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Benthic macroinvertebrate variability as an indicator of aquatic health in the Bone River, Gorontalo, Indonesia

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Abstract. *Kadim MK, Pasisingi N, Olii AH, Hertika AMS, Arfiati D, Yuli EH, Baderan DWK, Suciyono. 2025. Benthic macroinvertebrate variability as an indicator of aquatic health in the Bone River, Gorontalo, Indonesia. Biodiversitas 26: 1247-1256.* The Bone River in Gorontalo, Indonesia is at risk of pollution due to anthropogenic activities in the surrounding area. Macroinvertebrates serve as bioindicators of pollution based on their community characteristics, including sedentary behavior, limited mobility, and sensitivity to water quality. This study aims to assess macroinvertebrate communities and evaluate the water quality of the Bone River watershed using the Biological Monitoring Working Party-Average Score Per Taxon (BMWP-ASPT) biotic index. Macroinvertebrate community variability was examined across 12 observation stations. Sampling was conducted during periods of low river discharge and in the absence of precipitation. Observation stations were purposefully selected based on prevailing ecological conditions (preferably riffle areas) and potential contamination sources from land use activities. Macroinvertebrate samples were collected between April and August during the 2021-2023 period and were identified at the family level. A total of 7,456 individuals, representing 43 genera, were recorded, with *Platybaetis, Cheumatopsyche, Chironomus,* and *Coxelmis* being widely distributed along the river. Moderate diversity, a high evenness index, and the dominance index suggest that no single macroinvertebrate species dominates the community. The BMWP-ASPT values ranged from 3.08 to 6.77, indicating varying levels of pollution in the Bone River. The findings demonstrate a progressive decline in river health, with worsening conditions observed downstream over the study period.

Keywords: Bioassessment, BMWP-ASPT, macroinvertebrate, pollution, river

INTRODUCTION

Rivers serve as crucial ecosystems and vital sources of life for surrounding communities. They provide essential water resources for basic human needs, including drinking water, household activities, agriculture, fisheries, tourism, and economic activities such as industrial applications and housing development (Liu et al. 2020). However, various anthropogenic activities, including industrial and domestic waste disposal, contribute to the degradation of river water quality (Baderan et al. 2023; Suciyono et al. 2024). Industrial discharges often introduce hazardous chemicals, while domestic wastewater contributes nutrients and organic matter, accelerating eutrophication. Additionally, agricultural runoff, containing fertilizers and pesticides, exacerbates water quality issues by increasing nutrient loads and introducing toxic substances into aquatic ecosystems (Sanae et al. 2021; Sudarso et al. 2021). These impacts not only threaten aquatic biodiversity (Barbieri et al. 2020) but also pose risks to human health and livelihoods (Olii et al. 2024). Furthermore, anthropogenic modifications disrupt aquatic ecosystems by altering river flow and sediment transport (Long et al. 2021).

One of the primary rivers supporting local communities in Gorontalo Province, Indonesia is the Bone River. It is widely used for domestic activities, agriculture, and tourism (Kadim and Pasisingi 2024) and is located within the Bogani Nani Wartabone National Park. Additionally, Sahami and Habibie (2020) identified the Bone River as a habitat for Nike fish, a species of significant economic importance to the people of Gorontalo. However, human activities along the river threaten the ecological balance of aquatic organisms. River sediments, which serve as habitats for macroinvertebrates, can accumulate pollutants, making these organisms particularly vulnerable to contamination (Liao et al. 2022). The presence of pollutants eliminates more sensitive species, thereby altering macroinvertebrate diversity and abundance (Santos and Ferreira 2020; Kadim and Risjani 2022). Macroinvertebrate communities integrate environmental changes with the physical, chemical, and ecological characteristics of their habitats (Costa et al. 2021). Due to their sensitivity to contaminants, these organisms are widely recognized as effective indicators for water quality monitoring (Hartati et al. 2024), particularly in riverine ecosystems (Kefford et al. 2020).

Benthic macroinvertebrates are extensively used as bioindicators of water quality due to their high sensitivity to changes in aquatic conditions (Abdullah et al. 2022). Their universality allows their application across various aquatic systems (Larras and Usseglio-Polatera 2020), and their significant species diversity and abundance enhance their effectiveness as ecological indicators (Kadim et al. 2022a). Moreover, macroinvertebrates respond to a wide range of environmental stressors. Their benthic nature and relatively long-life cycles, compared to organisms such as algae and plankton, make them particularly useful for assessing long-term water quality trends (Sumudumali and Jayawardana 2021).

The composition of macroinvertebrate communities provides insights into river ecosystem health, as certain species serve as bioindicators. The presence or absence of specific taxa can indicate ecological degradation (Kadim et al. 2022b). For example, in polluted sections of the Brantas River watershed in Malang (Hertika et al. 2024) and the Renggeh River (Sudarso et al. 2021), the absence of families such as Glossosomatidae, Lepidostomatidae, and Perlodidae has been linked to significant ecological decline. Biotic indices, which integrate species diversity with ecological sensitivity, have been widely used to assess aquatic environmental quality. Several indices have been developed based on the presence of benthic macroinvertebrates (Kumar et al. 2020; Lu et al. 2021). However, the application of a single, standardized biotic index is often impractical due to geographic variations in macroinvertebrate species composition and river biotypology (Arslan et al. 2016). Consequently, researchers often utilize multiple indices for comprehensive assessments.

