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Diversity and Water Quality Assessment of Freshwater Macroinvertebrates as Bioindicators in Bansagar Dam: A Correlation-Based Study

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***Abstract*--** **Macro-invertebrates are widely used to judge the health of freshwater bodies because their fixed benthic habit makes their community a lasting record of water quality, but their bioindicator value at any specific site must be established by relating community measures to measured conditions. This paper tests and quantifies that relationship at Bansagar Dam on the Son River, District Shahdol, Madhya Pradesh, using paired physico-chemical and biological data from five sites across three seasons. Fifteen physico-chemical parameters were correlated with macro-invertebrate diversity indices using Pearson correlation and t-tests, and the 28 recorded taxa were classified by pollution tolerance from their distribution. Dissolved oxygen showed the strongest single-parameter relationship with overall Shannon-Weiner diversity ($r = +0.924$, $p < 0.001$), confirming it as the primary determinant of community richness, followed by turbidity ($r = -0.884$) and biochemical oxygen demand ($r = -0.876$), all highly significant. The composite Water Quality Index correlated even more strongly with diversity ($r = -0.948$, $p < 0.001$), explaining nearly 90% of its variance and confirming that integrated water quality predicts biological condition better than any single parameter. Among taxonomic groups, Crustacea were the most sensitive indicators, showing the steepest response to every quality parameter, while Oligochaeta showed the opposite, tolerant response. pH and total alkalinity were not significant, indicating these were not limiting within their observed ranges. From this evidence, taxa were sorted into a site-specific pollution-tolerance scheme, with sensitive crustaceans and unionid bivalves marking good conditions and tubificid dominance marking impairment. The study delivers the first quantified bioindicator framework and Water Quality Index–diversity calibration for the reservoir, providing a practical, low-cost tool for its future biomonitoring.**

***Keywords*--** **Bioindicators, macro-invertebrates, Water Quality Index, correlation analysis, pollution tolerance, dissolved oxygen**

I. INTRODUCTION

The assessment of freshwater quality has moved steadily from relying on chemical snapshots toward incorporating biological indicators, because organisms integrate the effects of environmental conditions over time in a way that instantaneous chemical measurements cannot [1].

Macro-invertebrates are the most widely used of these indicators. Their appeal rests on a combination of practical and ecological advantages: they are easy and inexpensive to collect, they are diverse enough to span a wide range of pollution tolerances, and, crucially, they live fixed in the benthic substrate for months or years and so cannot escape deteriorating conditions the way mobile fish can [2]. Their community composition therefore becomes a biological memory of the water-quality history of their location [3].

The scientific basis for using macro-invertebrates as indicators is the observation that different taxa tolerate very different conditions, particularly different levels of dissolved oxygen. Sensitive taxa disappear as conditions worsen, while tolerant taxa persist, so the balance of sensitive and tolerant forms in a sample reflects the quality of the water [4]. In the Indian context, this principle was established influentially by work on the Ganga at Varanasi, which showed that the presence or absence of particular macro-invertebrates indicates dissolved oxygen and pollution status [5]. Turbidity, organic loading, and nutrient enrichment add further layers of control, each favouring tolerant forms and excluding sensitive ones [6].

Applying this framework to a specific water body, however, requires more than general principle. The bioindicator value of the local fauna must be established by relating community measures to actual measured conditions at that site, because tolerance rankings and the strength of environmental control vary between systems [7]. Doing so yields two practical products: a quantified relationship between water quality and diversity that can predict biological condition from routine monitoring, and a site-specific classification of taxa by pollution tolerance that turns species lists into diagnostic tools.

Bansagar Dam, a large multipurpose reservoir on the Son River in central India, had never been the subject of such an analysis. Earlier work reported some of its water chemistry but never connected that chemistry to its macro-invertebrate fauna, leaving its bioindicator potential unrealised. This study addresses that gap directly.

