

Aquatic Macroinvertebrates as Bioindicators of Freshwater Ecosystem Health: Ecological Significance, Assessment Methods and Evidence from India

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Abstract

Freshwater ecosystems are among the most biologically diverse and ecologically important environments, providing water, food, fisheries, nutrient cycling, irrigation, recreation and other ecosystem services. Increasing urbanisation, agricultural intensification, industrialisation, wastewater discharge, habitat modification, excessive water abstraction and climate change are placing severe pressure on freshwater ecosystems. Conventional physicochemical monitoring provides important information about water quality, but it often represents conditions only at the time of sampling. Aquatic macroinvertebrates provide a complementary biological assessment because they are relatively sedentary, diverse, widespread and respond to environmental stress over longer periods. This article reviews the ecological significance of aquatic macroinvertebrates as bioindicators of freshwater ecosystem health, with particular emphasis on Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, Hemiptera, Odonata, Mollusca, Annelida and Crustacea. Major bioassessment approaches, including taxa richness, Shannon–Wiener diversity, EPT richness, Biological Monitoring Working Party (BMWP), Average Score Per Taxon (ASPT), Family Biotic Index and pollution-tolerance measures, are examined. Recent Indian evidence published in 2025 demonstrates the practical value of macroinvertebrate communities. A study of Deepor Beel, Assam, recorded 467 individuals belonging to 14 families, eight orders and three phyla and detected deterioration in richness and diversity at sites exposed to greater anthropogenic pressure. Nationally, the Central Pollution Control Board's 2025 assessment identified 296 polluted river stretches on 271 rivers, based on water-quality data from 2022–2023. The number of polluted stretches declined from 351 in 2018 to 296 in 2025, although substantial water-quality challenges remain. Global evidence also demonstrates serious freshwater biodiversity pressure: the WWF Living Planet Report 2024 reported an average 85% decline in monitored freshwater wildlife populations between 1970 and 2020. The review concludes that macroinvertebrate-based biomonitoring can provide a cost-effective and ecologically meaningful complement to chemical monitoring. However, region-specific tolerance values, seasonal sampling, taxonomic capacity and integration with physicochemical and molecular approaches are required for robust freshwater assessment.

Keywords: Aquatic Macroinvertebrates, Bioindicators, Freshwater Ecosystem, Biomonitoring, Water Quality, EPT Index, BMWP, Biodiversity, India, Ecological Health.

Introduction

Freshwater ecosystems include rivers, streams, lakes, ponds, reservoirs, wetlands, floodplain systems and springs. Although freshwater occupies only a small proportion of the Earth's surface, it supports a disproportionately large share of global biodiversity and provides

essential services to human societies. Freshwater environments are increasingly exposed to multiple anthropogenic pressures. These include:

- Domestic Sewage;
- Industrial Effluents;
- Agricultural Runoff;
- Pesticides And Fertilisers;
- Sedimentation;
- Plastics and Emerging Contaminants;
- Mining;
- Urbanisation;
- River Fragmentation;
- Dams And Water Abstraction;
- Invasive Species
- Climate-Related Changes in Temperature and Hydrological Regimes.

The 2024 WWF Living Planet Report provides an important global context. It reported a 73% average decline in monitored vertebrate wildlife populations between 1970 and 2020, while freshwater populations showed the steepest decline at 85%. Freshwater ecosystems therefore require monitoring approaches capable of detecting both chemical contamination and ecological consequences. Water-quality assessment traditionally relies on measurements such as:

- pH
- Dissolved Oxygen (DO);
- Biochemical Oxygen Demand (BOD);
- Chemical Oxygen Demand (COD);
- Electrical Conductivity;
- Turbidity;
- Total Dissolved Solids;
- Nutrients;
- Heavy Metals
- Microbiological Parameters.

