Aquatic Insects as Nature's Environmental Monitors: Biodiversity, Water Quality and Ecosystem Resilience in India

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Abstract

Aquatic insects are key players in the ecological balance, biodiversity and sustainability of freshwater ecosystems. They are essential components of rivers, lakes, ponds, wetlands and streams, contributing to nutrient cycling, organic matter decomposition, energy transfer and food-web stability. Apart from their ecological roles, aquatic insects also function as natural environmental monitors since their diversity, abundance and distribution reflect changes in water quality, pollution loads, habitat conditions and climate variability. The present paper focuses on aquatic insects with an emphasis on their ecological significance as bioindicators of freshwater ecosystem health, particularly in India. The study uses an analytical approach based on secondary data from published research studies, freshwater biodiversity assessments and national water-quality monitoring reports. The relationship between aquatic insect diversity and environmental quality is demonstrated by evidence from Indian freshwater ecosystems such as Western Ghats, Himalayan rivers and Kerala wetlands. A total of 72 species of aquatic insects in 38 families has been reported for the Jatinga River in Northeast India . In the Muthirapuzha River in Kerala , 3,278 individuals belonging to seven orders and 37 families were recorded . The Central Pollution Control Board, in its 2025 assessment, had identified 296 polluted river stretches across 271 rivers across the country. The article emphasizes the importance of biomonitoring methods based on the richness of insects such as Ephemeroptera, Plecoptera and Trichoptera (EPT), the Shannon–Wiener diversity, Biological Monitoring Working Party (BMWP) scores, and the Family Biotic Index. It argues that integrating aquatic insect monitoring with traditional physicochemical water quality assessment can boost environmental governance, freshwater conservation and ecosystem resilience in India.

Keywords: *Aquatic Insects; Biodiversity; Bioindicators; Water Quality; Freshwater Ecosystems; EPT Index; Ecosystem Resilience; Environmental Monitoring; India.*

Introduction

Freshwater aquatic systems are among the most valuable natural resources that sustain ecological balance, economic development and human well-being. Rivers, lakes, ponds, streams and wetlands provide essential services such as drinking water, irrigation for agriculture, fishery resources, industrial water supply, recreational activities and maintenance of biodiversity. India’s freshwater ecosystems are of paramount importance for agriculture, rural

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livelihoods, fisheries and regional economic development. However, freshwater ecosystems are gradually under the influence of urbanization, industrial activities, agricultural effluents, raw sewage, waste disposal, habitat deterioration and climate change. These ecological stresses affect water quality and threaten the biodiversity of aquatic species. Aquatic insects are an important biological component of freshwater ecosystems. Mayflies, stoneflies, caddisflies, dragonflies and damselflies, aquatic beetles, water bugs, and a variety of aquatic fly larvae are among the assemblage. These organisms are found in different ecological niches and play a role in aquatic food webs dynamics. One of the most important features of aquatic insects is their sensitivity to environmental changes. Certain insect taxa are more sensitive to organic pollutants, low dissolved oxygen concentrations and habitat disturbance, whereas others can persist in conditions of relatively degraded ecology.

For example:

- Mayflies (Ephemeroptera) generally indicate relatively favourable water conditions, although tolerance varies among families.
- Stoneflies (Plecoptera) are commonly associated with clean, well-oxygenated freshwater habitats.
- Caddisflies (Trichoptera) include several pollution-sensitive groups.
- Chironomid larvae can tolerate a wider range of environmental conditions, including organically enriched habitats.

Therefore, presence or absence, abundance and diversity of aquatic insects are important indicators of ecological health of water bodies. Biological monitoring, unlike conventional water-quality monitoring which gives a snapshot of conditions at a specific time, can provide an indication of the environmental conditions experienced by aquatic organisms over longer periods of time. Therefore, aquatic insects are becoming increasingly important in environmental research, fresh water management and biodiversity conservation.

Review of Literature

Several researchers have examined aquatic insect diversity, ecological functions and their usefulness in freshwater biomonitoring.

