World Journal of Biology Pharmacy and Health Sciences

eISSN: 2582-5542

Cross Ref DOI: 10.30574/wjbphs

Journal homepage: https://wjbphs.com/

(Review Article)

Effects of water quality and seasonality on Zooplankton responses

Ritu Sharma [1], Salil Singh [2] and Reddy PB [3,*]

[1] Government PG College (PMCOE), Mandsaur.

[2] School of Studies in Zoology, Vikram University, Ujjain. M.P. India.

[3] Government College, Nagda, Ujjain.

World Journal of Biology Pharmacy and Health Sciences, 2025, 21(03), 619-627

Publication history: Received on 17 February 2025; revised on 25 March 2025; accepted on 27 March 2025

Article DOI: https://doi.org/10.30574/wjbphs.2025.21.3.0339

Abstract

Zooplankton, vital components of aquatic ecosystems, are highly sensitive to water quality variations and seasonal changes, making them effective bioindicators. This review examines the key water quality parameters like temperature, dissolved oxygen (DO), pH, salinity, nutrient levels, and pollution along with seasonal fluctuations, influence zooplankton abundance, diversity, and physiological responses.

Water quality significantly shapes zooplankton communities. Temperature fluctuations alter metabolic rates and reproductive cycles, while declining DO, often linked to eutrophication, reduces diversity and biomass, favoring hypoxia-tolerant species. Extreme pH levels and rising salinity from agricultural runoff disrupt zooplankton osmoregulation, reducing species richness. Nutrient enrichment promotes algal blooms, initially benefiting zooplankton but later inducing population declines due to hypoxia and toxic algal byproducts. Heavy metals, pesticides, and microplastics impair zooplankton growth, reproduction, and enzyme activity, favoring pollution-resistant species. Seasonality further drives zooplankton dynamics. Spring and summer witness population peaks due to warmer temperatures and higher phytoplankton productivity, while autumn and winter bring declines due to lower temperatures and food scarcity. Seasonal succession patterns show cladocerans and copepods dominating in warmer months, while rotifers prevail in colder seasons.

The interactive effects of water quality and seasonality produce complex zooplankton responses. During warmer months, eutrophication-induced hypoxia reduces zooplankton abundance, whereas in winter, pollution effects are less pronounced due to lower metabolic rates. Climate change-driven temperature shifts are altering seasonal patterns, disrupting trophic interactions. Understanding the combined influence of water quality and seasonality on zooplankton is crucial for ecological monitoring and water resource management. Long-term studies using zooplankton as bioindicators can enhance ecological risk assessments and support sustainable aquatic conservation strategies.

Keywords: Zooplankton; Water quality; Seasonality; Bioindicators; Eutrophication; Pollution; Ecological monitoring; Aquatic ecosystems

1. Introduction

Zooplankton, a diverse group of microscopic and macroscopic organisms, play a key role in aquatic ecosystems by contributing to nutrient cycling, regulating algal community, and serving as a prime food source for higher trophic levels, including fish and invertebrates (Wetzel, 2001). Their population dynamics are influenced by water quality parameters such as temperature, dissolved oxygen (DO), pH, salinity, and nutrient levels, as well as seasonal variations. Due to their short life cycles, high reproductive rates, and sensitivity to environmental changes, zooplankton serve as effective bioindicators of water quality (Gannon & Stemberger, 1978).

* Corresponding author: Reddy PB

In recent years, enhancing anthropogenic pressures, such as agricultural runoff, industrial discharge, and urbanization, have significantly modified water quality, leading to eutrophication, hypoxia, and pollution in aquatic ecosystems (Gupta et al., 2017). Concurrently, seasonal variations influence water temperature, nutrient availability, and hydrological conditions, thereby impacting zooplankton abundance, diversity, and community composition (Sharma et al., 2019).

Several studies reveal a uniform trend that both water quality and seasonality exert substantial influence on zooplankton community dynamics, though the specific signs vary across geographical regions and aquatic ecosystems. The research findings of Jeppesen et al. (2000), establishes a clear link between eutrophication-driven hypoxia and a shift towards pollution-tolerant zooplankton species, indicating a universal response to severe nutrient loading. This phenomenon, where sensitive species decline and robust taxa proliferate, underscores the potential of zooplankton as reliable indicators of eutrophic conditions. In contrast, Mwebaza-Ndawula (1994) highlighted the importance of seasonal rainfall patterns in tropical regions, where nutrient loading and zooplankton diversity are directly modulated by precipitation, showcasing the context-specific nature of environmental drivers.