Although these measurements are essential, they provide a snapshot of environmental conditions. Biological communities can integrate environmental changes over weeks or months and therefore provide additional information about ecological condition. Aquatic macroinvertebrates are particularly useful because their abundance and community composition respond to changes in dissolved oxygen, organic enrichment, habitat structure, sedimentation, toxic substances and nutrient availability. A global review of macroinvertebrate bioassessment found that more than 70% of applications used single or multimetric approaches and that 92% of reviewed studies reported successful detection of environmental degradation using macroinvertebrates in at least some responses.

Objectives of the Study

The major objectives are:

1. To examine the ecological importance of aquatic macroinvertebrates as indicators of freshwater ecosystem health.
2. To explain the relationship between macroinvertebrate community structure and water-quality conditions.
3. To identify major macroinvertebrate groups useful in freshwater biomonitoring.
4. To examine commonly used biological indices.
5. To review recent Indian evidence, particularly studies available during 2025.
6. To analyse the usefulness and limitations of macroinvertebrate-based biomonitoring.
7. To suggest an integrated framework for freshwater ecosystem assessment in India.

Methodology

This article adopts a review and secondary-data analytical approach. Scientific literature, institutional reports and recent Indian studies concerning aquatic macroinvertebrates, freshwater biodiversity and biological water-quality assessment were reviewed. Particular attention was given to:

- Peer-Reviewed Studies;
- Cpcb Water-Quality Information;
- Recent Indian Macroinvertebrate Research;
- Global Freshwater Biodiversity Assessments;
- Biological Indices
- Methodological Literature Concerning Freshwater Biomonitoring.

The article does **not** claim that the author personally sampled the sites discussed. Numerical values from individual studies are reported as published observations and are identified accordingly.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates are animals without a backbone that are large enough to be observed without a microscope, generally including organisms retained by standard aquatic sampling nets.

Major groups include:

Group	Examples	General indicator significance
Ephemeroptera	Mayflies	Generally sensitive to pollution
Plecoptera	Stoneflies	Highly sensitive; often associated with well-oxygenated water
Trichoptera	Caddisflies	Many taxa sensitive to pollution
Diptera	Chironomids	Several taxa tolerate organic enrichment
Coleoptera	Water beetles	Useful indicators of habitat and water conditions
Hemiptera	Water bugs	Useful for habitat and pollution assessment

Odonata	Dragonflies, damselflies	Reflect habitat and water-quality conditions
Mollusca	Snails, mussels	Useful for pollution and habitat assessment
Annelida	Oligochaetes, leeches	Several taxa associated with organically enriched waters
Crustacea	Amphipods, isopods, cladocerans	Respond to water chemistry and habitat changes

The response of these organisms varies by species and family; therefore, broad assumptions based only on taxonomic group should be avoided.

Why Macroinvertebrates Are Effective Bioindicators

- **Sedentary nature:** Many benthic macroinvertebrates have limited mobility and remain associated with a particular habitat. Consequently, their community composition reflects local environmental conditions.
- **Relatively long biological exposure:** Chemical measurements can change rapidly following rainfall, discharge or dilution. Macroinvertebrate communities integrate environmental exposure over longer periods.
- **Different pollution tolerances:** Macroinvertebrates exhibit different levels of tolerance.

For example: Sensitive taxa → moderate-tolerance taxa → highly tolerant taxa

Changes in the relative abundance of these groups can indicate ecological deterioration.

- **High diversity:** Freshwater macroinvertebrates occupy multiple ecological niches and respond to different environmental pressures.
- **Ease of sampling:** Kick sampling, Surber sampling, hand-net sampling and artificial substrates can be used for many streams and shallow-water environments.
- **Ecological relevance:** Macroinvertebrates occupy important positions in freshwater food webs. They participate in:
 - Decomposition;
 - Nutrient Cycling;
 - Primary-Consumer Pathways;
 - Predator-Prey Interactions
 - Energy Transfer to Fish and Other Organisms.

