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Macrozoobenthos-Based Biomonitoring of River Water Quality Using BMWP–ASPT: Evidence from Kali Jarak, East Java, Indonesia

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Abstract
Macrozoobenthos are key benthic invertebrates that play an essential role in nutrient cycling and are widely recognized as biological indicators of freshwater ecosystem health. However, freshwater ecosystems are increasingly exposed to anthropogenic pressures, including domestic activities, agricultural practices, and other human disturbances, which may contribute to changes in water quality and aquatic habitat conditions. Such pressures highlight the need for biological assessments that can capture ecological responses to environmental changes. This study assessed the diversity of macrozoobenthos in Kali Jarak, Wonosalam District, East Java, to evaluate its potential as a bioindicator of water quality. Samples were collected using purposive sampling across three stations with three replications. Identification was performed to the genus level, and data were analyzed using Shannon–Wiener diversity index, dominance index, and the Biological Monitoring Working Party–Average Score per Taxon (BMWP–ASPT) method. A total of 19 genera were recorded. Diversity index values ranged from 1.19 to 1.70, while dominance index values ranged from 0.27 to 0.43. The BMWP scores (47–66) and ASPT values (6.0–6.7) indicated that all stations were in the "excellent" category of water quality. Correlation analysis revealed significant relationships between certain genera and physico-chemical parameters: temperature with *Austrotinodes* and *Macrelmis*, pH and discharge with *Baetis*, current with *Dicranota*, BOD with *Prodiamesa* and *Rhitrogena*, and COD with *Euphaea*. Overall, the findings confirm that macrozoobenthos diversity provides a sensitive and reliable biological indicator for monitoring river water quality, supporting its application in freshwater biomonitoring and sustainable watershed management.

Keywords: Bioindicator, BMWP-ASPT, Kali Jarak, Macrozoobenthos, Water quality.

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1. Introduction

River ecosystems are increasingly threatened by multiple anthropogenic pressures, including agricultural runoff, domestic waste, deforestation, and recreational use (Anwar, 2025). These disturbances accelerate nutrient enrichment, increase organic load, and disrupt ecosystem stability, especially in tropical rivers that sustain both biodiversity and local livelihoods (Tanaka *et al.*, 2021). Conventional approaches for water quality assessment rely heavily on physico-chemical

measurements such as dissolved oxygen, pH, or nutrient concentrations. While informatif, such parameters often represent only short-term conditions and may fail to capture cumulative or chronic impacts (Muntalif *et al.*, 2023). In contrast, biological monitoring offers a more integrative approach by incorporating the long-term responses of organisms to environmental changes (Sumudumali & Jayawardana, 2021).

Macrozoobenthos, comprising benthic invertebrates such as insect larvae, mollusks, crustaceans, and annelids, are recognized as reliable bioindicators of aquatic ecosystem health. Their limited mobility, relatively long life cycles, and wide taxonomic diversity enable them to reflect local environmental conditions with high sensitivity (Feio *et al.*, 2022). Certain taxa decline in abundance when exposed to organic pollution or low dissolved oxygen, while more tolerant groups may increase in dominance (Tampo *et al.*, 2021). Such contrasting responses provide a robust ecological signal that can be translated into biotic indices for water quality assessment. Community diversity alone may not adequately reflect ecological degradation, as the presence and distribution of macrozoobenthos taxa also depend on their tolerance to environmental disturbances.

The application of biotic indices is necessary to provide a more comprehensive assessment of river water quality. The Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT) indices are widely used approaches that evaluate ecological conditions based on the environmental sensitivity of macroinvertebrate families. While BMWP represents the cumulative tolerance scores of recorded families, ASPT provides the average score per scoring taxon, offering complementary information on the ecological quality of aquatic environments. The combined application of these indices with macrozoobenthos community analysis and physicochemical measurements can provide a more integrated understanding of freshwater ecosystem conditions (Zeybek *et al.*, 2014).

Despite the proven advantages of biological monitoring, its application in Indonesia, particularly in East Java, remains limited. Most river assessments still emphasize chemical standards, leaving a gap in ecological-based monitoring (Sulistiyowati & Awaliyah, 2025). This is problematic because rivers in upstream areas often serve as vital sources of irrigation, fisheries, and household water for downstream communities. Without biological assessments, subtle ecological degradation may go undetected until it manifests in reduced biodiversity or impaired ecosystem services.

Kali Jarak, located in the Wonosalam District of Jombang Regency, East Java, exemplifies such a vulnerable system. Originating from the Argowayang mountain cluster, this river functions as an important upstream catchment. It is extensively used for irrigation, aquaculture, and daily activities such as bathing and washing (Nadhifah, 2025). However, despite its ecological and socio-economic significance, no systematic bioindicator-based evaluation of water quality has been reported for this river. Studies from nearby catchments have revealed variable levels of pollution, underscoring the urgent need for localized, science-driven monitoring.

This study addresses that gap by providing the first comprehensive assessment of macrozoobenthos diversity in Kali Jarak as a bioindicator of water quality. The novelty of this study lies in integrating macrozoobenthos diversity and taxonomic composition, family-based BMWP-ASPT indices, and physicochemical parameters to provide a multi-level assessment of river ecological quality. This approach not only evaluates the ecological status of Kali Jarak but also identifies the potential of macrozoobenthos taxa as biological indicators for monitoring environmental conditions in tropical freshwater ecosystems.

