



Original Research Paper

Machine Learning Prediction of Macroinvertebrate Responses to Water Quality Variations

Dr. Jitesh Mahant^{1*}, Dr. Pankaj Tiwari²

^{1*}Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.jiteshmahant@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0000-7957-2754>

²Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.pankajtiwari@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0008-7787-0385>

Key Words	Abstract
Macroinvertebrates, Freshwater ecosystem, Water quality assessment, Aquatic biodiversity, Ecological indicators, Machine learning prediction, Environmental monitoring.	Introduction: The freshwater ecosystem hosts various aquatic organisms, where macroinvertebrates have a significant role in the ecological balance and determination of environmental health. The variation in water quality due to pollution, eutrophication, changes in habitats, and climatic factors has a direct impact on the distribution, abundance, and biodiversity of the macroinvertebrate community. Traditional ecological analysis methods usually rely on lengthy field analyses and may face challenges in predicting the biological response to changing environmental conditions. Hence, there is a need to predict the impact of variation in water quality on the response of aquatic animals. Materials & Methods: This research provides a machine learning-based ecological analysis method that will predict the macroinvertebrate response under different water quality conditions. Biological data such as abundance, diversity, and community analysis are combined with environmental data such as pH, temperature, Dissolved Oxygen, Turbidity, and Nutrient Content. This approach uses associations between changes in water quality and the behavior of macroinvertebrates to analyze the conditions of freshwater. Findings: This assessment illustrates that environmental condition changes affect the distribution and ecology of macroinvertebrates. Waters with good conditions have diverse and sensitive macroinvertebrates, while poor conditions favor pollution-resistant macroinvertebrates. Predictive analysis plays an instrumental role in highlighting the major environmental factors influencing aquatic biodiversity. Conclusion: This assessment underscores the significance of combining predictive methods with biological assessments in freshwater management. Machine-learning-based prediction is a valuable tool for predicting the impact of the environment on macroinvertebrates, which can be instrumental in the early detection of ecosystem deterioration and sustainable water management.

* Corresponding Author's email: ku.jiteshmahant@kalingauniversity.ac.in

Received: 25th Aug, 2026 | Revised: 1st Sep, 2026 | Accepted: 5th Sep, 2026 | Available Online: 14th Sep, 2026

(DOI): [10.70102/AEJ.2026.18.5s.32](https://doi.org/10.70102/AEJ.2026.18.5s.32)

Introduction

Freshwater ecosystems house various aquatic organisms as well as facilitate interactions that have ecological importance. Macroinvertebrates, such as aquatic insects, mollusks, crustaceans, and worms, form biological indicators because of their high susceptibility to changes in the environment (Ficsor & Csabai 2023; Sadykova et al. 2025). Information concerning the status of the freshwater ecosystem can be obtained from the distribution and diversity of the organisms.

Changes in the water quality brought about by pollution, agriculture, urbanization, and climate change greatly impact the community of macroinvertebrates (Schäfer et al. 2022; Yao et al. 2026; Sredić et al. 2024). Such factors as dissolved oxygen, temperature, pH, turbidity, and nutrients impact the numbers and types of organisms present in the water (Hussain & Taimooz 2024).

The conventional assessment procedures for water bodies involve frequent field testing along with laboratory analysis. It is difficult to predict the biological response to changing environmental conditions due to the complicated interaction between aquatic organisms and environmental conditions (Politikos et al. 2024; Najafzadeh et al. 2024).

There exist various possibilities to use machine learning techniques to determine relationships between environmental conditions and biological responses (Bourne et al. 2025; Krtolica et al. 2025). The current research aims to predict the reaction of macroinvertebrates to

varying water quality conditions using machine learning techniques.

Key Contributions

The major contributions of this study are:

- Assessment of the effect of water quality on the reactions of macroinvertebrate communities in freshwater.
- Construction of a predictive ecological model to understand the effects of environmental change on aquatic animal diversity.
- Ideas for environmental factors that affect the distribution of macroinvertebrates.

The organization of the remainder of this paper is as follows. Section 2 provides a review of the relevant literature concerning macroinvertebrate-based ecological assessments and water quality monitoring. The methodology applied for investigating biological and environmental features is presented in Section 3. Section 4 addresses the response observations and ecological consequences of the prediction model. Section 5 concludes the paper.

Review of Literature

Freshwater ecosystems are composed of many different kinds of aquatic creatures that help maintain ecological balance and sustainability of the environment. Among those organisms, macroinvertebrates serve as good biological indicators, because their presence, quantity, and diversity depend greatly on the changes of the environment (Ficsor & Csabai 2023; Sadykova et al. 2025). Species like aquatic insects, mollusks, and crustaceans react

differently to environmental pressure, which helps evaluate the state of the ecological environment in freshwater habitats.