Thus, changes in their community structure can have consequences beyond water quality alone.

Relationship Between Water Quality and Macroinvertebrates: Several physicochemical parameters strongly influence macroinvertebrate communities.

- **Dissolved Oxygen:** Sensitive taxa such as many Ephemeroptera, Plecoptera and Trichoptera require relatively well-oxygenated conditions. Organic pollution increases

microbial decomposition, which can reduce dissolved oxygen and favour more tolerant organisms.

- **BOD:** High BOD generally indicates increased biodegradable organic matter. Higher organic loading can therefore be associated with:
- **High BOD → oxygen consumption → lower DO → loss of sensitive taxa → increase in tolerant taxa**
- **Nutrients:** Excess nitrogen and phosphorus can stimulate eutrophication.

This may result in:

- Algal Growth;
- Reduced Water Transparency;
- Oxygen Depletion;
- Altered Food Resources
- Changes in Macroinvertebrate Composition.
- **Temperature:** Temperature affects:
- Metabolism;
- Growth;
- Emergence;
- Reproduction;
- Dissolved Oxygen Availability
- Species Distribution.

Climate change can therefore alter macroinvertebrate communities even without conventional pollution.

- **Sedimentation:** Fine sediments can:
- Clog Interstitial Spaces;
- Reduce Habitat Availability;
- Interfere With Respiration;
- Cover Benthic Food Resources
- Reduce Habitat Suitability for Sensitive Taxa.

Major Macroinvertebrate-Based Bioassessment Indices

Taxa Richness: Taxa richness is simply the number of taxa recorded.

$S = \text{Number of taxa}$

Greater richness can indicate greater habitat heterogeneity and ecological integrity, although naturally species-poor environments must be interpreted separately.

Shannon–Wiener Diversity Index: The Shannon–Wiener index is:

$$H' = -\sum_{i=1}^S p_i \ln p_i$$

where:

- SS = number of taxa;
- p_i = proportion of individuals belonging to taxon i .

Higher values generally indicate greater diversity and evenness.

Simpson's Index: A common form is:

$$D = \frac{1}{\sum p_i^2}$$

Lower dominance and greater diversity generally produce lower values of D , although the exact interpretation depends on the formulation used.

EPT Index: The EPT approach considers:

- E = Ephemeroptera
- P = Plecoptera
- T = Trichoptera

EPT richness is:

$$EPT = E + P + T$$

A relatively high representation of EPT taxa commonly indicates better ecological conditions, although interpretation must consider regional ecology.

BMWP: The Biological Monitoring Working Party system assigns tolerance scores to macroinvertebrate families. The overall BMWP score is:

$$BMWP = \sum \text{Family Scores}$$

Higher scores generally indicate communities containing more pollution-sensitive taxa.

Average Score Per Taxon: ASPT is calculated as:

$$ASPT = \frac{BMWP}{N}$$

where:

N = number of scoring taxa/families.

The BMWP/ASPT approach is among the most widely used macroinvertebrate-based bioassessment methods.

Indicative Tolerance Pattern

Macroinvertebrate group	General pollution sensitivity	Indicative ecological interpretation
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Plecoptera	High	Usually associated with clean, oxygen-rich water
Ephemeroptera	High–moderate	Often associated with good water quality
Trichoptera	High–moderate	Frequently useful in EPT assessment
Odonata	Variable	Habitat and water-quality indicator
Coleoptera	Variable	Habitat-dependent
Hemiptera	Variable	Often tolerant of moderate disturbance
Mollusca	Variable	Some taxa tolerate substantial pollution
Chironomidae	Often tolerant	Can increase under organic enrichment
Oligochaeta	Often tolerant	Frequently associated with organically enriched sediments
Hirudinea	Variable/tolerant	Can indicate disturbed conditions

Important: Tolerance is taxon-specific. Family-level classifications should therefore be calibrated for regional conditions before being used for regulatory decisions.