The Biological Monitoring Working Party (BMWP) scoring system is one of the most widely used biotic indices for evaluating water quality in lotic environments. Originally developed in the United Kingdom (Armitage et al. 1983), the BMWP is included in the Water Framework Directive and is extensively applied across the European Union. Several countries, including Indonesia, have adapted the BMWP by incorporating region-specific benthic macroinvertebrate indicator families (Malvandi et al. 2020; Ochieng et al. 2020; Roveri et al. 2020; Singh et al. 2022; Hertika et al. 2024; Sudaryanti and Herawati 2024). This system assigns pollution sensitivity scores ranging from 1 to 10 to macroinvertebrate families, with higher scores indicating greater sensitivity. The BMWP score is the cumulative sum of the scores of all taxa present in a sample, with values exceeding 100 typically indicating clean water conditions, whereas scores below 10 denote severe pollution. The Average Score Per Taxon (ASPT), calculated by dividing the BMWP score by the number of taxa present, serves as an additional indicator of water quality, with higher ASPT values suggesting a predominance of pollution-sensitive taxa (Armitage et al. 1983).

The Bone River watershed was selected for this study due to the high level of anthropogenic impact and the lack of comprehensive research over the past five years. The objectives of this study are: (i) to assess macroinvertebrate communities along the Bone River watershed; (ii) to evaluate water quality using the BMWP-ASPT biotic index, complemented by biodiversity indices. This study provides a three-year (2021-2023) monitoring dataset on the health of the Bone River. The selection of macroinvertebrates as bioindicators is based on their ecological significance as riverine organisms. Each species exhibits varying levels of sensitivity and tolerance to water quality changes induced by pollution (Hertika et al. 2024).

MATERIALS AND METHODS

Study area

The Bone River, Gorontalo, Indonesia, watershed spans 1,856 km^2, with a mainstream length of 100 km, and drains into Tomini Bay (Kaharu et al. 2022). Land use within the watershed includes natural forests (upstream), agriculture, settlements, commercial areas, mining, and household-scale industries (Kadim and Pasisingi 2024). This study was conducted over three years (2021-2023) along the main flow of the Bone River Basin, covering areas from upstream to downstream. The primary objective was to assess river pollution levels by evaluating macroinvertebrate communities and physicochemical parameters. Sampling was carried out in April and August of 2021, 2022, and 2023 at 12 observation stations, which were purposively selected based on ecological conditions (preferably riffle areas) and potential pollution sources (Figure 1). These periods were specifically chosen to coincide with relatively low water discharge and the absence of rainfall, minimizing data variability caused by external factors such as high river discharge during the rainy season. Increased water flow during heavy rainfall complicates macroinvertebrate sampling and may yield unrepresentative ecological data. Standardizing the sampling period across years ensured data comparability, allowing the study to accurately reflect ecological conditions under stable hydrological circumstances. A detailed description of observation sites is presented in Table 1.

Sampling procedures

Macroinvertebrates were collected using hand nets (mesh size: 500 μm) with the kicking technique in shallow waters, covering a total length of 10 m at each station (Kadim et al. 2022a). The hand net used in this study had a rectangular frame measuring 40 cm in width and 20 cm in height, with a bag-shaped net design and a 200 cm-long handle. Collected samples were carefully separated from organic debris, sediment, and mud before being stored in small bottles and preserved with 95% ethanol for identification. In the laboratory, macroinvertebrate specimens were hand-sorted and identified using a binocular microscope and identification keys. Identification was performed up to the family and genus levels. Additionally, water quality parameters, including temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), were measured at each sampling location.