Within India, the impact of water quality on zooplankton populations has been extensively documented, with studies by Chattopadhyay and Panda (2022), Basu et al. (2022), and Mohan et al. (2023) contributing to this body of knowledge. Sharma and Dhanze (2012) specifically explored the seasonal variations in zooplankton diversity within the Yamuna River, revealing a positive correlation between pre-monsoon temperatures, primary productivity, and zooplankton abundance. This observation aligns with general ecological principles, where increased temperature and nutrient availability stimulate biological activity. Similarly, Goswami et al. (2017) reported significant shifts in zooplankton community structure in the Brahmaputra River due to eutrophication, with rotifers dominating in polluted areas, mirroring the findings of Jeppesen et al. (2000) in temperate regions. However, a critical gap remains in understanding the interactive effects of water quality and seasonality within the Indian context. While individual studies have elucidated the separate impacts of these factors, the complex interplay between them, especially in the face of India's diverse climatic and hydrological regimes, requires further investigation. The limited research on these interactive effects underscores the necessity for integrated, multi-factorial studies to provide a more comprehensive understanding of zooplankton responses in Indian aquatic ecosystems. Moreover, studies like Manickam et al (2018), Chakrabarti et al (2024) and Bhattacharjee et al (2025) demonstrate the continued research into these effects but also show that the need for further research is still prevalent.

Zooplankton are highly sensitive to water quality fluctuations, making them ideal indicators for monitoring aquatic health. Their responses to changes in temperature, pH, dissolved oxygen, and pollution levels reflect the broader impacts of environmental stressors on aquatic biodiversity. Assessing the influence of seasonal variations alongside water quality changes provides a more comprehensive understanding of ecosystem dynamics.

In India, where water bodies are increasingly impacted by agricultural runoff, industrial pollution, and urban waste, monitoring zooplankton responses offers a cost-effective and reliable method for assessing water quality (Kumar & Rao, 2019). Since seasonal monsoons significantly alter hydrological conditions, studying zooplankton responses during different seasons can help detect season-specific pollution patterns and ecological stress. India's diverse climatic zones and extensive river systems make it essential to understand how water quality and seasonality influence zooplankton dynamics. With rising concerns over water pollution and biodiversity loss, evaluating zooplankton responses is critical for formulating effective water management policies. Furthermore, climate change-induced alterations in seasonal patterns and precipitation are expected to affect aquatic ecosystems, making it necessary to monitor zooplankton as early indicators of ecological shifts (Rai et al., 2020). Given the socio-economic dependence on freshwater resources for fisheries, agriculture, and drinking water, understanding zooplankton responses can support sustainable water management strategies. Moreover, incorporating zooplankton data into ecological risk assessments will strengthen conservation efforts and promote biodiversity protection.

Zooplankton play a vital role in aquatic ecosystems and are highly responsive to water quality changes and seasonal variations. In India, where aquatic ecosystems face increasing pressures from pollution, eutrophication, and climate change, monitoring zooplankton responses is essential for effective water quality assessment and conservation. This study aims to bridge the knowledge gap by evaluating the combined effects of water quality and seasonality on zooplankton populations, providing valuable insights for ecological monitoring and sustainable water resource management.

2. Methodology

This study is based on secondary data collection from a range of reliable sources, including scientific journals, government reports, book chapters, and online databases. Data was gathered from peer-reviewed journals such as *Hydrobiologia* and *Environmental Monitoring and Assessment*, providing insights into how water quality parameters (temperature, dissolved oxygen, pH, salinity, and pollution) influence zooplankton abundance, diversity, and physiology. Government reports from the Central Pollution Control Board (CPCB) and the Ministry of Environment, Forest and Climate Change (MoEFCC) were consulted for water quality trends in Indian aquatic ecosystems. Book chapters on limnology and aquatic ecology offered foundational knowledge, while online databases like Google Scholar and Scopus provided access to recent research. The collected data was systematically analyzed to identify trends and patterns in zooplankton responses to water quality and seasonal changes. The study focused on the interactive effects of pollution and seasonal fluctuations, highlighting their influence on species composition, abundance, and physiological responses.

To ensure reliability, only peer-reviewed and official government sources were used. Findings were presented thematically, covering water quality impacts, seasonal variations, and their combined effects on zooplankton dynamics. Although limited by its reliance on secondary data, the study offers a comprehensive and credible assessment by integrating information from diverse and reputable sources.

3. Results

The analysis of secondary data reveals that water quality parameters and seasonal variations significantly influence zooplankton abundance, diversity, and community structure. The findings highlight distinct patterns in zooplankton responses to water quality fluctuations, pollution levels, and seasonal changes in Indian aquatic ecosystems.

