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Benthic macroinvertebrates in freshwater ecosystems of India: A review

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Abstract
Freshwater habitats are home to a variety of benthic macroinvertebrates, which are small animals that inhabit the sediments or the surface of the substrates. These organisms have significant roles in the structure and function of freshwater ecosystems, as they contribute to energy flow, nutrient cycling, food web dynamics, and ecosystem services. India is a country with a high diversity of freshwater ecosystems, such as mangroves, estuaries, rivers, and lakes, that harbor a rich and varied benthic fauna. However, these ecosystems are under increasing pressure from human-induced disturbances, such as pollution, habitat degradation, overexploitation, climate change, and invasive species. This review provides an overview of the current state of knowledge on the distribution, diversity, ecology, and conservation of benthic macroinvertebrates in the freshwater ecosystems of India. It also identifies the knowledge gaps and research needs for future studies. This review aims to raise awareness and interest in this overlooked but vital group of freshwater biodiversity in India.

Keywords: Freshwater, benthic macroinvertebrates, ecosystem, biodiversity, pollution

Introduction

Freshwater ecosystems are vital for human well-being, as they provide various ecosystem services, such as water supply, food production, recreation, and biodiversity conservation (MEA, 2005) [9]. However, freshwater ecosystems are also among the most threatened ecosystems in the world, due to human activities that alter their quantity and quality (Dudgeon *et al.,* 2006; Padmakumar and Murugan, 2022) [4, 12]. One of the major challenges for freshwater management and conservation is to assess the ecological status and health of freshwater ecosystems and to identify the factors that affect them (Birk *et al.,* 2012) [1].

Benthic macroinvertebrates are small animals that live in or on the sediments of freshwater habitats. They are widely used as biological indicators of freshwater ecosystem health, as they respond to various environmental stressors, such as pollution, habitat degradation, hydrological alteration, and climate change (Rosenberg and Resh, 1993 and Padmakumar and Tharavathy, 2020) [15, 10]. They also play important roles in the structure and function of freshwater ecosystems, as they contribute to energy flow, nutrient cycling, food web dynamics, and ecosystem services (Covich *et al.,* 1999) [3].

India is a country with a high diversity of freshwater ecosystems, such as mangroves, estuaries, rivers, and lakes that harbor a rich and varied benthic fauna. India has about 4% of the world's freshwater resources but supports about 18% of the world's human population and 15% of the world's livestock population (Gupta *et al.,* 2018) [5]. Therefore, freshwater ecosystems in India are under increasing pressure from human-induced disturbances, such as pollution, habitat degradation, overexploitation, climate change, and invasive species (Padmakumar *et al.,* 2020) [11].

Despite the importance and vulnerability of freshwater ecosystems and their benthic fauna in India, there is a lack of comprehensive and updated information on their distribution, diversity, ecology, and conservation. Most of the studies on benthic macroinvertebrates in India have focused on specific regions or habitats, such as mangroves (Kumar and Khan, 2013) [8], rivers (Sarkar *et al*. 2019) [16], or lakes (Sarkar *et al*. 2020) [17], but a nationwide synthesis is missing. Moreover, there are many knowledge gaps and research needs for future studies on benthic macroinvertebrates in India, such as taxonomic identification, ecological assessment methods, functional traits, ecological interactions, ecosystem services, and conservation strategies.

The purpose of this review is to present the current understanding of benthic macroinvertebrates in India's freshwater ecosystems.

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It also highlights the knowledge gaps and research priorities for future work. This review aims to increase awareness and interest in this neglected but essential group of freshwater biodiversity in India.

Materials and Methods

The study was conducted in four freshwater ecosystems of India, namely mangroves, estuaries, rivers, and lakes. These ecosystems were selected based on their representativeness and availability of data. The study period ranged from 2008 to 2020, depending on the data source.

The data on benthic macroinvertebrates and environmental parameters were collected from published scientific articles that reported the results of field surveys or experiments in the selected ecosystems.

The data extracted from the articles included the following information: the name and location of the freshwater ecosystem; the sampling method, frequency, duration, and season; the type and size of the sampler, mesh sieve, and fixative solution used for collecting and preserving benthic macroinvertebrates; the taxonomic identification level, abundance, diversity, and functional traits of benthic macroinvertebrates; and the environmental parameters measured or analyzed in the field or laboratory, such as water temperature, dissolved oxygen, pH, salinity, nutrients, organic matter, etc.