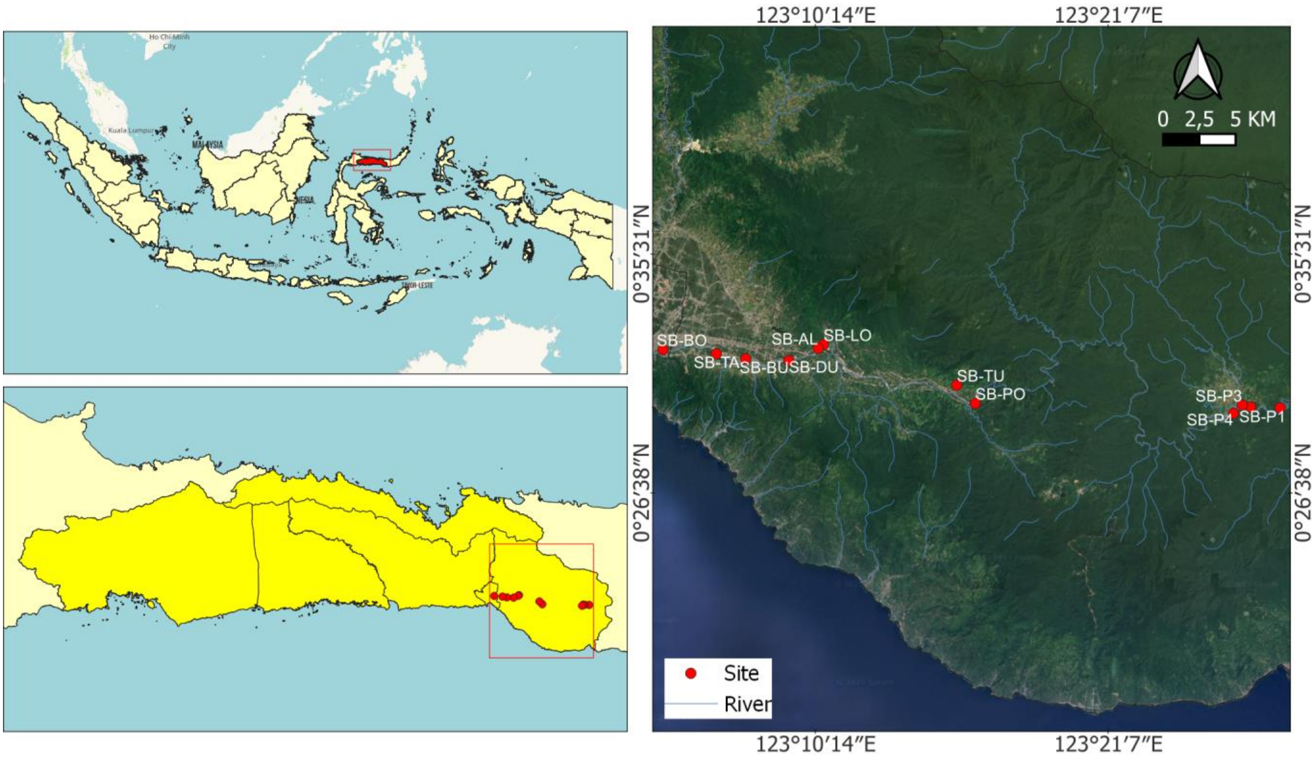

Figure 1. Location of the sampling sites in the Bone River, Gorontalo, Indonesia

Table 1. Description of observation sites

Sampling locations	Code	Coordinate*	Land use
Pinogu Village, Bone Bolango District	SB-P1	0°29'48.07"N 123°27'30.57"E	Primary forest
Pinogu Village, Bone Bolango District	SB-P2	0°29'50.00"N 123°26'25.62"E	Primary forest and plantation
Pinogu Village, Bone Bolango District	SB-P3	0°29'54.15"N 123°26'6.19"E	Agriculture and plantation
Pinogu Village, Bone Bolango District	SB-P4	0°29'35.93"N 123°25'46.72"E	Settlement, agriculture, plantation
Poduwoma Village, Bone Bolango District	SB-PO	0°29'58.34"N 123°16'11.21"E	Settlement, sand quarry, river rafting
Tulabolo Village, Bone Bolango District	SB-TU	0°30'38.60"N 123°15'29.70"E	Settlement
Lombongo Village, Bone Bolango District	SB-LO	0°32'9.18"N 123°10'32.38"E	Agriculture and settlement
Alale Village, Bone Bolango District	SB-AL	0°32'0.99"N 123°10'20.59"E	Dam, agriculture, and settlement
Duano Village, Bone Bolango District	SB-DU	0°31'33.52"N 123° 9'15.12"E	Agriculture and sand quarry
Bubeya Village, Bone Bolango District	SB-BU	0°31'37.63"N 123° 7'38.89"E	Settlement, agriculture, farm
Tanggilingo Village, Bone Bolango District	SB-TA	0°31'48.83"N 123° 6'33.66"E	Settlement, agriculture, sand quarry
Botu Village, Gorontalo City	SB-BO	0°31'57.95"N 123° 4'34.61"E	Settlement, agriculture, former sand quarry

Note: *N: North; E: East

Data analysis

After the identification and quantification of benthic macroinvertebrates (Table 2), several ecological indices were calculated, including the diversity index (H'), evenness index (E), dominance index (D), and BMWP-ASPT index. These indices were selected to comprehensively assess the ecological health of the Bone River, as they capture different aspects of macroinvertebrate community structure and their responses to environmental changes. The BMWP-ASPT index, specifically designed for biomonitoring, evaluates water quality by considering the sensitivity and tolerance of macroinvertebrate taxa to pollution, making it a crucial tool for achieving the study's objectives. Measurements and analyses of physicochemical parameters were conducted using the Pollution Index (IP). All data were processed and visually presented in graphs and tables using Microsoft Excel. The results were then subjected to descriptive analysis, where they were interpreted in relation to field conditions and relevant literature.

The BMWP-ASPT method assesses biotic indices by identifying macroinvertebrate families based on their tolerance levels using the BMWP-ASPT table. Once the most tolerant macroinvertebrates are identified, the aquatic biotic index is determined according to the values listed in Table 3.

Table 2. Metrics and indices calculated for macroinvertebrate in Bone River, Gorontalo, Indonesia

Metric (sources)	Equation	Description
Family Richness (n/a)	-	Total number of taxa (families) collected in a sample.
Shannon Diversity (H') (Magurran 2021; Hertika et al. 2024)	$H' = -\sum[(ni/N) \ln(ni/N)]$	Takes into account both species richness (number of species) and evenness (number of individuals in each species). Where, ni: number of individuals/species; N: total number of individuals.
Evenness (E') (Magurran 2021; Hertika et al. 2024)	$E' = H'/\ln S$	Expresses how evenly individuals are distributed among species. Where, H': Shannon-Weaver diversity index; lnS: Natural logarithm of the total number of species.
Dominance (D') (Magurran 2021; Hertika et al. 2024)	$D' = \sum(ni/N)^2$	Measures how much a species dominates an ecosystem. Where, ni: number of individuals per species; N: total number of individuals.
Bellan-Santini Dominance (D%) (Arslan et al. 2016)	$D\% = Ni/Nt \times 100$	Quantifies the dominance of a species. Where, Ni: number of individuals of species i; Nt: total number of macrobenthic specimens.
Soyer Frequency (F%) (Arslan et al. 2016)	$F\% = m/M \times 100$	Estimates frequency of a species in a sampling area. Where m: number of stations where the species was found; M: total stations×total sampling periods.
Pollution Index (IP) (Keputusan Menteri Lingkungan Hidup Republik Indonesia No. 115 Tahun 2003)	$IP_j = \sqrt{\frac{(C_i/L_{ij})_M^2 + (C_i/L_{ij})_R^2}{2}}$	Determines pollution levels relative to permitted water quality parameters. Where, Ci: concentration of the water quality parameter; Lij: standard concentration; M: maximum value; R: average value.
Biological Monitoring Working Party Average Score Per Taxon (BMWP-ASPT) (Galbrand et al. 2007)	$ASPT = \frac{\text{Total BMWP index score}}{\text{Number of families found and have a score}}$	Assesses river water quality based on macroinvertebrate assemblages and their tolerance to pollution.

Table 3. The category of water quality based on ASPT value

Aspt value	Water quality
>6.0	Excellent water quality
5.5-6.0	Very good water quality
5.0-5.5	Good water quality
4.5-5.0	Moderate water quality
4.0-4.5	Moderately-poor water quality
<4.0	Poor water quality

RESULTS AND DISCUSSION

Aquatic invertebrates serve as reliable indicators of environmental pollution and are commonly used to assess environmental quality due to their varying sensitivity to contaminants. These community function as bioindicators and complement traditional physical and chemical analyses. Traditional biomonitoring primarily relies on taxonomic differentiation and the tolerance levels of specific taxa to contaminants. Evaluating the impact of pollution on aquatic ecosystems typically involves both physicochemical water quality analysis and biomonitoring through bioassessment.