2. Methods

2.1 Study Area

The study was conducted in Kali Jarak, located in Wonosalam District, Jombang Regency, East Java, Indonesia. The river originates from the Argowayang mountain cluster and flows approximately 17.34 km before joining the Kali Pakel (Badan Pusat Statistik Kabupaten Jombang, 2026). Three sampling stations (Figure 1) were established along the river, representing upstream,

midstream, and downstream sections. These sites were selected based on differences in surrounding land use, community activities, and accessibility. The upstream site is characterized by forested catchments, the midstream section by agricultural and settlement areas, and the downstream area by mixed land use with more intensive human activity.

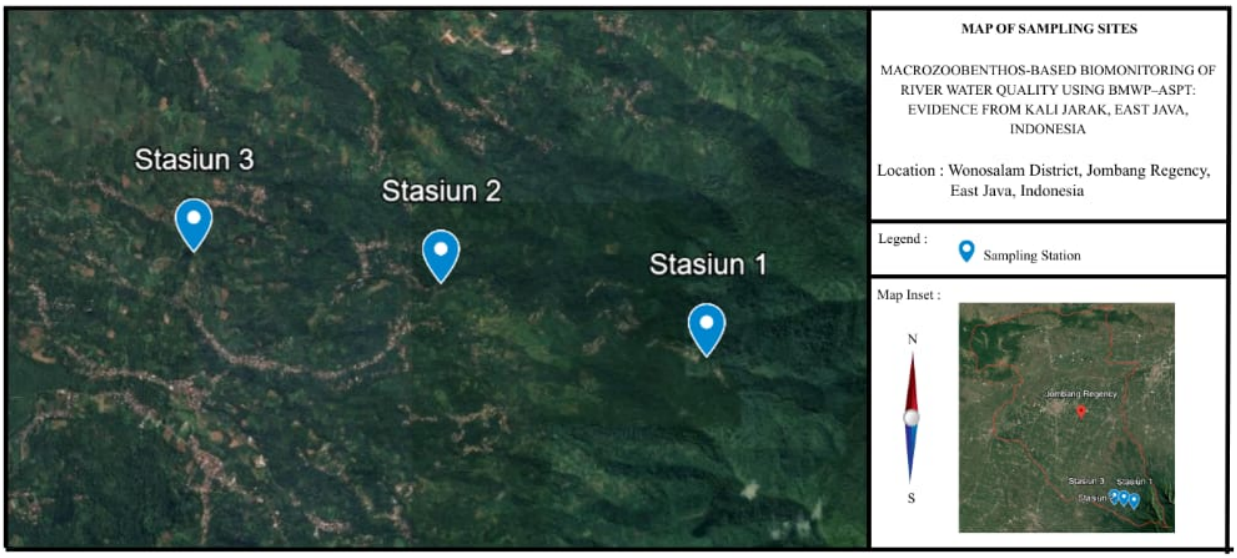


Figure 1. Sampling stations map

2.2 Sampling of Macrozoobenthos

Macrozoobenthos samples were collected during the rainy season at March 2022. A purposive sampling method was applied, with three replications at each station. Sampling was performed using a Surber net and hand-picking from riverbed substrates such as rocks, gravel, and leaf litter within designated plots. Collected organisms were preserved in 70% ethanol and transported to the laboratory for identification.

2.3 Physico-Chemical Parameters

At each station, water quality parameters were measured in situ and ex situ. Parameters included temperature, pH, current velocity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), and discharge. Measurements were performed using portable meters and standard methods recommended by APHA (Bridgewater, 2017).

2.4 Identification of Specimens

Macroinvertebrate specimens were examined under a stereomicroscope and identified to the genus level based on their morphological characteristics using taxonomic identification keys and freshwater macroinvertebrate identification guides (Gerber & Gabriel, 2002; Oscoz *et al.*, 2011; Rufusova *et al.*, 2017).

2.5 Data Analysis

Macrozoobenthos diversity at each sampling station was assessed using the Shannon–Wiener diversity index (Krebs, 1985):

$$H' = -\sum pi \ln pi$$

where (H') is the Shannon–Wiener diversity index, (p_i) is the proportion of individuals belonging to taxon (i), calculated as (N_i/N), (N_i) is the number of individuals belonging to taxon (i), (N) is the total number of individuals across all taxa at the sampling station, and (S) is the total number of taxa recorded. The natural logarithm (ln) was used in the calculation. Higher (H') values

indicate greater taxonomic diversity, reflecting both taxon richness and the evenness of individual distribution among taxa.

The dominance of macrozoobenthos taxa was evaluated using Simpson's dominance index (Odum, 1993):

$$D = \sum (Ni/N)^2$$

where (D) is Simpson's dominance index, (N_i) is the number of individuals belonging to taxon (i), (N) is the total number of individuals across all taxa at the sampling station, and (S) is the total number of taxa recorded. The index ranges from values approaching (1/S) to 1, with higher values indicating greater dominance by one or a few taxa, whereas lower values indicate a more even distribution of individuals among taxa. Both indices were calculated separately for each sampling station to characterize macrozoobenthos community structure.

The biological water quality of Kali Jarak was assessed using the Biological Monitoring Working Party (BMWP) score and the Average Score per Taxon (ASPT). The BMWP method assigns sensitivity scores ranging from 1 to 10 to macroinvertebrate families according to their tolerance to organic pollution, with higher scores generally indicating greater sensitivity to pollution (Bartram & Ballance, 1996). The BMWP score for each sampling station was calculated by summing the sensitivity scores of all scoring families recorded at that station. Each family was counted only once per station, irrespective of its abundance.The ASPT was calculated by dividing the total BMWP score by the number of scoring families recorded at the corresponding station, following the method described by Bartram and Ballance (1996):

$$\text{ASPT} = \frac{\text{BMWP score}}{\text{total number of families}}$$

Water quality was interpreted based on ASPT values according to the classification reported by Mandaville (2002): Excellent (ASPT ≥ 6.0), very good (5.5–6.0), good (5.0–5.5), moderate (4.5–5.0), moderately-poor (4.0–4.5), and poor (<4.0). The BMWP and ASPT results were used to characterize biological water quality at each sampling station.

