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Assessment of ecological health and water quality of Kewai River in Anuppur District (M.P.) using benthic macroinvertebrates as bioindicators

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Abstract
The present investigation was systematically conducted to evaluate the spatial and ecological health parameters of the Kewai River situated within the mineral-rich Anuppur district of Madhya Pradesh, India. Utilizing benthic macroinvertebrates as active biological monitors, structural ecosystem dynamics were analyzed alongside ongoing anthropological pressures. The river, a vital hydrological lifeline feeding the greater Son River system, experiences constant stress from adjacent open-cast coal mining infrastructures (specifically the Jamuna-Kotma and Sohagpur operational belts), thermal effluents, and untreated urban discharges. Seasonal sample extractions were executed across four distinct biological monitoring stations (S1 to S4) engineered to capture varying intensities of pollution inputs. A comprehensive total of 34 discrete macroinvertebrate family groups spanning three biological phyla (Arthropoda, Mollusca, and Annelida) were successfully recorded. The resulting baseline biological community structure mapped a visible over-abundance of highly pollution-tolerant benthic organisms, most notably Chironomidae (Diptera) and Tubificidae (Oligochaeta), at stations directly subject to active mine-water discharge zones (S2 and S3). Conversely, highly pollution-sensitive groups encompassing the Ephemeroptera, Plecoptera, and Trichoptera (EPT assemblage) were strictly confined to the ecologically uncompromised upstream reference zone (S1). Integrated biological performance metrics, including the Shannon-Wiener Diversity Index (H'), Simpson's Dominance Index (D), and the comprehensive Hilsenhoff Family Biotic Index (HFBI), were calculated to determine structural organic and trace-chemical degradation. The computed HFBI matrix values registered from 4.2 (indicating clean water status at S1) up to a severe 7.8 (depicting highly poor biological quality at S3). This provides direct diagnostic evidence of significant eco-system degradation prompted by acid mine drainage (AMD) and ongoing industrial chemical leaching. This study explicitly proves that benthic macroinvertebrate community assemblages function as exceptionally viable, cost-effective biosensors for long-term health tracking of riverine setups adjacent to high-intensity mining zones, highlighting an immediate, crucial prerequisite for active regional eco-restoration and strictly enforced drainage basin management.

Keywords: Benthic macroinvertebrates, bioindicators, Kewai River, Anuppur Basin, coal mining runoff, hilsenhoff index, biological integrity

Introduction

Freshwater lotic networks represent some of the most dynamic yet highly threatened natural habitats across the globe, currently enduring accelerated rates of ecological decay due to intensive industrial setups, spatial urban expansions, and aggressive underground resource extractions. Within the central geopolitical zones of India, the natural river channels traversing the Shahdol and Anuppur administrative divisions are of core conservation interest as they form fundamental headwaters feeding mega drainage catchments such as the Narmada and Son systems.

The Kewai River originates from the pristine high-altitude zones of the Bairagi Hills near Kelhari within the Korea territory of Chhattisgarh and charts a journey of roughly 70 kilometers before draining into the Son River near Bachha village in the Anuppur district of Madhya Pradesh. Along this pathway, the river operates as a highly crucial socio-economic and hydrological baseline, satisfying regional agricultural parameters, municipal uses, and supporting distinct local aquatic ecosystems.

Nevertheless, the structural trajectory of the Kewai River intersects directly with the geographic layouts of the Jamuna-Kotma and Sohagpur coalfields, which contain extensive reserves of high-grade coal. Consequently, the rapid proliferation of heavy open-cast mining layouts, heavy vehicular washing docks, massive coal washing stacks, and regional urban footprints has applied monumental ecological pressure on this river ecosystem. The systematic release of Acid Mine Drainage (AMD), containing high loads of sulfate radicals, suspended silt particulates, and elevated dissolved concentrations of toxic trace heavy metals such as Iron (Fe), Manganese (Mn), and Aluminium (Al), fundamentally restructures the natural micro-benthic sediment baseline of the river bed.

Conventional assessment methodologies for analyzing water chemistry indices relies entirely on physicochemical tests, measuring immediate levels of parameters like pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Total Dissolved Solids (TDS). Although chemical assays yield high-resolution, instant quantification of incoming pollutants, they fail to track the long-term biological variations and chronic ecological shocks generated by fluctuating point and non-point discharge events. Aquatic organisms, by contrast, inhabit the lotic column perpetually and function as live, continuous integration systems reflecting historical and ongoing environmental transformations.

Among diverse aquatic assemblages, benthic macroinvertebrates are globally valued as exceptionally robust and highly dependable biological indicators for evaluating riverine ecological status. These organisms remain closely associated with the bottom substrates—

comprising fine sands, silts, organic leaf litter, gravels, and large cobbles—for a minimum of one or more phases of their lifecycle. Due to their low locomotion capacity, they are physically incapable of migrating away from localized toxicity impacts, making them highly sensitive tools to map shifts in underlying sediment health and toxic trace chemical concentrations. Furthermore, individual taxonomic groups display highly specific tolerances to environmental degradation. Sensitive groups face immediate local extinction at the onset of structural degradation, whereas highly resilient forms proliferate exponentially in heavily degraded ecological conditions.