Macroinvertebrate community structure of Bone River

Between 2021 and 2023, a total of 7,456 macroinvertebrate individuals were recorded in the Bone River, representing diverse taxonomic groups. The community was primarily composed of Ephemeroptera (37.4%), Diptera (23.4%), Trichoptera (21%), and Coleoptera (14.1%), while Hemiptera, Lepidoptera, Odonata, Decapoda, Mollusca, and Oligochaeta collectively accounted for 4.1%. Macroinvertebrate richness varied across years, with the highest diversity observed in 2022, where 14-29 taxa were recorded per station, compared to 15-26 taxa in 2021 and 16-24 taxa in 2023. The lowest species richness was recorded at SB-P1 in 2021, while SB-AL exhibited the highest. In 2022, SB-TA and SB-TU had the highest species richness. Density assessments revealed that SB-P1 consistently had the highest macroinvertebrate density across all three years, with 344 ind/m^2 in 2021, 288 ind/m^2 in 2022, and 397 ind/m^2 in 2023. Conversely, the lowest densities were recorded at SB-LO (112 ind/m^2) in 2021, SB-DU (86 ind/m^2) in 2022, and SB-BO (108 ind/m^2) in 2023. A total of 43 genera were identified, with *Platybaetis* (Ephemeroptera) exhibiting the highest relative abundance (14.9%), followed by *Cheumatopsyche* (14.6%), *Chironomus* (12.8%), and *Coxelmis* (9.6%). These four genera were consistently present at all observation stations across all years, with a frequency (F%) of 100%. Detailed species composition, distribution, frequency, and dominance percentages are presented in Table 4.

Calculation of diversity, dominance and evenness index of macroinvertebrates in the Bone River is presented in Figure 2. Biotic index, evenness index (E') at sampling locations from 2021 to 2023 ranged from 0.69-0.92; 0.68-0.81; and 0.7-0.88, respectively. Overall, in each sampling period, the evenness value of macroinvertebrates at the research location was always >0.6. According to Sumekar and Widayat (2021), the evenness index (E) >0.6 indicates that the allocation of individuals for each family at each station has high evenness, meaning that no genus dominates so that the distribution of families in each order is uniform and even.

Table 4. Distributions dominance (D%) and frequency (F%) of macroinvertebrates at the stations

