynamics, and habitat conditions, which directly regulate the structure and diversity of zooplankton communities.

Physico-Chemical Parameters

Seasonal water samples were collected from selected stations of Bommakal Freshwater Lake during morning hours (08:00–10:00 a.m.) using acid-washed polyethylene bottles. In situ measurements of water temperature, pH, and transparency were recorded at the sampling sites. Dissolved oxygen (DO) was estimated by Winkler's method; while biochemical oxygen demand (BOD) was determined using the standard 5-day incubation method. Total dissolved solids (TDS), total hardness, alkalinity, free carbon dioxide (CO₂), and chlorides were analyzed following standard titrimetric and gravimetric procedures. Nutrients such as nitrates and phosphates were estimated by colorimetric methods, and major cations (Na⁺ and K⁺) were analyzed using flame photometry. All analyses were carried out according to standard methods (APHA, 1985; Trivedy & Goel, 1986; Wetzel & Likens, 2000).

Zooplankton Sampling and Estimation

Zooplankton samples were collected seasonally from each sampling station during morning hours (08:00–10:00 a.m.), simultaneously with water sampling. A total volume of 50 L of surface water was filtered through a silk bolting cloth (No. 25; mesh size 56 µm) to concentrate zooplankton organisms. The concentrated samples were transferred into labeled 50 ml plastic bottles and preserved immediately with 4% neutral formalin to maintain morphological integrity.

In the laboratory, zooplankton samples were thoroughly mixed and examined using compound and stereo microscopes. Quantitative estimation was carried out using the Sedgwick–Rafter counting cell, and zooplankton density was expressed as individuals per liter (ind. L⁻¹) following standard methods (APHA, 1985; Ward & Whipple, 1959). Zooplankton taxa were identified up to genus or species level using standard taxonomic keys and monographs (Edmondson, 1959; Pennak, 1978; Sharma & Michael, 1987). Seasonal variations in species composition, abundance, and dominance were analyzed to evaluate their potential as bioindicators of freshwater ecosystem health under changing environmental conditions.

RESULTS AND DISCUSSION

Freshwater lakes represent some of the most productive yet ecologically fragile aquatic ecosystems, particularly in tropical and semi-arid regions where pronounced climatic variability and escalating anthropogenic pressures exert strong control over water quality and biological integrity. Zooplankton assemblages, positioned at a critical junction of aquatic food webs, serve as key regulators of energy transfer between primary producers and higher trophic levels. Owing to their short life cycles, high reproductive rates, and differential tolerance to environmental stressors, zooplankton communities respond rapidly and predictably to variations in temperature, nutrient enrichment, dissolved oxygen, and hydrological regimes, rendering them exceptionally sensitive indicators of ecosystem condition. Substantial evidence indicates that alterations in zooplankton species composition, abundance, and dominance structure reliably reflect processes such as eutrophication, organic pollution, and climate-induced stress in freshwater lakes (Jeppesen et al., 2011; Nandini & Sarma, 2013; Basińska et al., 2021). In Indian freshwater ecosystems, particularly shallow lakes influenced by monsoon-driven hydrological fluctuations, seasonal succession patterns of zooplankton have been extensively employed to evaluate trophic status and ecological integrity (Sharma & Michael, 1987; Altaff, 2004; Goswami et al., 2021). The zooplankton dynamics recorded in Bommakal Freshwater Lake closely mirror these global and regional trends, underscoring the robustness of zooplankton-based bioindicator approaches as powerful tools for assessing freshwater ecosystem health under rapidly changing environmental and climatic conditions.

