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Seasonal Distribution, Diversity, and Pollution Indicators of Zooplankton in Surface Water Bodies of Mahendergarh District

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Abstract
Water quality is crucial for sustaining both human life and the environment, particularly in freshwater bodies that support biodiversity and provide essential resources for agriculture, industry, and domestic use. In Mahendergarh district, Haryana, India, the degradation of surface water quality, primarily due to anthropogenic activities such as agricultural runoff, industrial discharges, and urban sewage, has led to the eutrophication of water bodies like the JLN Canal, Chalak Nala, and Khatoti Khurd Pond. This study focuses on the seasonal distribution, diversity, and pollution indicators of zooplankton in these water bodies, utilizing them as bioindicators to assess water quality. The study identified 27 genera of zooplankton, categorized into four major groups: Rotifera, Copepoda, Cladocera, and Protozoa. Seasonal variations in zooplankton abundance and diversity were observed, with the highest populations recorded during the pre-monsoon season, which coincided with increased phytoplankton growth due to nutrient enrichment. The monsoon season brought a decline in zooplankton abundance due to dilution and turbidity, while post-monsoon showed slight recovery. Key species such as Thermocyclops hyalinus and Brachionus angularis were found to be reliable bioindicators of eutrophication and organic pollution, particularly at Chalak Nala (Site 2), where pollution levels were highest. These findings underscore the potential of zooplankton monitoring for managing water quality in Mahendergarh's surface water bodies. By tracking changes in zooplankton populations and correlating them with environmental factors, this research offers valuable insights for sustainable water management in the region.
Keywords: *Water Quality, Zooplankton, Bioindicators, Eutrophication, Mahendergarh, Seasonal Variations, Pollution, Sustainable Water Management.*

1. INTRODUCTION

Water quality is a significant concern worldwide, as it directly impacts both human health and the environment. Freshwater bodies, such as lakes, rivers, canals, and ponds, are critical resources that support biodiversity, provide water for agriculture and domestic consumption, and sustain industrial processes. However, these water bodies are increasingly threatened by pollution from various anthropogenic activities, including agricultural runoff, industrial effluents, urban sewage, and climate change (Baruah et al., 1993; Adeyemi & Olawoyin, 2009). In Mahendergarh district, Haryana, India, the growing demand for water for irrigation, industrial uses, and urban development has contributed to the degradation of surface water quality. These changes, particularly due to nutrient overload, have led to the eutrophication of many water bodies in the region. In this context, the study of zooplankton—the tiny, often microscopic organisms that live in the water column—becomes crucial. Zooplankton are essential members of aquatic ecosystems, acting as the primary consumers of phytoplankton and serving as food for higher trophic levels, such as fish and invertebrates. Due to their sensitivity to changes in water quality, zooplankton populations are often used as bioindicators for assessing the ecological health of aquatic environments (Hosmani, 2008).

The dynamics of zooplankton populations can provide valuable information about the physical, chemical, and biological conditions of a water body. Zooplankton are influenced by a range of factors, including water temperature, pH, dissolved oxygen levels, nutrient concentrations, and the presence of pollutants (George et al., 2004). The abundance and diversity of zooplankton vary across different seasons due to fluctuations in these factors, with certain species thriving in nutrient-rich, eutrophic environments while others are more common in oligotrophic or moderately polluted waters (Badaoui et al., 2015). Therefore, understanding the seasonal distribution and diversity of zooplankton, as well as identifying pollution-tolerant species, can provide insights into the water quality and ecological condition of freshwater systems. This study focuses on the seasonal distribution, diversity, and pollution indicators of zooplankton in three

surface water bodies in Mahendergarh district: JLN Canal (Site 1), Chalak Nala (Site 2), and Khatoti Khurd Pond (Site 3). These water bodies are critical for local agriculture, irrigation, and domestic water supply. However, they have been subjected to varying degrees of pollution, including nutrient enrichment, sewage discharge, and industrial effluents, making them important sites for studying the relationship between zooplankton and water quality.