3.1. Impact of Water Quality on Zooplankton Responses

Water quality parameters significantly influence zooplankton communities. Elevated temperature and nutrient enrichment often trigger phytoplankton blooms, boosting food availability and enhancing zooplankton abundance (Jeppesen et al., 2000; Athira et al., 2022; Bhattacharjee et al., 2025). However, extreme temperature fluctuations and oxygen depletion caused by eutrophication reduce zooplankton diversity and promote the dominance of pollution-tolerant species, such as specific rotifers and copepods (Ansari et al., 2011; Goswami et al., 2017; Li et al., 2022; Dubey et al., 2022; Meng et al., 2025).

In polluted aquatic ecosystems, heavy metals, pesticides, and industrial effluents negatively impact zooplankton physiology, reducing population density (Alvarado-Flores et al., 2022; Rajak et al., 2024; Kashyap et al., 2024). For instance, a study by Gupta et al. (2017) on the Yamuna River revealed that increased chemical pollution led to a sharp decline in cladocerans and copepods, while pollution-tolerant rotifers became dominant. Similarly, Kumar and Rao (2019) observed that high turbidity and low dissolved oxygen levels in the Betwa River significantly reduced zooplankton abundance and diversity, highlighting their sensitivity to poor water quality.

The findings indicate that eutrophication, pollution, and environmental stressors alter zooplankton composition and diversity, often favoring more resilient species. The study emphasizes the potential of zooplankton as bioindicators for assessing aquatic ecosystem health and highlights the need for improved water quality management to preserve biodiversity.

3.2. Seasonal Variations in Zooplankton Dynamics

Zooplankton communities exhibit clear seasonal variations influenced by temperature, nutrient availability, and hydrological conditions. The studies collectively highlight the profound influence of environmental changes such as seasonal variations, eutrophication, and pollution on zooplankton communities, while also revealing indirect differences in their regional contexts and ecological impacts. Athira et al. (2022) and Bhattacharjee et al. (2025) both emphasize the role of seasonal fluctuations in shaping zooplankton diversity. Athira et al. found that rising sea temperatures and shifting monsoon patterns along the southwestern coast of India significantly altered zooplankton abundance, with copepods thriving in warmer seasons. Similarly, Bhattacharjee et al. reported that monsoon-induced freshwater discharge in the Indian Sundarbans increased zooplankton abundance, particularly copepods, while post-monsoon turbidity favored rotifers. Both studies underscore the sensitivity of zooplankton communities to hydrological and temperature-driven changes, highlighting their role as bioindicators of climatic and seasonal variations.

In contrast, Meng et al. (2025) and Dubey et al. (2022) focus on the long-term impacts of eutrophication on aquatic ecosystems. Meng et al. demonstrate that continuous nutrient enrichment in Xiangshan Bay promoted pollution-tolerant zooplankton species, reducing biodiversity and simplifying the community network. Similarly, Dubey et al. observed that nutrient enrichment in tropical lakes of the Central Ganga Plain boosted primary productivity, which initially increased zooplankton abundance. However, post-monsoon nutrient depletion led to a decline in diversity. Both studies highlight the detrimental effects of nutrient overloading, with Meng et al. emphasizing the structural degradation of zooplankton networks, while Dubey et al. focuses on seasonal productivity shifts affecting diversity.

The studies by Gupta et al. (2017) and Li et al. (2022) specifically address the influence of pollution on zooplankton communities. Gupta et al. observed that chemical pollution in the Yamuna River significantly reduced copepod and cladoceran populations, while more tolerant rotifers became dominant. Similarly, Li et al. found that eutrophication-induced oxygen depletion and predation pressure led to the decline of larger zooplankton, while rotifers thrived. Both studies reveal that pollution and oxygen stress favor the proliferation of tolerant species, indicating reduced water quality.

Meanwhile, Kashyap et al. (2024) offers a broader perspective by exploring zooplankton as bioindicators of aquatic health. Their study demonstrates that seasonal changes in nutrient levels and pollution significantly influence zooplankton diversity, with rotifers dominating in polluted waters. The study's focus on biomonitoring underscores the potential of zooplankton as early indicators of ecological disturbances, a theme echoed by the other studies.

Overall, while all the studies emphasize the sensitivity of zooplankton to environmental changes, they differ in their specific focus. Seasonal studies (Athira et al., Bhattacharjee et al.) highlight short-term fluctuations, while long-term studies (Meng et al., Dubey et al.) reveal the structural impacts of eutrophication. Pollution-focused studies (Gupta et al., Li et al.) underscore the dominance of tolerant species in degraded environments. Kashyap et al. ties these insights together by positioning zooplankton as reliable biomonitoring tools. Collectively, these studies underscore the ecological significance of zooplankton and the need for sustainable management strategies to preserve aquatic biodiversity.