Table 1: Seasonal assessment of physico-chemical parameters of Bommakal Fresh water Lake, Karimnagar District, Telangana (June 2022 – May 2023)

Season	Temperature	PH	Electrical Conductivity	Total Dissolved Solids	Transparency	Dissolved Oxygen	Biochemical Oxygen Demand	Free Co ₂
Monsoon	27.41	7.15	0.30	137.68	56.00	8.69	8.37	12.20
Postmonsoon	23.20	7.29	0.26	221.25	66.62	7.26	13.00	10.13
Premonsoon	33.40	7.47	0.38	341.81	73.12	5.94	5.35	11.61
Season	Total Alkalinity	Total Hardness	Chlorides	Nitrates	Phosphates	Sodium	Potassium	Ammonia
Monsoon	136.56	78.43	34.12	0.60	2.22	6.59	1.38	1.24
Postmonsoon	161.87	120.62	51.43	0.44	1.14	5.71	1.14	1.14
Premonsoon	192.75	175.25	57.01	0.34	1.80	4.95	1.79	1.17

Physico-Chemical Characteristics

The seasonal variation of physico-chemical parameters in Bommakal Freshwater Lake indicates noticeable fluctuations influenced by monsoonal inflow and dry-season concentration effects. Slightly alkaline pH, moderate electrical conductivity, and increasing total dissolved solids from monsoon to pre-monsoon reflect progressive mineral concentration due to evaporation. Higher dissolved oxygen during monsoon and reduced levels during pre-monsoon, along with elevated biochemical oxygen demand during post-monsoon, indicate seasonal organic loading and microbial activity. Nutrient concentrations, particularly nitrates, phosphates, and ammonia, showed moderate enrichment, suggesting favourable conditions for zooplankton development and indicating a moderately productive condition with favourable nutrient availability for sustaining zooplankton communities. a moderately productive to eutrophic status of the lake (APHA, 1985; Wetzel & Likens, 2000).

Rotifera

Rotifera constituted a dominant and ecologically significant component of the zooplankton assemblage in Bommakal Freshwater Lake, represented by seven species belonging to the genera *Brachionus*, *Keratella*, *Filinia*, *Asplanchna*, *Polyarthra*, and *Lecane*. Rotifers are widely recognized as sensitive bioindicators of trophic status due to their short life cycles, rapid population turnover, and strong response to variations in nutrient availability, organic enrichment, and dissolved oxygen levels (Sharma & Michael, 1987; Nandini & Sarma, 2013; Basińska et al., 2021).

The rotifer community exhibited pronounced seasonal variation, with a total abundance of 608 individuals recorded during the study period. Among the seasons, post-monsoon supported the highest rotifer density (321 individuals), followed by monsoon (147 individuals) and pre-monsoon (140 individuals). Monthly trends showed a gradual increase in abundance from June to November, with peak densities during October and November, clearly indicating favourable post-monsoon conditions for rotifer proliferation. Species-wise analysis revealed the dominance of *Brachionus calyciflorus* and *Brachionus angularis*, particularly during the post-monsoon season. The prevalence of these taxa is characteristic of nutrient-enriched waters with relatively high organic availability, as *Brachionus* species are known for their tolerance to elevated organic load and fluctuating dissolved oxygen conditions. Moderate abundance of *Keratella cochlearis* and *Polyarthra* sp. suggests periods of relatively stable environmental conditions, whereas the comparatively lower density of *Asplanchna* sp., a predatory rotifer, reflects regulated prey availability within the zooplankton community. Seasonally, the post-monsoon peak in rotifer abundance can be attributed to optimal temperature, enhanced nutrient input through runoff, and moderate dissolved oxygen concentrations, which collectively promote rapid reproduction and population expansion. In contrast, reduced abundance during the monsoon season may be linked to dilution effects caused by increased water volume, while the decline during pre-monsoon months is associated with higher water temperature, reduced water levels, increased ionic concentration, and declining dissolved oxygen. Such stressful conditions restrict species diversity and favour only tolerant forms.

Table 2: Monthly variation in Rotifera abundance of Bommakal Freshwater Lake, Karimnagar District, Telangana (June 2022 – May 2023)

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Tot
<i>Brachionus calyciflorus</i>	7	9	10	11	19	21	18	14	11	8	6	5	139
<i>Brachionus angularis</i>	5	7	8	9	17	19	17	13	10	7	5	4	121
<i>Keratella cochlearis</i>	4	5	6	7	12	14	13	10	9	6	4	3	93
<i>Filinia longiseta</i>	3	4	5	6	10	11	10	8	6	5	3	2	73
<i>Asplanchna sp.</i>	2	3	4	4	7	8	7	5	4	3	2	1	50
<i>Polyarthra sp.</i>	3	4	5	6	11	13	12	9	7	5	3	2	80
<i>Lecane sp.</i>	1	2	3	4	8	9	8	6	5	3	2	1	52
TOTAL	25	34	41	47	84	95	85	65	52	37	25	18	608

