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Seasonal Variations in Zooplankton Diversity and Water Quality Across Selected Freshwater Lakes in Northern India

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ABSTRACT

Aquatic ecosystems, which include a wide variety of habitats such as lakes, rivers, ponds, and estuaries, are among the most intricate and ecologically varied environments on Earth. However, both natural seasonal changes and man-made stressors like pollution and habitat modification are posing a growing danger to these ecosystems. The seasonal diversity and distribution of zooplankton species in three freshwater lakes in northern India—Tilyaar Lake (Rohtak), Karna Lake (Karnal), and Tikkar Taal (Panchkula)—are thoroughly examined in this research. Four primary taxonomic groups—Copepoda (18 species), Rotifera (31 species), Cladocera (18 species), and Ostracoda (6 species)—accounted for the 73 zooplankton species that were discovered. The zooplankton diversity was highest during the pre-monsoon season and lowest during the monsoon season, most likely as a result of surface runoff and rainfall dilution effects. The species diversity was highest in Tilyaar Lake and lowest in Tikkar Taal, with Copepods predominating in Rohtak, Rotifers and Ostracods peaking in Karnal, and Cladocera being most prevalent in Panchkula. Total Dissolved Solids (TDS), Nitrate, Sulfate, Turbidity, and Biological Oxygen Demand (BOD) were among the physico-chemical parameters that showed substantial seasonal fluctuation in water quality analysis, with the majority of these parameters peaking during the Post-Monsoon season. The relationship between BOD levels and zooplankton abundance is inverse, indicating that a larger organic load during the winter months promotes more biological activity, which in turn affects community structure. The study emphasizes how crucial zooplankton are as bioindicators for evaluating aquatic health because of how sensitively their variety and density react to human inputs like sewage discharge and environmental changes. For the ecological monitoring and management of freshwater resources under the stresses of urbanization and climatic fluctuation, the study provides important baseline data on species composition, seasonal population dynamics, and water quality variations.