Statistical analyses were conducted using PAST software version 4.03. Correlation analysis was performed to examine relationships between physicochemical parameters and macrozoobenthos community characteristics. In addition, Canonical Correspondence Analysis (CCA) was applied to explore the relationships between macrozoobenthos taxa and environmental variables, including temperature, pH, current velocity, discharge, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD).

3. Results and Discussion

3.1 Macrozoobenthos Diversity

A total of 19 macrozoobenthos genera belonging to seven orders and 14 families were recorded across the three sampling stations in Kali Jarak, East Java, Indonesia. The assemblages comprised members of Diptera, Ephemeroptera, Plecoptera, Trichoptera, Odonata, Coleoptera, and Tricladida. The taxonomic composition varied among stations, indicating spatial differences in community structure along the river. Although several genera occurred at more than one station, their abundances differed considerably, suggesting that the local environmental conditions may influence the distribution and relative contribution of individual taxa.

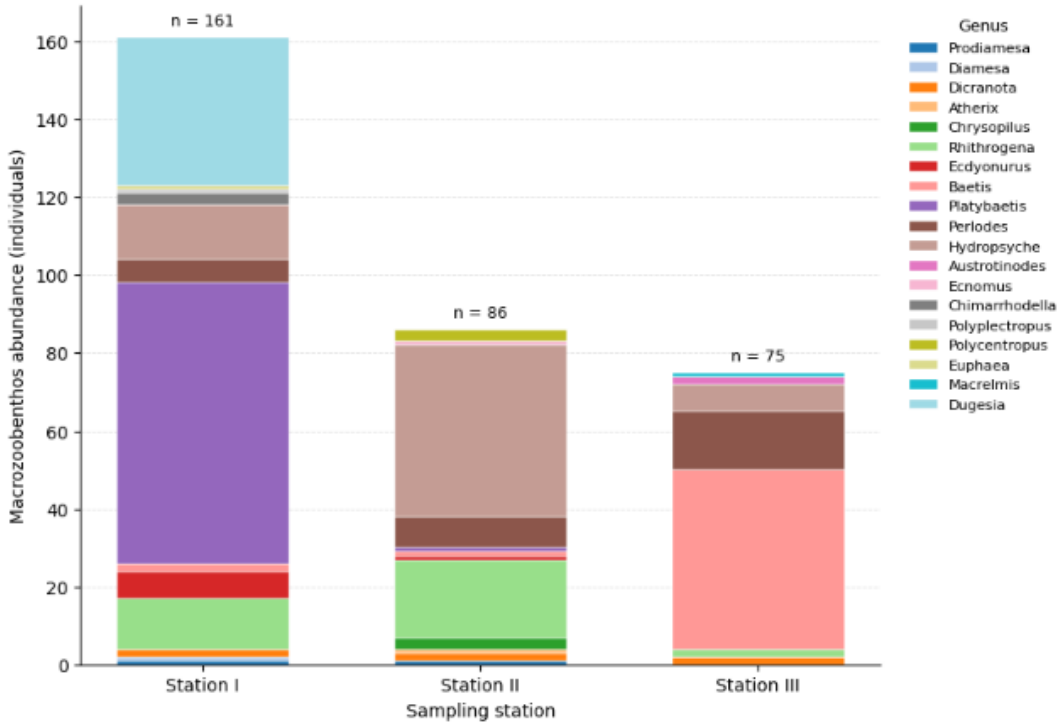


Figure 2. Macrozoobenthos Composition & Abundance across Sampling Stations



Figure 3. Abundant genus of macrozoobenthos in Kali Jarak (A) *Platybaetis,* (B) *Dugesia,* (C) *Hydropsyche,* (D) *Rhithrogena,* (E) *Perlodes*.

Station I exhibited the greatest genus richness, with 13 genera, followed by Station II with 12 genera and Station III with 7 genera (Figure 2). This pattern indicates a decline in observed genus richness toward the downstream station. The upstream reach, located within a relatively forested catchment, provided heterogeneous substrates such as rocks, gravel, and leaf litter that created suitable microhabitats for a wide range of invertebrates (Baker *et al.*, 2016). In contrast, the downstream station, where riparian vegetation is reduced and human activities are more concentrated, was characterized by fewer genera, with the absence of several sensitive groups. The observed reduction in richness downstream is consistent with patterns reported from other tropical rivers, where increased organic input and physical disturbance reduce habitat quality (Prakoso *et al.*, 2023). Thus, diversity patterns in Kali Jarak provide strong ecological evidence of the influence of land use and community activity on freshwater ecosystems.

At the genus level, *Platybaetis* was the most abundant taxon at Station I, with 72 individuals, followed by *Dugesia* (38 individuals) and *Hydropsyche* (14 individuals). Station II was characterized by the predominance of *Hydropsyche* (44 individuals), followed by *Rhithrogena* (20 individuals). In contrast, *Baetis* dominated Station III, with 46 individuals, followed by *Perlodes* (15 individuals) (Figure 3). These differences indicate that the three stations supported distinct patterns of genus-level abundance rather than a uniform macrozoobenthos assemblage throughout the river. The contrasting distributions of *Platybaetis*, *Hydropsyche*, and *Baetis* are particularly relevant to understanding community structure. The dominance of *Platybaetis* at Station I and *Baetis* at Station III indicates that different genera within the same family, Baetidae, contributed most strongly to the assemblages at these locations. Meanwhile, the high abundance of *Hydropsyche* at Station II indicates a substantial contribution from Hydropsychidae. Such patterns highlight the importance of examining macrozoobenthos composition below the order level, because broad taxonomic groupings may conceal differences in the distribution of individual genera.