Table 3: Monthly variation in Cladocera abundance of Bommakal Freshwater Lake, Karimnagar District, Telangana (June 2022 – May 2023)

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Tot
<i>Daphniacarinata</i>	4	5	6	7	14	16	15	12	9	7	5	4	124
<i>Moina micrura</i>	5	6	7	8	15	18	17	14	11	8	6	5	138
<i>Ceriodaphnia sp.</i>	3	4	5	6	11	12	11	9	7	5	3	2	78
<i>Bosmina sp.</i>	2	3	4	5	8	9	8	7	5	4	3	2	63
<i>Alona sp.</i>	1	2	3	4	6	7	6	5	4	3	2	1	44
TOTAL	15	20	25	30	54	62	57	47	36	27	19	14	406

Overall, the dominance of adaptable and environmentally tolerant rotifer taxa (*Brachionus* spp.), combined with moderate physico-chemical enrichment, indicates that Bommakal Freshwater Lake maintains favourable ecological conditions while experiencing seasonal environmental variability.”and experiencing increasing environmental stress, though it has not yet reached a severely degraded state. The clear post-monsoon dominance and seasonal fluctuation pattern of Rotifera strongly demonstrate their effectiveness as reliable bioindicators for assessing freshwater ecosystem health and detecting early signs of eutrophication in semi-arid tropical lakes (Altaff, 2004; Goswami et al., 2021; Karpowicz et al., 2023).

Cladocera

Cladocera formed an important component of the zooplankton community in Bommakal Freshwater Lake, represented by five species belonging to the genera *Daphnia*, *Moina*, *Ceriodaphnia*, *Bosmina*, and *Alona*. Cladocerans are efficient filter feeders and are widely regarded as sensitive indicators of nutrient enrichment,

food availability, and overall water quality due to their close dependence on phytoplankton abundance and physico-chemical conditions (Lampert, 1987; Sharma & Kotov, 2013).

The cladoceran population exhibited clear monthly and seasonal fluctuations, with a total abundance of 406 individuals recorded during the study period. Among the seasons, post-monsoon supported the highest cladoceran density (220 individuals), followed by pre-monsoon (96 individuals) and monsoon (90 individuals). Monthly trends showed a gradual increase from June onwards, reaching peak abundance during October and November, and subsequently declining during late summer months.

Species-wise analysis revealed *Moina micrura* (138 individuals) as the most dominant cladoceran, followed by *Daphnia carinata* (124 individuals). Both species attained maximum abundance during post-monsoon months (October–November), reflecting favourable conditions such as moderate temperature, increased nutrient availability, and enhanced phytoplankton biomass. These

taxa are well known for their tolerance to nutrient-rich and productive freshwater condition and rapid population growth under nutrient-rich environments. Moderate abundance of *Ceriodaphnia* sp. and *Bosmina* sp. indicates stable ecological conditions, while the relatively lower density of *Alona* sp. suggests its preference for comparatively less disturbed microhabitats.

Seasonally, the post-monsoon peak in cladoceran abundance can be attributed to increased food availability following monsoonal nutrient influx, coupled with optimal temperature and improved water transparency. During the monsoon season, comparatively lower abundance may result from dilution effects and increased turbulence caused by rainfall, which can negatively affect filtering efficiency. The decline observed during the pre-monsoon period is likely due to elevated temperature, reduced water level, increased ionic concentration, and higher predation pressure, all of which impose physiological stress on cladoceran populations.

Ecologically, the dominance of *Moina* and *Daphnia*, both recognized as indicators of nutrient enrichment, suggests that Bommakal Freshwater Lake supports a moderately productive and ecologically balanced freshwater environment. "The clear seasonal pattern—post-monsoon dominance, monsoon moderation, and pre-monsoon decline—demonstrates the strong influence of environmental changes on cladoceran community structure. These observations confirm the usefulness of cladoceran assemblages, along with rotifers, as reliable bioindicators for assessing freshwater ecosystem health and trophic status in semi-arid tropical lakes (Lampert, 1987; Jeppesen et al., 2011; Sharma & Kotov, 2013).