Ordo/Class	Family	Score	Genus	F%	Station (D%)												D% (Average)
					SB-P1	**SB-P2**	**SB-P3**	**SB-P4**	**SB-PO**	**SB-TU**	**SB-LO**	**SB-AL**	**SB-DU**	**SB-BU**	**SB-TA**	**SB-BO**	
Ephemeroptera	Baetidae	4	*Platybaetis*	100	7.9	9.8	17.6	15.7	11.0	29.8	6.6	7.8	18.2	5.9	24.6	23.6	14.9
			Baetis	94.4	6.2	7.5	11.4	11.4	6.1	2.1	4.7	8.0	3.5	9.2	9.9	1.4	6.8
	Leptophlebiidae	10	*Atalophlebia*	91.7	10.7	26.4	10.9	3.8	8.1	5.0	3.6	3.3	2.5	2.7	2.7	2.2	6.8
			Neoleptophlebia	41.7	0	0	2.4	0	0	0.9	1.4	1.0	1.8	0.4	0.5	0.1	0.7
	Heptagenidae	10	*Heptagenia*	86.1	20.3	14.6	3.2	0.4	8.4	5.9	8.0	3.5	3.1	3.4	3.2	2.0	6.3
	Caenidae	7	*Caenis*	83.3	0.7	1.4	3.1	2.9	0.4	0.4	2.9	1.2	4.6	1.2	3.0	0.9	1.9
Trichoptera	Hydropschydae	5	*Cheumatopsyche*	100	15.1	4.9	9.2	15.2	11.0	10.4	21.5	29.1	16.7	18.7	13.6	9.2	14.6
			Hydropsche	91.7	1.6	0.6	0.7	1.6	1.9	3.0	1.7	2.0	1.8	3.3	1.0	0.5	1.7
	Hyrobiosidae		*Atopsyche*	55.6	0.3	0	0	0	2.1	0.5	1.0	0.5	1.6	0.5	0.5	0.5	0.6
	Philopotamidae	8	*Chimarra*	50.0	1.2	2.0	7.3	0.9	1.0	0.7	1.1	0.4	0.3	0.4	0.2	0	1.3
	Odontoceridae	10	*Psilotreta*	36.1	2.3	0	0	0	1.4	0.5	0.6	0.8	2.0	0	0.6	0	0.7
	Ecnomidae		*Ecnomus*	38.9	0	0	0	0	2.3	0.8	1.3	3.6	1.7	0.9	0.9	0.2	1.0
	Glossosomatidae	8	*Glossosoma*	38.9	0.7	0.7	0.7	0.8	0.6	1.8	0	0	0	0	0	0	0.4
	Sericosmatidae	10		33.3	3.7	4.2	0.5	1.3	0	0	0	0	0	0	0	0	0.8
Diptera	Chironomidae	2	*Chironomis*	100	6.6	9.2	14.8	14.8	2.3	15.5	18.1	3.4	20.7	15.4	18.9	14.4	12.8
			Diamesinae	80.6	5.2	5.4	5.5	11.3	1.9	3.3	0.4	2.1	1.0	1.3	1.9	1.1	3.4
	Ceratopogonidae	6	*Bezzia*	75.0	0.9	1.3	1.8	6.1	1.7	1.1	2.7	1.5	1.5	0.3	0.9	0.5	1.7
	Athericidae	8	*Atherix*	19.4	1.5	1.3	0	0.9	0	0	0	0	0	0.2	0	0	0.3
	Empididae	6	*Hemirodromia*	50.0	0.4	0	0	0	0.8	0.5	1.5	2.9	0.6	4.5	0.5	0.7	1.0
	Simulidae	5	*Simulidae*	63.9	0	0	0.6	0.6	0.8	3.0	1.4	0.9	0.2	0.4	2.6	0.5	0.9
	Tipulidae	5	*Tipula*	66.7	0.6	1.1	0.7	0.3	2.0	0.2	1.4	0.9	5.3	0.5	0.3	2.2	1.3
			Dicronata	58.3	0.3	0.2	0.4	0.3	3.4	0.6	1.2	1.2	0	0.2	0.9	1.9	0.9
			Limnophila	33.3	0	0	0	0	0.4	0.9	0.7	0.5	0	0.2	0.3	4.6	0.6
	Tabanidae		*Tabanus*	41.7	0	0.8	0.9	1.2	0.3	0.4	0.9	0	0	0.7	0	0	0.4
Coleoptera	Elmidae	5	*Coxelmis*	100	10.2	4.6	2.4	6.2	14.2	7.0	11.1	16.0	4.9	17.5	10.9	10.1	9.6
			Notriolus	72.2	1.7	1.2	0.6	1.3	0.7	0	0.9	3.0	1.3	2.2	0.5	1.3	1.2
			Cylloepus	36.1	0.3	0.8	1.7	0.3	0.8	0.4	0	0	0	0.7	0	1.0	0.5
	Hydrophilidae	5	*Berosus*	38.9	0.8	0.7	0.2	0	0.4	0.2	0.4	0	0.2	0.1	0.3	1.0	0.4
	Prosopistomatidae		*Prosopistoma*	25.0	0	0	0	0	2.8	0	0.8	0	0.5	0.8	0.6	1.9	0.6
	Psephenidae		*Pshepenus*	75.0	0	1.0	0.6	0.8	4.1	1.2	0.6	2.1	3.3	1.9	0.2	1.7	1.5
	Lampyridae		*Lampyris*	27.8	0	0	1.0	0.4	0.7	1.3	0	0	0	0.2	0	0	0.3
Hemiptera	Veliidae	3	*Rhagovelia*	33.3	0	0	0	0	0.5	0.5	0.6	0	0	0.3	0.3	0.2	0.2
	Naucoridae	5	*Naucoris*	27.8	0	0.1	0.7	0.9	0.9	0	0	0	0	0.2	0	0.7	0.3
Lepidoptera	Pyralidae		*Eoophyla*	69.4	0	0.4	1.1	0.4	4.3	1.0	1.4	1.1	0.5	0.9	0	1.4	1.0
Odonata	Ghompidae	8	*Stylurus*	22.2	0.2	0	0	0	0.7	0	0.2	0	0	0	0.3	0.3	0.1
	Libellulidae	8		11.1	0.3	0	0	0	0	0.4	0	0	0	0	0	0	0.1
	Cordulidae	8	*Somatchlora*	44.4	0.2	0	0	0	1.4	0.4	0.9	0.4	1.0	0.4	0	0.2	0.4
Molusca	Thiaridae		*Tharebia*	8.3	0	0	0	0	0	0	0	0	0	0	0	1.6	0.1
			Melanoidase	11.1	0	0	0	0	0	0	0.2	0	0	2.1	0	3.4	0.5
	Neritidae	6	*Septaria*	11.1	0	0	0	0	0	0	0	0	0	0.2	0	1.7	0.2
			Neritina	16.7	0	0	0	0	0.3	0	0	1.0	0	1.4	0	5.6	0.7
	Mytilidae		*Lithopgaga*	2.8	0	0	0	0	0	0	0	0	0	0	0	0.3	0.03
Decapoda	Grabsidae		*Varuna*	8.3	0	0	0	0	0	0.3	0	1.7	0	0	0	0	0.2
	Atyidae		*Paratya*	5.6	0	0	0	0	0	0	0	0	0	0.9	0	1.2	0.2
Oligochaeta	Lumbricidae	1	*Lumbriculus*	5.6	0	0	0	0	0.2	0	0	0	1.0	0	0	0	0.1

Note: *Score from Biological Monitoring Working Party index

The diversity index (H') ranged from 1.85 to 3.04 (2021); 1.77 to 2.51 (2022); 1.83 to 2.49 (2023). In general, based on the diversity index value during the sampling period, it shows that the macroinvertebrate diversity in the Bone River is in the moderate category. According to Sumekar and Widayat (2021), if a body of water has a range of H' values between >1.0 to <3.3, then the waters are included in the moderate category, namely a balanced ecosystem. The dominance index value (D') for all stations during the sampling period was in the range of less than 0.5, so if referring to Roswell et al. (2021) it can be said that there are no dominant species. The evenness index can be compared to the diversity index for most macroinvertebrate community analyses (Kadim et al. 2022a). The dominance index is related to the evenness index, where if a sampling location shows no dominant individuals, it will generally be followed by an increasingly even distribution of individuals for each group (Pritchard and Martel 2020). During the sampling period, it was recorded that SB-P1 in 2021 had a diversity index value of 3.04 with an evenness index value reaching 0.92, which indicates that the level of macroinvertebrate diversity and the distribution of the number of individuals of each type at this station are more even compared to other stations.

Water quality parameters

Environmental parameter data for DO, pH, BOD, and COD at each station are presented in Table 5. The highest average Dissolved Oxygen (DO) levels were recorded at the two upstream stations, SB-P1 and SB-P2, with values exceeding 8 mg/L. In contrast, the lowest DO value of 7 mg/L was observed at the downstream station SB-BO. The pH levels varied along the river, with the upstream section of the Bone River exhibiting lower average pH values compared to the middle and downstream sections. The highest recorded pH value of 8.3 was observed at SB-LO, located in Lombongo Village, marking the peak value during the sampling period.