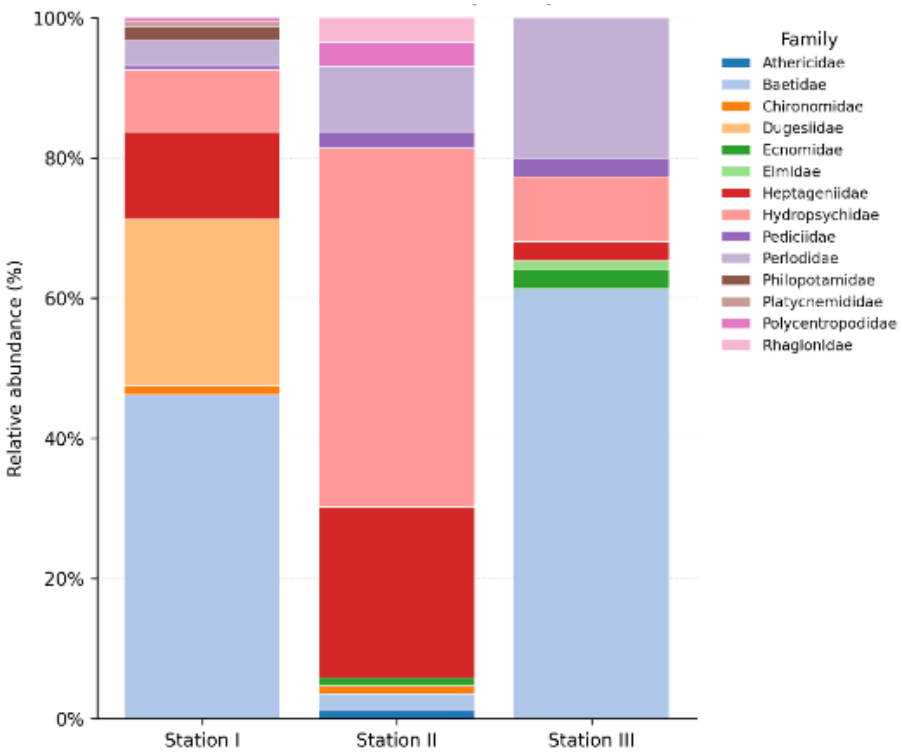


Figure 4. Relative Abundance by Family

Family-level composition revealed additional differences among sampling stations. *Baetidae* accounted for approximately 46.0% of the recorded abundance at Station I and 61.3% at Station III, whereas *Hydropsychidae* represented 51.2% at Station II (Figure 4). Heptageniidae also contributed substantially at Stations I and II, while *Perlodidae* was particularly prominent at Station III. These patterns indicate that the assemblages differed in their relative representation of families with potentially distinct ecological requirements. The substantial representation of Baetidae at Stations I and III and Hydropsychidae at Station II is relevant to bioindicator-based assessment. Baetidae includes taxa with varying environmental tolerances, meaning that its presence or relative abundance alone cannot establish whether a site is ecologically healthy or disturbed (Marpaung *et al.,* 2014). Similarly, Hydropsychidae comprises filter-feeding caddisfly larvae whose occurrence can be influenced by current velocity, suspended particles, and food availability (Ficsór & Csabai, 2021). Heptageniidae and Perlodidae also provide useful ecological context because members of these families are commonly associated with flowing-water habitats, although their tolerance ranges are not uniform (Boonsoong & Braasch, 2013; Fabanjo & Inayah, 2021). The distribution of these families may help identify environmental differences among

stations when interpreted alongside hydrological and physicochemical measurements. However, their occurrence alone is insufficient to determine the severity of environmental disturbance.