Despite the undeniable regional reliance on the Kewai River and the massive operational footprint of open-cast coal mining setups, comprehensive research documenting biological micro-invertebrate community distribution across this specific basin remains highly non-existent. Earlier exploratory works in the region focused entirely on high-level checklists of local ichthyofauna in 2016 or basic chemical profiles in 2017, completely overlooking the foundational structure of benthic food webs. Addressing this critical information deficit, this study was structured to provide a reliable baseline checklist of macroinvertebrate groups along the Kewai River within Anuppur, map spatial variations induced by local heavy industries, and apply standardized biotic indexes to mathematically validate the ecological degradation of this vital aquatic resource.

Materials and Methods

1. Spatial Grid and Core Stations

To thoroughly map the overarching gradient of industrial and municipal disturbances, four distinct biological monitoring stations (S1 to S4) were strategically fixed along the lotic course of the Kewai River within the geographical borders of the Anuppur district:

- **Station 1 (S1 - Upstream Reference Baseline):** Positioned at the entry vector of the river flow into Anuppur. The channel features high current velocities, clean gravel-cobble substrate configurations, high canopy shade, and minimal human access.

- **Station 2 (S2 - Jamuna-Kotma High Impact Mining Zone):** Fixed downstream of heavy mine water pumping outfalls and large open overburden rock piles. The riverbed exhibits heavy coal particulate siltation.

- **Station 3 (S3 - Midstream Urban-Industrial Agglomeration Zone):** Placed near centralized municipal outfalls and industrial thermal power cooling channels. The benthic line shows thick structural deposition of highly anaerobic organic mud.

- **Station 4 (S4 - Downstream Confluence Recovery Zone):** Tracked near Bachha village, immediately prior to the confluence point with the primary Son River channel, chosen to assess downstream transport profiles.

2. Field Sampling Operations and Protocols

Biotic sampling campaigns were systematically performed across an exhaustive 12-month monitoring frame, categorizing the data collection into three core seasonal indices: Pre-monsoon (March to May), Monsoon (June to September), and Post-monsoon (October to January). Quantitative and qualitative benthic macroinvertebrate collection was executed utilizing a standardized D-frame Kick Net (500 µm mesh configuration) paired with a high-precision Surber Sampler (covering a 0.09 m^2 footprint) for accurate population density values. At every chosen plot, rocky and gravelly sub-layers were energetically kicked over a fixed 3-minute interval to safely guide the dislodged biological organisms into the trailing net. In flat pools featuring thick sand baselines, a Hand Grab sampler was deployed, with retrieved sediments washed via a 0.5 mm sorting sieve to cleanly isolate infaunal specimens.

3. Lab Curation and Taxonomic Analysis

Isolated macroinvertebrate specimens were carefully transferred into wide white sorting trays directly at the field sites using fine entomological brushes and soft laboratory forceps. Cleaned individuals were preserved in durable airtight plastic vials filled with a 4% Formalin solution or 70% high-grade Ethyl alcohol depending on specific soft-body or shelled morphology requirements. In the laboratory environment, the structural elements of every individual were washed using double-distilled water and analyzed under a high-definition Stereo-Zoom Microscope (Model: Magnus MSZ-TR). Taxa classification was systematically pursued to the lowest achievable family level using specialized, peer-reviewed taxonomic identification manuals, including Dudgeon’s Tropical Asian Streams manual, Subba Rao’s handbook of Indian Freshwater Mollusca, and Merritt & Cummins' aquatic insect keys.

4. Computation of Mathematical Biotic Metrics

To mathematically model the structural architecture of the benthic communities, three classical biological diversity parameters were computed via the PAST software toolkit: (1) The Shannon-Wiener Index (H') to isolate distribution evenness and taxonomic richness; (2) The Hilsenhoff Family Biotic Index (HFBI) to evaluate targeted organic and trace chemical tolerances using the standardized formula HFBI = sum(ni * ai) / N, where ni stands for individual count within a specific family, ai represents the standard family pollution tolerance rating (scaled from 0 indicating ultra-sensitive up to 10 denoting ultra-tolerant), and N maps total population counts; and (3) The specialized EPT Index, capturing the specific macroinvertebrate family rich-counts inside the clean-water orders Ephemeroptera, Plecoptera, and Trichoptera.

Results

A total of 2,450 macroinvertebrate individuals representing 34 distinct families were collected and identified during the study period. The phylum Arthropoda (Class Insecta) was the most dominant group, accounting for 62% of the overall abundance, followed by Mollusca (Gastropoda and Bivalvia) at 25%, and Annelida (Oligochaeta and Hirudinea) at 13%. The distribution data tables indicate intense structural variations among the designated monitoring stations, illustrating clear biological responses to environmental degradation.

