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Macroinvertebrate-Based Biomonitoring for Evaluating Ecological Integrity of Freshwater Ecosystems

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ABSTRACT

Freshwater ecosystems are increasingly threatened by pollution, habitat degradation, urbanization, and climate-induced environmental changes. Monitoring the ecological integrity of these ecosystems is essential for biodiversity conservation and sustainable water resource management. The present study evaluates the effectiveness of macroinvertebrate communities as bioindicators for assessing the ecological status of freshwater ecosystems. Macroinvertebrates are ideal indicators because of their sensitivity to physicochemical alterations, limited mobility, and differential tolerance to pollutants. The study investigates the composition, diversity, abundance, and seasonal variation of macroinvertebrate fauna in selected freshwater habitats subjected to varying levels of anthropogenic stress. Water quality parameters including temperature, pH, dissolved oxygen, alkalinity, conductivity, turbidity, nitrates, phosphates, and biological oxygen demand were analyzed simultaneously to establish ecological relationships. Biological indices and diversity measures were used to assess pollution levels and habitat quality. The findings indicate that freshwater ecosystems with better water quality supported higher diversity of pollution-sensitive taxa, whereas degraded habitats showed dominance of tolerant organisms and reduced biodiversity. Seasonal changes significantly influenced macroinvertebrate distribution and ecological responses. The study confirms that macroinvertebrate-based biomonitoring is an efficient and cost-effective method for long-term assessment of freshwater ecosystem health. The results highlight the urgent need for conservation measures, pollution control strategies, and sustainable watershed management to protect freshwater biodiversity and maintain ecological stability.

Keywords: *Macroinvertebrates; Biomonitoring; Freshwater ecosystems; Water quality; Biodiversity; Bioindicators; Vainganga river; Ecological Integrity.*

1.0 Introduction

Freshwater ecosystems are critical components of the global environment because they support immense biodiversity and provide essential ecosystem services for human survival. Rivers, streams, lakes, wetlands, and reservoirs function as habitats for diverse aquatic organisms while simultaneously supporting agriculture, fisheries, domestic activities, recreation, and industrial development [50]. Despite their ecological and economic significance, freshwater ecosystems are among the most threatened habitats due to rapid environmental degradation and increasing anthropogenic pressures.

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Water quality and aquatic biodiversity are closely interconnected. The chemical, physical, and biological characteristics of water directly influence the structure and functioning of aquatic communities [39]. Human-induced activities such as untreated sewage disposal, industrial discharge, agricultural runoff, urbanization, deforestation, and sand mining have significantly altered freshwater ecosystems worldwide [61, 10]. These activities increase nutrient loading, sedimentation, organic pollution, and toxic contamination, ultimately reducing biodiversity and ecosystem productivity [56].

Freshwater organisms exhibit varying levels of tolerance to environmental disturbances, making them valuable indicators of ecosystem health. Among aquatic organisms, macroinvertebrates are widely recognized as efficient bioindicators because they are relatively sedentary, easy to sample, and highly responsive to pollution and habitat modifications [21]. Macroinvertebrates include insects, mollusks, annelids, and crustaceans that inhabit benthic regions of freshwater systems. Their distribution and abundance reflect long-term ecological conditions and provide insight into the biological integrity of aquatic habitats [58].

The use of macroinvertebrates in biomonitoring has become increasingly important because traditional physicochemical assessments alone cannot adequately represent ecological conditions over extended periods. Biological monitoring integrates the cumulative effects of pollutants and environmental stressors on aquatic communities, thereby providing a more holistic understanding of ecosystem health [60]. Macroinvertebrate diversity indices and pollution tolerance metrics are therefore widely applied in freshwater ecological assessments across the world.

Seasonal variations and hydrological dynamics also strongly influence macroinvertebrate assemblages and water quality characteristics [22]. Factors such as rainfall, runoff, sediment transport, eutrophication, and temperature fluctuations alter habitat structure and nutrient availability, thereby affecting aquatic biodiversity [44]. Consequently, ecological monitoring of freshwater ecosystems requires integration of biological, physical, and chemical parameters for accurate environmental assessment.

The present study focuses on evaluating the ecological integrity of freshwater ecosystems using macroinvertebrate-based biomonitoring techniques. By analyzing macroinvertebrate diversity in relation to physicochemical characteristics of water, the study aims to provide valuable information regarding pollution status, habitat quality, and biodiversity conservation. The findings will contribute to sustainable freshwater management strategies and support ecological restoration initiatives for protecting aquatic ecosystems.