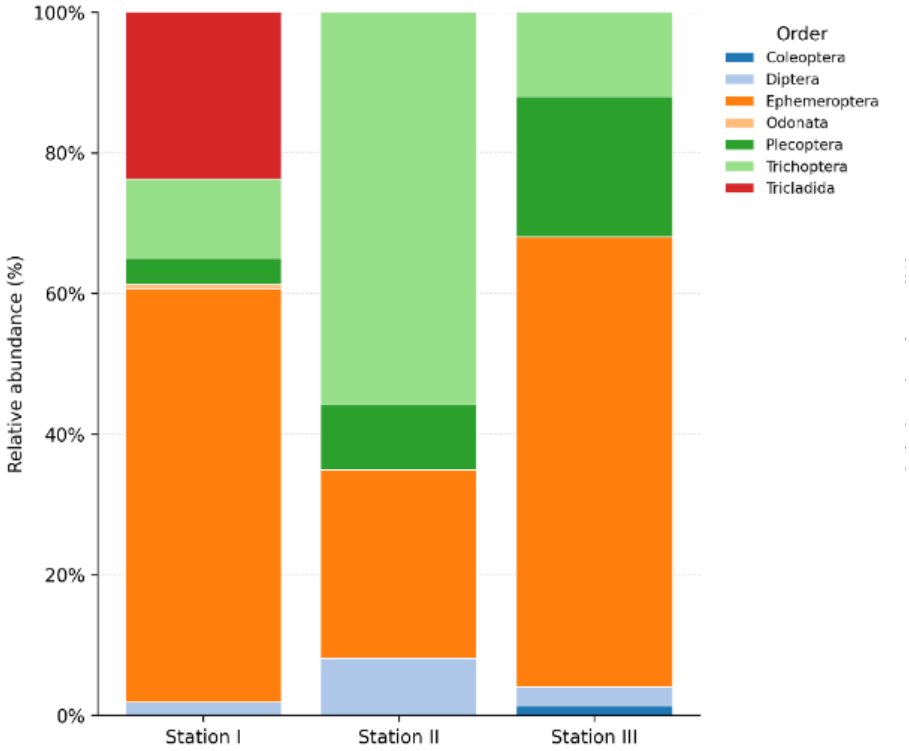


Figure 5. Relative Abundance by Order

The relative composition of macrozoobenthos orders varied among sampling stations. Ephemeroptera represented approximately 58.4% of the recorded abundance at Station I and 64.0% at Station III, whereas Trichoptera accounted for 55.8% at Station II (Figure 5). The substantial contribution of Ephemeroptera at Stations I and III indicates that this order was an important component of the river assemblages, while the predominance of Trichoptera at Station II reflects a different community composition. The presence of Ephemeroptera and Trichoptera is ecologically relevant because many members of these orders are associated with flowing freshwater habitats and can respond to changes in water quality, dissolved oxygen, and substrate conditions (Amaral *et al.*, 2015; Wibowo *et al.*, 2017).

The notable contribution of Plecoptera at Station III may indicate the availability of suitable microhabitats and relatively favorable oxygen conditions, as many stonefly nymphs are associated with well-oxygenated, flowing waters (Eichert *et al.*, 2025). The occurrence of Diptera at all stations indicates their broad distribution across the study area. This pattern may be associated with the ecological diversity of Diptera larvae, which occupy a wide range of freshwater habitats and exhibit varying tolerances to environmental disturbance (Cañedo-Argüelles *et al.*, 2016). Their widespread occurrence therefore does not necessarily indicate either good or poor water quality; interpretation depends on the taxa present and their relative abundance. In contrast, the restriction of Odonata and Tricladida to Station I and Coleoptera to Station III suggests differences in habitat suitability or local environmental conditions. Odonata larvae are associated with diverse aquatic habitats, and their distribution can be influenced by vegetation, substrate, flow conditions, and prey availability (Pires *et al.*, 2020). Tricladida are generally free-living flatworms whose occurrence may depend on substrate conditions, food resources, and water quality (Benítez-Álvarez *et al.*, 2023). Similarly, aquatic Coleoptera occupy diverse habitats, with their distribution influenced by flow, vegetation, and substrate characteristics (Stanković *et al.*, 2018). Nevertheless, the presence of these orders at only one station should not be interpreted as evidence of specific environmental conditions without further supporting data.

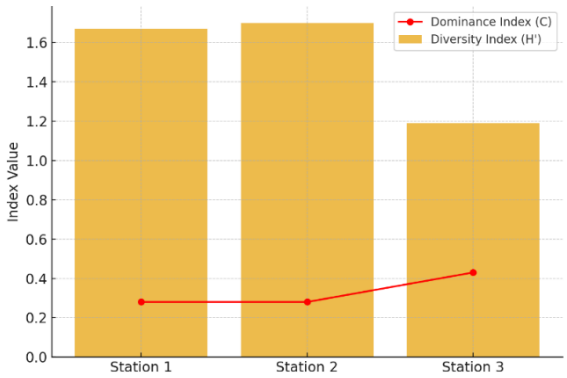


Figure 6. Macrozoobenthos Diversity and Dominance across Stations

The structure of macrozoobenthos communities in Kali Jarak can be further understood through analysis of diversity and dominance indices, which provide insight into ecological balance and community stability. The Shannon–Wiener diversity index (H′) values ranged between 1.19 and 1.70 (Figure 6), indicating moderate diversity across all sampling stations. Notably, the upstream and midstream sites recorded higher diversity values (>1.6), whereas the downstream site displayed the lowest value (1.19). This decline in diversity downstream signals reduced habitat quality and possible stress from increasing anthropogenic inputs (Rak & Samsudin, 2025).

Complementary to this, the Simpson dominance index (C) values ranged from 0.27 to 0.43 (Figure 6), suggesting that no single taxon overwhelmingly dominated the assemblages. However, the downstream station exhibited a relatively higher dominance value (0.43). Examination of community composition reveals differences in dominant genera across stations. At the upstream station, taxa such as *Baetis* and *Austrotinodes* were abundant, reflecting clean, well-oxygenated waters with heterogeneous substrates (Aissani *et al.*, 2026; Braun *et al.*, 2014). In the midstream section, *Macrelmis* and *Euphaea* were frequently encountered, consistent with moderate environmental quality and mixed substrate conditions (González-Córdoba *et al.*, 2020; Dudgeon, 1989). In contrast, the downstream community was characterized by higher relative abundance of tolerant genera such as *Prodiamesa*, which thrive in areas influenced by organic enrichment and elevated BOD (Aydemir *et al.*, 2025).

3.2 Biotic Indices (BMWP-ASPT)

While diversity and dominance indices describe overall community structure, biotic indices such as the Biological Monitoring Working Party (BMWP) and Average Score per Taxon (ASPT) provide more direct assessments of water quality based on the ecological sensitivity of macrozoobenthos taxa.

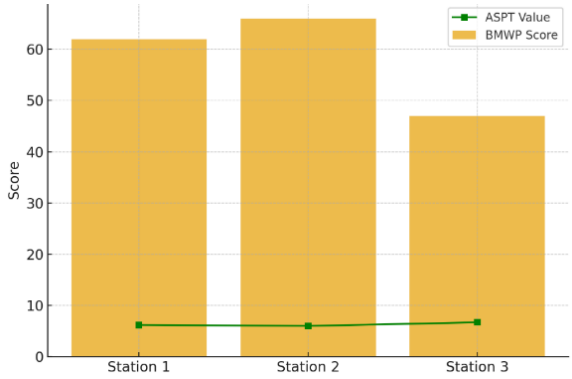


Figure 7. BMWP and ASPT Scores across Stations

In Kali Jarak, BMWP scores ranged from 47 to 66, with the midstream station recording the highest score (66), followed by the upstream station (62), while the downstream station had the lowest score (47), suggesting greater ecological stress potentially associated with anthropogenic inputs (Figure 7). ASPT values ranged from 6.0 to 6.7, indicating generally high ecological quality.