INTRODUCTION

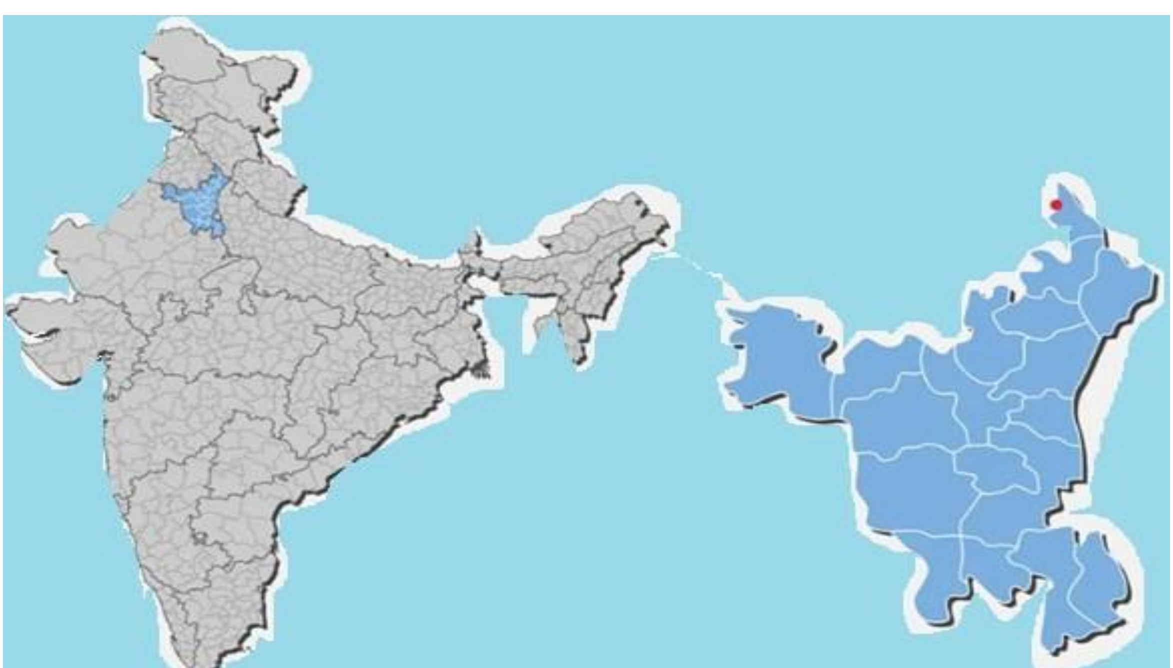
The most varied ecosystem on Earth is the aquatic environment, which includes bays, marshes, swamps, rivers, streams, ponds, lakes, and oceans. There is a remarkable variety of biological life in these water bodies, most of which has not yet been well investigated (Nath and Baruah, 2021). The worrisome rate at which the human population is growing raises serious concerns for humanity. The environment suffers as a result of this unregulated population increase. The environment's overall quality deteriorates as a result of human activities that increase contaminants in the air, water, and soil (Weber and Sciubba, 2018). Water's capacity to purify itself and preserve ecological equilibrium is astounding. This is mostly accomplished by the function of biotic components, which support the restoration of water quality and the preservation of an oligotrophic or clean water status in bodies of surface water. Since there could not be enough water available during dry seasons, people have grown more conscious of the need to save water throughout time (Ganesan, 2009). Although ecological changes are naturally caused by seasonal fluctuations, they have become more frequent due to anthropogenic stresses that also impact the richness of freshwater animals (Dudgeon *et al.*, 2006). Seasonal variation can cause significant year-round shifts in the pond and lake ecosystems' physical, chemical, and zooplankton features (Verma, 2020). Seasonally, lake nutrient contents vary, with the greatest concentrations being found in spring and summer as a result of runoff from fertilized agricultural land (Mischler *et al.*, 2014). Seasonally, dissolved oxygen concentrations in canals also fluctuate, reaching their highest at moderate water temperatures in the spring and fall. When food supplies like algae and aquatic plants are plentiful in the spring and summer, zooplankton populations also exhibit seasonal change, frequently rising (Florencio *et al.*, 2020). However, when the water cools and the amount of food available decreases, these populations usually decline in the fall and winter. Seasons also affect the species makeup of zooplankton, with certain species flourishing in warmer months and others in colder ones. lake ecosystem health and function can be greatly impacted by these seasonal changes in physical, chemical, and biological elements. The essential elements of the aquatic environment are zooplankton and phytoplankton (Mishra, 2014). In an aquatic environment, the zooplankton community is important for the transmission of energy between various trophic levels and for controlling the water body's overall production. The living forms that inhabit the aquatic ecosystem vary in tandem with any changes in the physico-chemical variables of the environment (Smitha and Venkataramana 2013). The two types of plankton, phytoplankton and zooplankton, are vital components of marine food webs because they transport energy to higher trophic species such as fish, bivalves, and crustaceans. (Saravanakumar *et al*., 2008, Limbu and Kyewalyanga, 2015, Moto *et al*., 2018). A vital component of freshwater environments is zooplankton. These tiny creatures, which vary in size from microns to centimeters, float on water currents (CSIRO, 2000). Zooplankton have a major influence on lakes because of their crucial role in aquatic food webs. They affect fish productivity, water quality, algal densities, and the cycling of pollutants and nutrients (Sarang and Manoj, 2007). The whole aquatic food chain is impacted by zooplankton, which graze on phytoplankton and transmit energy to higher trophic levels, including fish. Zooplankton are crucial markers of trophic status, pollution levels, and changes in water quality. The dynamics of plankton populations, especially the quantity of zooplankton, which are a major source of food for many aquatic species, have a significant impact on fish populations. Throughout the year, the dominant species of phytoplankton can shift with the changing seasons, which in turn affects the aquatic food chain and leads to changes in the ecosystem (Carpenter *et al*., 1985). Assessing the general health of these ecosystems requires an understanding of the ecological health of biodiversity in water reservoirs, including freshwater bodies, estuaries, and marine environments. Since zooplankton are essential to food webs and extremely sensitive to changes in environmental factors and water quality, their research is an essential part of this evaluation (Baxi *et al*., 2018).

Climate change is gradually affecting lake ecosystems as the physical and biological characteristics of lakes are altered by variations in temperature, precipitation patterns, and the frequency of extreme weather events. As a direct outcome of climate change, rising temperatures can cause a variety of biological disruptions in lake environments. Warmer water temperatures cause aquatic organisms' metabolic rates to increase, which in turn increases their demand for oxygen and lowers the amount of dissolved oxygen in the water (Poff *et al*., 2002). This can lead to hypoxia or even anoxia in deeper lake sections, particularly during summer stratification, creating harsh conditions for oxygen-sensitive creatures like fish and amphibians. These changes change species composition, reduce biodiversity, and impact ecological functions like flood control and water purification. (Reid *et al*, 2019) Climate change also affects seasonal activities like fish spawning and plant development, which are directly tied to water temperature and seasonal cycles. Among the environmental factors influencing the composition of phytoplankton populations in lakes are temperature, light penetration, nutrient availability, and water chemistry. These factors affect the diversity and number of phytoplankton groups, each of which serves a distinct purpose in the lake ecosystem. Common phytoplankton kinds in lakes include dinoflagellates, cyanobacteria (blue-green algae), diatoms, and green algae (Reynolds, 2006). Thorough analysis of the physical, chemical, and biological characteristics of water is part of the process of determining its quality. This procedure is essential for assessing the water's biological impacts, natural quality, and appropriateness for a range of intended applications, especially those that might have an influence on human health and the aquatic ecosystem's general health (Chapman, 1996). We can make sure that water bodies continue to be healthy and able to sustain biodiversity and human activity by evaluating these attributes. As bioindicators, zooplankton offer important information about the condition of the ecosystem, especially with regard to pollution levels, nutrient cycling, and the effects of seasonal fluctuations. Researchers can better comprehend the dynamic connections within aquatic ecosystems and the possible impacts of both natural and human influence by keeping an eye on zooplankton groups.