Copepoda

Copepoda represented a structurally and functionally important group of the zooplankton community in Bommakal Freshwater Lake, comprising *Cyclops* sp., *Mesocyclops* sp., *Diaptomus* sp., *Heliodiaptomus* sp., and nauplius larvae. Copepods play a key role in freshwater food webs as primary consumers and secondary producers, and their community composition is closely linked to water quality, trophic status, and climatic variability, making them valuable indicators of ecosystem health (Williamson & Reid, 2020; Karpowicz et al., 2023).

The copepod population showed distinct monthly and seasonal variations, with a total abundance of 286 individuals recorded during the study period. Seasonally, post-monsoon supported the highest copepod density (163 individuals), followed by monsoon (64 individuals) and pre-monsoon (59 individuals). Monthly abundance increased gradually from June, peaked during October and November, and declined sharply towards late summer months, reflecting seasonal changes in environmental conditions. Among the species, *Cyclops* sp. (79 individuals) was the most dominant copepod, followed by *Mesocyclops* sp. (68 individuals) and nauplius larvae (56 individuals). The dominance of cyclopoid copepods, particularly *Cyclops* and *Mesocyclops*, is indicative of nutrient-enriched conditions, as these taxa are known for their adaptability to fluctuating dissolved oxygen levels and moderate organic pollution. Calanoid copepods such as *Diaptomus* sp. and *Heliodiaptomus* sp. occurred in relatively lower abundance, suggesting comparatively stable but moderately productive conditions.

Seasonally, the post-monsoon peak in copepod abundance can be attributed to favourable temperature, enhanced nutrient availability following monsoonal runoff, and increased food resources in the form of phytoplankton and smaller zooplankton. During the monsoon season, reduced copepod abundance may be associated with dilution effects, increased turbulence, and washout of planktonic organisms. The pre-monsoon decline in copepod density is likely due to elevated water temperature, reduced water volume, increased ionic concentration, and heightened metabolic stress, which collectively limit copepod survival and reproduction.

Ecologically, the predominance of cyclopoid copepods along with abundant nauplius larvae suggests active reproduction and a stable, moderately productive condition of Bommakal Freshwater Lake. "The clear seasonal pattern—post-monsoon dominance, monsoon moderation, and pre-monsoon decline—demonstrates the strong influence of environmental changes on copepod community structure. These results confirm the usefulness of copepod assemblages, in combination with rotifers and cladocerans, as effective bioindicators for assessing freshwater ecosystem health in semi-arid tropical regions experiencing environmental stress.

Table 4: Monthly variation in Copepoda abundance of Bommakal Freshwater Lake, Karimnagar District, Telangana (June 2022 – May 2023)

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Tot
<i>Cyclops sp.</i>	3	4	5	6	10	12	11	9	7	5	4	3	79
<i>Mesocyclops sp.</i>	2	3	4	5	9	11	10	8	6	5	3	2	68
<i>Diaptomus sp.</i>	2	2	3	4	7	8	7	6	5	4	2	1	51
<i>Heliodiaptomus sp.</i>	1	2	2	3	6	7	6	5	4	3	2	1	42
<i>Nauplius larvae</i>	2	3	4	4	8	9	8	6	5	4	2	1	56
TOTAL	10	14	18	22	40	47	42	34	27	21	13	8	286

Table 5: Monthly variation in Ostracoda abundance of Bommakal Freshwater Lake, Karimnagar District, Telangana (June 2022 – May 2023)

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Tot
<i>Cypris sp.</i>	4	4	5	5	6	5	4	4	3	4	5	5	54
<i>Heterocypris sp.</i>	3	4	4	4	4	3	3	3	3	3	4	4	42
<i>Candona sp.</i>	2	2	3	3	3	3	2	2	2	3	3	3	31
<i>Ilyocypris sp.</i>	1	2	3	2	3	2	2	1	1	2	2	2	23
TOTAL	10	12	15	14	16	13	11	10	9	12	14	14	150

Ostracoda

Ostracoda constituted a relatively stable but ecologically informative component of the zooplankton assemblage in Bommakal Freshwater Lake, represented by four species belonging to the genera *Cypris*, *Heterocypris*, *Candona*, and *Ilyocypris*. Ostracods are benthic-planktonic microcrustaceans that respond sensitively to changes in water quality, substrate condition, and organic matter availability, making them useful indicators of environmental stability and moderate pollution levels in freshwater ecosystems (Meisch et al., 2019; Kulköylüoğlu & Yılmaz, 2021).