1.1 Zooplankton as Bioindicators of Water Quality

Zooplankton are considered key bioindicators due to their rapid response to environmental changes. They are sensitive to variations in physical parameters such as temperature, light, and turbidity, as well as chemical factors like pH, dissolved oxygen (DO), and concentrations of nutrients such as nitrogen and phosphorus (Sanyogita & Khushboo, 2011). Moreover, the species composition of zooplankton can shift significantly in response to pollution levels. For example, species like Brachionus angularis (rotifer) and Thermocyclops hyalinus (copepod) are often found in eutrophic waters, where high nutrient levels promote the growth of algae and other primary producers (Akbulut, 2004; Hosmani, 2008). In eutrophic environments, the increase in nutrient load often leads to algal blooms, which, upon decaying, consume large amounts of oxygen, reducing oxygen levels in the water.

This oxygen depletion can severely affect zooplankton populations, particularly species that are sensitive to low oxygen conditions, such as Daphnia pulex (cladoceran). Therefore, the presence or absence of certain zooplankton species can provide a clear indication of the degree of eutrophication or organic pollution in a water body (Devi & Ray, 2016). Studies have also shown that certain zooplankton species, such as Brachionus calyciflorus and Cyclops viridis, are commonly found in polluted or nutrient-rich water bodies, making them reliable bioindicators for organic pollution (Sanyogita & Khushboo, 2011; Kumar & Kumari, 2022). By tracking the seasonal variations in zooplankton populations and their relationship to water quality parameters, this study aims to evaluate the pollution levels of the surface water bodies in Mahendergarh.

1.2 Seasonal Variations in Zooplankton Populations

Seasonal fluctuations in zooplankton populations are influenced by a combination of environmental factors, including water temperature, nutrient availability, and hydrological changes. In the pre-monsoon season, warmer temperatures, longer days, and increased solar radiation enhance the growth of phytoplankton, which in turn supports a higher density of zooplankton (Kumar & Kumari, 2022). Zooplankton abundance typically peaks during this period, as these organisms capitalize on the abundant food supply.

In contrast, during the monsoon season, heavy rainfall leads to the dilution of water bodies and increases turbidity, which can reduce the availability of light for primary producers. This often results in a decrease in phytoplankton abundance and, consequently, a reduction in zooplankton populations. Additionally, the influx of runoff water can introduce pollutants and sediment, further affecting zooplankton survival and distribution (Tasevska et al., 2010). Post-monsoon, the water quality often improves due to sedimentation and decreased nutrient loading, leading to a slight recovery in zooplankton populations as environmental conditions stabilize (Mulani et al., 2009). Understanding these seasonal dynamics is important for identifying trends in water quality and for implementing effective management strategies for the conservation of aquatic biodiversity in Mahendergarh district. This study aims to track these seasonal variations in zooplankton populations across the three study sites and assess how different environmental factors, including water quality, influence their distribution.

1.3 Objectives of the Study

The primary objective of this study is to assess the seasonal distribution and diversity of zooplankton in three surface water bodies of Mahendergarh district and identify pollution bioindicators that can be used to monitor water quality. Specifically, this study aims to:

1. Evaluate Zooplankton Diversity: To identify the genera of zooplankton present in the study sites and determine their seasonal variations.
2. Assess Zooplankton Abundance: To measure the zooplankton population density (individuals per liter) across different seasons.
3. Identify Pollution Indicators: To track the presence of pollution-sensitive species and correlate their abundance with water quality parameters such as nutrient concentrations and pH.
4. Examine Seasonal Changes in Water Quality: To understand how seasonal changes in water quality, driven by factors such as temperature, rainfall, and nutrient loading, affect zooplankton populations.

By achieving these objectives, this study will provide valuable insights into the health of Mahendergarh's surface water bodies and contribute to the development of sustainable water management practices for the region.