As previous ecological researches show, there are some parameters of water quality that have great importance in forming communities of macroinvertebrates. Such factors as dissolved oxygen content, temperature, pH value, turbidity, and nutrient content influence the distribution of species, their survival, and reproductive ability. The communities of macroinvertebrates in high-quality water environments are usually diverse and include many sensitive species, while in polluted environments diversity is low and tolerant species prevail.

Traditional monitoring techniques for freshwater largely rely on physical and chemical measures, as well as biological sampling from the field (Yao et al. 2026; Sadykova et al. 2025). While these techniques offer valuable ecological information, ongoing assessment of vast aquatic habitats poses certain difficulties in terms of time, financial, and resource allocation. Moreover, there are only limited opportunities to predict further biological community behavior under different environmental circumstances using these techniques.

The development of the data-based approach to ecological assessments has opened up new ways of understanding the complicated interactions of environmental factors and biological response. Machine learning tools can help with ecological research by revealing interactions between the variability of water quality and the shifts in macroinvertebrate community structure (Schäfer et al. 2022).

Predictive modeling techniques can be used to identify potential ecological threats.

Nevertheless, most of the current research concentrates more on assessing water quality than the response of aquatic organisms to changes in their environment (Krtolica et al. 2025; Yao et al. 2026). Not much research has been done on predicting the response of macroinvertebrate communities taking into account different environmental aspects simultaneously. Thus, an ecological approach that will help us learn about the response of freshwater macroinvertebrates to changes in their environment is necessary.

Materials and Methods

This study is concerned with examining the connection between water quality variability and macroinvertebrate reactions to assess freshwater ecosystem conditions. The evaluation method takes into account both environmental and biological attributes to assess how the response of aquatic creatures is affected by varying habitat conditions.

The study looks at freshwater ecosystem observations involving the presence of macroinvertebrates along with water quality attributes. Biological attributes involve species presence, abundance, diversity trends, and tolerance ability of various macroinvertebrates. Some of the environmental variables, such as water temperature, pH level, dissolved oxygen, turbidity, and nutrient concentration, are used to indicate habitat variation.

The collected environmental data are analyzed to establish patterns between the

environment and macroinvertebrate community dynamics. The predictive tool is used to establish the impact that changes in water quality will have on the distribution and response of aquatic organisms. The methodology as a whole involves

data collection, response evaluation, relationship analysis, and predictions about macroinvertebrate dynamics under varying water conditions.

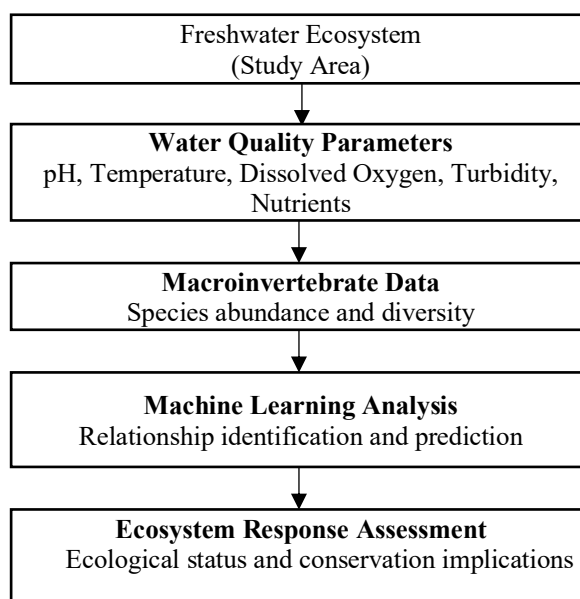


Figure 1: Framework for assessing macroinvertebrate responses to water quality variations

Figure 1 is the model used to determine the reaction of macroinvertebrates to freshwater conditions through water quality parameters and biological observation.

Results and Discussion

The relation between water quality variability and macroinvertebrate response has been analyzed in order to understand the state of ecology in freshwater ecosystems. It is evident from the analysis that variations in environmental factors have a direct effect on the composition, abundance, and diversity of macroinvertebrates in the ecosystem. Variability in water quality factors creates various habitat conditions, which cause variation in sensitive and tolerant aquatic organism distribution. This analysis clearly

demonstrates that freshwater ecosystems with ideal water conditions have diverse macroinvertebrate communities. Higher levels of dissolved oxygen and stable temperature conditions result in the presence of sensitive organisms in the ecosystem, thus suggesting higher ecological quality. Conversely, higher pollution levels and poorer water quality have adverse effects on macroinvertebrate communities.