Abhijna, Ratheesh and Biju Kumar (2013) investigated the distribution and diversity of aquatic insects in Vellayani Lake, Kerala. Their study recorded 60 species belonging to 37 families and eight orders. The Shannon diversity index varied between sampling stations, indicating spatial differences in ecological conditions. The study also identified the usefulness of EPT taxa and pollution-tolerant insect groups in evaluating freshwater quality.

Balachandran et al. (2012) studied the diversity and distribution of aquatic insects in the Aghanashini River of the Central Western Ghats. Their research highlighted the importance of freshwater insects in processing organic matter, transporting energy and supporting riparian and floodplain food webs.

Anamika et al. (2021) reviewed the diversity and distribution of aquatic entomofauna in India. The study discussed ten major aquatic insect orders and identified Coleoptera, Hemiptera, Odonata and Ephemeroptera among the important groups represented in Indian freshwater habitats.

Harinagaraj, Joseph and Josekumar (2024) examined aquatic insects as bioindicators in the Muthirapuzha River, Kerala. Their seasonal investigation recorded 3,278 individuals representing seven orders and 37 families. The study found that diversity indices and EPT composition varied across seasons, highlighting the importance of aquatic insects in assessing organic pollution and water quality.

A study of the Jatinga River (2024) in Northeast India documented 72 aquatic insect species belonging to 58 genera and 38 families. The researchers applied BMWP, ASPT, SIGNAL2 and EPT indicators to assess environmental

conditions. Their findings indicated comparatively good water quality at upstream locations, with declining conditions downstream.

Central Pollution Control Board (2025) assessed polluted river stretches in India using water-quality information. The report identified 296 polluted stretches across 271 rivers, demonstrating the continuing importance of effective freshwater monitoring and restoration.

The literature indicates that aquatic insects provide an important scientific basis for understanding freshwater biodiversity, pollution levels and ecosystem health.

Objectives of the Study

The major objectives of the article are:

1. To examine the diversity and distribution of aquatic insects in Indian freshwater ecosystems.
2. To analyse the ecological functions of aquatic insects in maintaining ecosystem balance.
3. To understand the relationship between aquatic insect diversity and freshwater quality.
4. To evaluate the usefulness of aquatic insects as biological indicators of environmental pollution.
5. To examine the impact of urbanisation, industrialisation and agricultural activities on aquatic insect populations.
6. To identify the importance of aquatic insect conservation in strengthening freshwater ecosystem resilience.
7. To suggest suitable policy measures for integrating biological monitoring into India's freshwater management programmes.

Research Methodology

The present study is based on secondary information collected from published research articles, scientific journals, environmental reports and government publications.

Research design: Descriptive and analytical research.

Nature of data: Secondary data.

Geographical coverage: Selected freshwater ecosystems of India, particularly Kerala, the Western Ghats, Northeast India and Himalayan river systems.

Sources of data:

- Central Pollution Control Board reports.
- Published scientific research articles.
- Environmental and biodiversity assessments.
- Research publications on aquatic insects.
- Government reports on freshwater pollution.

Analytical methods:

- Descriptive statistical analysis.

- Comparative analysis of insect diversity.
- Shannon–Wiener diversity index.
- EPT richness and percentage.
- Biological Monitoring Working Party (BMWP).
- Average Score Per Taxon (ASPT).
- Family Biotic Index.

The article uses published study-level observations for its statistical discussion. These figures are not presented as original field-survey findings or as a nationally representative aquatic insect census.

Analysis and Discussion: Aquatic Insects and Freshwater Ecosystem Health in India

Diversity of Aquatic Insects in Indian Freshwater Ecosystems

India possesses diverse freshwater habitats ranging from Himalayan streams and Western Ghats rivers to wetlands, lakes, reservoirs and agricultural ponds. These habitats support different aquatic insect communities depending on altitude, temperature, water flow, vegetation, dissolved oxygen and nutrient availability.