Evidence from India - 2025

National River Pollution Situation: The **2025 CPCB assessment** provides important national context for freshwater ecological monitoring.

The assessment covered **623 rivers** and identified:

- **296 polluted river stretches**
- distributed across **271 rivers**
- in **32 States/Union Territories**.

The number of polluted river stretches declined from:

Year	Polluted river stretches
2018	351
2022	311
2025	296

Thus, the number declined by approximately **15.7% between 2018 and 2025**.

The 2025 CPCB report also identified:

- 149 polluted river stretches that had been delisted; and
- improvement in water quality in 71 polluted stretches compared with the 2018 assessment.

This national situation demonstrates why biological monitoring can complement conventional water-quality monitoring.

Deepor Beel, Assam: 2025 Macroinvertebrate Evidence

One of the most relevant Indian studies published in 2025 examined macroinvertebrates in **Deepor Beel**, a Ramsar wetland in Assam.

The study sampled three locations during post-monsoon and winter seasons of 2023–2024.

Published observations

Parameter	Reported value
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Individuals recorded	467
Families	14
Orders	8
Phyla	3
Mollusca abundance	53.74%
Arthropoda abundance	45.18%
Annelida	Remaining proportion
Viviparidae	16.27%
Lymnaeidae	15.84%
Planorbidae	15.84%

The study reported decreasing richness and diversity from less disturbed areas towards locations affected by garbage dumping and residential activity.

Saprobic assessment: The reported scores were:

Sampling station	Saprobic score	Reported interpretation
Station 1	4.90	Moderately polluted
Station 2	4.66	Moderately polluted
Station 3	5.50	Good environmental condition

The study also associated Gerridae, Hydrophilidae and Hirudidae with increasing organic loads represented by BOD and COD at Stations 1 and 2.

This provides a useful contemporary Indian example of how biological communities can differentiate sites subjected to different degrees of anthropogenic pressure.

Recent Indian Research Evidence

A 2025 study examining the Dikhow River system in Assam described benthic macroinvertebrates as useful indicators because of their relatively sedentary nature and sensitivity to organic loading, thermal changes, substrate modification and toxic pollution. Earlier Indian research has similarly demonstrated the usefulness of macroinvertebrates in wetland and river assessments. For example, research in the Central Himalayas found seasonal differences in macroinvertebrate density and relationships with turbidity, transparency, dissolved oxygen and water temperature. These findings support the use of biological communities as a complement to conventional physicochemical measurements.

Statistical Summary of Key 2025 Evidence

Selected freshwater statistics relevant to biomonitoring

Indicator	Statistic	Year/source
Polluted river stretches in India	296	CPCB 2025
Rivers containing polluted stretches	271	CPCB 2025
Rivers assessed	623	CPCB 2025
Polluted stretches in 2018	351	CPCB
Polluted stretches in 2022	311	CPCB
Polluted stretches in 2025	296	CPCB
Deepor Beel macroinvertebrate individuals	467	2025 study
Deepor Beel families	14	2025 study

Deepor Beel orders	8	2025 study
Deepor Beel phyla	3	2025 study
Mollusca proportion in Deepor Beel	53.74%	2025 study
Arthropoda proportion	45.18%	2025 study
Global freshwater wildlife population decline	85%	WWF, 2024

The CPCB statistics describe **water-quality pollution**, whereas the Deepor Beel figures describe a **specific biological community**; they should therefore not be interpreted as directly equivalent measurements.

Advantages of Macroinvertebrate Biomonitoring

- **Ecological integration:** Macroinvertebrates integrate multiple environmental stressors over time.
- **Cost effectiveness:** Once taxonomic expertise and sampling protocols are established, biological monitoring can be relatively economical.
- **Early warning:** Changes in sensitive taxa may reveal ecological deterioration before severe visible ecosystem changes occur.
- **Local applicability:** Sampling can be performed in:
 - Rivers;
 - Streams;
 - Ponds;
 - Lakes;
 - Wetlands;
 - Reservoirs
 - Irrigation Channels.
- **Complementary information:** Biological indicators provide information about ecological effects rather than merely pollutant concentrations.