The ostracod community recorded a total abundance of 150 individuals during the study period and exhibited comparatively lower seasonal fluctuation than other zooplankton groups. Seasonally, post-monsoon supported the highest abundance (58 individuals), followed by monsoon (51 individuals) and pre-monsoon (41 individuals). Monthly distribution showed relatively uniform occurrence throughout the year, with a slight increase during October and November and reduced abundance during late summer months.

Among the recorded species, *Cypris sp.* (54 individuals) was the most dominant ostracod, followed by *Heterocypris*

sp. (42 individuals). These taxa are known for their tolerance to fluctuating environmental conditions and moderate organic enrichment. *Candona sp.* and *Ilyocypris sp.* occurred in lower abundance, reflecting their preference for relatively stable microhabitats and cleaner substrates. The dominance of *Cypris* and *Heterocypris* suggests favourable benthic conditions with moderate organic matter availability.

Seasonally, the post-monsoon increase in ostracod abundance can be attributed to improved habitat conditions, availability of detritus, and moderate water temperature following monsoonal recharge. The comparatively stable abundance during the monsoon season indicates resilience of ostracods to hydrological disturbance, while the decline during the pre-monsoon period may be linked to reduced water levels, increased temperature, and elevated ionic concentration, which adversely affect benthic micro crustaceans.

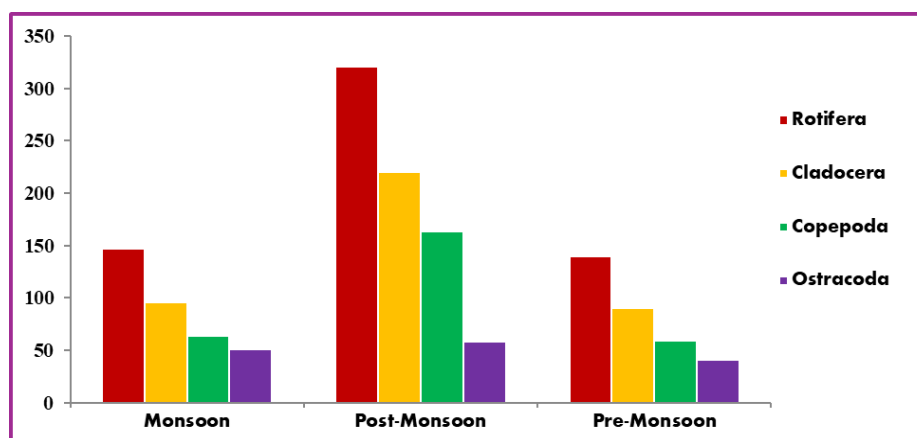
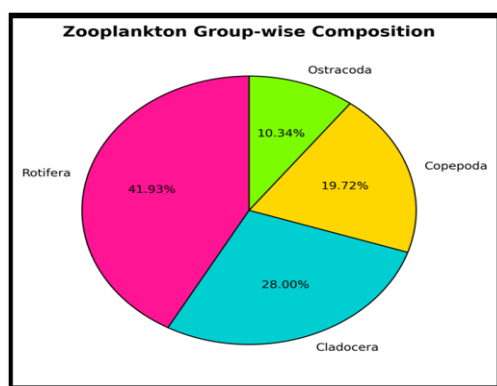
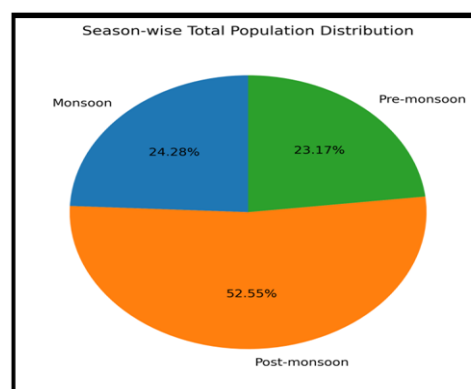
Ecologically, the consistent presence of ostracods throughout the study period indicates moderate ecological stability of Bommakal Freshwater Lake. Their relatively lower sensitivity compared to rotifers and cladocerans, combined with dominance of tolerant taxa, suggests a