Materials and methods:

Study area

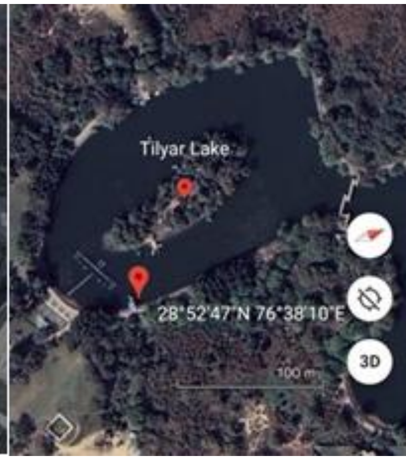
The northern Indian state of Haryana has a subtropical climate that ranges from semi-arid to sub-humid. With scorching summers, chilly winters, and moderate rainfall, the area has a climate that combines elements of the continental and monsoon seasons. The research study were carried out on Karnal (29° 41' 8.2644" N 76° 59' 25.9692" E) is situated in Haryana's center region, Rohtak (28° 53' 43.8540" N 76° 36' 23.8068" E) Haryana's western and Panchkula (30° 41' 26.7972" N 76° 49' 42.7044" E) The city of Panchkula is situated in Haryana's northeast. The comparatively low annual rainfall, which varies by region of the state, is between 200 and 700 mm.



Location of Haryana in Indian map (https://www.vectorstock.com)

Location Sites

Karna Lake in Karnal



Tilyar Lake in Rohtak

Tikkar Taal in Panchkula

Sample collection

Physico-chemical parameters

Water samples were collected for physicochemical study, with dissolved oxygen (DO) levels measured immediately at the sampling locations and other parameters examined in the laboratory. A total of sixteen parameters were examined from the water samples that were gathered during the research period. Alkalinity, phosphate, sulphate, nitrate, chloride, dissolved oxygen (DO), pH, electrical conductivity, turbidity, total hardness, calcium hardness, magnesium hardness, total dissolved solids (TDS), dissolved oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) were among these parameters. All of these water quality metrics' analytical processes were conducted in accordance with APHA (2012) recommendations. For primary productivity investigations, zooplankton filters with a 65 mm mesh size were used to filter water samples in order to reduce the interference of suspended particles and zooplankton. To guarantee the even dispersion of plankton prior to examination, the water samples were gathered in plastic bottles and kept undisturbed for a short while.

Study of seasonal abundance of zooplanktons in water

Zooplankton identification and enumeration were conducted in accordance with the established procedures described by Zheng (1984) and Moniruzzaman (1997). According to APHA's (1995) recommendations, the Sedgwick Rafter plankton counting cell was used for zooplankton counting and analysis. The estimation of zooplankton diversity and abundance is guaranteed to be accurate and consistent with this procedure. A specialized tiny counting chamber called the Sedgwick Rafter counting cell is used to make it easier to precisely count and identify planktonic animals, especially zooplankton. It is a known-volume, rectangular glass cell that is intended to contain a certain volume of material for microscopic analysis. This program makes it possible to identify species, count zooplankton in a given water sample systematically, and estimate its density. As a typical procedure to stop biological activity and avoid degradation, hardy zooplankton species were preserved right away after collecting using a 4% formalin solution. This made it easier for the lab to accurately analyze the samples both quantitatively and qualitatively. By using the Lackey's drop method for microscopic analysis, zooplankton taxa based on uniform volumetric sample may be identified and counted. It is crucial to remember, nevertheless, that some zooplankton groups—especially soft-bodied creatures like Rotifers—are extremely vulnerable to chemical preservatives. These taxa may experience severe morphological changes as a result of formalin preservation, which might jeopardize the precision of population estimates and species identification. Live observations are therefore advised for these groups in order to preserve the integrity of morphological traits and to get trustworthy taxonomic and ecological data (Mishra, 2014).