The physical and chemical parameters recorded during sampling reflect the water quality of the Bone River at that time, though these values fluctuate, particularly in flowing water systems. Despite these variations, the river's water quality remains conducive to organism growth. This is supported by key environmental factors, including a fast-flowing current, high Dissolved Oxygen (DO) levels, and a rocky substrate. The presence of riffle flow facilitates oxygen diffusion, ensuring that DO levels remain above 7 mg/L at all stations. The relatively high DO concentration provides adequate respiratory support for macroinvertebrates (Croijmans et al. 2021).

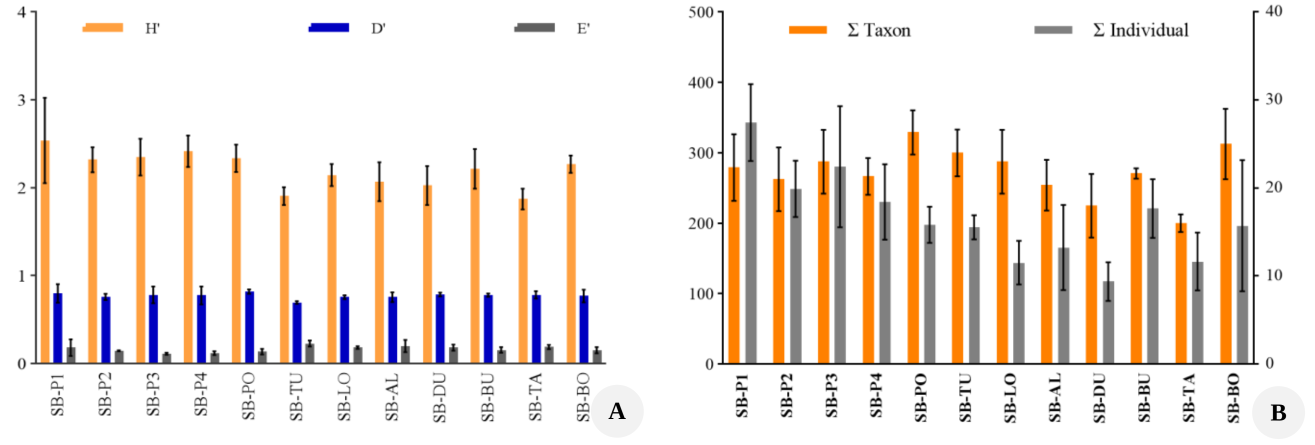

Figure 2. A. Diversity (H'), dominance (D'), evenness index (E'); B. Taxon and individual number of macroinvertebrates in the Bone River, Gorontalo, Indonesia

Table 5. Environmental parameter data at each station. Figures are indicated in minimum-maximum and (average)

Site	DO (mg/L)	pH	COD (mg/L)	BOD (mg/L)
SB-P1	7.82-8.63 (8.18)	6.0-6.7 (6.2)	9.26-10.76 (9.78)	2.24-2.81 (2.54)
SB-P2	7.84-8.5 (8.13)	6.0-6.7 (6.2)	9.12-10.76 (9.96)	2.34-2.84 (2.67)
SB-P3	7.79-8.1 (7.93)	6.1-6.6 (6.2)	10.48-14.36 (12.12)	2.45-2.89 (2.72)
SB-P4	7.57-7.65 (7.67)	6.0-6.6 (6.3)	13.59-14.91 (14.4)	2.75-3.98 (3.23)
SB-PO	7.27-7.32 (7.43)	6.4-8.3 (7.3)	41.46-54.0 (46.86)	5.21-6.42 (5.78)
SB-TU	7.6-7.75 (7.81)	6.7-8.3 (7.5)	39.87-47.42 (43.54)	6.72-8.81 (7.98)
SB-LO	7.57-7.7 (7.77)	6.1-8.4 (7.3)	36.72-44.75 (40.31)	5.9-9.88 (7.86)
SB-AL	7.56-7.81 (7.8)	6.3-8.3 (7.4)	35.57-44.0 (38.38)	7.77-12.3 (9.24)
SB-DU	7.56-7.63 (7.69)	6.2-8.3 (7.3)	36.28-42.0 (38.5)	7.94-9.2 (8.56)
SB-BU	7.54-7.72 (7.81)	6.2-7.9 (7.3)	37.54-45.0 (41.6)	7.94-13.4 (9.6)
SB-TA	7.6-7.7 (7.8)	6.2-8.2 (7.4)	35.14-46.29 (40.65)	7.72-9.89 (8.56)
SB-BO	7.0-7.6 (7.54)	6.3-8.2 (7.3)	36.22-44.88 (41.72)	7.12-13.4 (9.19)

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are critical parameters for assessing river water quality (Nayar 2020). Water quality can be categorized based on BOD values as follows: unpolluted (<2.9 mg/L), lightly polluted (3.0-4.9 mg/L), moderately polluted (5.0-14.9 mg/L), and heavily polluted (>15 mg/L) (Wikurendra et al. 2022; Varol and Tokatli 2023). According to Kadim and Pasisingi (2024), unpolluted waters typically exhibit COD values below 20 mg/L but must be greater than 4 mg/L.

In this study, BOD and COD levels, particularly in the middle and lower reaches of the river, exceeded quality standards. The BOD values at stations SB-TU to SB-BO surpassed the Class III water quality standard set by Indonesian Government Regulation No. 22 (2021), classifying these sections as moderately polluted. Additionally, COD values at SB-PO, SB-TU, and SB-BO exceeded Class III standards, with SB-PO to SB-BO classified as polluted waters. The results of the water quality analysis for the Bone watershed, based on the Pollution Index, are presented in Table 6.