The major aquatic insect orders include:

Order	Common name	Ecological significance
Ephemeroptera	Mayflies	Sensitive indicators of water quality; food for fish
Plecoptera	Stoneflies	Generally associated with clean, oxygen-rich waters
Trichoptera	Caddisflies	Organic matter processing & biological monitoring
Odonata	Dragonflies and damselflies	Predators that regulate aquatic insect populations
Coleoptera	Aquatic beetles	Decomposition and food-web support
Hemiptera	Water bugs	Predation and regulation of aquatic organisms
Diptera	Aquatic flies	Organic matter processing and nutrient cycling
Megaloptera	Alderflies and dobsonflies	Predation and freshwater food-web functioning

The distribution of these insects differs according to the ecological characteristics of individual water bodies.

Statistical Evidence from Selected Indian Studies

Published studies provide useful quantitative evidence about aquatic insect diversity and their relationship with freshwater conditions.

Aquatic insect diversity in selected Indian freshwater ecosystems

Study location	**Major statistical observations**
Vellayani Lake, Kerala (2013)	60 species, 37 families and 8 orders
Muthirapuzha River, Kerala (2014–15 study)	3,278 individuals, 37 families and 7 orders
Jatinga River, Northeast India (2018–19 study)	72 species, 58 genera and 38 families
Achenkovil River, Kerala (2019–20 study)	10,736 individuals, 36 species, 35 genera and 21 families

The data reveal considerable variation in aquatic insect diversity across geographical regions and freshwater habitats. The Jatinga River recorded 72 species, whereas Vellayani Lake recorded 60 species. However, these figures should not be directly interpreted as evidence that one ecosystem is healthier than another because thesampling duration, habitat characteristics, sampling methods and identification levels differed.

Aquatic Insects as Indicators of Water Quality

Aquatic insects are valuable indicators because different insect groups possess different levels of tolerance to environmental stress. The presence of pollution-sensitive organisms generally indicates favourable environmental conditions, while the dominance of pollution-tolerant organisms may suggest organic pollution or habitat deterioration. For example, mayflies, stoneflies and caddisflies are collectively used in the EPT index.

Relationship between aquatic insect groups and environmental conditions

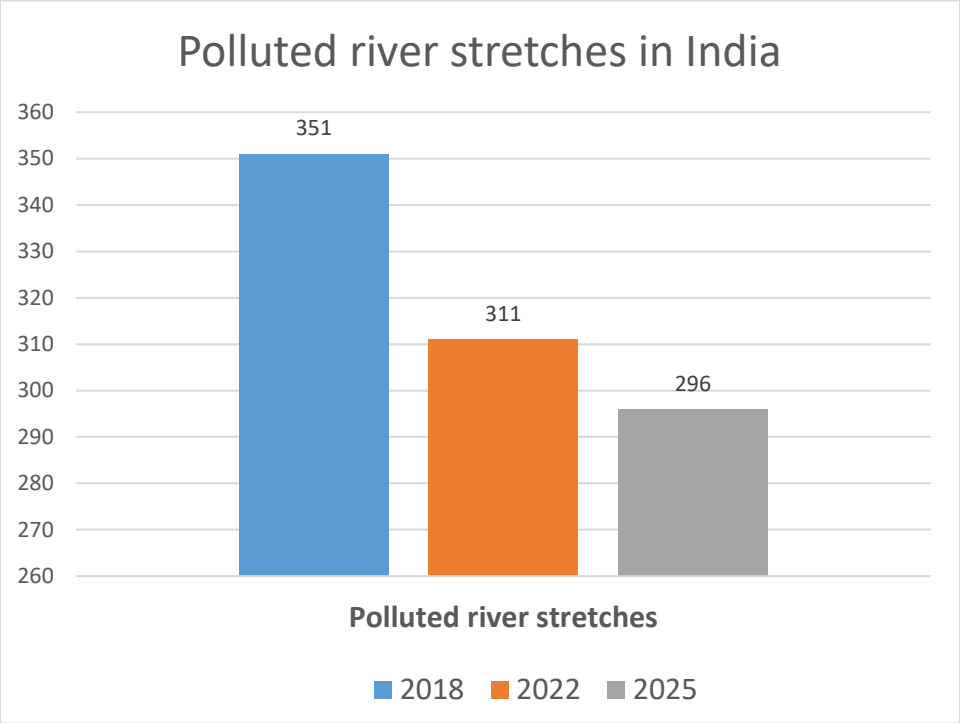
Aquatic insect group	**General sensitivity**	**Environmental interpretation**
Ephemeroptera	Many families are sensitive	Often associated with good water quality
Plecoptera	Generally highly sensitive	Usually indicates clean, oxygen-rich water
Trichoptera	Varies by family	Several families indicate favourable conditions
Chironomidae	Varies, with many tolerant taxa	Some species tolerate organic pollution
Odonata	Variable	Reflects habitat and ecological conditions
Hemiptera	Variable	Provides information on habitat characteristics