Results and discussion

Over the course of the investigation, 73 zooplankton species from four major taxonomic families were identified (Figure 1). Among these were Copepoda (18), Rotifera (31), Cladocera (18) and Ostracoda (6 species). With 55 species documented in all 3 lakes, during Pre Monsoon season had the largest zooplankton variety, whereas the monsoon season had the lowest diversity, with just 44 species (Figures 6, 7, and 8). In terms of spatial species richness, Tilyaar Lake was the most diverse, whereas Tikkar Taal had the least diversity (Table 1). Significantly, Panchkula (Tikkar Taal) had the highest concentration of Cladocera species (34). The greatest populations of Ostracoda and Rotifers were seen at Karnal (Karna lake) and Copepods species were studied in Rohtak (Tilyaar Lake), respectively (Figure 2). Increased sewage discharges from surrounding residential areas may be the cause of these higher abundances, since they lead to organic enrichment and changed water quality. According to Kuvadiya *et al*. (2020), zooplankton density was lowest during the monsoon (21.97%), highest during the winter (39.56%), and low during the summer (38.46%). The measured zooplankton density values (individuals per liter), which showed a considerable fall during the monsoon season and highest abundance during the winter, further confirmed this seasonal tendency. The diluting effect brought on by intense rainfall and surface runoff, which reduces nutrient contents and disturbs zooplankton populations, explains the decreased density during the monsoon (Goswami and Mankodi, 2012). Their research suggests that copepods and the predominance of Brachionus species might be used as bioindicators of pollution and the impact of residential sewage in freshwater bodies. On the other hand, great species diversity—where no single species dominates in terms of population—is frequently seen in non-polluted aquatic habitats; this ecological balance is a sign of improved water quality (Jani *et al*., 2022). The seasonal fluctuations in a number of physico-chemical parameters throughout the chosen research locations are depicted in Figures 3, 4, and 5. At all lakes, Total Dissolved Solids (TDS) exhibited higher concentrations during the Post-Monsoon season compared to the Pre-Monsoon and Monsoon periods, likely due to changes in water volume and flow dynamics during seasonal transitions. Total Hardness remained relatively stable throughout all seasons, with only minor fluctuations, indicating that hardness, driven by calcium and magnesium salts, is less affected by seasonal changes, although slight variations were noted in the Monsoon and Post-Monsoon periods. Magnesium levels slightly increased during the post-monsoon period, suggesting the influence of water chemistry changes from precipitation and runoff. Iron concentrations showed significant seasonal variation, peaking during the post-monsoon due to higher runoff carrying iron-rich sediments. Chloride levels remained fairly consistent, with minor fluctuations in the Monsoon, as chloride is a conservative ion less prone to seasonal variation unless impacted by external factors like anthropogenic activities. Sulphate concentrations also fluctuated seasonally, with higher levels observed in the post-monsoon period, likely driven by sulfate-rich runoff and natural hydrological processes. Fluoride concentrations were generally consistent, with slight increases during the Monsoon and Post-Monsoon, possibly due to leaching from fluoridated minerals during rainfall. Nitrate concentrations peaked in the post-monsoon period, reflecting the influence of fertilizer and nutrient runoff, particularly in agricultural areas. pH remained stable across seasons, though slight decreases in the Monsoon and increases in the post-monsoon were observed, likely due to rainfall interactions with natural buffering capacities and inputs from organic matter. Total Alkalinity increased during the post-monsoon, likely due to the dissolution of bicarbonates and carbonates from the soil during the rains, while Pre-Monsoon and Monsoon levels were more stable. Colour values varied considerably, with higher values during the post-monsoon period, attributed to increased turbidity and organic material from runoff. Finally, turbidity levels were notably higher during the post-monsoon due to runoff carrying suspended particles, while Pre-Monsoon and Monsoon turbidity levels were generally lower, though some variation was observed in the Monsoon due to rainfall. With the greatest values seen in post monsoon and the lowest in monsoon across all locations, the inverse trend of biological oxygen demand (BOD) suggested that there was a greater organic load and microbiological activity during the colder months. The winter season had higher levels of zooplankton abundance and biological oxygen demand (BOD), while the monsoon season had lower levels of both (Figures 6). This implies that seasonal fluctuations, which are probably caused by elements like temperature, nutrition availability, and water dilution during rains, have an impact on both zooplankton population dynamics and BOD levels. The correlation matrix for the seasonal variations of the parameters reveals insightful relationships across different seasons (Table-2). A strong positive correlation of 0.86 is observed between the Pre-Monsoon and Monsoon seasons, indicating that parameters measured in the Pre-Monsoon tend to follow similar trends during the Monsoon. This suggests that environmental conditions in these two seasons have related impacts on the parameters. Even stronger is the correlation between Pre-Monsoon and Post-Monsoon, with a value of 0.95, highlighting that the conditions affecting the parameters in the Pre-Monsoon season have a significant lasting influence into the post-monsoon period. Parameters that are high during the Pre-Monsoon are likely to remain elevated throughout the post-monsoon. Additionally, a strong correlation of 0.86 is noted between the Monsoon and Post-Monsoon seasons, showing that the trends in the Monsoon are closely mirrored in the post-monsoon. In conclusion, these high correlations across the different seasons (Pre-Monsoon, Monsoon, and Post-Monsoon) suggest consistent environmental or chemical conditions, with the strongest relationships observed between Pre-Monsoon and Post-Monsoon, signifying their enduring influence on the parameters.