BMWP-ASPT result

Macroinvertebrates are permanent inhabitants of river ecosystems, allowing them to reflect not only current environmental conditions but also past changes that occurred before sampling. Monitoring biological components, including diversity, abundance, and the presence of sensitive taxa, is crucial for assessing water quality and ecosystem health. In this study, a total of 35 macroinvertebrate families were identified. A declining trend in diversity and evenness values was observed from 2021 to 2023, particularly at upstream stations (SB-P1, SB-P2, SB-P4) and middle-reach stations (SB-PO, SB-TU, SB-AL, SB-BU). This decline was influenced by factors such as reductions in species richness and individual abundance, as well as the dominance of certain taxa at specific stations during the sampling period. The results of the BMWP-ASPT analysis, used to assess the ecological health of the Bone River, are presented in Figure 3.

Table 6. Results of analysis the water quality conditions of the Bone Watershed, Gorontalo, Indonesia in 2021-2023 using the Pollution Index

Stations	2021		2022		2023	
	IP	Category	IP	Category	IP	Category
SB-P1	0.48	Good	0.64	Good	0.32	Good
SB-P2	0.48	Good	0.64	Good	0.53	Good
SB-P3	0.47	Good	0.63	Good	0.53	Good
SB-P4	0.46	Good	0.62	Good	0.51	Good
SB-PO	0.78	Good	0.54	Good	1.9	Lightly polluted
SB-TU	0.9	Good	0.98	Good	1.16	Lightly polluted
SB-LO	0.96	Good	1.27	Lightly polluted	1.61	Lightly polluted
SB-AL	1.02	Lightly polluted	1.06	Lightly polluted	1.15	Lightly polluted
SB-DU	1.07	Lightly polluted	1.02	Lightly polluted	1.14	Lightly polluted
SB-BU	1.04	Lightly polluted	1.05	Lightly polluted	1.18	Lightly polluted
SB-TA	1.15	Lightly polluted	1.01	Lightly polluted	1.16	Lightly polluted
SB-BO	0.98	Good	0.85	Good	1.14	Lightly polluted

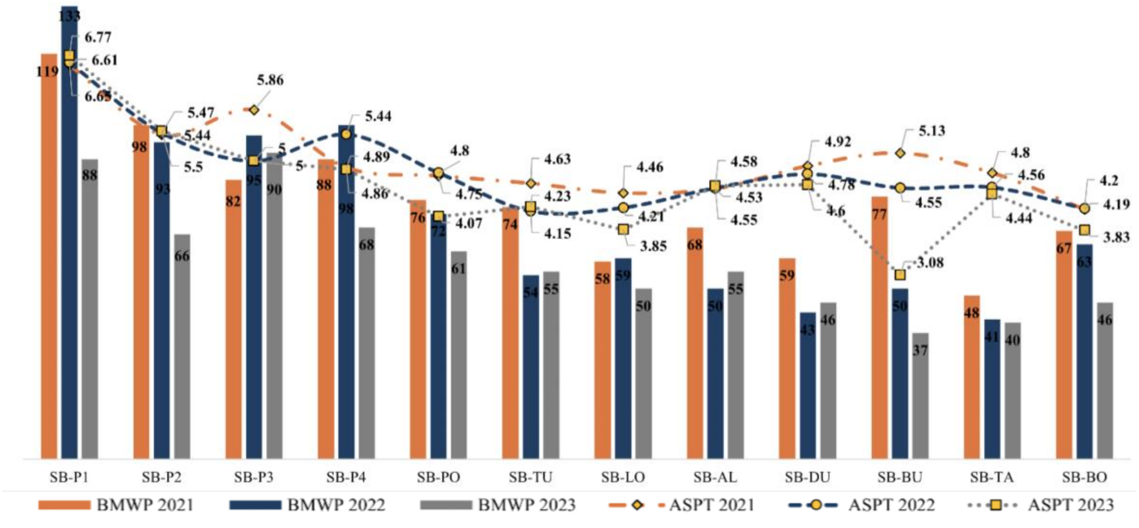

Figure 3. BMWP-ASPT score of the Bone River from 2021 to 2023

The BMWP score calculations ranged from 37 to 133, while the ASPT scores varied between 3.08 and 6.77. According to Galbrand et al. (2007), the ASPT scores classify the Bone River's water quality into six categories: excellent, very good, moderate, moderately poor, and poor. In 2021 and 2022, the Bone River fell into five category groups based on ASPT scores. However, in 2023, it shifted to six categories, with SB-LO, SB-BU, and SB-BO recording ASPT scores below 4.0, placing them in the poor category. This indicates a decline in river health conditions in 2023. Additionally, BMWP and ASPT scores declined at all stations except SB-P1. SB-P1 consistently recorded the highest ASPT values, maintaining an excellent water quality classification in 2021, 2022, and 2023.

Discussion

The ecological implications of species diversity in riverine ecosystems are closely linked to the river's hydrological and morphological characteristics. Greater species diversity is indicative of a more stable ecosystem, whereas a decrease in diversity and species numbers suggests the presence of external stressors, such as pollution, which can negatively impact riverine ecosystems (Pebriani et al. 2022). Lei et al. (2020) revealed that a reduction in species numbers and an increase in individual abundance can lead to ecosystem instability. In this study, water quality at each observation station was assessed based on physical-chemical variables and biotic indices, with comparisons made between stations. Both analyses indicated that the upstream sampling stations were in relatively good condition but exhibited slight pollution effects (especially at SB-P4), whereas the downstream stations were more polluted. Nevertheless, the water quality of the Bone River remains within an optimal range that can support various macroinvertebrate genera, preventing the dominance of any particular genus. The diversity index (H') ranged from 1.177 to 3.04, indicating a moderate level of diversity, which suggests that macroinvertebrate diversity in the river is influenced by anthropogenic activities. Lu et al. (2021) noted that diversity index values ranging from 1 to 3 indicate moderate to serious ecological disturbances. As posited by Suciyono et al. (2024), disturbances in the watershed, particularly due to anthropogenic activities, can affect the river's physical condition, leading to reductions in diversity index values and the evenness of benthic macroinvertebrates.