National Freshwater Pollution: Statistical Analysis

The ecological significance of aquatic insects becomes clearer when considered alongside India's freshwater pollution situation. According to the Central Pollution Control Board's 2025 assessment, 296 polluted river stretches were identified across 271 rivers based on water-quality data from 2022 and 2023.

Polluted river stretches in India

Assessment year	Polluted river stretches
2018	351
2022	311
2025	296



Source: CPCB, Polluted River Stretches for Restoration of Water Quality – 2025.

The number of identified polluted river stretches declined from 351 in 2018 to 296 in 2025.

The reduction is: 351 – 296 = 55

Percentage reduction: $\frac{55}{351} x\ 100 = 15.67\%$

Thus, the number of identified polluted stretches declined by approximately 15.67% between the 2018 and 2025 assessments.

This improvement is encouraging, but the continued identification of 296 polluted stretches demonstrates that freshwater pollution remains a major environmental concern. Importantly, CPCB's river-pollution figures are not aquatic insect measurements. They provide national environmental context for the need to strengthen biological monitoring.

Seasonal Variation in Aquatic Insect Diversity

Seasonal variation is an important factor influencing aquatic insect populations. The Muthirapuzha River study reported differences in insect composition across pre-monsoon, monsoon and post-monsoon seasons.

Important observations included:

- Ephemeroptera represented 27% of the recorded order-level composition during the monsoon.
- Ephemeroptera represented 25% during the post-monsoon season.
- Diptera represented 22.7% during the pre-monsoon season.
- Shannon–Wiener diversity, Simpson dominance and Margalef richness were highest during the post-monsoon season.

These observations suggest that seasonal hydrological conditions influence aquatic insect communities and their ecological distribution.

Seasonal patterns in aquatic insect communities

Season	**Observed ecological pattern**
Pre-monsoon	Greater representation of Diptera in the Muthirapuzha study
Monsoon	Increased representation of Ephemeroptera
Post-monsoon	Highest reported Shannon and Margalef indices

Seasonal changes in water flow, temperature, dissolved oxygen, food availability and sediment movement can influence insect abundance and distribution.

Role of Aquatic Insects in Nutrient Cycling and Food-Web Stability: Aquatic insects contribute to ecosystem functioning through several interconnected processes.

1. Organic matter decomposition: Many aquatic insect larvae feed on decaying leaves, organic debris and microorganisms. They help break down organic material into smaller particles, facilitating nutrient recycling.
2. Food-web support: Aquatic insects are important food sources for fish, amphibians, birds and other aquatic organisms. Their availability influences fish production and the ecological stability of freshwater habitats.
3. Regulation of aquatic populations: Predatory insects such as dragonfly and damselfly larvae help regulate populations of mosquitoes and other aquatic organisms.
4. Energy transfer: Aquatic insects transfer energy from algae, detritus and microorganisms to higher trophic levels.
5. Ecosystem resilience: A diverse aquatic insect community contributes to the stability of freshwater ecosystems by supporting multiple ecological functions.

Research on the Aghanashini River also highlights the importance of aquatic insects in organic matter processing and energy movement between streams, river channels and floodplains.