Limitations: Macroinvertebrate biomonitoring is not without limitations.

- **Taxonomic difficulty:** Species-level identification requires considerable expertise.
- **Seasonal variation:** Rainfall, monsoon flows, temperature and life cycles can strongly influence abundance.
- **Natural geographic variation:** A naturally oligotrophic mountain stream cannot be evaluated using exactly the same biological expectations as a lowland tropical wetland.
- **Multiple stressors:** A reduction in sensitive taxa may result from:
 - Pollution;
 - Habitat Alteration;
 - Temperature;
 - Flow Modification;
 - Sedimentation;

- Natural Seasonal Variation.

Therefore, macroinvertebrate results should not automatically be interpreted as evidence of a particular pollutant.

- **Taxonomic resolution:** Family-level identification is convenient but can mask species-specific differences in pollution tolerance.
- **Index transferability:** Indices developed in temperate regions may not perform identically in tropical ecosystems. Recent research has therefore emphasised regional calibration and development of appropriate multimetric systems.

Integration with Physicochemical Monitoring

The strongest assessment framework combines biological and chemical measurements.

Recommended monitoring framework

Component	Examples
Biological	Macroinvertebrates, fish, algae
Chemical	BOD, COD, nutrients, metals
Physical	Temperature, turbidity, flow
Habitat	Substrate, riparian vegetation
Microbiological	Coliforms, microbial indicators
Emerging contaminants	Pharmaceuticals, pesticides, microplastics
Spatial	Upstream–downstream comparison
Temporal	Pre-monsoon, monsoon, post-monsoon

This integrated approach helps distinguish whether biological degradation is associated with pollution, habitat modification, hydrological changes or natural variability.

Suggested Monitoring Protocol for Indian Freshwaters

A practical monitoring programme could follow the sequence:

Step 1: Site selection

Select:

- Reference Site;
- Upstream Site;
- Impact Site;
- Downstream Site.

Step 2: Habitat characterisation

Record:

- Substrate;
- Depth;
- Velocity;
- Vegetation;
- Canopy;

- Bank Condition.

Step 3: Macroinvertebrate collection

Use standardised:

- Kick Sampling;
- Surber Sampling;
- Hand-Net Sampling; Or
- Artificial Substrates.

Step 4: Laboratory identification

Identify organisms preferably to family and, where feasible, genus/species.

Step 5: Calculate biological metrics

Calculate:

S, H', EPT, BMWP, ASPTS, \ H', \ EPT, \ BMWP, \ ASPT

along with appropriate tolerance and functional metrics.

Step 6: Physicochemical assessment

Measure:

pH, DO, BOD, COD, temperature, EC, nutrients, turbidity
pH, \ DO, \ BOD, \ COD, \
temperature, \ EC, \ nutrients, \ turbidity

Step 7: Statistical analysis

Possible methods include:

- correlation analysis;
- PCA;
- cluster analysis;
- redundancy analysis;
- NMDS;
- regression;
- multimetric scoring.

Step 8: Final ecological classification

Combine biological, chemical and habitat information.

Findings of the Study

The major findings of this review are as follows:

1. Aquatic macroinvertebrates provide a strong biological complement to conventional physicochemical monitoring because community composition integrates environmental conditions over time.