Rivers are the primary source of drinking water in rural India. Knowing the quality of river water utilized for human and animal consumption is therefore crucial [53]. The biggest sub-basin of the river Godavari is the Vainganga (sometimes spelled Wainganga). It is one among Maharashtra's biggest rivers, spanning around 120 km and covering 36,306 sq km in the district of Gondia. It begins at an elevation of 640 meters above sea level in the Mahadeo Hills, which are located close to Mundara hamlet in the Seoni district in Southern-Central Madhya Pradesh on the southern slopes of the Satpura range. It exits at Site-V (Ghatkuroda) to enter Bhandara district after entering Gondia district at Site-I (Dangorli).

It naturally divides the districts of Gondia on its east bank and Bhandara on its west bank as it flows south. It is located between longitudes 79o 47''-80o 29'' E and latitudes 21o 22'' and 21o 38'' N. It is 754 km long from its starting point to the point where it meets the Godavari River [45, 52]. Along the varied environment of deciduous woods, floodplains, agricultural land, cities, villages, streams, lakes, reservoirs, and other natural features, the study area has the highest biodiversity.

There is a vast and distinctive variety of plants and animals in its water. For all of their needs—irrigation, transportation, fishing, drinking, farming, bathing, cleaning, industries, recreation, etc.—the locals living within its watershed are totally reliant on its water. Vidarbha Irrigation Development Corporation is building the Dhapewada Lift Irrigation Project, a large irrigation project, at Site 4 (Kawalewada) for Environmental Clearance (No.J-12011/29/2008-IA.I), Government of Maharashtra. The project involves a barrage across this river to supply 16 tanks throughout the district.

In India's Deccan Plateau, the Gondia district, sometimes known as "The District of Lakes," is located in the far east of Maharashtra state. Madhya Pradesh's Balaghat district borders it to the north, Chhattisgarh's Rajnandgaon district borders it to the east, and Maharashtra's Bhandara and Chandrapur districts border it to the west and south, respectively. The district's capital, Gondia City, is situated on the Mumbai-Kolkat railway line, 996 kilometers from Mumbai and 130 kilometers from Nagpur. A wide range of lotic and lentic water bodies, such as streams, rivulets, springs, rivers, lakes, reservoirs, ponds, and other wetlands, hills, and forest ecosystems with a broad range of flora and fauna, are found in this district. Since rice is the main crop grown in its enormous catchment area, Gondia City is referred to as "Rice City." Along with its tributaries and the streams in this area, the river Vainganga is one of the lotic ecosystems that provides the largest diversity of creatures. The changing environmental conditions are felt by its water.

It serves as the most practical and affordable supply of food and water for the communities that live along its banks as well as for households, businesses, and agricultural within its catchment area. Water from the river Vainganga's tributaries, including Bagh, Bawanthadi, Chulband, and other streams, as well as surface and urban runoff, is discharged into the area. Its biota is dynamically impacted by this [46].

Contaminants from home, agricultural, and industrial effluents that are frequently concentrated in water bodies due to over-extraction degrade the quality of surface water. Toxic byproducts are created when these contaminants interact or break down [54]. A wide variety of both biotic and abiotic elements are present in the Vainganga River. It made it possible for a wide variety of living forms, particularly macroinvertebrates, to flourish in this location. In both its standing and flowing streams, they are numerous. However, neither their richness, variety, or population dynamics have been examined, nor have they been utilized to assess the district's bio-health.

2.0 Literature Survey

In freshwater streams in the Garhwal area, Joshi et al. [47] investigated the seasonal fluctuation and relationship between benthic macroinvertecrates and environmental factors. According to their research, the most prevalent orders that indicate high water quality are Plecoptera and Ephemeropera. Additionally, they found that species richness had a negative link with total hardness, pH, chlorides, and phosphates and a positive correlation with dissolved oxygen, but there was no correlation with nitrates, alkalinity, free carbon dioxide, or TDS.

Chakrabarty and Das [31] investigated how sediment redox potential and water quality affected macroinvertebrate populations and discovered a direct relationship between the Margalef index, sediment redox potential, and the Water Quality Index (WQI). They found that while the Shannon-Weiner index indicated light pollution to acceptable water quality, the redox potential declined as the Margalef index climbed.

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In the Paradip region of India, Samantray et al. [55] used the NSFWQI to evaluate the water quality of the Mahanadi and Atharabanki rivers as well as the Taldanda canal. They discovered that the Mahanadi and Taldanda canals were good, falling under the "B" category, while the Atharabanki river had poor water quality, falling under the "C-D" category (most polluted) because of its acidic pH, low DO, and high BOD, which resulted in the lowest NSFWQI.