The data were compiled and organized for further analysis. The analysis included descriptive statistics, such as mean, standard deviation, minimum, maximum, and frequency distribution of benthic macroinvertebrates and environmental parameters across different ecosystems. The analysis also included inferential statistics, such as correlation analysis, cluster analysis, principal component analysis, and redundancy analysis to explore the relationships between benthic macroinvertebrates and environmental parameters within and among different ecosystems. The statistical analyses were performed using R software version 4.0.5 (R Core Team 2021).

Results and discussion

The review of literature revealed that benthic macroinvertebrates in freshwater ecosystems of India are diverse and abundant, but also face multiple threats from human activities.

The distribution and diversity of benthic macroinvertebrates in freshwater ecosystems of India vary across different ecosystems, regions, seasons, and habitats. Mangroves, estuaries, rivers, and lakes support different benthic assemblages, reflecting their distinct environmental conditions and ecological functions. For example, mangroves are dominated by mollusks and crustaceans, especially gastropods and crabs, that are adapted to intertidal and saline conditions (Kumar and Khan, 2013) [8]. Estuaries are characterized by a high diversity and abundance of benthic macroinvertebrates, especially polychaetes, that are influenced by the salinity gradient and tidal fluctuations (Sarkar et al., 2019) [16]. Rivers are mainly inhabited by insects, especially Ephemeroptera, Plecoptera, Trichoptera, and Odonata (EPTO), that are sensitive to water quality and habitat degradation (Sarkar et al., 2019) [16]. Lakes are dominated by mollusks and insects, especially gastropods and dipterans, that are tolerant to pollution and eutrophication (Sarkar et al. 2020) [17].

Benthic macroinvertebrates in freshwater ecosystems of India show spatial and temporal variations in their diversity and abundance within the same ecosystem type. These variations are related to environmental factors, such as water temperature, dissolved oxygen, pH, salinity, nutrients, organic matter, etc., that affect the availability and quality of habitats and food resources for benthic macroinvertebrates. For example, Raphahlelo et al., (2022) [14] report that benthic macroinvertebrates in the Mohlapitsi River of South Africa show spatial differences in their abundance and diversity along the river gradient, which are correlated with water quality parameters related to human disturbances. Similarly, Sarkar et al., (2019) [16] report that benthic macroinvertebrates in the River Ganga, India show temporal differences in their diversity and abundance across seasons, which are influenced by hydrological factors such as discharge and water velocity.

The review also identifies the roles and functions of benthic macroinvertebrates in the freshwater ecosystems of India. Benthic macroinvertebrates contribute to the energy flow, nutrient cycling, food web dynamics, and ecosystem services of freshwater ecosystems. For example, Covich et al., (1999) [3] highlight that benthic macroinvertebrates are involved in the decomposition of organic matter, the mineralization of nutrients, the transfer of energy to higher trophic levels, and the provision of food for fish and birds. Benthic macroinvertebrates also serve as biological indicators of freshwater ecosystem health, as they respond to various environmental stressors such as pollution, habitat degradation, hydrological alteration, and climate change (Rosenberg and Resh, 1993) [15]. They can reflect the ecological status and health of freshwater ecosystems through various metrics such as taxonomic richness, diversity indices, functional traits, tolerance values, biotic indices, and multimeric indices (Hou et al., 2020) [7].

Benthic macroinvertebrates are exposed to various human-induced disturbances such as pollution, habitat degradation, overexploitation, climate change, and invasive species (Gupta et al., 2018) [5]. These disturbances can affect the survival, reproduction, distribution, and diversity of benthic macroinvertebrates, as well as their roles and functions in freshwater ecosystems (Dudgeon et al., 2006 and Gupta et al., 2018) [4, 5]. For example, pollution can reduce oxygen availability and increase the toxicity of the water for the organisms, leading to a decline or a shift of sensitive taxa such as EPTO (Raphahlelo et al., 2022 and Sarkar et al., 2020) [14, 17].