Major Threats to Aquatic Insect Biodiversity in India: Aquatic insect populations face multiple environmental pressures.

Environmental threat	Impact on aquatic insects
Industrial pollution	Toxic effects and habitat degradation
Domestic sewage	Reduced oxygen and organic enrichment
Agricultural pesticides	Direct toxicity to aquatic organisms
Fertiliser runoff	Eutrophication and altered water chemistry
Plastic pollution	Habitat disturbance and ecological stress
Sand mining	Destruction of streambed habitats
Deforestation	Increased sedimentation and loss of riparian vegetation
Climate change	Changes in temperature, water flow and seasonal patterns
Dam construction	Changes in river connectivity and habitat structure

These environmental pressures can reduce sensitive insect populations, alter community composition and weaken ecosystem functioning.

Scientific Methods for Measuring Aquatic Insect Diversity

The following indices are useful for evaluating freshwater ecosystem health.

a. **Shannon–Wiener Diversity Index:** $H^{!} = -\sum_{i=1}^{S} P_i \ln P_i$

Where

$H^{!}$ = Shannon diversity index

S = Total number of species or taxa

P_i = Proportion of individuals belonging to the ith taxon

A higher value generally indicates greater diversity and evenness, although interpretation depends on sampling conditions.

b. EPT Index = $EPT\ \% = \frac{Number\ of\ EPT\ Individuals}{Total\ Aqatic\ insect\ individuals}\ x\ 100$

A higher EPT percentage often indicates favourable water conditions, especially when sensitive families are well represented.

c. Margalef's Richness Index = $D = \frac{S-1}{\ln N}$

Where:

- S = Number of taxa
- N = Total number of individuals

d. Family Biotic Index: The Family Biotic Index uses the relative abundance of different insect families and their assigned pollution-tolerance scores.

$$FBI = \frac{\sum n_i t_i}{N}$$

Where

FBI = Family Biotic Index

n_i = Number of individuals in each family

t_i = Pollution-tolerance score

N = Total number of individuals

Higher scores generally indicate greater organic pollution under the relevant index calibration. These methods provide a scientific foundation for assessing ecological quality through aquatic insect communities.

Regional Importance: Indian Freshwater Ecosystems

India's freshwater ecosystems provide valuable opportunities for aquatic insect research like.

- Western Ghats: Important biodiversity region with diverse streams, rivers and forest-associated aquatic insect communities.
- Himalayan region: Mountain streams support specialised aquatic insects and sensitive ecological communities.
- Northeast India: Rivers and wetlands support diverse aquatic insect populations.
- Kerala: Lakes and rivers provide important habitats for aquatic insects and other freshwater organisms.
- Telangana: Rivers such as the Godavari and Krishna, along with reservoirs, tanks and village ponds, offer opportunities for aquatic insect biodiversity surveys and water-quality assessment.

In Telangana, systematic research could examine the relationship between aquatic insect diversity and water quality in the Musi, Krishna and Godavari river systems, as well as selected irrigation tanks and freshwater wetlands.

Major Findings of the Study: The analysis of published research and environmental statistics leads to the following findings.

- ❖ High ecological importance: Aquatic insects play an essential role in maintaining freshwater biodiversity, nutrient cycling and food-web stability.
- ❖ Bioindicator significance: The diversity and distribution of aquatic insects provide useful information about water quality and ecological disturbances.
- ❖ Regional biodiversity variation: Published Indian studies demonstrate considerable differences in aquatic insect diversity across rivers, lakes and wetlands.
- ❖ Importance of sensitive species: Ephemeroptera, Plecoptera and Trichoptera are particularly useful groups for evaluating freshwater ecological conditions.
- ❖ Seasonal influence: Aquatic insect populations change according to monsoon conditions, water flow, temperature and habitat characteristics.
- ❖ Continuing pollution pressure: The CPCB's 2025 assessment identified 296 polluted river stretches across 271 rivers, demonstrating the continuing need for freshwater restoration.