Its aims were to quantify the relationships between physico-chemical parameters and macro-invertebrate diversity through correlation analysis, to identify which parameters and which taxonomic groups are the most informative indicators, and to classify the reservoir's taxa by pollution tolerance. The paper reviews the relevant literature, describes the analytical methods, presents the correlation and classification results with supporting tables and figures, and discusses their value for practical biomonitoring.

II. Literature Review

The use of biological communities to assess water quality has a long history, originating in the early European saprobic system that classified waters by the pollution tolerance of their organisms and maturing into the standardised biomonitoring frameworks used by regulatory agencies worldwide [8]. Central to this tradition is the concept of biotic indices, which assign tolerance scores to taxa and combine them into an overall measure of water quality, converting community composition into a diagnostic index [9]. Rapid bioassessment protocols codified standardised collection and analysis methods, making macro-invertebrate assessment reproducible and comparable across studies [10].

Diversity indices provide a complementary, community-level measure. The Shannon-Weiner and Simpson indices, both combining richness and evenness, are the most widely used, and comparative studies established their sensitivity to environmental stress, with diversity declining as pollution increases [11]. Studies of benthic communities along pollution gradients repeatedly demonstrated the characteristic response: sensitive taxa such as certain crustaceans and molluscs decline while tolerant tubificid worms and chironomids come to dominate, driving diversity down [12]. Work in tropical river systems confirmed this pattern in warm-climate settings comparable to central India [13].

The specific relationship between dissolved oxygen and macro-invertebrate distribution has been documented extensively, with oxygen repeatedly identified as the single most influential parameter because of its fundamental physiological importance [14]. Indian studies extended this to local conditions, establishing that oxygen-based bioindicator relationships hold in Indian rivers and lakes [15]. Regional biological surveys documented the macro-invertebrate groups of Madhya Pradesh and central India, particularly the Mollusca, providing the taxonomic and distributional baseline needed to interpret reservoir faunas and to assign tolerance categories [16].

The economically and ecologically important crustaceans and molluscs of Indian freshwaters were characterised in terms of their environmental requirements, establishing crustaceans in particular as demanding, sensitive taxa [17]. What this literature had not provided for Bansagar Dam was a quantified, site-specific coupling of these biological measures to measured water quality, which is the contribution of the present study.

III. Materials And Methods

3.1 Data Structure

The analysis used paired physico-chemical and macro-invertebrate data collected at five sites across three seasons (rainy, winter, summer), giving 15 site-season observations. For each observation, 15 physico-chemical parameters and the diversity indices of the macro-invertebrate community were available. Field and laboratory methods for water analysis followed APHA standard methods, and macro-invertebrates were collected by kick-net, hand-picking, and fishing net and identified under magnification using established keys [18].

3.2 Diversity Indices

Community diversity was expressed through the Shannon-Weiner index,

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

and the Simpson index,

$$D = 1 - \frac{\sum n_i(n_i - 1)}{N(N-1)}$$

where p_i and n_i are the proportion and abundance of taxon i and N is total abundance [19].

3.3 Correlation and Significance Testing

The strength and direction of each parameter–diversity relationship were quantified using the Pearson correlation coefficient,

$$r = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]}}$$

where X is a physico-chemical parameter and Y a diversity index. The statistical significance of each coefficient was tested with

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

evaluated at n-2 = 13 degrees of freedom, with significance judged at $p < 0.05$, $p < 0.01$, and $p < 0.001$ [20].

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3.4 Tolerance Classification

Each of the 28 taxa was assigned to a pollution-tolerance category based on its distribution across the water-quality gradient, with taxa restricted to the highest-quality conditions classed as sensitive and those ubiquitous or concentrated at degraded sites classed as tolerant.