1.4 The Study Area: Mahendergarh District

Mahendergarh district, located in Haryana, India, is an agriculturally significant region. The district is home to several surface water bodies, including canals, ponds, and rivers, which serve as vital sources of irrigation and domestic water. However, the rapid urbanization, agricultural runoff, and industrial discharge in recent years have led to a deterioration in water quality, particularly in the JLN Canal, Chalak Nala, and Khatoti Khurd Pond. These water bodies are frequently subjected to contamination from sewage and agricultural runoff, resulting in elevated levels of nutrients such as nitrogen and phosphorus. The study sites were selected due to their importance as freshwater resources and their varying degrees of pollution. Site 1, JLN Canal, is an artificial water body used primarily for irrigation and is affected by both domestic and agricultural pollution. Chalak Nala (Site 2) is a natural stream that receives runoff from nearby settlements, leading to high nutrient loading, while Khatoti Khurd Pond (Site 3) is a pond that experiences seasonal variations in water quality due to changes in agricultural practices and rainfall patterns.

2. METHODOLOGY

Sampling Sites and Period: The study was conducted over a two-year period (2022-2024) at three surface water bodies in Mahendergarh district:

- Site 1 (JLN Canal)
- Site 2 (Chalak Nala)
- Site 3 (Khatoti Khurd Pond)

Sampling Method:

- Monthly water samples were collected between 7:00 AM to 9:30 AM.
- Zooplankton samples were obtained using plankton nets and preserved in a 5% formaldehyde solution.
- The collected samples were identified using standard taxonomic keys.

Seasonal Sampling: The study considered three seasons:

- Pre-monsoon
- Monsoon
- Post-monsoon

Data Analysis:

- Zooplankton density (individuals per liter) was calculated.
- Species diversity was assessed by calculating the Shannon-Wiener Index.
- The presence of pollution indicators was evaluated by tracking the abundance of specific genera known to indicate various pollution levels (e.g., eutrophication, organic pollution).

4. Results

4.1 Zooplankton Diversity

A total of 27 genera of zooplankton were identified, belonging to four major groups:

- **Rotifera** (14 genera)
- **Copepoda** (7 genera)
- **Cladocera** (3 genera)
- **Protozoa** (3 genera)

Table 1: Zooplankton Abundance (Ind/L) Across Different Seasons

Season	Site 1 (JLN Canal)	Site 2 (Chalak Nala)	Site 3 (Khatoti Khurd Pond)	Remarks
Pre-monsoon	206	271	237	Peak zooplankton abundance due to high phytoplankton levels.
Monsoon	168	204	181	Decreased due to water dilution from rainfall.

Post-monsoon	196	246	213	Slight recovery after monsoon due to improved water quality.

Table 1 illustrates the seasonal variation in zooplankton abundance at three sites in Mahendergarh district. The highest zooplankton densities were observed during the pre-monsoon season at all sites, with Site 2 (Chalak Nala) recording the highest abundance (271 individuals per liter). This peak corresponds with increased phytoplankton growth, which provides more food for zooplankton. During the monsoon season, zooplankton abundance decreased across all sites due to dilution from rainfall and increased turbidity, which reduces phytoplankton growth. Post-monsoon, there was a slight recovery in zooplankton populations, especially at Site 2 and Site 3, due to improved water quality as sediments settled and nutrient levels stabilized. However, densities did not fully return to pre-monsoon levels, indicating lasting impacts of the monsoon's nutrient dynamics.

4.2 Abundance and Distribution

Zooplankton populations varied across the three sites and seasons. The highest density was observed during the pre-monsoon season, with a decrease in abundance during the monsoon season due to dilution by rainfall.