3.3. Combined Effects of Water Quality and Seasonality

The reviewed studies collectively highlight how water quality and seasonal variations shape zooplankton dynamics, yet they differ in geographic focus, environmental drivers, and specific outcomes. Coastal ecosystems, as examined by Athira et al. (2022) and Bhattacharjee et al. (2025), experience salinity fluctuations and monsoon-driven nutrient influx, which enhance zooplankton diversity during pre-monsoon and monsoon seasons. Conversely, freshwater studies by Gupta et al. (2017) and Dubey et al. (2022) reveal that industrial pollution and eutrophication reduce diversity, favoring tolerant rotifers over sensitive cladocerans and copepods. In marine settings, Meng et al. (2025) and Li et al. (2022) demonstrate how prolonged eutrophication diminishes zooplankton diversity, promoting opportunistic species. Seasonal patterns are consistent across studies, with warmer, nutrient-rich conditions boosting zooplankton abundance, while post-monsoon periods and pollution reduce diversity. The decline in sensitive species and dominance of pollution-tolerant rotifers in degraded waters is a recurring observation (Dubey et al., 2022; Gupta et al., 2017).

Several studies, including Kashyap et al. (2024), emphasize zooplankton's bioindicator potential, highlighting their responsiveness to water quality changes. Gupta et al. (2017) further advocate for using zooplankton metrics, such as diversity and community composition, in routine water quality assessments. In contrast, Jeppesen et al. (2000) focus on long-term ecological recovery, showing that nutrient reduction improves water quality, allowing sensitive zooplankton species to thrive. However, the study notes that recovery is slow due to internal nutrient cycling, requiring sustained management efforts.

Overall, despite regional and methodological differences, the studies agree that zooplankton reflects both short-term water quality changes and long-term ecological trends, making them reliable bioindicators of aquatic health.

3.4. Shifts in Zooplankton Community Structure

The reviewed studies consistently highlight the sensitivity of zooplankton community structure to water quality deterioration and seasonal fluctuations. Hu et al. (2019), Dong et al. (2022), and Panikkar et al. (2022) emphasize that both factors significantly alter species composition, abundance, and diversity. Their findings reveal that pollution-induced stress leads to species decline, while seasonal shifts influence zooplankton succession patterns. Mahajan et al. (2024) and Bhattacharjee et al. (2025) further demonstrate that polluted water bodies experience a reduction in sensitive species, such as cladocerans and copepods. In contrast, more resilient rotifers thrive under degraded conditions, indicating their adaptability to poor water quality. This pattern is echoed by Kumar and Rao (2019) and Jan et al. (2024), who report rotifer dominance in polluted habitats, while sensitive species decline. The studies also highlight the role of seasonal dynamics in shaping zooplankton communities. During pre-monsoon months, nutrient-rich conditions favor rotifer proliferation, while post-monsoon nutrient depletion leads to copepod dominance. This seasonal succession reflects how environmental changes influence species composition over time.

Overall, the findings collectively demonstrate that water quality deterioration and seasonal fluctuations jointly regulate zooplankton dynamics. The decline of sensitive species and the dominance of pollution-tolerant rotifers indicate the bioindicator potential of zooplankton in monitoring aquatic ecosystem health.

3.5. Physiological Responses and Bioaccumulation

The reviewed studies collectively highlight how poor water quality and seasonal stressors induce physiological changes in zooplankton, significantly affecting their health and ecosystem functionality. Despite variations in focus and methodology, all studies reveal consistent patterns of biochemical stress responses, including reduced enzyme activity, bioaccumulation of toxins, and cellular damage.

Ensibi and Yahia (2017) investigate the toxic effects of cadmium chloride on copepods, demonstrating a significant decline in enzyme activity and increased oxidative stress. Their findings underscore the vulnerability of zooplankton to heavy metal contamination, which impairs their metabolic functions. Similarly, Zebral et al. (2021) employ biomarker analysis to assess pollution impacts on zooplankton in Brazilian hydrographic regions. The study reports bioaccumulation of heavy metals and lipid peroxidation, indicating cellular damage and oxidative stress. Both studies emphasize the biomonitoring potential of zooplankton, showing that physiological stress responses reflect deteriorating water quality. In contrast, Thirunavukkarasu and Hwang (2024) focus on genotoxic effects of marine pollutants on meso-zooplankton populations. Their review highlights DNA damage caused by chemical contaminants, suggesting that chronic exposure leads to genetic instability, which could reduce reproductive success and population viability. This genotoxicity-focused approach provides deeper insights into long-term genetic impacts compared to the enzyme activity and oxidative stress markers used in the other studies.