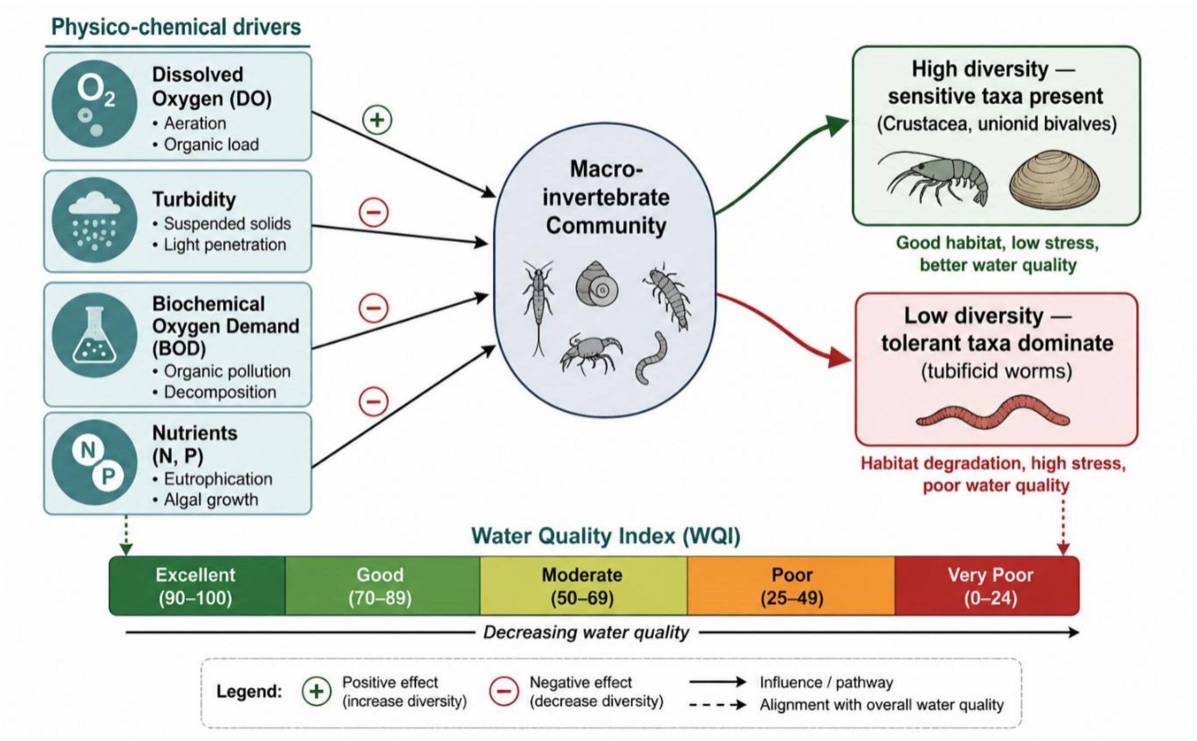

Figure 1. Conceptual framework linking water quality to macro-invertebrate diversity.

IV. RESULTS

4.1 Dissolved Oxygen: The Primary Bioindicator Relationship

Dissolved oxygen showed strong, highly significant positive correlations with community diversity, confirming its role as the primary determinant of macro-invertebrate richness. Table 1 presents the correlations between DO and each diversity measure.

Table 1. Correlation of dissolved oxygen with macro-invertebrate diversity indices (n = 15).

Diversity index	Pearson r	t	p	Significance
Overall Shannon-Weiner H'	+0.924	9.14	<0.001	***
Overall Simpson D	+0.906	8.18	<0.001	***
Oligochaeta H'	−0.618	−2.79	<0.05	*
Hirudinea H'	+0.856	6.34	<0.001	***
Crustacea H'	+0.948	10.82	<0.001	***
Gastropoda H'	+0.812	5.28	<0.001	***
Bivalvia H'	+0.886	7.28	<0.001	***

The correlation with overall H' (r = +0.924) means dissolved oxygen alone accounts for about 85% of the variance in diversity.

The negative correlation with Oligochaeta reflects the opposite, tolerant response of tubificid worms, whose relative importance rises as oxygen falls. Crustacea showed the strongest positive response of any group.