- Importance of biological monitoring: Chemical analysis alone cannot fully explain ecological conditions. Biological assessment provides complementary information about the long-term effects of environmental stress.
- Conservation requirement: Protection of aquatic insect habitats is essential for sustaining freshwater biodiversity and ecosystem resilience.
- Research gaps: India requires more long-term, standardised aquatic insect monitoring programmes, particularly in reservoirs, wetlands, small streams and agricultural water bodies.
- Policy relevance: Integrating aquatic insect monitoring into national and state-level water-quality programmes could strengthen freshwater conservation and environmental management.

Suggestions and Policy Recommendations: To strengthen aquatic insect biodiversity and freshwater ecosystem resilience in India, the following measures are suggested.

- **Strengthening Biological Monitoring:** Government environmental agencies should integrate aquatic insect-based biomonitoring into existing water-quality monitoring programmes. Regular surveys should be conducted in rivers, lakes, reservoirs, wetlands and ponds.
- **Conservation of Freshwater Habitats:** Natural riverbanks, wetlands, stream vegetation and aquatic habitats should be protected from encroachment, excessive sand mining and uncontrolled construction activities.
- **Control of Water Pollution:** Strict implementation of pollution-control regulations is necessary to reduce industrial effluents, untreated sewage, agricultural chemicals and plastic waste entering freshwater ecosystems.
- **Development of Aquatic Biodiversity Research:** Universities, colleges and research institutions should undertake systematic investigations of aquatic insect diversity, seasonal distribution and ecological relationships.
- **Integration with Environmental Education:** Aquatic insect conservation should be included in environmental education, biodiversity awareness programmes and undergraduate and postgraduate research projects.
- **Promotion of Sustainable Agriculture:** Farmers should be encouraged to adopt integrated pest management, organic farming practices and reduced chemical pesticide applications to minimise contamination of freshwater habitats.
- **Establishment of Regional Biodiversity Databases:** State-level aquatic insect biodiversity databases should be developed to record species distribution, population abundance, pollution sensitivity and seasonal changes.
- **Strengthening Institutional Coordination:** CPCB, State Pollution Control Boards, universities, biodiversity boards and local governments should collaborate in developing integrated freshwater conservation programmes.
- **Climate Change Adaptation:** Monitoring programmes should examine the effects of rising temperatures, irregular rainfall, droughts and floods on aquatic insect populations.
- **Special Focus on Telangana:** Telangana should promote aquatic insect biodiversity surveys in the Godavari and Krishna river basins, Musi River, reservoirs and village tanks. Such studies could provide useful baseline information for water-quality management and freshwater conservation.

Conclusion

Aquatic insects are important biological components of freshwater ecosystems and serve as natural indicators of environmental conditions. Species diversity, dispersion and abundance are important indicators of the ecological status of rivers, lakes, ponds, wetlands and streams. The present study suggests that aquatic insects are important in nutrient cycling, decomposition of organic matter, energy transfer, food-web dynamics and ecological balance. Due to their sensitivity to changes in water quality, they are useful indicators for detecting environmental disturbances and for

evaluation of the status of freshwater ecosystems. Investigations carried out in India on the Vellayani Lake, Muthirapuzha River, Achenkovil River and Jatinga River suggest that the diversity of aquatic insects is important in ecological evaluation. The CPCB in its 2025 assessment identified 296 polluted stretches of rivers spread across 271 rivers, highlighting the need for robust freshwater conservation and pollution control measures. One of the important findings of this study is that management of freshwater ecosystems should not be based only on physicochemical assessments of water quality. Conventional environmental assessments should include biological surveillance of aquatic insects to give a more complete picture of the health of the ecosystem. India should enhance research on aquatic biodiversity, establish regional biomonitoring databases, safeguard natural freshwater ecosystems, and foster collaboration among environmental organizations, academic institutions, and local communities. “Protecting aquatic insects is not only about saving little freshwater creatures, but about a vital commitment to preserving biodiversity, ensuring water security, fostering sustainable advancement and building ecological robustness.

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