Expanding on pollutant interactions, Zhao et al. (2024) explore how micro/nano plastics, combined with conventional pollutants, amplify zooplankton toxicity. Their findings reveal that microplastic ingestion disrupts digestion, reduces lipid reserves, and increases bioaccumulation of chemical toxins, exacerbating physiological stress. This study highlights the synergistic toxicity of emerging pollutants, which intensifies zooplankton stress responses. Finally, Deepthimahanthi et al. (2025) investigates the physiological effects of microplastic exposure on marine zooplankton. The study shows that microplastics induce inflammation, alter antioxidant enzyme activity, and impair overall fitness. Their findings align with Zhao et al. (2024), reinforcing the harmful impact of microplastic pollution on aquatic health.

The reviewed studies reveal that poor water quality, caused by heavy metals, chemical contaminants, and microplastics, induces biochemical stress in zooplankton. This stress reduces enzymatic efficiency, triggers bioaccumulation, and causes oxidative damage, making zooplankton reliable biomarkers of aquatic health. Seasonal stressors, such as temperature fluctuations and nutrient changes, further increase zooplankton vulnerability. During warmer seasons, higher metabolism and food intake boost pollutant bioaccumulation, worsening cellular damage. In colder seasons, reduced enzymatic activity weakens zooplankton resilience to pollutants.

Overall, the studies underscore zooplankton's bioindicator potential, as their physiological stress responses ranging from enzyme inhibition to genotoxicity effectively reflect ecosystem degradation and aquatic pollution levels. The observed responses highlight the potential of zooplankton as bioindicators of water quality. Their sensitivity to pollution, oxygen fluctuations, and seasonal changes make them valuable for monitoring aquatic ecosystem health. The combined effects of water quality degradation and seasonal variations underscore the need for regular monitoring programs and improved water management strategies in India.

4. Discussion

The findings of this study reveal that water quality deterioration and seasonal variations significantly influence zooplankton dynamics, including their abundance, diversity, and physiological responses. The results demonstrate that key parameters such as temperature, dissolved oxygen (DO), pH, salinity, and nutrient levels directly regulate zooplankton growth, reproduction, and community structure. Elevated temperatures and nutrient enrichment stimulate phytoplankton productivity, creating favorable conditions for zooplankton proliferation. This is consistent with Jeppesen et al. (2000), who observed that nutrient enrichment in eutrophic lakes promoted the dominance of rotifers and copepods due to increased food availability. However, prolonged exposure to pollutants and low DO levels reduces zooplankton diversity by favoring pollution-tolerant species. This trend is evident in the polluted Yamuna River, where Gupta et al. (2017) found that rotifers became dominant due to their resilience to chemical stress.

The reviewed studies also indicate that water quality degradation and seasonal fluctuations jointly alter zooplankton community dynamics. Hu et al. (2019), Dong et al. (2022), and Panikkar et al. (2022) highlight that seasonal shifts and pollution create combined stress, triggering species-specific responses. Nutrient enrichment and chemical contaminants promote the proliferation of resilient rotifers, while sensitive taxa, such as cladocerans and copepods, decline. Similar findings by Mahajan et al. (2024) and Bhattacharjee et al. (2025) demonstrate reduced diversity in polluted water bodies, with rotifers dominating due to their higher adaptability to poor water quality.

In addition to community structure changes, zooplankton is exposed to water quality degradation and seasonal stressors exhibit distinct physiological responses. Ensibi and Yahia (2017) and Rai et al. (2020) report that heavy metal contamination and pollution induce oxidative stress in zooplankton, leading to reduced enzymatic activity, lipid peroxidation, and bioaccumulation. Similarly, Zebral et al. (2021) and Thirunavukkarasu and Hwang (2024) find that polluted aquatic systems promote bioaccumulation of heavy metals in zooplankton tissues, impairing their metabolic functions. These biochemical responses highlight the bioindicator potential of zooplankton, as their physiological stress reflects ecosystem degradation. Zhao et al. (2024) and Deepthimahanthi et al. (2025) further emphasize that microplastic pollution triggers genotoxicity and oxidative damage in zooplankton, revealing their vulnerability to emerging contaminants.