Notably, Station III exhibited the highest ASPT (6.7) despite having the lowest BMWP score and genus richness (7 genera). This difference reflects the distinct calculation principles of the indices: BMWP represents the cumulative scores of recorded families, whereas ASPT represents their mean score (ASPT = BMWP / number of scoring families). Thus, a site with relatively low taxonomic richness may still have a high ASPT if its recorded families predominantly comprise highly sensitive taxa. These findings underscore the value of combining biotic indices with physicochemical measurements in river health assessments. Whereas physicochemical measurements provide information on water conditions at the time of sampling, macroinvertebrate-based indices integrate biological responses to environmental conditions over time, offering a complementary perspective on ecological quality (Patang *et al.*, 2018).

3.3 Water Quality and Social Activity

Physico-chemical measurements across the three stations in Kali Jarak revealed that, overall, the river maintains conditions favorable for sustaining aquatic life, although localized variation was evident (Figure 8).

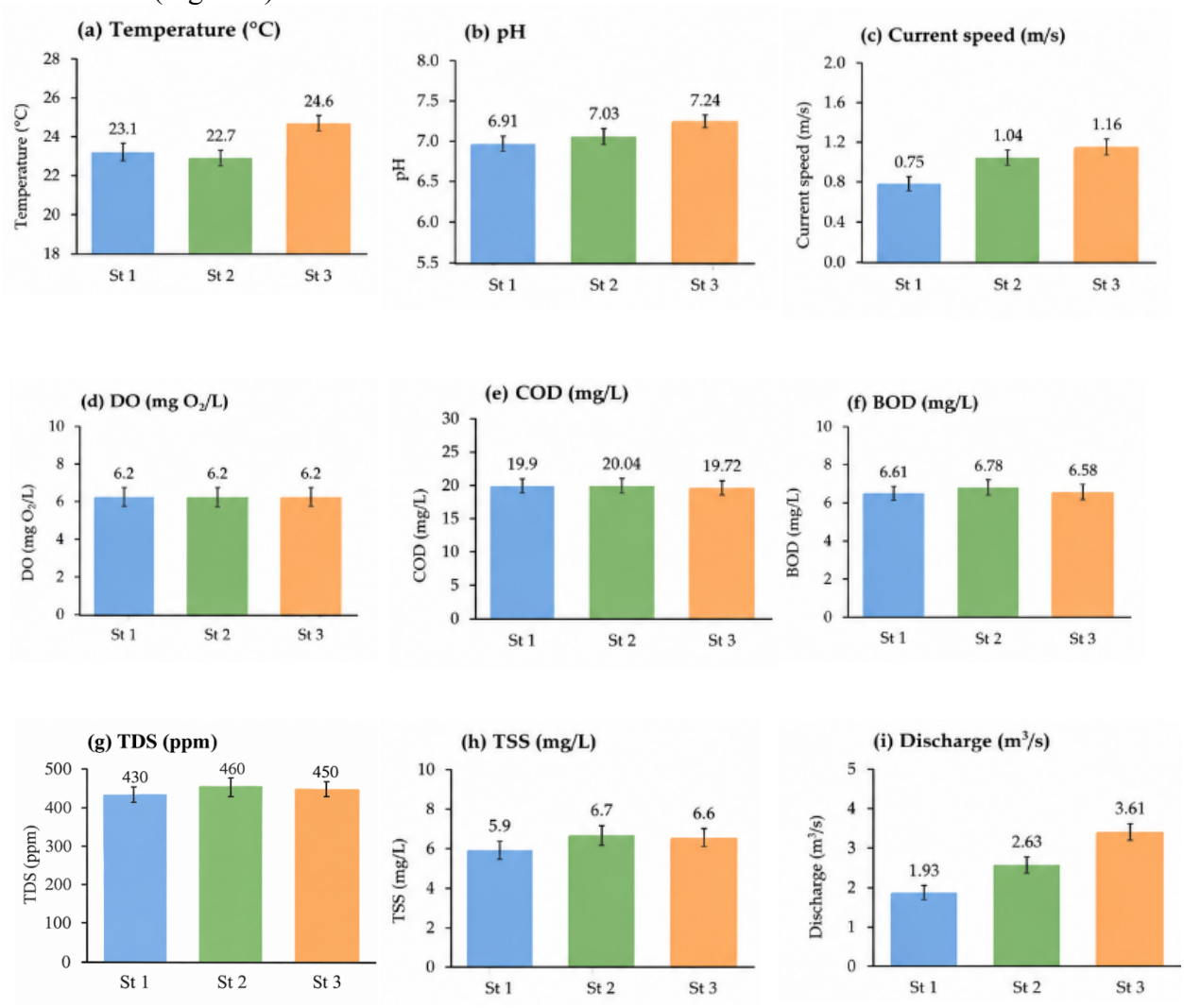


Figure 8. Physicochemical parameters of Kali Jarak River at three sampling stations. Values are means ± standard deviation (SD).