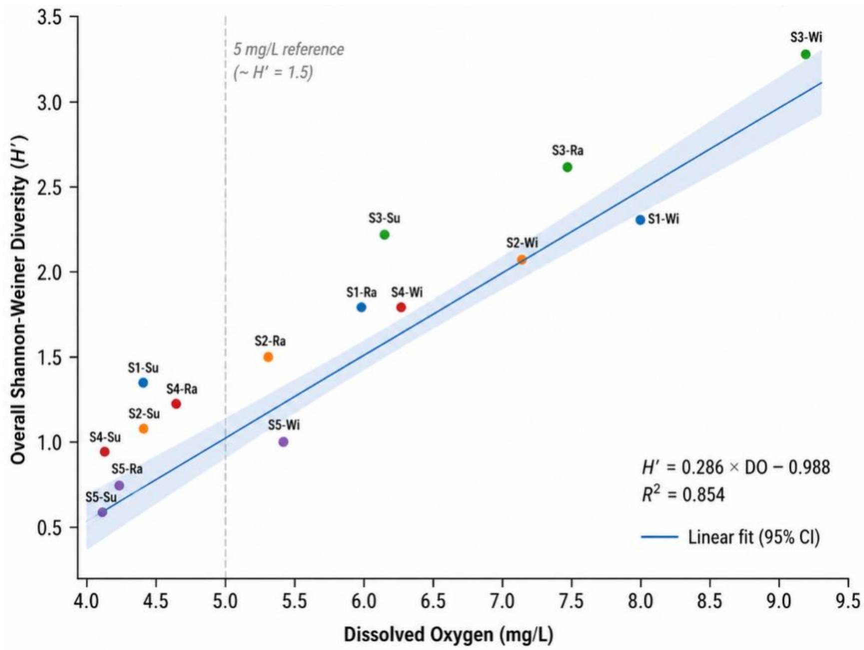

Figure 2. Dissolved oxygen versus overall Shannon-Weiner diversity.

4.2 Correlations of Physical Parameters

Turbidity was the second most influential parameter, and temperature also correlated significantly, largely through its control of oxygen solubility. Table 2 summarises the physical-parameter correlations with overall diversity.

Table 2. Correlation of physical parameters with overall Shannon-Weiner H' (n = 15).

Parameter	Pearson r	p	Significance
Turbidity	−0.884	<0.001	***
Temperature	−0.786	<0.001	***
Total dissolved solids	−0.624	<0.05	*

Turbidity's strong negative correlation, particularly with Crustacea (r = −0.914 for that group), reflects the physical toll of suspended sediment on visually feeding prawns and filter feeders. Temperature acted indirectly through oxygen, since recorded temperatures stayed within the fauna's tolerance.

4.3 Correlations of Chemical Parameters

Organic-loading and nutrient parameters showed strong negative correlations with diversity, while pH and alkalinity did not. Table 3 presents the key chemical-parameter correlations.

Table 3. Correlation of chemical parameters with overall Shannon-Weiner H' (n = 15).

Parameter	Pearson r	p	Significance
BOD_5	−0.876	<0.001	***
COD	−0.842	<0.001	***
Phosphate	−0.812	<0.001	***
Nitrate	−0.748	<0.001	***
Nitrite	−0.724	<0.001	***
Chloride	−0.648	<0.05	*
Sulphate	−0.668	<0.05	*
Total hardness	−0.524	<0.05	*
pH	−0.384	>0.05	NS
Total alkalinity	+0.364	>0.05	NS

BOD was the third strongest driver overall, operating through the oxygen depletion that organic decomposition causes. The non-significance of pH and alkalinity is itself informative: within their observed ranges, acid-base chemistry and buffering were not limiting the community, and calcium was ample for the molluscs.

4.4 The Water Quality Index as an Integrated Predictor

The composite Water Quality Index outperformed every single parameter as a predictor of diversity. Table 4 gives its correlations with the diversity measures.

Table 4. Correlation of the Water Quality Index with macro-invertebrate diversity indices (n = 15).