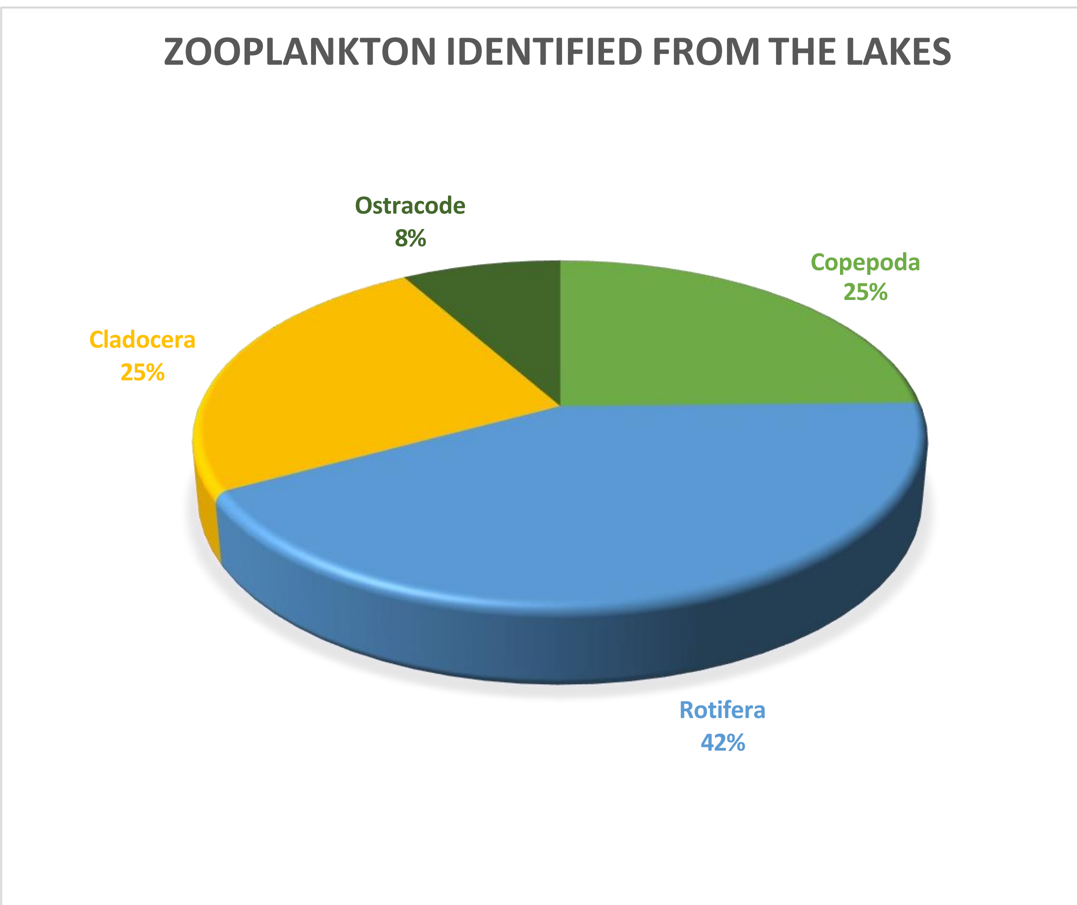


Figure 1: Distribution of identified Zooplanktonic groups

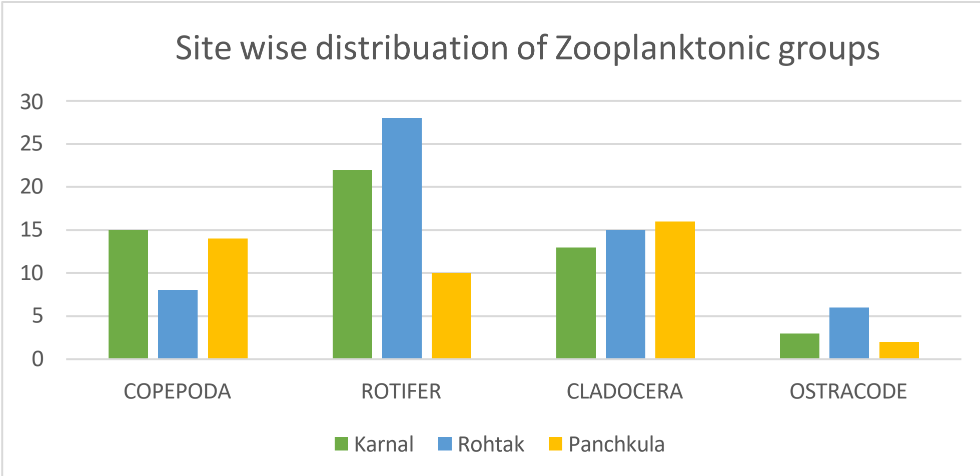


Figure 2 Site wise distribution of zooplanktonic groups: Karnal- Karna Lake, Rohtak- Tilyaar Lake and Panchkula- Tikkar Taal