The river Vainganga differs from other rivers in India in terms of channel morphology, water flow fluctuation, and total sediment load transfer, according to Sinha and Brahmankar's [59] investigation of the river's hydrological, morphological, and sediment transport features. Despite a broad catchment area where structural restrictions on drainage patterns impact the fluvial processes, they found low to moderate flow and a very modest sediment load.

In order to describe the downstream of the Kunda River in Khargone, Madhya Pradesh, Mahajan et al. [48] investigated physicochemical parameters and algal flora. They found that the river was gradually becoming more polluted as a result of inputs from sewage channels, which led to an increase in pH, electrical conductivity, turbidity, chlorides, total hardness, and alkalinity, as well as a corresponding decrease in DO. Additionally, they discovered that Bacillariophyceae and Cyanophyceae, two of the Chlorophyceae algae groups, predominate in river water.

Using physicochemical parameters in conjunction with macrobenthos and vertebrates, Dutta et al. [43] conducted hydrobiological analysis and found that while high diversity occurred during September to November, this coincided with increased clarity, optimal water flow, the availability of suitable substrate, and rich algal growth, low macrobenthic diversity occurred during June to August due to floods that increased turbidity, suspended matter, and transparency.

Begum and Harikrishna [23] investigated the water quality in streams of the Cauvery River in the Mandya district using physicochemical parameters and rotifer diversity. They found that the sensitive species vanished as a result of higher levels of turbidity, total dissolved solids (TDS), and sodium chloride (NaCl), as well as lower levels of DO. Using physicochemical parameters and benthic macroinvertebrates using the NEPBIOS system, Sharma et al. [57] conducted a qualitative evaluation of the water quality of the Behta River in Himachal Pradesh. They documented the various compositions of 30 genera from 10 families in the Insecta, Mollusca, and Oligochaeta. They suggested lowering point and non-point sources of pollution in order to enhance the Class-III (moderately contaminated) water quality at station-II in comparison to the Class-II (good) water quality.

In their study of the variety of leech fauna in freshwater wetlands in Tamil Nadu and West Bengal, Mandal and Nandi [49] identified 27 species from 13 genera and 4 families. They identified 12 species from Tamil Nadu's lacustrine wetlands and 22 species from West Bengal's palustrine and lacustrine wetlands. Additionally, they noted that the greater diversity of leech species favors macrophytic vegetation dominated by water hyacinth and sluggish, eutrophic waters.

The function of biodiversity in freshwater and marine benthic ecosystems was studied by Covich et al. [38]. They noted that the impacts of biodiversity shifts vary throughout time and space and are contingent upon particular biological characteristics or functional roles of individual species. According to their opinion, the experiments that examine the various impacts of both natural and man-made disturbances while taking into account a larger variety of species with varying life-history characteristics, such as sizes, biomass, longevity, etc., provide a helpful tool for comprehending how biodiversity regulates ecosystem processes. They proposed ways to broaden the geographical and temporal dimensions in experimental designs and to extend biodiversity beyond species richness by integrating interactions at the multitrophic level.

Nelson [51] conducted surveys of stream macroinvertebrates in the Cle Elum and Bumping River Watersheds as part of the Storage Dam Fish Passage Study, Yakima Project, Washington. He found that the macroinvertebrate crops above the reservoirs were low due to the regional geology and low alkalinity, while they were highest in the Bumping watershed with functional-feeding groups and high coarse particulate organic matter (CPOM), which was low in the Cle Elum.

3.0 Research Methodology

Aquaculture, industry, irrigation, residential usage, biodiversity protection, and other factors all depend on the water quality of an aquatic ecosystem. For the purpose of managing and improving a body of water, data on its physical, chemical, geological, and biological characteristics should be gathered. The current study is based on the monthly variance in these characteristics. Therefore, an effort was undertaken to assess the acceptability of the water from the Vainganga River under investigation based on these water quality indicators.

3.1 Area of study

The current study was conducted in aquatic environments at five points along the Vainganga River, which flows through the Gondia region of Maharashtra State, India. The district of Gondia spans 5640.51 square kilometers, extending from 20° 39'' to 21° 38'' N and 79° 27'' to 80° 42'' E.

Five sample locations were chosen along the Vainganga River, which flows through the Gondia district between latitudes 21o 22'' and 21o 38'' N and longitudes 79o 47'' and 80o 29'' E, at an elevation of around 300 to 325 meters above sea level. As shown in Table 1, the water samples were taken from five different sampling locations.