Table 2: Zooplankton Diversity (Genus-Level) at Each Sampling Site

Genus	Site 1 (JLN Canal)	Site 2 (Chalak Nala)	Site 3 (Khatoti Khurd Pond)	Pollution Status
Rotifera	Brachionus angularis, Brachionus caudatus, Asplanchna sp.	Brachionus angularis, Brachionus pilicates, Asplanchna intermedia	Brachionus sp., Brachionus caudatus, Keratella sp.	Dominant across all sites
Copepoda	Cyclops bicuspiditus, Cyclops viridis	Cyclops bicuspiditus, Eucyclops sp., Thermocyclops hyalinus	Cyclops viridis, Mesocyclops sp.	Indicates organic pollution
Cladocera	Daphnia pulex, Daphnia magna	Daphnia cuculata, Daphnia pulex	Daphnia magna	Present in all sites but in low abundance
Protozoa	Vorticella sp., Paramecium caudatum	Vorticella sp., Paramecium aurilia	Paramecium aurilia	Low presence across all sites

Table 2 presents the diversity of zooplankton genera at each site. Rotifers were dominant across all sites, with species like *Brachionus angularis* and *Brachionus caudatus* being common, indicating eutrophic conditions at all sites. Copepods such as *Cyclops bicuspiditus* and *Thermocyclops hyalinus* were abundant at Site 2, which suggests organic pollution and high nutrient levels. Cladocerans, including *Daphnia pulex*, were present in low numbers at all sites, indicating their sensitivity to pollution, especially organic enrichment. Protozoans like *Vorticella sp.* and *Paramecium caudatum* were observed but in low abundance, suggesting that moderate pollution can still support these organisms but at a limited level.

4.3 Pollution Indicators

Species like **Thermocyclops hyalinus** and **Brachionus angularis** were found to be reliable bioindicators of water quality. Site 2 (Chalak Nala) showed the highest number of pollution indicator species, suggesting its eutrophic status.

Table 3: Pollution Indicators of Zooplankton at Sites 1, 2, and 3

Site	Dominant Group	Pollution Indicators	Highest Pollution Indicator	Seasonal Abundance Trend	Pollution Status
Site 1 (JLN Canal)	Rotifera, Copepoda	Brachionus angularis, Cyclops sp.	Low Pollution	High in pre-monsoon, low in	Low Pollution

				monsoon, moderate in post-monsoon	
Site 2 (Chalak Nala)	Rotifera, Copepoda	Thermocyclops hyalinus, Brachionus angularis	High Pollution	Very high in pre-monsoon, moderate in monsoon, high in post-monsoon	High Pollution
Site 3 (Khatoti Khurd Pond)	Copepoda, Rotifera	Brachionus calyciflorus, Daphnia pulex	Moderate Pollution	Moderate in all seasons	Moderate Pollution

Table 3 identifies pollution indicators at each site and their seasonal abundance trends. Site 2 (Chalak Nala) showed the highest levels of pollution, with species such as *Thermocyclops hyalinus* and *Brachionus angularis* indicating eutrophic and organic-rich conditions. The abundance of these species was highest in the pre-monsoon season, reflecting nutrient enrichment and high food availability. Site 1 (JLN Canal) exhibited low pollution, with typical seasonal variation, showing peak zooplankton abundance in the pre-monsoon and a moderate recovery post-monsoon. Site 3 (Khatoti Khurd Pond) demonstrated moderate pollution levels, with a balanced zooplankton community across all seasons, indicating that the site experiences less severe nutrient enrichment but still supports a diverse range of zooplankton species.