2. Sensitive groups, particularly many Ephemeroptera, Plecoptera and Trichoptera, are useful for identifying relatively good ecological conditions, while tolerant groups can become more dominant under organic enrichment and disturbance.
3. BMWP, ASPT, EPT richness, Shannon–Wiener diversity and taxa richness are among the most frequently used bioassessment metrics.
4. The 2025 Deepor Beel study demonstrates the practical application of macroinvertebrates in Indian wetlands. It recorded 467 individuals representing 14 families, eight orders and three phyla and identified differences in ecological condition among sites.
5. The 2025 CPCB assessment identified 296 polluted river stretches across 271 rivers, demonstrating the continuing need for effective freshwater monitoring in India.
6. The decline in India's identified polluted river stretches from 351 in 2018 to 296 in 2025 indicates improvement in the national assessment, but the remaining 296 stretches represent a substantial continuing management challenge.
7. Global freshwater biodiversity trends reinforce the importance of biological monitoring. WWF's 2024 assessment reported an 85% decline in monitored freshwater wildlife populations between 1970 and 2020.
8. Biological assessment should not replace chemical monitoring. Rather, the two approaches should be integrated.
9. India requires greater development and calibration of tropical and region-specific macroinvertebrate tolerance values.

Suggestions

- **Establish long-term biomonitoring programmes:** Indian rivers, wetlands and lakes should be monitored systematically using biological as well as chemical indicators.
- **Develop Indian tolerance databases:** A national database of macroinvertebrate:
 - Taxonomy;
 - Abundance;
 - Distribution;
 - Pollution Tolerance;
 - Functional Traits;
 - Environmental Preferences

should be developed.

- **Standardise sampling:** Standard protocols should be adopted across State Pollution Control Boards and research institutions.
- **Strengthen taxonomic expertise:** Universities and environmental laboratories should establish training programmes in aquatic entomology and benthic taxonomy.
- **Integrate biological and chemical indices:** Macroinvertebrate indices should be used alongside:

- BOD;
- COD;
- DO;
- Nutrient Levels;
- Metals;
- Microbial Indicators;
- Habitat-Quality Assessments.
- **Include molecular tools:** Environmental DNA (eDNA), DNA barcoding and metabarcoding can complement conventional taxonomic identification, especially where immature organisms are difficult to identify.
- **Increase seasonal monitoring:** Indian monitoring should cover:
 - Pre-Monsoon;
 - Monsoon;
 - Post-Monsoon;
 - Winter

where practical.

- **Protect reference sites:** Relatively undisturbed streams and wetlands should be identified and protected as reference ecosystems.
- **Restore riparian habitats:** Vegetated riparian zones can reduce:
 - Sedimentation;
 - Nutrient Runoff;
 - Thermal Stress;
 - Habitat Degradation.
- **Promote citizen science:** Universities, colleges, schools and local communities can participate in simplified macroinvertebrate monitoring under expert supervision.

Conclusion

Aquatic macroinvertebrates are valuable indicators of freshwater ecosystem health because they respond to changes in water chemistry, habitat structure, organic pollution, oxygen availability and other environmental pressures. Their diversity, abundance, functional characteristics and tolerance patterns provide information about ecological condition that cannot always be obtained from a single physicochemical measurement. The evidence reviewed in this article demonstrates their relevance to India's freshwater-management challenges. The 2025 CPCB assessment identified 296 polluted river stretches across 271 rivers, while a 2025 study of Assam's Deepor Beel demonstrated clear relationships between

macroinvertebrate community characteristics and anthropogenic disturbance. At the global level, the reported 85% decline in monitored freshwater wildlife populations between 1970 and 2020 highlights the urgency of improving freshwater ecosystem assessment and conservation. Macroinvertebrate monitoring should therefore be incorporated into broader freshwater-management programmes rather than treated as an alternative to conventional water-quality analysis. The most scientifically robust framework combines macroinvertebrate community assessment, physicochemical monitoring, habitat evaluation, statistical analysis and, increasingly, molecular approaches. For India, the future of freshwater biomonitoring lies in developing regionally calibrated biological indices, improving taxonomic capacity, standardising sampling methods and creating long-term biological datasets. Such an integrated approach can strengthen early detection of ecological degradation and support evidence-based conservation and restoration of rivers, lakes and wetlands.

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