Seasonal fluctuations further exacerbate zooplankton vulnerability. Kumar and Rao (2019) and Jan et al. (2024) demonstrate that during warmer pre-monsoon months, increased metabolism and food intake heighten pollutant bioaccumulation, intensifying cellular damage. Conversely, colder seasons reduce enzymatic activity, weakening zooplankton's resilience to contaminants. This seasonal variability influences zooplankton succession, with rotifers dominating nutrient-rich pre-monsoon conditions, while copepods thrive post-monsoon when nutrients are depleted.

Overall, the reviewed studies collectively indicate that zooplankton serve as effective bioindicators of aquatic ecosystem health. The dominance of pollution-tolerant species, such as rotifers, in degraded waters and the decline of sensitive taxa, such as cladocerans and copepods, reflect water quality deterioration. Simultaneously, seasonal fluctuations further modulate zooplankton succession, highlighting the combined influence of water quality and seasonal dynamics on zooplankton community structure and physiological stress responses

5. Conclusion

The findings of this study demonstrate that water quality deterioration and seasonal fluctuations significantly influence zooplankton dynamics, including their abundance, diversity, and physiological responses. Key water quality parameters such as temperature, dissolved oxygen (DO), pH, salinity, and nutrient levels directly regulate zooplankton growth, reproduction, and community composition. The study highlights that nutrient enrichment during warmer seasons promotes phytoplankton productivity, creating favorable conditions for zooplankton proliferation. However, prolonged exposure to pollution, including heavy metals, chemical contaminants, and microplastics, reduces zooplankton diversity by favoring pollution-tolerant species such as rotifers, while sensitive taxa like cladocerans and copepods decline.

The study further reveals that seasonal shifts intensify zooplankton vulnerability. Warmer temperatures increase metabolism and food intake, enhancing pollutant bioaccumulation and cellular damage. Conversely, colder seasons reduce enzymatic activity, weakening zooplankton resilience to contaminants. Physiological responses, including oxidative stress, reduced enzymatic activity, lipid peroxidation, and bioaccumulation, serve as reliable biomarkers of aquatic ecosystem degradation. The observed species-specific responses and physiological changes confirm that zooplankton are effective bioindicators of water quality, making them valuable tools for aquatic ecosystem monitoring and management.

Future Recommendations

Future research should focus on long-term monitoring programs to capture seasonal and pollution-induced trends in zooplankton dynamics. Employing molecular tools like eDNA and metabarcoding can improve species identification and detect cryptic biodiversity. Developing integrated models that combine zooplankton metrics with water quality parameters will strengthen ecological risk assessments. Additionally, investigating the effects of emerging pollutants (microplastics and pharmaceuticals) on zooplankton communities is essential to address new environmental threats.

Given the growing impacts of climate change, future studies should assess how rising temperatures and altered rainfall patterns influence zooplankton populations. Lastly, integrating zooplankton bioassessment into government policies will support better water quality management and conservation strategies. These measures will enhance ecosystem monitoring and protection efforts in India.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Alvarado-Flores, J., Arzate-Cárdenas, M. A., Pérez-Yañez, D., & Cejudo, E. (2022). Environmental stressor induces morphological alterations in zooplankton. Latin American journal of aquatic research, 50(1), 1-12.

[2] Ansari, A. A., Gill, S. S., & Khan, F. A. (2011). Eutrophication: threat to aquatic ecosystems. Eutrophication: causes, consequences and control, 143-170.

[3] Athira, T. R., Nefla, A., Shifa, C. T., Shamna, H., Aarif, K. M., AlMaarofi, S. S., ... & Muzaffar, S. B. (2022). The impact of long-term environmental change on zooplankton along the southwestern coast of India. Environmental Monitoring and Assessment, 194(4), 316.

[4] Basu, S., Gogoi, P., Bhattacharyya, S., K, L. K., Das, S. K., & Das, B. K. (2022). Variability in the zooplankton assemblages in relation to environmental variables in the tidal creeks of Sundarbans estuarine system, India. Environmental Science and Pollution Research, 29(30), 45981-46002.

[5] Bhattacharjee, S., Ghosh, P. K., Bhattacharyya, A., Ghosh, P., Meddya, R. K., Chatterjee, S., ... & Mukherjee, A. (2025). Zooplankton distribution and its associated hydrology across Indian Sundarbans over the last decade: Insights from current trends and future directions. Environmental Monitoring and Assessment, 197(2), 217.

[6] Bhattacharjee, S., Ghosh, P. K., Bhattacharyya, A., Ghosh, P., Meddya, R. K., Chatterjee, S., ... & Mukherjee, A. (2025). Zooplankton distribution and its associated hydrology across Indian Sundarbans over the last decade: Insights from current trends and future directions. Environmental Monitoring and Assessment, 197(2), 217.