Table 1: Checklist and Spatial Distribution of Major Macroinvertebrate Families in Kewai River

Phylum / Taxa	Common Name	S1	S2	S3	S4	Tolerance (ai)
Arthropoda (Insecta)						
Heptageniidae (Ephemeroptera)	Mayfly Nymph	+++	-	-	+	4
Baetidae (Ephemeroptera)	Mayfly Nymph	+++	+	-	++	4
Perlidae (Plecoptera)	Stonefly Nymph	++	-	-	-	1
Hydropsychidae (Trichoptera)	Caddisfly Larvae	+++	-	-	+	4
Chironomidae (Diptera)	Blood Midges	+	+++	+++	++	8
Gerridae (Hemiptera)	Water Striders	++	++	++	++	5
Dytiscidae (Coleoptera)	Diving Beetles	++	+	+	+	5
Mollusca (Gastropoda)	River Snails	+	++	+++	++	6
Annelida (Oligochaeta)	Sludge Worms	-	+++	+++	+	9
Annelida (Hirudinea)	Leeches	-	++	++	+	8

Table 2: Computed Biotic Indices across Different Sampling Stations

Metric Index	Station 1 (S1)	Station 2 (S2)	Station 3 (S3)	Station 4 (S4)	Water Quality Inference
Total Abundance (N)	420	780	890	360	Reflects density inflation at polluted sites.
Shannon Index (H')	2.91	1.42	1.15	2.10	Lower values signify severe stress.
EPT Richness Index	12	1	0	4	Severe decline due to mining toxic elements.
HFBI Score	4.12	7.15	7.82	5.85	S1: Clean; S2-S3: Poor to Very Poor.

Discussion

1. Spatial Impact of Coal Mining Runoff and Effluents

The spatial biological patterns mapped throughout the Kewai River indicate acute, localized environmental degradation corresponding with extractive setups. At Station 1 (Upstream), the pronounced occurrence of sensitive macroinvertebrates—namely the Ephemeroptera, Plecoptera, and Trichoptera (EPT) orders—confirms an uncompromised freshwater habitat. These specialized insect larvae depend on elevated concentrations of dissolved oxygen, minimal water turbidity, and clean rocky substrates to securely anchor their gill structures and complete feeding loops.

However, as the river enters the mining belts near Station 2, the biotic matrix undergoes a profound composition change. The sensitive EPT groups face total localized extinction or sharp declines, systematically replaced by a massive dominance of Chironomidae larvae and Tubificidae worms. This structural transformation can be traced directly to Acid Mine Drainage (AMD) and massive iron stone depositions. The discharged effluents carry heavy fractions of suspended coal particles that systematically settle onto the bottom gravel layers, filling the micro-interstitial spaces of the riverbed. This effectively eliminates the living niches of clean-water scraping and filtering insects while explicitly favoring burrowing organisms that inhabit thick, oxygen-depleted sediment layers.

At Station 3, the cumulative biological impacts are further compounded by urban nutrient discharges and fly-ash leaching from nearby thermal operations. The resulting organic enrichment decreases dissolved oxygen values during critical pre-monsoon flow dips, inducing localized eutrophication. The massive proliferation of pulmonate gastropods and sludge worms at this location highlights high concentrations of decomposing organic matter. These resilient species possess evolutionary adaptations, such as specialized cutaneous breathing mechanisms or high hemoglobin reserves, enabling them to safely thrive in heavy-impact industrial channels that remain highly toxic to standard aquatic life.

2. Seasonal Structural Dynamics

Seasonal cycles exercise an important regulatory influence on the manifestation of toxicity footprints along the Kewai River. During pre-monsoon phases, the river discharge declines to minimal baselines, maximizing the concentration of industrial contaminants due to the complete loss of natural dilution dynamics. Consequently, calculated HFBI scores peak aggressively during late spring, documenting maximum ecosystem stress. Monsoon floods temporarily alter this layout by carrying high volumes of loose topsoils into the main channel, generating elevated mechanical scouring that flushes out macrobenthic communities across all stations. Subsequently, the post-monsoon phase functions as an ecological stabilization frame, allowing intermediate-tolerant groups like Odonates to slowly re-colonize downstream areas.

Conclusion & Management Suggestions

The baseline bio-monitoring investigation reveals that the Kewai River within the Anuppur district is undergoing serious ecological degradation, transiting from a clean upstream reference baseline to a highly compromised, degraded channel across mining and urban industrial outputs. The distribution footprints of benthic biological indicators reliably validated these changes, showing a total loss of sensitive indicator groups and a massive overpopulation of pollution-tolerant taxa in heavy-impact mining zones. The high HFBI values (7.15 to 7.82) calculated for the industrial sectors mathematically prove that untreated mine waters are actively destroying the biological integrity of this river basin.

To counteract this degradation, immediate remediation actions must be enforced: (1) Industrial units and mine operating bodies (SECL) must adopt active neutralization cells using structured limestone arrays to treat all Acid Mine Drainage prior to environmental release; (2) Intensive biological stabilization using heavy vegetative bands must be deployed on overburden rock dumps to check heavy rain-induced siltation; and (3) Strategic artificial wetlands must be built along urban agricultural feeder streams to securely trap toxic chemical loads naturally.

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