The Vainganga River is the biggest sub-basin of the Godavari River and one of its principal tributaries. Because of its importance due to irrigation and the economy, it serves as the district's backbone and pivot. For those residing within its catchment area, which spans 61093 square kilometers, it serves as a lifeline. It begins in the Satpura range's Mahadeo hills in Madhya Pradesh's Seoni district, where it runs for over 150 km before entering Gondia district at site 1 (Dangorli). At site 3 (Chandori), it bends south and then west, creating a depression that divides the districts of Gondia on its eastern bank and Bhandara on its western bank. Its whole research span was around 120 kilometers long.

Along the alluvium on sandy, loamy red and clayey black soil, its water runs over the multi-habitat beds that are made up of rocks, boulders, cobbles, silt, clay, sand, pebbles, gravels, etc. There are several tiny rapids and pools in this shallow, medium-flowing river. With the exception of the wet months, the catchment area is largely clean. A range of habitats, including pools, runs, vegetative regions, and riffles, were included in each sampling site and were deemed typical. The sedimentary, muddy banks include several types of soil particles. Its watershed is characterized by varying degrees of household, industrial, agricultural, and human activities.

Along its catchment region, the river mostly collects surface runoffs from streams, floodplains, forests, and communities, as well as agricultural and urban runoffs. It receives the discharge of the tributaries Bagh, Bawanthadi, and Chulbandh. In the research region, there are no significant chemical industries located on its bank. The lakes and/or streams that are close to the river are where the majority of the companies in this district discharge their wastewater. Along with fishing, other activities along the river under observation include cleaning clothing, caring for animals, cremating dead people, etc.

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3.2 Description of the site

Site 1: This location is located at 21o 59'4.03'' N and 80o 19' 34.75'' E, close to the hamlet of Dangorli. This is where the Vainganga River meets its tributary Bagh as it enters the Gondia district. This location is around 29 kilometers from Gondia City, the district headquarters, and 318 meters above mean sea level (amsl). Agricultural area, forests, streams, and settlements upstream of the Vainganga and Bagh rivers in the north and east, respectively, provide it with runoff water. It is where human remains are cremated, clothing, animals, and automobiles are washed, and idols are submerged (Figure 1).

Figure 1: Site 1 Views (Where it Meets the Tributary Bagh)



Site 2: This location is around 35 kilometers from site 1 and 20 kilometers from Gondia city. At an elevation of 316 meters above sea level, the settlement of Dhapewada is situated on its river at coordinates 21o 53'12.13'' N and 80o 29' 48.79'' E. The communities along its bank, as well as many streams and forests, provide it with runoff water. Since a fair is held there once a year, it is the location of congruence. Other popular activities at this location include washing garments and animals and immersing idols (Figure 2).

Figure 2: Perspectives of Site 2 (Congregation site)



Site 3: This location, which is 287 meters above sea level, is close to the settlement of Chandori (Kh) at 21o 50'44.97'' N and 79o 95' 34.41'' E. Here, the Vainganga River and its tributary the Bawanthadi meet. This location is around 32 kilometers from site-II and 40 kilometers from the city of Gondia. Water for this location comes from the Bawanthadi River, as well as runoff from nearby farms, streams, forests, and communities. Villagers from both sides use canoes to cross the river. At this location, operations include washing livestock and clothing, growing fruits and vegetables, and cremating human remains (Figure 3).

Figure 3: Site 3 Views (Where it Meets the Tributary Bawanthadi)



4.0 Conclusion

The monsoon season had the least amount of biodiversity, whereas winter and summer saw the most. Rich and steady diversity was also shown by the diversity indexes' values. Very excellent water quality was indicated by ASPT scores above 5 and BMWP values over 300. Stable and healthy food chains were indicated by the dominance of predators, which were followed by collectors, shredders, and scrappers. Good water quality was also suggested by the negative association of BOD and turbidity and the positive correlation of DO with pollution-sensitive taxa.

The river Vainganga has cleaner and higher-quality water, as shown by the higher percentage EPT, Shannon-Weiner index, Simpson index, evenness, and Margalef' index values. Water quality was classified as Class-A (very good) based on BMWP and ASPT results. Sound circumstances were reflected by the percentage composition of functional feeding groups, which showed dominating predators followed by collectors, shredders, and scrappers. The large number of shredders suggested clear water and a natural, pristine, and stable community structure.

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