Temperature ranged within the optimal tolerance for tropical freshwater organisms, while pH values remained close to neutral across all sites, providing a stable environment for diverse macrozoobenthos. Measurements of pH across all stations indicated values close to neutral (6.9–7.4), suggesting that the river maintains stable chemical conditions suitable for most freshwater

organisms. Neutral pH provides an environment favorable for sensitive taxa such as *Baetis*, which were recorded in the upstream and midstream sites (Ab Hamid & Rawi, 2017). No extreme acidity or alkalinity was detected, implying that pH is not currently a limiting factor for biodiversity in Kali Jarak. Similarly, temperature remained relatively constant along the river (23–25 °C), reflecting the influence of shaded upstream habitats and open downstream areas. Although the variation was minor, slightly higher temperatures downstream may be linked to reduced canopy cover and slower flow velocity (Garner, *et al.*, 2017). Taxa such as *Austrotinodes* and *Macrelmis* were more abundant in cooler, faster-flowing upstream waters, suggesting that even small temperature differences can influence the distribution of certain genera (Madsen *et al.*, 2015).

Hydrological parameters, particularly current velocity and discharge, exhibited a downstream gradient in Kali Jarak. The upstream station recorded the fastest current and lowest discharge, reflecting the steep gradient and narrow channel typical of headwater streams. In contrast, the midstream section displayed moderate velocity with slightly higher discharge as tributaries entered the main channel. The downstream site, characterized by a wider channel and slower flow, showed the highest discharge but the lowest velocity. These differences are ecologically significant for macrozoobenthos. Faster currents in the upstream section promote higher dissolved oxygen concentrations and create heterogeneous habitats (riffles, cobbles, and leaf packs), which support diverse taxa such as *Baetis* and *Macrelmis* (Braun *et al.*, 2014; Harrison *et al.*, 2004). In the midstream, moderate flow conditions sustain a balanced assemblage, while also allowing for taxa that tolerate slight increases in organic input (Sudarso *et al.*, 2025). Downstream, reduced velocity and higher discharge favor deposition of fine sediments and organic matter, creating habitats more suitable for tolerant taxa like *Prodiamesa* (Lencioni *et al.*, 2012).

Together with DO, BOD, COD, and TDS, these parameters confirm that while basic chemical conditions remain within acceptable limits, the gradual downstream shift in water quality is already mirrored by changes in macrozoobenthos community structure. Dissolved oxygen (DO) was consistently high at the upstream and midstream stations, reflecting well-aerated flows, but declined slightly downstream where water turbulence was reduced and organic inputs were greater (Cahyani *et al.*, 2026). Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) provided clearer signals of anthropogenic influence. Both parameters were lowest upstream, moderate at the midstream station, and highest downstream. This pattern suggests increasing organic enrichment along the river continuum (Afwa *et al.*, 2021). Similarly, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) concentrations increased downstream, consistent with sediment input and waste disposal from surrounding human activity (Helard *et al.*, 2021). While all measured parameters remained within acceptable limits according to national water quality standards, the gradient clearly indicates growing ecological stress toward the lower reaches of the river.

The spatial distribution of water quality parameters corresponds closely with differences in land use and community activity. The upstream site is located in a relatively undisturbed forested catchment, where minimal agricultural runoff results in low BOD and COD values. In contrast, the midstream station is influenced by moderate agricultural activities and household wastewater, although water quality indicators still reflect good ecological conditions. The downstream site, however, receives more intensive input from daily human practices, including bathing, washing, and aquaculture. These activities contribute to the elevated organic load observed in BOD and COD data and are reflected biologically in reduced macrozoobenthos diversity and increased dominance of tolerant taxa (Kadim & Pasisingi, 2024; Albini *et al.*, 2023).

3.4 Correlation Analysis

To provide an integrated interpretation of biological and physico-chemical data, Canonical Correspondence Analysis (CCA) was employed to examine the relationships between macrozoobenthos genera and measured environmental parameters. This multivariate approach is particularly useful because it simultaneously considers multiple gradients to explain community structure. By visualizing the alignment of taxa with specific parameters, CCA strengthens the

evidence that macrozoobenthos serve as sensitive indicators of water quality variation along Kali Jarak (Figure 9).

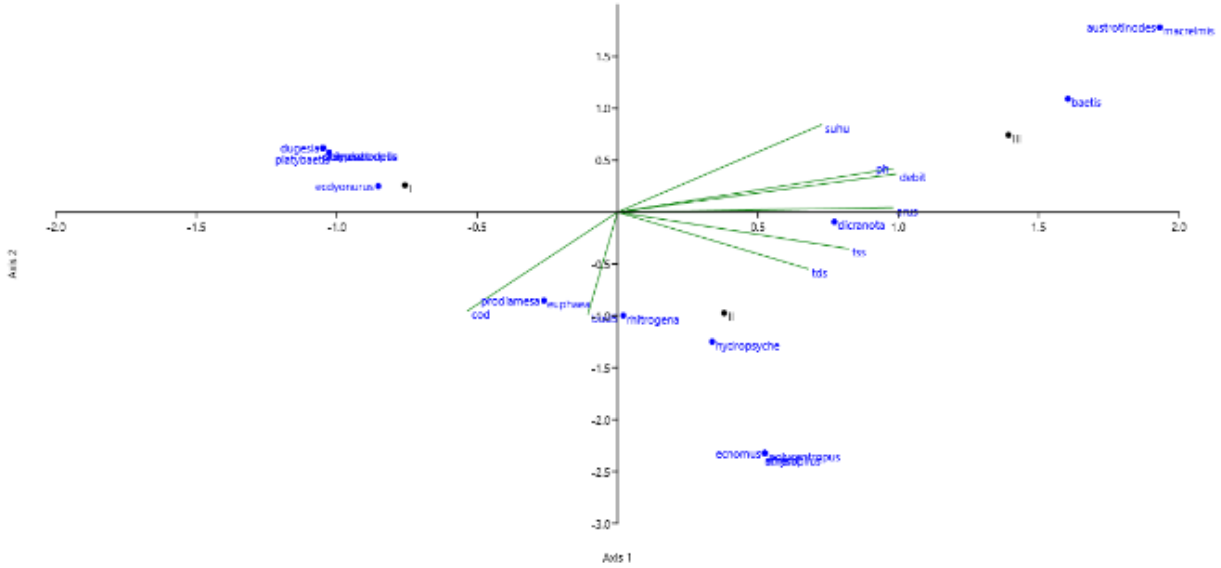


Figure 9. CCA analysis between macrozoobenthos genera and environmental parameters