	Zooplankton species	Karnal	Rohtak	Panchkula
S. No	**COPEPODA**	**Karna Lake**	**Tilyaar Lake**	**Tikkar Taal**
1	*Ectocyclops sp.*	+	+	+
2	*Neodiaptomus sp. 1*	+	+	+
3	*Thermocyclops decipiens*	+	+	+
4	*Heliodiaptomus viduus Sp 1*	+	+	+
5	*Heliodiaptomus viduus Sp 2*	+	-	+
6	*Copepod naupliar stage Sp*	+	+	+
7	*Neodiaptomus sp. (Microsetella noryegica)*	+	+	+
8	*Acrocalanus gracilis*	+	-	-
9	*Neodiaptomus sp. 2*	+	-	-
10	*Calanus finmarchicus*	+	-	+
11	*Sinodiptomus (Rhinediaptomus) indicus*	+	+	+
12	*Paraclanus parvus*	+	-	-
13	*Centropagus abdominalis*	-	-	+
14	*Macrosetella gracilis*	+	-	-
15	*Thermocyclops hyalinus*	+	+	+
16	*Diacyclops bicuspidatus odessanus.*	+	-	+
17	*Oithona nana*	-	-	+
18	*Microsetella rosea*	-	-	+
	ROTIFER			
1	*Keratella sp.*	+	+	-
2	*Monogononta Sp.1*	-	+	+
3	*Monogononta Sp. 2*	+	+	-
4	*Brachionus bidentatus Sp.1*	+	+	-
5	*Brachionus caudatus*	-	+	-
6	*Keratella tropica*	+	+	-
7	*Brachionus quadridentatus*	+	-	-
8	*Brachionidae (Brachionus dimiatus Bryce) Sp.2*	+	+	+
9	*Brachionus bidentatus Anderson Sp 1*	-	+	-
10	*Brachionus bidentatus Anderson Sp 2*	+	+	+

11	*Brachionus budapestinesis var punctus*	+	+	-
12	*Brachionus rubens*	+	+	+
13	*Brachionus calyciflorus*	+	-	+
14	*Brachionidae Sp. B. rubens Ehrenberg,*	+	+	+
15	*B. calyciflorus Pallas*	+	+	-
16	*B. calyciflorus Sp. (A mictic female carrying haploid meiotic eggs (embryos))*	-	+	-
17	*Brachionus calyciflorus Sp3*	+	+	+
18	*Brachionidae Sp. Keratella tropica*	-	+	+
19	*Brachionidae Sp. Brachionus calyciflorus*	-	+	-
20	*Brachionus diversicornis*	-	+	-
21	*B, Quadridentatus*	-	+	-
22	*B. dimidiatus*	+	+	-
23	*Filinia sp 1*	+	+	-
24	*Filiniidae (Filinia longiseta) Sp2*	+	+	+
25	*Trichocera porcellus*	+	+	+
26	*Testudinella sp. 1*	+	+	-
27	*Testudinella (Monogononta Sp)*	+	+	-
28	*A. Brightwelli*	-	+	-
29	*A. Anuraeopsis*	+	+	-
30	*Asplanchna Sp 1*	+	-	-
31	*Asplanchna Sp 2*	+	+	-
	CLADOCERA			
1	*Moina Sp. 1*	-	+	-
2	*Moina Sp. 2*	+	+	+
3	*Moina Weismanni*	+	+	+
4	*Moinodaphnia macleayi*	+	+	+
5	*Moina brachiata*	+	-	+
6	*Ceriodaphnia Sp 1*	+	+	+
7	*Ceriodaphnia reticulate*	+	+	+
8	*Ceriodaphnia reticulata*	+	+	+
9	*Ceriodaphnia cornuta Sp 1*	+	+	+
10	*Ceriodaphnia cornuta Sp2*	-	+	-
11	*Daphnia magna Sp1*	-	+	+
12	*Daphnia magna sp 2*	+	-	+
13	*Daphnia carinata*	-	+	+
14	*Daphnia lumholtzi*	+	+	+
15	*Daphnia pulex*	+	+	+
16	*Diaphanosoma Sarsi*	+	+	+

17	*Diaphanosoma Excisum*	+	-	+
18	*Diaphanosoma spinulosum* Herbst, 1967	-	+	+
	OSTRACODE			
1	*Strandesia elongata*	-	+	-
2	Cypris	+	+	+
3	*Cypretta fontinalis*	-	+	-
4	*Cyprinotus nudus*	+	+	+
5	*Eucypris bispinosa*	-	+	-
6	Seed Shrimps (seed-shrimps-ostracoda)	+	+	-