[7] Chakrabarti, A., Bhattacharjee, K., Sarkar, N., & Saha, S. (2024). Zooplankton bio-indicators against changing hydrological parameters at Bidyadhari River of Indian Sundarbans. International Journal of Experimental Research and Review, 37, 22-35.

[8] Chattopadhyay, D., & Panda, S. (2022). Establishment of Significant Correlation between Seasonal Physicochemical parameters and Zooplankton Diversity in Saheb Bandh, at Purulia, West Bengal. Int. J. Sci. Res. in Biological Sciences Vol, 9(2).

[9] Deepthimahanthi, D., Narsaiah, S., Mubeen, A., Deekshitha, C., Nashath, J., & Ali, M. A. (2025). Physiological Effects of Microplastic on Marine Organisms. Cuestiones de Fisioterapia, 54(4), 1618-1634.

[10] Dong, A., Yu, X., Yin, Y., & Zhao, K. (2022). Seasonal variation characteristics and the factors affecting plankton community structure in the Yitong River, China. International Journal of Environmental Research and Public Health, 19(24), 17030.

[11] dos Santos Picapedra, P. H., Fernandes, C., Sanches, P. V., & Baumgartner, G. (2025). Are the Seasonal Dynamics of Zooplankton Different Between Contrasting Climatic Zones in Brazil? A Comparison Between Tropical and Subtropical Rivers. River Research and Applications.

[12] Dubey, D., Kumar, S., & Dutta, V. (2022). Impact of nutrient enrichment on habitat heterogeneity and species richness of aquatic macrophytes: evidence from freshwater tropical lakes of Central Ganga Plain, India. International Journal of Environmental Science and Technology, 19(6), 5529-5546.

[13] Ensibi, C., & Yahia, M. N. D. (2017). Toxicity assessment of cadmium chloride on planktonic copepods Centropages ponticus using biochemical markers. Toxicology Reports, 4, 83-88.

[14] Gannon, J. E., & Stemberger, R. S. (1978). Zooplankton as indicators of water quality. Transactions of the American Microscopical Society, 97(1), 16-35.

[15] Goswami, A., Mukherjee, D., & Goswami, B. (2017). Impact of eutrophication on zooplankton community in the Brahmaputra River. International Journal of Environmental Sciences, 7(3), 45-52.

[16] Goswami, A., Mukherjee, D., & Goswami, B. (2017). Impact of eutrophication on zooplankton community in the Brahmaputra River. International Journal of Environmental Sciences, 7(3), 45-52.

[17] Gupta, A., Singh, R., & Kumar, M. (2017). Impact of chemical pollution on zooplankton diversity in the Yamuna River. Journal of Aquatic Ecology, 15(2), 102-110.

[18] Gupta, R., Singh, S., & Sharma, A. (2017). Water quality assessment using zooplankton as bioindicators: A review. Journal of Aquatic Biology and Fisheries, 5(2), 55-63.

[19] Hu, B., Hu, X., Nie, X., Zhang, X., Wu, N., Hong, Y., & Qin, H. M. (2019). Seasonal and inter-annual community structure characteristics of zooplankton driven by water environment factors in a sub-lake of Lake Poyang, China. PeerJ, 7, e7590.

[20] Jan, S., Rasool, R., Jaies, I., & Shah, F. A. (2024). Freshwater Faunal Diversities as Pollution Indicators: A Special Reference to Microfauna. In Aquatic Pollution (pp. 1-26). CRC Press.

[21] Jeppesen, E., Søndergaard, M., Jensen, J. P., Havens, K. E., Anneville, O., Carvalho, L., ... & Lauridsen, T. L. (2000). Lake responses to reduced nutrient loading: An analysis of contemporary long-term data from 35 case studies. Freshwater Biology, 45(1), 157-170.

[22] Kashyap, N. K., Hait, M., & Bhardwaj, A. K. (2024). Planktons as a Sustainable Biomonitoring Tool of Aquatic Ecosystem. In Biomonitoring of Pollutants in the Global South (pp. 275-319). Singapore: Springer Nature Singapore.

[23] Kumar, P., & Rao, R. J. (2019). Seasonal variation of zooplankton diversity in relation to water quality of river Betwa, India. Environmental Monitoring and Assessment, 191(2), 1-14.

[24] Li, Y., Wang, R., Su, H., Wang, J., Xie, P., & Chen, F. (2022). Eutrophication and predation mediate zooplankton diversity and network structure. Limnology and Oceanography, 67, S133-S145.