The ordination results revealed clear ecological patterns. Genera such as *Baetis* were closely aligned with pH and discharge, indicating preference for well-oxygenated, alkaline waters with strong flow typically found in upstream reaches (Li *et al.*, 2025). *Austrotinodes* and *Macrelmis* clustered near temperature and current velocity, reflecting their association with cooler, stable, fast-flowing habitats (Schmitt *et al.*, 2016; Sotomayor *et al.*, 2023). These taxa act as indicators of relatively undisturbed environmental conditions.

In contrast, tolerant taxa showed associations with stress-related parameters. *Prodiamesa* aligned with BOD and TSS, highlighting its tolerance to elevated organic load and suspended particles (Chakraborty *et al.*, 2022). *Rhitrogena* and *Euphaea* were positioned near COD and TDS, suggesting that while they are somewhat sensitive to chemical pollutants, they persist in moderately impacted conditions (Mebane *et al.*, 2020, Chakravarty & Gupta, 2024). The CCA also illustrated that downstream assemblages were generally closer to BOD, COD, TSS, and TDS vectors, while upstream assemblages clustered with pH, temperature stability, discharge, and higher current velocity.

These findings confirm a clear ecological gradient: sensitive taxa dominate under high-quality upstream conditions, while tolerant genera proliferate in downstream habitats influenced by organic enrichment and sediment input. The application of CCA thus provides robust evidence that macrozoobenthos not only reflect single-parameter changes but also integrate multiple environmental stressors, making them reliable bioindicators for tropical river monitoring and management. Unlike chemical measures that only capture instantaneous conditions, taxa-specific responses integrate both short-term fluctuations and long-term stressors.

Overall, the integration of biological indices, community composition, and physicochemical parameters provides a comprehensive understanding of river health in Kali Jarak. The consistent patterns across multiple lines of evidence illustrate the potential influence of human activities on ecological integrity. Although the river generally remains in good condition, the signs of environmental stress observed at the downstream site highlight the need for proactive management. However, this study was conducted during a single sampling period, which coincided with the rainy season. Therefore, the findings represent the ecological conditions of Kali Jarak during this particular period and may not fully capture seasonal variations in macrozoobenthos community composition and water quality. Future monitoring studies should incorporate sampling across both wet and dry seasons to provide a more comprehensive understanding of temporal changes in macrozoobenthos assemblages and their responses to environmental fluctuations. Such monitoring would further strengthen the application of macrozoobenthos as bioindicators for detecting

ecological changes and supporting community-based strategies for sustainable freshwater management.

4. Conclusion

This study confirms that the overall water quality of Kali Jarak remains in the "excellent" category, as indicated by macrozoobenthos diversity, community indices, and biotic scores (BMWP and ASPT). A total of 19 genera were recorded, and diversity values at the upstream and midstream sites reflect relatively balanced communities. Biotic indices further classified these sections as having "Excellent" ecological conditions. However, evidence of localized ecological stress was detected in the downstream reach, where diversity declined, tolerant taxa became more dominant, and BOD, COD, TSS, and TDS values increased. Canonical Correspondence Analysis (CCA) confirmed that sensitive taxa were closely associated with favorable upstream conditions (neutral pH, high DO, fast current, stable temperature), while tolerant genera were aligned with stress-related parameters downstream. In summary, Kali Jarak still supports a good ecological status, but pressures from human activity at the lower sections are beginning to affect biological communities. This emphasizes the importance of early intervention through sustainable watershed management and community-based monitoring to prevent further degradation and to maintain the river's ecological integrity.

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6. Conflict of Interest Declaration

The authors declare that they have no competing interests that could have influenced the research, authorship, or publication of this article.

7. Author Contribution Statement

This journal uses Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Hernanda Afra Haniyyah	✓	✓	✓		✓	✓	✓	✓	✓					
Dwi Suheriyanto	✓	✓		✓				✓		✓		✓		
Eko Budi Minarno	✓			✓				✓		✓		✓		
Indana Zulfa Fauzia										✓	✓			

C : **C**onceptualization
I : **I**nvestigation
R : **R**esources
Vi : **Vi**sualization
Su : **Su**pervision

M	:	**M**ethodology	D	:	**D**ata Curation	P:	**P**roject administration
So	:	**So**ftware	O	:	Writing - **O**riginal Draft	Fu : acquisition	**Fu**nding
Va	:	**Va**lidation	E:		Writing - Review & **E**diting		
Fo	:	**Fo**rmal analysis					

8. Generative AI Statement

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely to assist with language refinement, grammatical editing, and improving the clarity and readability of the manuscript. The original research ideas, study design, data collection, data processing, statistical analyses, and interpretation of results were entirely conducted by the authors using the relevant analytical software. No research data, statistical analyses, or scientific interpretations were generated by artificial intelligence. All AI-assisted text was critically reviewed and revised by the authors to ensure accuracy and scientific integrity. The authors take full responsibility for the content of the final manuscript. ChatGPT was used only as a supportive writing tool and is not credited with authorship.

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