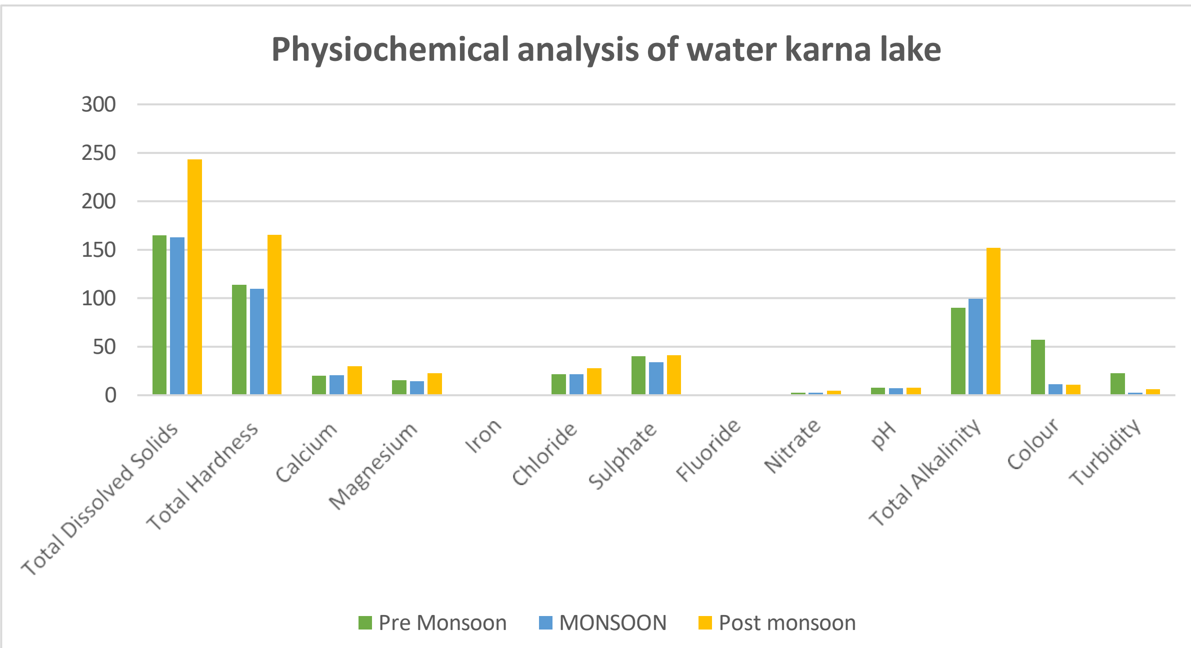


Figure 3: Physico-chemical Parameters of Karna Lake

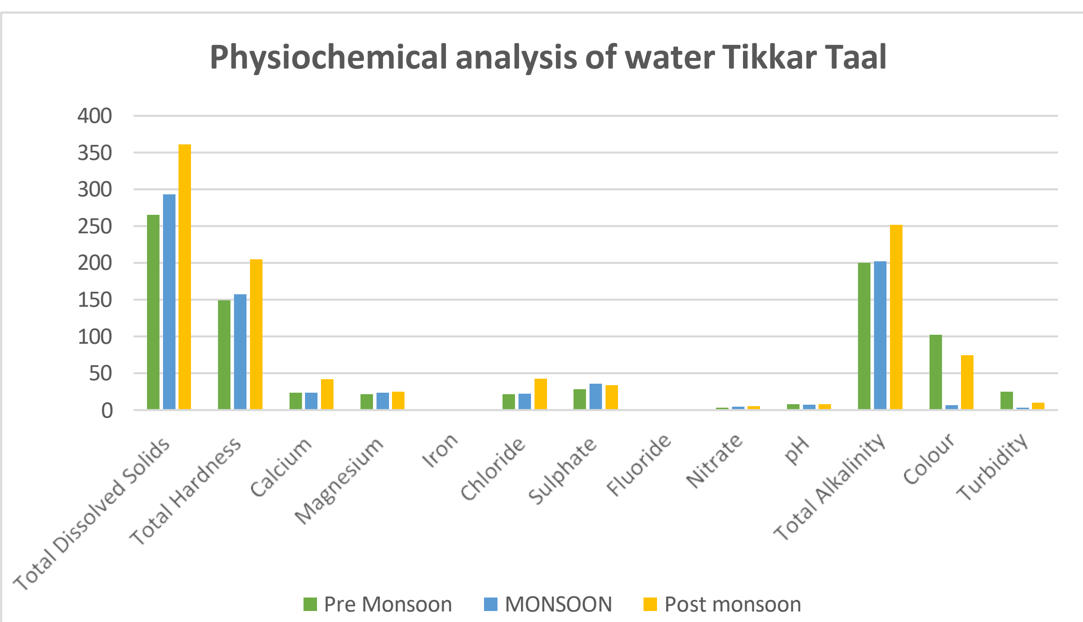


Figure 4: Physico-chemical Parameters of Tikkar Taal

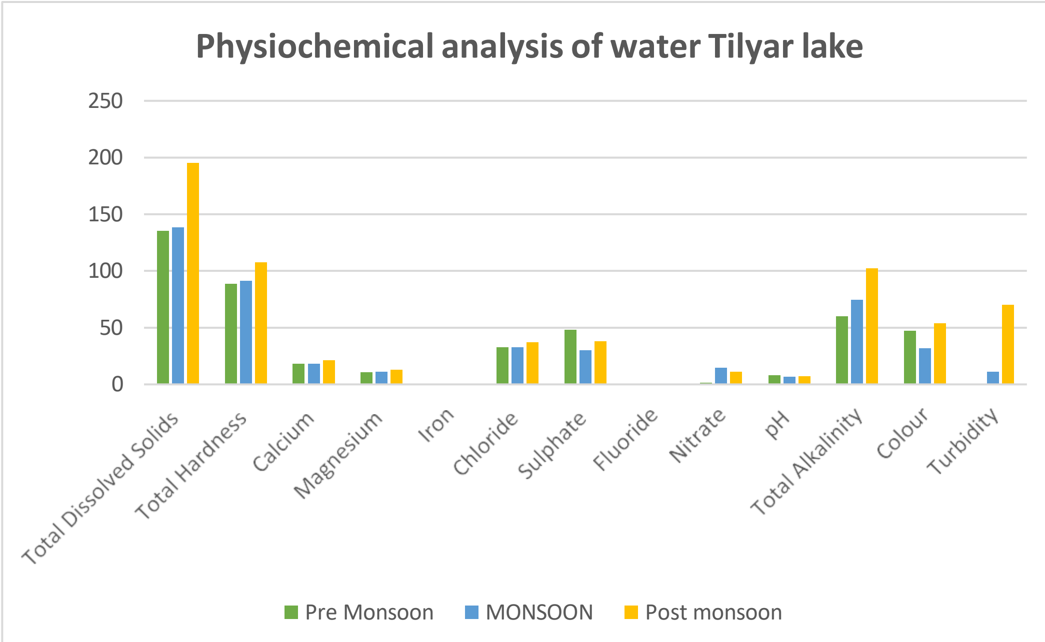


Figure 5 Physico-chemical Parameters of Tilyar lake

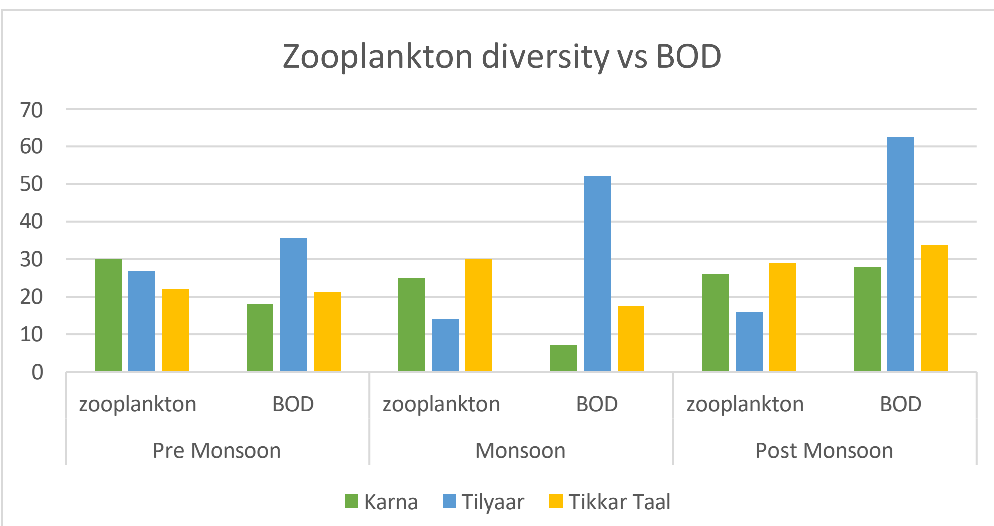


Fig 6 Co- relationship between Zooplankton and BOD

Pearson correlation coefficient matrix

	Pre Monsoon Mean	Monsoon Mean	Post Monsoon Mean
Pre Monsoon Mean	1	0.856327	0.947187
Monsoon Mean	0.856327	1	0.855801
Post Monsoon Mean	0.947187	0.855801	1

Table 2 The correlation matrix for the seasonal variations of the physiochemical parameters

CONCLUSION

The results of this study clearly show that the variety and abundance of zooplankton in freshwater lakes are correlated with seasonal variations and human activity. Because of steady water conditions and advantageous biological niches, the Pre-Monsoon season had the highest zooplankton diversity. In contrast, the Monsoon season had lower diversity and density because of nutrient dilution and physical disruptions from heavy rains. On the other hand, zooplankton numbers peaked during the winter, which was correlated with higher BOD levels, which suggested more organic matter and microbial activity. Among the research sites, Tilyaar Lake was found to have the most biological diversity, indicating either comparatively superior water quality or more conducive conditions for species sustenance. Conversely, species dominance differences between lakes—for example, the prevalence of Copepods in Rohtak or Cladocera in Panchkula-emphasize regional environmental elements that impact community structures, such as runoff and sewage discharge. The study reaffirms how important zooplankton are as sensitive bioindicators of ecological disturbance, trophic status, and water quality. In addition to physicochemical data, routine zooplankton community monitoring provides a useful method for evaluating the ecological integrity of freshwater systems. Such ecological studies are crucial for putting conservation plans, pollution control measures, and sustainable lake management techniques into action, especially in light of the growing challenges posed by urbanization, climate change, and agricultural runoff. As a result, the study offers a solid scientific basis for upcoming ecological monitoring, policy development, and adaptive resource management in freshwater environments.

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