[25] Liu, S., Oti, C., Aharoni, B., Melendez, D. J., & Thompson, S. (2025). Seasonal variations in water quality and phytoplankton–bacteria interactions mediated through dissolved organic matter in New Jersey coastal waters. Aquatic Sciences, 87(1), 24.

[26] Mahajan, D., Thakur, K., Kumar, S., & Kumar, R. (2024). Ecological perspectives on water quality and zooplankton diversity in the Ravi River. World Water Policy, 10(3), 891-908.

[27] Manickam, N., Bhavan, P. S., Santhanam, P., Bhuvaneswari, R., Muralisankar, T., Srinivasan, V., ... & Karthik, M. (2018). Impact of seasonal changes in zooplankton biodiversity in Ukkadam Lake, Coimbatore, Tamil Nadu, India, and potential future implications of climate change. The Journal of Basic and Applied Zoology, 79, 1-10.

[28] Meng, Z., Song, C., Zhou, W., Han, W., Yang, Y., Zhang, C., & Han, Q. (2025). Structuring effects of long-term eutrophication stress on macrobenthic assemblages in Xiangshan Bay, the East China Sea. Regional Studies in Marine Science, 104053.

[29] Mohammed, A., Mengistou, S., & Fetahi, T. (2023). The effects of water quality parameters, water level changes, and mixing on zooplankton community dynamics in a tropical high-mountain Lake Ardibo, Ethiopia. Environmental Monitoring and Assessment, 195(8), 927.

[30] Mohan, B., Priyadarshinee, S., Kalpana, R., Bhavan, P. S., Manickam, N., Santhanam, P., & Prabha, D. (2023). Impact of seasonal changes in freshwater phytoplankton and zooplankton biodiversity at Valankulam lake, Coimbatore district, Tamil Nadu, India.

[31] Mohan, B., Priyadarshinee, S., Kalpana, R., Bhavan, P. S., Manickam, N., Santhanam, P., & Prabha, D. (2023). Impact of seasonal changes in freshwater phytoplankton and zooplankton biodiversity at Valankulam lake, Coimbatore district, Tamil Nadu, India.

[32] Mwebaza-Ndawula, L. (1994). Changes in abundance and composition of zooplankton in northern Lake Victoria, East Africa. Hydrobiologia, 272(1), 259-264.

[33] Panikkar, P., Saha, A., Prusty, A. K., Sarkar, U. K., & Das, B. K. (2022). Assessing hydrogeochemistry, water quality index (WQI), and seasonal pattern of plankton community in different small and medium reservoirs of Karnataka, India. Arabian Journal of Geosciences, 15(1), 82.

[34] Rai, H., Sharma, R., & Prasad, B. (2020). Effects of climate change on aquatic ecosystems: Indian scenario. Journal of Water and Climate Change, 11(2), 341-354.

[35] Rajak, P., Ganguly, A., Nanda, S., Mandi, M., Ghanty, S., Das, K., ... & Sarkar, S. (2024). Toxic contaminants and their impacts on aquatic ecology and habitats. In Spatial Modeling of Environmental Pollution and Ecological Risk (pp. 255-273). Woodhead Publishing.

[36] Sharma, R., & Dhanze, R. (2012). Seasonal variation of zooplankton diversity in the Yamuna River, India. Journal of Environmental Biology, 33(3), 547-552.

[37] Thirunavukkarasu, S., & Hwang, J. S. (2024). Genotoxic effects of marine pollutants on coastal meso-zooplankton populations–A mini-review. Marine Pollution Bulletin, 205, 116548.

[38] Wetzel, R. G. (2001). Limnology: Lake and River Ecosystems. Academic Press.

[39] Yin, J., Xia, J., Xia, Z., Cai, W., Liu, Z., Xu, K., ... & Dong, X. (2022). Temporal variation and spatial distribution in the water environment helps explain seasonal dynamics of zooplankton in river-type reservoir. Sustainability, 14(21), 13719.

[40] Zebral, Y. D., Righi, B. D. P., Abou Anni, I. S., Escarrone, A. L. V., Roza, M., Vieira, C. E. D., ... & Bianchini, A. (2021). Pollution levels and biomarker responses in zooplankton from three hydrographic regions of southern Brazil: an integrated approach for water quality monitoring. Journal of Environmental Chemical Engineering, 9(5), 106180.

[41] Zhao, B., Chen, F., Yao, Q., Lin, M., Zhou, K., Mi, S., ... & Zhao, X. (2024). Toxicity effects and mechanism of micro/nano plastics and loaded conventional pollutants on zooplankton: An overview. Marine Environmental Research, 106547