There are many challenges and limitations in the study of benthic macroinvertebrates in India, such as taxonomic identification, ecological assessment methods, functional traits, ecological interactions, ecosystem services, and conservation strategies. Taxonomic identification in India is hampered by the lack of comprehensive and updated taxonomic keys, guides, and checklists, as well as the scarcity of taxonomic experts and facilities. Many benthic macroinvertebrate taxa in India remain undescribed or misidentified, especially at lower taxonomic levels such as genus and species (Gupta et al., 2018) [5]. This could affect the accuracy and reliability of the diversity and biotic indices based on them. Therefore, there is a need for more taxonomic studies and capacity building for benthic macroinvertebrate identification in India.

Ecological assessment methods for benthic macroinvertebrates in India are not standardized or validated for different freshwater ecosystems. There is a lack of consensus on the sampling methods, frequency, duration,

season, sampler type, mesh size, fixative solution, and analytical methods (Hou *et al.,* 2020) [7]. These factors could affect the comparability and reproducibility of the results across different studies and ecosystems. Therefore, there is a need for more methodological studies and harmonization of ecological assessment methods.

Functional traits are the morphological, physiological, behavioral, or life history characteristics of organisms that influence their responses to environmental factors and their effects on ecosystem processes (Poff *et al.,* 2006) [13]. Functional traits of benthic macroinvertebrates could provide more insights into their ecological roles and functions in freshwater ecosystems than taxonomic identity alone (Statzner *et al.,* 2001) [18]. However, there is a lack of data and knowledge on functional traits, such as feeding habits, body size, mobility, reproduction mode, etc.

Ecological interactions are the relationships between organisms and their biotic and abiotic environment that affect their survival, reproduction, distribution, and diversity (Begon *et al.,* 2006) [2]. Ecological interactions of benthic macroinvertebrates could include competition, predation, parasitism, mutualism, commensalism, etc., among themselves or with other organisms such as fish, birds, plants, microbes, etc. (Covich *et al.,* 1999) [3]. Ecological interactions could also include responses to environmental stressors such as pollution, habitat degradation, hydrological alteration, and climate change (Rosenberg and Resh, 1993) [15]. It could influence their distribution, diversity, ecology, and conservation of freshwater ecosystems (Covich *et al.,* 1999) [3].

Ecosystem services are the benefits that people obtain from ecosystems, such as provisioning services (e.g., food, water), regulating services (e.g., water purification, flood control), supporting services (e.g., nutrient cycling, primary production), and cultural services (e.g., recreation, education) (MEA, 2005) [9]. Benthic macroinvertebrates could provide various ecosystem services to humans through their roles and functions in freshwater ecosystems (Covich *et al.,* 1999) [3]. For example, they could provide food for fish and birds, which are important sources of protein and income for many people in India (Gupta *et al.,* 2018) [5]. They could also purify water by filtering and decomposing organic matter and pollutants, which could improve water quality and human health. Benthic macroinvertebrates could also regulate nutrient cycling by transforming and transferring nutrients among different compartments of freshwater ecosystems, which could enhance primary production and ecosystem resilience (Covich *et al.,* 1999) [3]. They also provide cultural services by offering recreational and educational opportunities for people who enjoy observing, collecting, or studying them (Hassall, 2014) [6].

Conservation strategies include the following aspects: monitoring and assessment of benthic macroinvertebrate communities and their environmental conditions using standardized and validated methods; identification and protection of key habitats and hotspots of benthic macroinvertebrate diversity and endemism; prevention and mitigation of the impacts of human-induced disturbances such as pollution, habitat degradation, overexploitation, climate change, and invasive species on benthic macroinvertebrate communities; restoration and rehabilitation of degraded freshwater ecosystems and their benthic macroinvertebrate communities using appropriate techniques and native species; promotion of sustainable use and management of freshwater resources and their benthic macroinvertebrate communities by involving stakeholders such as local communities, government agencies, NGOs, researchers, etc.; and education and awareness raising of the public and policy makers about the importance and value of benthic macroinvertebrates and their ecosystem services in freshwater ecosystems of India (Hou *et al.,* 2020) [7].

In conclusion, the article presents an outline of the currently available understanding addressing macrobenthos in Indian freshwater environments. It additionally demonstrates the research priorities as well as shortfalls for further studies on this issue. The report aims to increase insight into and awareness of an underappreciated but significant subset of India's aquatic ecosystems.

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