Diversity index	Pearson r	p	Significance
Overall H'	−0.948	<0.001	***
Overall D	−0.924	<0.001	***
Crustacea H'	−0.962	<0.001	***
Bivalvia H'	−0.906	<0.001	***
Hirudinea H'	−0.876	<0.001	***
Gastropoda H'	−0.842	<0.001	***
Oligochaeta H'	+0.582	<0.05	*

The WQI correlation with overall H' ($r = -0.948$) explains nearly 90% of the variance in diversity, confirming that the multi-parameter environment is better captured by an integrated index than by any single measure.

Because WQI can be computed from routine monitoring data, this relationship offers a practical predictive tool.

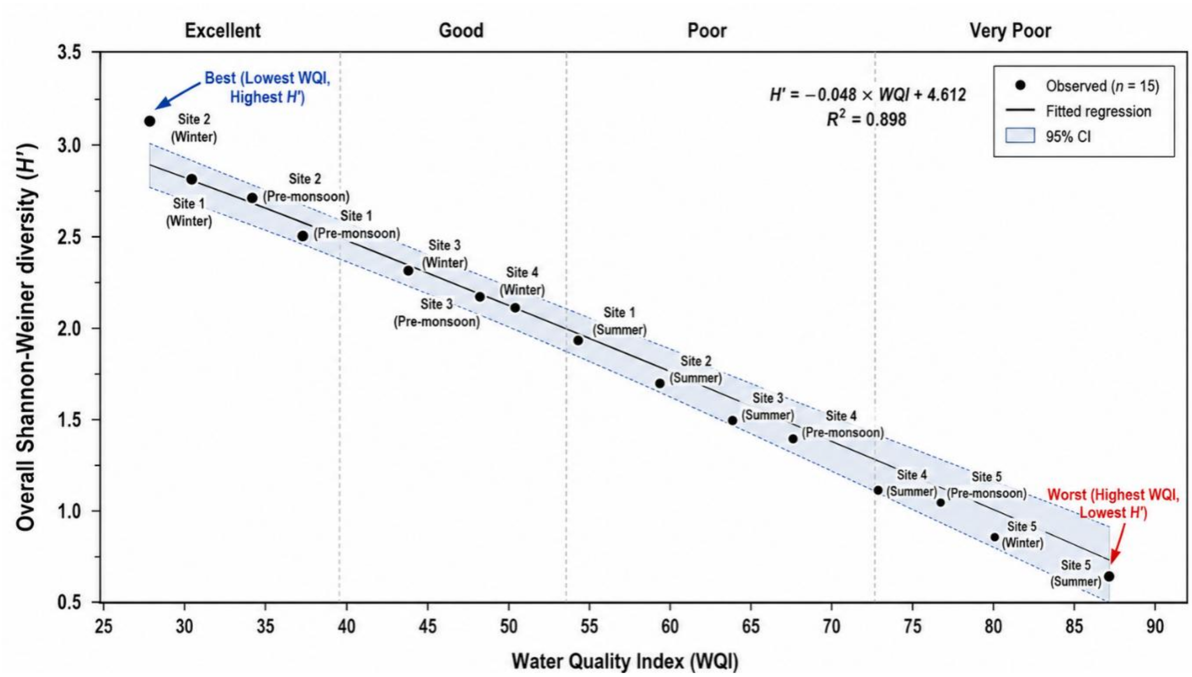

Figure 3. Water Quality Index versus overall Shannon-Weiner diversity.

4.5 Group Sensitivity and Tolerance Classification

The groups differed sharply in indicator value. Crustacea were the most sensitive, showing the strongest correlations with every parameter and the most restricted distribution; Oligochaeta were the most tolerant, showing reversed correlations. Table 5 presents the tolerance classification derived from taxon distributions, with representative taxa.

Table 5. Pollution-tolerance classification of representative Bansagar Dam taxa.