Table 4: Zooplankton Population Density (Ind/L) by Site and Season

Site	Pre-monsoon (Ind/L)	Monsoon (Ind/L)	Post-monsoon (Ind/L)	Seasonal Variation
Site 1 (JLN Canal)	206	168	196	Highest in pre-monsoon, lowest in monsoon
Site 2 (Chalak Nala)	271	204	246	High abundance in all seasons, especially pre-monsoon
Site 3 (Khatoti Khurd Pond)	237	181	213	Moderate across all seasons

Table 4 summarizes the zooplankton population density at each site across the three seasons. Site 1 (JLN Canal) showed the highest population density in the pre-monsoon season (206 individuals per liter) and the lowest in the monsoon (168 individuals per liter), reflecting typical seasonal fluctuations due to changes in phytoplankton availability. Site 2 (Chalak Nala) maintained a relatively high abundance in all seasons, particularly pre-monsoon (271 individuals per liter), suggesting continuous nutrient enrichment and high productivity. Site 3 (Khatoti Khurd Pond) exhibited moderate zooplankton density throughout the seasons (237 in pre-monsoon), indicating stable but moderate pollution levels. This stability at Site 3 suggests a less extreme environment for zooplankton compared to the other sites.

Table 5: Bioindicator Species and Pollution Assessment

Bioindicator Species	Site 1 (JLN Canal)	Site 2 (Chalak Nala)	Site 3 (Khatoti Khurd Pond)	Pollution Implication
Thermocyclops hyalinus	Rare	Common	Rare	Indicator of eutrophic conditions
Brachionus angularis	Common	Common	Moderate	Indicates organic pollution
Daphnia pulex	Rare	Common	Moderate	Sensitive to pollution, especially organic
Vorticella sp.	Moderate	Common	Rare	Present due to organic matter

Table 5 focuses on the bioindicator species at each site and their pollution implications. Species like *Thermocyclops hyalinus*, found commonly at Site 2, are indicators of eutrophic conditions, suggesting that Chalak Nala has high nutrient levels and organic pollution. Similarly, *Brachionus angularis* is abundant at both Site 1 and Site 2, indicating the presence of organic pollution but at higher levels in Site 2. *Daphnia*

pulex was found in moderate abundance at Site 3, showing that the pond experiences moderate pollution. Vorticella sp., observed at Site 2, is another bioindicator of organic matter, further supporting the idea that Chalak Nala is an organic-rich, polluted environment. These findings highlight the usefulness of zooplankton as bioindicators in assessing pollution levels across different water bodies.

4. DISCUSSION

The study of zooplankton diversity and their seasonal distribution in Mahendergarh district's surface water bodies revealed significant variations across the different seasons and sites. The findings highlight the profound impact of environmental changes, such as seasonal fluctuations in temperature, nutrient levels, and hydrological dynamics, on the zooplankton populations in the region. The highest zooplankton density was observed during the pre-monsoon season, particularly at Site 2 (Chalak Nala), which had the highest abundance of 271 individuals per liter. This seasonal peak is likely driven by the increased availability of nutrients, such as nitrogen and phosphorus, which stimulate the growth of phytoplankton, the primary food source for zooplankton (Kumar & Kumari, 2022). These findings are consistent with previous studies that show zooplankton populations typically peak during periods of high phytoplankton growth in eutrophic waters (Akbulut, 2004; Hosmani, 2008). In contrast, the monsoon season brought a reduction in zooplankton abundance due to water dilution, which likely decreased phytoplankton concentrations and consequently limited food availability for zooplankton (Tasevska et al., 2010).

The results also demonstrate the sensitivity of zooplankton populations to the varying pollution levels across the three study sites. Site 2 (Chalak Nala) exhibited consistently high zooplankton abundance throughout the year, but particularly in the pre-monsoon and post-monsoon periods, indicating its eutrophic status. The increased presence of Thermocyclops hyalinus and Brachionus angularis, species known to thrive in nutrient-rich, polluted waters, points to the high pollution levels at this site (Sanyogita & Khushboo, 2011; Kumar & Kumari, 2022). These species are considered reliable bioindicators of organic pollution, especially in environments with excessive nutrient loading (George et al., 2004; Devi & Ray, 2016). In contrast, Site 1 (JLN Canal), which experienced low pollution levels, showed a more typical seasonal variation with peak zooplankton abundance in the pre-monsoon season and moderate populations during post-monsoon, consistent with the findings from similar studies on less polluted aquatic environments (Baruah et al., 1993; Hosmani, 2008).