The loss of pollution-sensitive taxa can significantly impact the Functional Feeding Groups (FFG) of macroinvertebrates (Johnson and Ringler 2014). For example, collector and scraper groups, which are commonly found in minimally disturbed areas (Sudarso et al. 2021), may be particularly susceptible to pollution. In this study, pollution-sensitive collectors such as Leptophlebiidae and Heptagenidae, and scrapers such as Glossosomatidae, were frequently observed in upstream sampling locations. The physical conditions of the river in these areas, characterized by riffle flow, a substrate composed of pebbles, gravel, and cobbles, and a moderately swift current, provided a suitable environment for these larvae. The availability of Fine Particulate Organic Matter (FPOM), derived from surrounding riverine vegetation, further supported their survival. However, as the river flows downstream, the abundance of these families declined due to decreased input of Coarse Particulate Organic Matter (CPOM), which is linked to reduced riparian vegetation shading. This decline in CPOM consequently affected FPOM availability.

Changes in CPOM availability can lead to shifts in macroinvertebrate feeding ecology, particularly among collector and shredder groups. The study found that downstream stations were characterized by higher abundances of collector taxa such as Baetidae, Hydropsychidae, and Chironomidae, as well as the scraper taxon Elmidae. Further downstream, despite reduced shading (Kadim and Pasisingi 2024), it is hypothesized that food sources primarily originate from fine particles transported by land erosion caused by anthropogenic activities, including agriculture.

The study also demonstrated the significant influence of water physicochemical variables on macroinvertebrate community composition. Specifically, four taxa, Platybaetis (Baetidae), Cheumatopsyche (Hydropsychidae), Chironomidae, and Coxelmis (Elmidae), showed the highest frequency of presence and increased dominance as BOD and COD levels rose. This indicates that these taxa possess high tolerance to elevated organic pollution levels. According to Sudaryanti (2022), Baetidae and Hydropsychidae thrive on various substrates, contributing to their widespread prevalence. The floating nature of Baetidae facilitates their dispersal, further explaining their high abundance. Chironomidae, known for its tolerance to organic pollution (Rossaro et al. 2022), exhibited significant dominance in polluted stations. High dominance of these taxa suggests that conditions at each station remain conducive to life despite pollution. As observed by Khan et al. (2021), water contamination is often linked to waste accumulation from domestic and agricultural sources, which degrades water quality.

The findings indicate that BOD and COD levels in the study area have surpassed prescribed quality standards. High BOD values suggest an increase in organic matter concentration, which also influences COD levels. It is postulated that elevated BOD and COD levels result from anthropogenic activities, leading to limited organic matter availability as a food source for macroinvertebrates. The impact of these pollutants on macroinvertebrates can be direct. Kadim and Pasisingi (2024) reported that anthropogenic activities in the Bone watershed have negatively affected the river's physical habitat, which consequently impacted BMWP-ASPT scores. Upstream stations (SB-P1, SB-P2 (excluding 2023), and SB-P3) exhibited BMWP scores exceeding 90 during the sampling period. Macroinvertebrate families at these stations included taxa with high BMWP scores (10), such as Leptophlebiidae, Philopotamidae, Heptagenidae, Glossosomatidae, Athericidae, and Ghompidae. ASPT calculations for these stations yielded scores greater than 5.5, classifying them as waters of good to excellent quality. These stations are located in primary forest areas with minimal human activity, ensuring favorable water quality, as corroborated by the Pollution Index (IP) analysis, which classified them as being in good condition. The measured water quality parameters did not exceed class II standards, maintaining optimal conditions for pollution-sensitive macroinvertebrates (Ecoton 2013).

In contrast, middle to downstream observation stations (SB-TU to SB-BO) exhibited moderate to poor water quality. These stations are situated in residential areas where agriculture and sand mining contribute to direct waste inputs, including heavy metals. Agricultural activities, particularly the use of chemical fertilizers and pesticides, introduce toxic substances into the river, increasing BOD and COD through organic waste runoff, depleting dissolved oxygen, and threatening macroinvertebrates (Khan et al. 2021). Sand mining exacerbates sedimentation, further deteriorating water quality and elevating BOD levels (Zou et al. 2019). Heavy metal contamination from mining also contributes to increased COD, reducing macroinvertebrate biodiversity and disrupting aquatic ecosystem balance (Koehnken et al. 2020). The Pollution Index analysis revealed that these stations experienced minor pollution, particularly in 2023, due to exceeding BOD and COD quality standards. BOD values ranged from 5.21 to 13.4 mg/L, while COD values ranged from 35.14 to 54.0 mg/L. This condition affected macroinvertebrate community composition, leading to a decline in BMWP-ASPT scores. The BMWP scores for middle to downstream stations consistently declined from 66 in 2021 to 49 in 2023, yielding ASPT scores below 5. The macroinvertebrate community at these stations primarily consisted of families with low BMWP contributions, such as Baetidae, Veliidae, Chironomidae, Lumbricidae, and Thiaridae (Armitage et al. 1983). The observed macroinvertebrate communities included pollution-tolerant families (Ecoton 2013), such as Caenidae, Simulidae, Hydropsychidae, and Elmidae. Notably, pollution-sensitive families, such as Glossosomatidae, were absent. These findings indicate a progressive decline in Bone River health, with the most severe degradation occurring downstream.

In conclusion, the study highlights the impact of anthropogenic activities on the ecological health of the Bone River, with upstream sections maintaining better water quality and macroinvertebrate diversity. However, increased BOD and COD levels downstream indicate pollution stress, leading to a decline in pollution-sensitive taxa. Functional Feeding Group shifts and decreasing BMWP-ASPT scores further confirm ecological degradation. Sand mining, agricultural runoff, and domestic waste are primary contributors to declining water quality. Immediate conservation measures, including watershed management and pollution control, are crucial to restoring river health. Regular biomonitoring using macroinvertebrate indices can aid in sustainable river management.

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