The predictive evaluation will enable us to see how the environment influences the biological response. It was noted that water quality characteristics had an effect on the structure of macroinvertebrate communities, and thus predictions about changes in ecosystems could be made depending on the environmental situation.



Original Research Paper

Table 1: Relationship Between Water Quality Conditions and Macroinvertebrate Responses

Water Quality Condition	Macroinvertebrate Response	Ecological Interpretation
Good water quality	High species diversity and abundance of sensitive organisms	Healthy aquatic ecosystem
Moderate environmental stress	Reduced sensitive species with mixed community structure	Transitional ecosystem condition
Poor water quality	Dominance of pollution-tolerant organisms	Ecological disturbance

Table 1 shows that macroinvertebrates provide important data concerning the status of the freshwater ecosystem. It is possible to increase knowledge regarding aquatic animals' behavior through incorporating predictive analysis with biological examination.

Conclusion

In the aquatic ecosystem, freshwater macroinvertebrates act as useful indicators for measuring the health of the ecosystem due to their sensitivity to environmental changes. In this study, the relation between water quality change and reactions of macroinvertebrate communities has been analyzed by considering some environmental and biological factors.

The proposed machine learning-based method helps to find out patterns between water properties and reactions of aquatic animals. The proposed framework can be helpful for detecting any disturbances in the ecosystem and sustainable use of freshwaters. Further research can consider long-term studies along with more environmental factors.

References

- [1] Bourne, Kimberly, Ryan SD Calder, Shan Zuidema, Celia Y. Chen, and Mark E. Borsuk. "Local land-use decisions drive losses in river biological integrity to 2099: Using machine learning to disentangle interacting drivers of ecological change in policy forecasts." *Meteorological Applications* 32, no. 1 (2025): e70024.
- [2] Ficsor, Mark, and Zoltan Csabai. "Machine learning model ensemble based on multi-scale predictors confirms ecological segregation and accurately predicts the occurrence of net-spinning caddisfly larvae species groups (Trichoptera: Hydropsychidae) at catchment-scale." *Ecological Indicators* 146 (2023): 109769.
- [3] Hussain, Lujain Ibrahim, and Sulaf Hamid Taimooz. "Measuring the Levels of Heavy Metal Pollution in Al-Diwaniyah River Water Using Oomycetes Fungus." *International Academic Journal of Science and Engineering* 11, no. 1 (2024): 312–316.
- [4] Krtolica, Ivana, Ilija Kamenko, Momir Paunović, Maja Raković, Ana Atanacković, Max Talanov, and Nataša Popović. "Use of Artificial Neural Networks (ANNs) to assess xenobiotics in a river catchment using

- macroinvertebrates as bioindicators." *Aquatic Toxicology* 286 (2025): 107466.
- [5] Najafzadeh, Mohammad, Elahe Sadat Ahmadi-Rad, and Daniel Gebler. "Ecological states of watercourses regarding water quality parameters and hydromorphological parameters: deriving empirical equations by machine learning models." *Stochastic Environmental Research and Risk Assessment* 38, no. 2 (2024): 665-688.
- [6] Politikos, Dimitris, Kostas Stefanidis, George Varlas, Anastasios Papadopoulos, and Elias Dimitriou. "Predicting the ecological quality of rivers: A machine learning approach and a what-if scenarios tool." *Environmental Modeling & Assessment* 29, no. 6 (2024): 1059-1077.
- [7] Sadykova, Dinara, Andrew C. Johnson, Yueming Qu, Peter A. Henrys, Monika D. Jürgens, Virginie DJ Keller, Nuria Bachiller-Jareno et al. "The relative importance of multiple environmental factors on river macroinvertebrate abundance across different groups based on a nationwide dataset from England." *Water Research* (2025): 125270.
- [8] Schäfer, Benjamin, Christian Beck, Hefin Rhys, Helena Soteriou, Paul Jennings, Allen Beechey, and Catherine M. Heppell. "Machine learning approach towards explaining water quality dynamics in an urbanised river." *Scientific Reports* 12, no. 1 (2022): 12346.
- [9] Sredić, S., N. Knežević, and I. Milunović. "Effects of Landfill Leaches on Ground and Surface Waters: A Case Study of a Wild Landfill in Eastern Bosnia and Herzegovina." *Archives for Technical Sciences* 30, no. 1 (2024): 97–106.
- [10] Yao, Siyang, Jutao Liu, Guofei Dai, Xinyuan Liu, Chunyun Wen, Ping Yang, Siyu Wan, and Yang Jian. "Decoding the interactive effect of water quality-land use on benthic macroinvertebrate biodiversity in rivers with an interpretable machine learning framework." *Global Ecology and Conservation* (2026): e04161.