Table 6: Season-wise Abundance and Percentage Contribution of Zooplankton Groups in Bommakal Freshwater Lake during June 2022 – May 2023

Zooplankton Group	Monsoon	Post-Monsoon	Pre-Monsoon	Total	Percentage %
Rotifera	147	321	140	608	42 %
Cladocera	96	220	90	406	28 %
Copepoda	64	163	59	286	20 %
Ostracoda	51	58	41	150	10 %
Total	352	762	336	1450	100 %

Table-7: Season-wise Percentage Distribution of Zooplankton Abundance in Bommakal Freshwater Lake during June 2022 – May 2023

Season	Total Population	Percentage %
Monsoon	352	24.28%
Post-monsoon	762	52.55%
Pre-monsoon	336	23.17%
Grand Total	1450	100%

**Fig-1:** Season-wise Abundance of Major Zooplankton Groups in Bommakal Freshwater Lake during June 2022 – May 2023**Fig-2:** Proportional Contribution of Major Zooplankton Groups in Bommakal Freshwater Lake during June 2022 – May 2023**Fig-3:** Seasonal percentage contribution of total zooplankton abundance in Bommakal Freshwater Lake, during June 2022 – May 2023

moderately productive system with benthic habitat integrity largely maintained.” The seasonal pattern of ostracods complements other zooplankton groups and strengthens the use of integrated zooplankton assemblages as reliable bioindicators for assessing freshwater ecosystem health under environmental stress in semi-arid tropical regions.

The observed seasonal variation in zooplankton assemblages of Bommakal Freshwater Lake demonstrates their effectiveness as bioindicators of freshwater ecosystem health under changing environmental conditions. Fluctuations in physico-chemical parameters, particularly nutrient availability, dissolved oxygen, temperature, and water level, strongly influenced zooplankton composition and abundance. Higher post-monsoon densities reflect favourable ecological conditions, whereas pre-monsoon declines indicate environmental stress. The dominance of eutrophic indicator taxa such as *Brachionus*, *Moina*, *Daphnia* and cyclopoid copepods, along with tolerant ostracods, confirms a moderately eutrophic status of the lake and highlights the sensitivity of zooplankton communities to environmental changes.

CONCLUSION

The present investigation clearly demonstrates that zooplankton assemblages of Bommakal Freshwater Lake respond sensitively and predictably to seasonal fluctuations in physico-chemical conditions influenced by monsoonal dynamics and anthropogenic activities. Variations in water temperature, nutrient availability, dissolved oxygen, and water level exerted strong control over the composition, abundance, and dominance structure of zooplankton communities. Consistently higher zooplankton abundance during the post-monsoon season reflects favourable ecological conditions associated with nutrient replenishment, improved water quality, and hydrochemical stability, whereas the pronounced decline during the pre-monsoon period indicates increasing environmental stress due to elevated temperature, reduced water volume, and increased ionic concentration. The dominance of adaptable and environmentally tolerant taxa such as *Brachionus*, *Moina*, *Daphnia*, *cyclopoid copepods*, and *ostracods* highlights the responsiveness of zooplankton communities to seasonal environmental changes and reflects a productive freshwater system

experiencing moderate ecological stress. The prevalence of these taxa indicates the ability of the zooplankton community to adjust to changing environmental conditions without severe ecological imbalance. Furthermore, seasonal succession patterns and shifts in indicator species composition clearly demonstrate the influence of environmental variability on overall ecosystem functioning.

Collectively, these findings confirm the effectiveness of zooplankton assemblages as reliable bioindicators for assessing freshwater ecosystem health under environmental change. The study further provides essential baseline ecological data that will support long-term monitoring, conservation planning, and sustainable management of freshwater lakes in semi-arid tropical regions experiencing increasing anthropogenic and climatic pressures.

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