At Site 3 (Khatoti Khurd Pond), zooplankton populations exhibited a more balanced distribution across the three seasons, reflecting moderate levels of pollution. The presence of species like Daphnia pulex and Brachionus calyciflorus suggests a mixed pollution condition at this site, with both eutrophic and oligotrophic characteristics. These species are sensitive to pollution but can still tolerate moderate levels of nutrient loading (Devi & Ray, 2016; Badaoui et al., 2015). The moderate abundance of these species in all seasons indicates that Khatoti Khurd Pond is subjected to intermittent pollution pressures but is still able to support a diverse zooplankton community. The findings are in line with earlier studies that found zooplankton diversity and abundance to be influenced by the seasonal variations in nutrient levels and the degree of eutrophication (Sanyogita & Khushboo, 2011; Trivedi & Karode, 2015).

The seasonal variations observed in this study further emphasize the importance of monitoring seasonal changes in both water quality and zooplankton populations. In particular, the monsoon season acts as a period of dilution, where the water quality is temporarily altered due to the influx of rainfall and runoff from agricultural fields, urban areas, and industrial activities. This dilution, coupled with the influx of pollutants, can disrupt the balance of zooplankton communities, reducing their abundance (Tasevska et al., 2010). However, the recovery observed in post-monsoon suggests that water bodies in Mahendergarh district have a certain level of resilience, particularly those that experience less severe pollution levels (Mulani et al., 2009). This resilience is critical for maintaining biodiversity and sustaining the food web in these ecosystems. Zooplankton diversity also serves as a valuable tool for detecting pollution in freshwater systems. As demonstrated in this study, Thermocyclops hyalinus and Brachionus angularis, which are found in Site 2 (Chalak Nala), are indicative of high pollution and eutrophic conditions. Similarly, the absence of these pollution-tolerant species at Site 1 (JLN Canal), where water quality is better, reinforces the idea that the composition of zooplankton communities reflects the ecological health of aquatic ecosystems (Devi & Ray, 2016; Hosmani, 2008). Therefore, the use of zooplankton as bioindicators can be an effective, non-invasive method for monitoring and managing water quality in Mahendergarh and other regions facing similar environmental challenges.

The findings of this study underscore the importance of incorporating zooplankton monitoring into water quality management strategies. Zooplankton not only reflect the physical and chemical conditions of water bodies but also provide early warnings of pollution-related issues that may not be immediately visible through chemical testing alone. This approach can inform decision-making for sustainable water management and pollution mitigation in Mahendergarh district, helping to protect aquatic biodiversity and improve water quality for agricultural, industrial, and domestic use (Badaoui et al., 2015; Trivedi & Karode, 2015).

5. CONCLUSION

The study has highlighted the critical role of zooplankton as bioindicators of water quality in Mahendergarh's surface water bodies. Through monitoring seasonal variations in zooplankton populations and their correlation with water quality parameters, the research offers significant insights into the health of these water bodies. The seasonal dynamics observed, with peak zooplankton densities in the pre-monsoon and a decline during the monsoon, reveal the profound effects of nutrient loading, turbidity, and rainfall on zooplankton communities. The presence of pollution-sensitive species such as Daphnia pulex and Brachionus angularis in varying abundance across the study sites further confirms the relationship between zooplankton diversity and pollution levels. Chalak Nala (Site 2), with its eutrophic status, showed the highest pollution indicator species, pointing to its urgent need for pollution control measures. Overall, the findings emphasize the importance of integrating zooplankton-based monitoring into water quality management strategies, which can help identify pollution hotspots, assess ecological health, and inform sustainable water management practices. This approach will be crucial for maintaining the ecological balance and improving water quality for agricultural, industrial, and domestic use in Mahendergarh district.

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