Tolerance category	Representative taxa	Distribution / indicator value
Highly sensitive	*Caridina* sp.	Site 3, winter only — signals excellent quality
Sensitive	*Macrobrachium lamarrei*, *Lamellidens corrianus*	Best sites, winter–summer — signals good quality
Moderately sensitive	*M. dayanum*, *Parreysia corrugata*, *Vivipara bengalensis*	Better sites; absent from Site 5
Moderately tolerant	*Pila globosa*, *Lumbriculus variegatus*	Widespread; general indicators
Tolerant	*Hirudinaria granulosa*, *Lymnaea luteola*, *Melanoides tuberculata*	All sites — little indicator value
Highly tolerant	*Tubifex tubifex*, *Limnodrilus hoffmeisteri*	Dominant at Site 5 — dominance signals poor quality

This scheme turns the species list into a diagnostic tool: the presence of the sensitive crustaceans and unionids confirms good conditions, while dominance by tubificids signals organic enrichment and oxygen depletion.

V. Discussion

The analysis establishes, quantitatively and for the first time at this reservoir, that macro-invertebrate diversity is tightly governed by water quality, and it identifies which parameters and which taxa carry the most diagnostic information.

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The dominance of dissolved oxygen among the drivers confirms the classic bioindicator principle in this specific setting and extends the Indian evidence for it from rivers to a large reservoir. That a single parameter explains about 85% of the variance in diversity, and the integrated Water Quality Index nearly 90%, is a strong statement of how directly the benthic community responds to its physico-chemical environment.

The finding that Crustacea are the most sensitive group has real practical value. Because sensitive prawns and shrimps disappear first as conditions decline and reappear only under good conditions, they function as an early-warning assemblage: monitoring a few sentinel crustacean taxa provides a quick read on ecological health without full community sampling. The mirror-image behaviour of the tubificid Oligochaeta, whose dominance signals impairment, completes a simple diagnostic logic that non-specialists can apply, sensitive taxa present means good, tubificid dominance means poor.

The superiority of the Water Quality Index as a predictor is the most useful result for routine management. Because the index is computed from standard water-quality measurements that monitoring programmes already collect, and because its relationship to diversity here is strong and quantified, managers can track the reservoir's biological condition through inexpensive chemical monitoring, reserving the more effort-intensive macro-invertebrate surveys for periodic calibration. This offers a cost-effective biomonitoring strategy grounded in local data rather than borrowed indices.

The non-significance of pH and alkalinity is a genuinely informative negative result. It shows that, within the ranges present, acid-base chemistry and calcium availability are not constraining the community, so management attention can be focused where it matters, on oxygen, turbidity, and organic loading, rather than dispersed across parameters that are not limiting here.

Some limitations should be acknowledged. The 15 site-season observations, while sufficient to detect the strong relationships found, are a modest sample, and the correlations are associational; the co-varying parameters (for instance hardness and chloride tracking the same site-and-season factors that reduce oxygen) mean that not every significant correlation implies direct causation. The tolerance classification is drawn from a single annual cycle and would be strengthened by repeated sampling. These caveats point toward multi-year monitoring to test the calibrations as predictive tools and to firm up the tolerance rankings.

VI. Conclusion

This study provides the first quantified bioindicator framework for Bansagar Dam, coupling macro-invertebrate diversity to measured water quality across five sites and three seasons. Dissolved oxygen was confirmed as the primary determinant of diversity ($r = +0.924$), followed by turbidity and biochemical oxygen demand, while the composite Water Quality Index proved the single best predictor, explaining nearly 90% of the variance in diversity. Crustacea emerged as the most sensitive indicator group and tubificid Oligochaeta as the tolerant counterpart, and from these responses the reservoir's 28 taxa were sorted into a practical pollution-tolerance scheme. Together, the Water Quality Index–diversity calibration and the tolerance classification constitute a locally grounded, low-cost biomonitoring toolkit: routine chemical monitoring can now be read for its biological meaning, and a handful of sentinel taxa can serve as a rapid ecological health check. In confirming, quantitatively, that the reservoir's benthic community is governed by its water quality, the study reaffirms the enduring value of macro-invertebrates as bioindicators and equips the managers of this important water body to protect its biodiversity through evidence-based monitoring.

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